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Enterprise Reengineering: A Strategic Framework and Methodology

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Abstract

Manufacturing companies find themselves, whether they like it or not, in a more global and changing reality. Fiercer competition, dynamic markets, new consumer habits, stronger environmental regulations, and new technological possibilities, are forcing manufacturing companies to change. The practical effects for European manufacturers are 1) new and innovative products, 2) global value chains, 3) automation, and, 4) a shift from products to solutions. This research is addressing the changes needed for operations in a single enterprise (a group of departments, a plant, or a group of closely located plants), to take advantage of the competitive situation.

For such "internal" operations, the new challenges require changes both in technology and practices. The main concern of this research is the practices, and how a reengineering of manufacturing and office operations can improve performance. The choice of scope is based on the assumption that operations activities are a major source for competitiveness. To reengineer operations activities in processes rather than functions, and to implement best practices wherever appropriate, can therefore provide dramatic competitive improvements.

The overall objective of this research is to:

• establish enterprise reengineering as an approach that enables manufacturing enterprises to achieve fit between market requirements and operations capabilities.

Enterprise reengineering is viewed as model-based and strategy-driven approach that enables manufacturers to realise the "soft" or infrastructural aspects of an operations strategy. To support such reengineering efforts, enterprises are viewed not only from a process perspective but also from a resource, materials, information, organisations, and control perspective. Modelling and analysing enterprises from these perspectives can support their effort to implement best practices, and ensure that the practices are combined in a way that supports the overall business strategy.

The overall objective is divided into more specific objectives:

- To develop a strategic framework for enterprise reengineering
- To develop a consistent and practical enterprise reengineering methodology to support the formulation and realisation of operations strategies
- To develop architecture for conceptual enterprise modelling that ensures a coherent, decomposed, and holistic picture of enterprise operations
- To establish "flow manufacturing" as a (optional) best practice programme for enterprise reengineering

Together, the strategic framework, the methodology, and the modelling architecture should enable enterprises to achieve their performance objectives through an enterprise reengineering effort. In cases where an enterprise mapping and analysis concludes that improvements in manufacturing planning and control, order management, layout and flow, or inventory, should be performed, the flow manufacturing programme should provide practical guidance and a set of principles to support reengineering.

In order to achieve these objectives, the following issues are reviewed in this thesis: 1) operations strategy, 2) enterprise reengineering, 3) flow manufacturing, 4) enterprise modelling, and, 5) change management. Based on these literature studies, a strategic framework, a methodology, a modelling architecture for enterprise reengineering and a flow manufacturing programme are proposed.

The major outcome of this research is an enterprise reengineering methodology, which includes strategic planning, and operations mapping, analysis, design, and implementation. The methodology consists of the following models, principles, and tools:

- A operations strategy checklist
- Four flow manufacturing design principles
- An architecture for conceptual enterprise modelling
- Seven change management principles
- A procedural guide for enterprise reengineering
- An operations performance audit sheet
- A five-step approach to flow manufacturing reengineering

The research is based on a case study of HÅG Fast, a very successful enterprise reengineering project carried out in 1991-1992. The case study demonstrates the usefulness of the methodology to analyse and understand enterprises, and the dramatic improvements in performance that can be achieved by implementing flow manufacturing practices. In addition, the enterprise reengineering methodology has been proved useful in several field studies.

Table of content

1.	INTF	RODUCTION	1
	1.1	MANUFACTURING TRENDS AND CHALLENGES	1
	1.1.1	General Trends	1
	1.1.2	Practical effects on manufacturing companies.	6
	1.2	RESEARCH DOMAIN	8
	1.2.1	Research tonic	8
	1.2.2	Research problem	.11
	1.2.3	Scone	.13
	1.2.4	Objectives	.14
	1.2.5	Limitations	.16
	1.3	SCIENTIFIC APPROACH	.17
	131	The issue of paradigm	17
	132	Approaches by Arbnor and Rierke	18
	133	The systems approach	21
	1.3.4	The "Goal-Means" version of the system approach	.21
	1.3.5	Systems theory	.22
	1.3.6	Methodological aspects of the systems approach	.24
	1.3.7	Research approach in this thesis	.25
	1.4	OUTLINE	.27
	1.5	ABBREVIATIONS	.30
	1.5	REFERENCES	32
	1.0		
2.	OPE	RATIONS STRATEGY	.35
	2.1	OPERATIONS MANAGEMENT	.35
	2.1.1	The contribution of operations management	.35
	2.1.2	Operations in the organisation	.38
	2.1.3	Operations strategy versus operations management	.39
	2.2	THE NATURE OF OPERATIONS STRATEGY	.40
	2.2.1	What is strategy	.40
	2.2.2	The strategy hierarchy.	.41
	2.2.3	Operations strategy development	.41
	2.2.4	The market perspective	.43
	2.2.5	The resource perspective	.44
	2.2.6	A definition of operations strategy.	.46
	2.3	A FRAMEWORK TO UNDERSTAND OPERATIONS STRATEGY	.48
	2.3.1	Operations strategy framework	.48
	2.3.2	Performance objectives for manufacturing	.49
	2.3.3	Some typical performance measures	.53
	2.3.4	Positioning and trade-offs	.54
	2.3.5	Strategic decisions areas for manufacturing	.56
	2.3.6	Infrastructural versus structural decisions	. 59
	2.3.7	Value chain decisions versus single enterprise decisions	.60
	2.3.8	A framework to structure operations strategy decisions	.61
	2.4	THE PRODUCT-PROCESS MATRIX	.69
	2.5	OPERATIONS STRATEGY DEVELOPMENT	.71
	2.5.1	The operations strategy process	.71
	2.5.2	Operations strategy formulation procedures	.73
	2.5.3	The operations strategy checklist	. 74
	2.6	SUMMARY	.76
	2.7	References	.76
2	TAKIM	EDDISE DEENCINEEDINC	٥ <u>م</u>
5.	ENT	EKTKISE KEENGINEEKING	.80
	3.1	ENTERPRISE ENGINEERING AND REENGINEERING	.80
	3.1.1	Historic roots - enterprise engineering	. 80
	3.1.2	The link to operations strategy	.81
	3.1.3	The scope of Enterprise Reengineering	. 83

	3.1.4	A definition of enterprise reengineering	
	3.1.5	Business process reengineering	85
	3.1.6	Enterprise integration	
	3.2	MAJOR ASSUMPTIONS FOR ENTERPRISE REENGINEERING	90
	3.2.1	Holonic systems as a source of inspiration	91
	3.2.2	The operations hierarchy	91
	3.2.3	<i>Core idea in enterprise reengineering – decomposed operations models</i>	
	3.3	A CONCEPTUAL FRAMEWORK FOR ENTERPRISE REENGINEERING	95
	3.3.1	The role of enterprise reengineering in operations strategy development	
	3.3.2	The strategic framework	
	3.3.3	The enterprise reengineering methodology	
	3.4	SUMMARY	
	3.5	REFERENCES	
4.	FLO	W MANUFACTURING	
	4.1	HISTORICAL ROOTS AND CONCEPTS	
	4.1.1	Historical roots – group technology	
	4.1.2	Functional manufacturing	
	4.1.3	Performance improvement through flow manufacturing	
	4.1.4	Flow building block – the operations area	104
	4.2	THE RELATIONSHIP TO OTHER PERFORMANCE IMPROVEMENT APPROACHES	
	4.2.1	Socio-technical design	
	4.2.2	Lean manufacturing	112
	4.2.3	Business process reengineering	114
	4.2.4	Quick response manufacturing	114
	4.2.5	Agile manufacturing	114
	4.3	DESIGN PRINCIPLES IN FLOW MANUFACTURING	115
	4.4	PROCESS DESIGN	117
	4.4.1	Product grouping	117
	4.4.2	Levels of product focus in flow manufacturing	119
	4.5	LAYOUT DESIGN	
	4.5.1	The basic layout types	121
	4.5.2	Material flow patterns inside and between operations areas	122
	4.5.3	One-piece flow	123
	4.6	JOB DESIGN	
	4.6.1	Core issues in job design	125
	4.6.2	Advantages and disadvantages of operations area teams	
	4.7	MANUFACTURING PLANNING AND CONTROL SYSTEM DESIGN	
	4.7.1	The decisions hierarchy	
	4.7.2	The control model for analysing MPC applications	
	4./.3	A schematic MPC system framework	133
	4./.4	MDC for strategies	130
	4.7.5	Material planning and about first surfaces	13/
	4./.0	waterial planning and snop floor options	
	4.8	EXPERIENCE FROM NORWEGIAN FLOW MANUFACTURING PROJECTS	142
	4.7 4 10	DUNIMAK I	144 1 <i>14</i>
	4.10	REPERENCES	140
5.	ENT	ERPRISE MODELLING	150
	5.1	MODELLING IN GENERAL	150
	5.2	ENTERPRISE MODELS	151
	5.2.1	Conceptual models	152
	5.2.2	Operational models	152
	5.2.3	Analytical models	153
	5.3	A GENERALISED MODELLING FRAMEWORK FOR ENTERPRISE ENGINEERING	154
	5.4	THE MINIMUM FORMALISM CHALLENGE	156
	5.5	CONCEPTUAL ENTERPRISE MODELS	
	5.5.1	Modelling domain: the wicked problems	158
	5.5.2	Epistemological meaning	159
	5.5.3	A definition of conceptual models	159

5.5.4	4 Conceptual enterprise models requirements	160
5.6	THE OPERATIONS MODEL-SET	161
5.6.1	Six enterprise perspectives	162
5.6.2	2 The operations model-set	162
5.6.3	3 Some advantages and limitations	169
5.7	SUMMARY	170
5.8	REFERENCES	171
6. CH	ANGE MANAGEMENT IN ENTERPRISE ENGINEERING	174
6.1	INTRODUCTION	174
6.2	KNOWLEDGE: A CORE ASPECT OF ENTERPRISE ENGINEERING	175
6.2.	I Knowledge and its connection to action	176
6.2.2	2 Knowledge creation: a core process in enterprise engineering	176
6.2.3	3 Knowledge conversion: Interaction between tacit and explicit knowledge	177
6.2.4	4 The organizational knowledge spiral	178
6.3	THE POLITICAL PROCESS OF ENTERPRISE ENGINEERING	180
6.3.	The enterprise viewed as an Actor Network	180
6.3.2	2 Technological development	181
6.3.	3 Resistance to change	181
6.3.4	4 Obstacles to innovation	
6.3.5	5 Comparison of design approaches	
6.3.0	5 Technology-based and socio-technical design	
6.3.2	7 Enterprise engineering – conflicts or harmony	
6.4	CHANGE MANAGEMENT PRINCIPLES	
6.5	SUMMARY	
6.6	REFERENCES	189
7. TH	E ENTERPRISE REENGINEERING METHODOLOGY – STRATEGIC PLA	NNING.
•••••		
7.1	INTRODUCTION	
7.2	STRATEGIC PLANNING	193
7.3	PART 1 UNDERSTAND AND REVISE BUSINESS OBJECTIVES	194
7.3.1	l Mission	194
7.3.2	2 External environment	195
7.3.3	3 Core capabilities	196
7.3.4	4 Business strategy formulation	
7.4	PART 2 DETERMINE THE CURRENT OPERATIONS STRATEGY	198
7.4.	Grouping products	198
7.4.2	2 Determine order-winners and qualifiers	
7.4.3	<i>B</i> Performance objectives	
7.4.4	Formulate the current operations strategy	
7.5	PART 3 GAP ANALYSIS	
7.6	PART 4 THE REVISED OPERATIONS STRATEGY	
1.1	A DETAILED OVERVIEW OF THE ENTERPRISE REENGINEERING PROCESS	
/.8	SUMMARY	
7.9	KEFERENCES	209
8. TH	E ENTERPRISE REENGINEERING METHODOLOGY - MAPPING AND	212
ANALYS	10	
8.1	MAPPING	212
8.1.	l Selection of data sources	
8.1.2	2 The mapping dataset	
8.1.	3 Initial data analysis	
8.1.4	4 The AS-IS operations model	219
8.2	ANALYSIS - OPERATIONS PERFORMANCE AUDIT	
8.2.	l Purpose	
8.2.2	2 Point of departure – lean manufacturing	
8.2.	An overview of critical areas for operations excellence	
8.2.4	A description of each area of excellence	
8.2.3	The use of the audit sheet for assessment and analysis	235

8.2	2.6 Choice of improvement area	
8.2	2.7 Summary	
8.3	References	239
о тт	IE ENTERDRICE DEENCINEERING METHODOLOGY DESIGN AND	
9. IL	IE EN LEKPKISE KEENGINEEKING NIE LIUUUUUG L- DESIGN AND MENTATION	241
INFLE	VIENTATION	
9.1	DESIGN AND IMPLEMENTATION IN GENERAL	
9.1	.1 Underlying change management principles for design and implementation	241
9.1	.2 The TO-BE operations model	
9.1	.3 The initiation of improvement initiatives	
9.1	.4 Detailed analysis and design	
9.1	5 Testing and implementation	
91	6 Measuring results and close out the project	247
92	FI OW MANUFACTURING	248
9.2	1 Step 1 Create product focused operations areas	
0.2	2.2 Step 2 Dimension each operations area in terms of equipment and people	247 253
9.2	Step 2. Dimension each operations area in terms of equipment and people	
9.2		233 260
9.2	.4 Step 4 Design of operations area learns	
9.2	Step 5 Moaify MPC system and information flows	
9.2	2.0 Summary of benefits of flow manufacturing	
9.3	SUMMARY	
9.4	References	
10	CASE STUDY: HÅG - AN OFFICE CHAIR MANUFACTURER	274
10.		••••••
10.1	INTRODUCTION	274
10.2	A NEW OPERATIONS STRATEGY FOR HÅG IN 1991	275
10.	2.1 Business objectives	
10.	2.2 A shift in market requirements in the 90s	
10.	2.3 The existing operations strategy	
10.	2.4 Gap analysis	
10.	2.5 A new operations strategy	
10.3	MAPPING	280
10	3.1 The manning data set	280
10.	 The mapping und service The existing control model 	282
10	3.3 Processes	282
10.	3.1 Posources and materials	
10.	2.5 Information	20J 281
10.	2.6 One anisation	204 201
10.	5.0 Organisation	
10.	5.7 Planning and control	
10.4	ANALYSIS	
10.5	DESIGN	
10.	5.1 The new control model	
10.	5.2 Processes	
10.	5.3 Resources and materials	
10.	5.4 Information	
10.	5.5 Organisation	
10.	5.6 Planning and control	
10.6	SUPPLIERS	
10.7	DISTRIBUTION SYSTEM	
10.8	Results	
10.9	Conclusion	
10.10	References	
11.	CONCLUSION	
11.1		201
11.1	KESEARCH STORY LINE	
11.2	EVALUATION OF QUALITY OF RESEARCH	
11.	2.1 Contribution to knowledge	
11.	2.2 Contribution to practice	
11.	2.3 Theoretical, practical and methodological foundation	
11.	2.4 Methodological coherence	

11.3	FUTURE WORK	304
11.4	CLOSURE: THE KEY POINTS OF THE ENTERPRISE REENGINEERING METHODOLOGY	306
11.5	References	308

1. Introduction

1.1 Manufacturing trends and challenges

The world is characterised by extensive changes. The times when companies could run their activities in stable environments are gone. Manufacturing companies find themselves, whether they like it or not, in an ever more global and changing reality.

To meet the emerging changes and the accompanying challenges, manufacturing companies have to be aware of, act in accordance with, and attempt to influence the trends that might determine their future. This was the background for a trend study initiated in 1999 by Næringslivets Idéfond, a development programme at the Norwegian University of Science and Technology (NTNU). The project aimed to identify driving forces and trends within manufacturing and logistics, and thereby provide support for decision-makers in industry and academia (Strandhagen et. al. 1999).

Below, a description is provided of the major trends identified by the study, as well as the challenges these trends represent to manufacturing companies trying to incorporate them in their operations strategy. Companies will find that improved performance is a must, and that competitiveness will imply radical changes in manufacturing operations.

1.1.1 General Trends

The major topics for Næringslivets Idefond's trend study were trends within society and policy, individuals/consumers, and technology, and how these trends will impact future logistics and manufacturing. The study was carried out during the spring of 1999 by an interdisciplinary team of academics and professionals with backgrounds in logistics, production management, operation research, sociology and history. The trends outlined in this section are the result of 50 interviews with Norwegian academics and professionals; each carefully selected to cover the major aspects of manufacturing and logistics and to ensure sufficient breadth.

Four major trends were identified that point to a new competitive reality for manufacturing companies:

- Globalisation
- Fragmentation of markets and individualisation
- Increased focus on environmental and sustainable development
- The enabling information and communication technology (ICT)

These trends are not claimed to be universal. The investigation was carried out in Norway, and the trends may be more valid in Europe than in other parts of the world. However, the findings of this study have been confirmed by other more recent and comprehensive initiatives. The U.S. Secretary of Commerce (2004) has for example carried out a comprehensive study termed "Manufacturing in America". This study concluded that, over the past two decades, three separate and powerful trends have reshaped the manufacturing sector globally. The first trend is the revolution in technology (both process technology and information technology) that has been under way for two decades, raising productivity in manufacturing and reducing costs worldwide. The second trend is the significant reduction in barriers to trade, particularly with respect to trade in manufactured goods. The third is the end to political divisions that have segmented markets for more than 70 years and the corresponding emergence of Russia, China, and other countries in the world trading system.

Similarly, the European Commission has carried out a comprehensive study to create "Manufuture - a vision for 2020" for EU manufacturing (EU publication office, 2004). This study identified six drivers for change in the EU manufacturing sector: 1) increasingly competitive global economic climate, 2) rapid advances in science and technology, 3) increased environmental challenges and sustainability requirements, 4) socio-demographic aspects, 5) the regulatory environment, standards, and intellectual property right systems, and 6) values and public acceptance of new technology. A third trend study performed by the manufacturers alliance in the USA, although focusing on the U.S. as the world engine for growth, came to similar conclusions: 1) the global market remains robust for manufacturing products, 2) technology increasingly drives growth, 3) value provided by manufacturing and the role of manufacturers is shifting from a "production" to a "solutions" model, 4) automation leaders have new opportunities to thrive in global economy, and 5) globalisation provides both competition and opportunity (Duesterberg and Preeg, 2004).

Although these studies define the trends somewhat differently, the trends identified seem to be coherent with the Norwegian trend study. Manufacturers worldwide are facing a competitive environment characterised by global markets and stronger competition, increasing consumption followed by increasing demand for variety of choices, stricter environmental regulations, and rapid advances in information technology. The four major trends of the Norwegian study are described in more detail below.

Globalisation

Globalisation means that diverse fragments of the world melt together and are forced to relate to each other. This implies that geographical distance and national borders have lost much of their original importance. Taste, communication, standards and even concepts are becoming global, and national control over economies is declining. International competition is rapidly replacing national competition due to open markets with increased size, accessibility and homogeneity.

The most central aspects of globalisation for manufacturing are:

- Technology is becoming more accessible everywhere, which allows rapid reproduction of products developed by others. The result is shorter product lifecycles and market situations that reward innovative companies.
- Deregulation and adjustment of trade regulations create global markets. According to data compiled by the World Trade Organisation (WTO), the average tariff rate for OECD countries is now down to 4 percent, while it was 40 percent at the end of World War II (OCED, 1999).

- Intensified global communication and worldwide movement patterns create global cultural and consumption flows. According to data compiled by the WTO, the volume of world export increased at an annual rate of 5.8 percent in the past 25 years, which is more than twice as fast as the growth in the world economy as a whole (WTO, 2002).
- Improved transport and communication infrastructures enable increasing globalisation of companies. Global companies produce components in the countries that are favourable regarding access to, and price on, workforce and knowledge at a given moment. The final production and customisation is often executed close to the markets.

The globalisation of markets opens up to new competitors. Global companies can utilise the lowest factor inputs available to supply almost identical items to different countries. Globalisation implies fiercer competition and requires new strategies for manufacturing and logistics. Today, local competition operates in global markets.

Fragmentation of markets and individualisation

The consumption of goods is increasing because of increased wealth in industrial countries, and because new countries are moving up the income scale. At the same time, markets are becoming more fragmented on price, quality, customisation, and service. Customisation of products and services, based on knowledge of consumer dispositions and trends, is therefore becoming a crucial factor for competitiveness in many markets. The result is increased buying power and pressure on companies to focus on certain highly dynamic market segments.

This trend has been elaborated in detail by Warde (1997), who performed a consumer study in the UK. According to Warde, two main forces are influencing consumer dispositions - individualisation and informalisation – which tend to reduce the class structure that characterised earlier consumption behaviour.

- *Individualisation* means people are less attached to social institutions and freer to choose their lifestyle, identity and consumer habits as individuals. What people have in common is their desire to maximise life quality. People are getting more concerned with their own wellbeing and less loyal to others. Each individual has distinctive ideas and different approaches to how a good life should be lived.
- *Informalisation* means that rigid, established and routinised patterns of consumption dissolve. People are free to consume and present themselves according to their own preferences, as moral, aesthetic, and social standards are relaxed.

However, there are counter-forces that create stronger attachment and more regulation by groups. A counter-force to individualisation is that people create imaginary communities to compensate for lack of sense of belonging. Belonging is sought in the invention of traditions, and in regional or local identities. A counter-force to informalisation is that people (e.g. young subcultures) use goods and services more extensively to express their distinction and belonging to social groups. Membership is recognised by shared taste in clothes, music, etc, and creates a high group regulation of consumption. Altogether, forces and counter-forces create four distinct and partly conflicting consumer trends as illustrated in figure 1.



Figure 1 Consumer trends (adapted from Warde, 1997)

Figure 1 shows forces and counter-forces that dissolute and transform the earlier class structuring of consumption. These forces have influenced consumer dispositions from the 1960s up until today, and have created four distinct and conflicting consumer trends:

- *Individual diversity* means that there is much greater diversity in consumer behaviour, that rules are relaxed and individual preferences released from the constraints of group approval.
- *Niche specialisation* means there is a growing differentiation of distinctive lifestyles. People are disembedded from traditional networks, and create their identity through sharing lifestyles (and consumption) with others. New niche-groups or "neo-tribes" are created.
- *Massification* (or the McDonaldisation of society) means that the passing of class differentiation and relaxed normative regulation leads to much greater uniformity in consumption. This trend opens up for global markets and sale of almost identical products in many different countries.
- *Collective distinction* means differentiation between social groups is increasing. National, regional, ethnic, and local identities are re-created and consumption is used to mark group belonging. Age, gender, education, interests, and social networks create different consumption practices.

Consumption is heterogeneous, and the outlined trends are conflicting in many aspects. However, what can be valid in the fashion industry may not apply to the food industry, and McDonaldisation may emerge in some market segments while the majority of the population tends towards greater consumer diversity. The "schizophrenic consumer" is a term that seems to become valid. Customers can no longer be separated in distinct consumer categories but instead belong to different categories in different situations. Thus, the markets are becoming more dynamic and fragmented. Fiercer competition and increased buying power require close market

surveillance and customer intimacy, together with manufacturing and logistics strategies that utilise customer knowledge to improve company market positions.

Increased focus on environmental and sustainable development

Economic growth and globalisation imply higher energy consumption, more pollution and more waste. However, public opinion is now aware of the environmental impact of products and manufacturing/logistics processes, and manufacturing companies are facing two major challenges:

- Consumers increasingly prefer green products
- Society puts pressure on manufacturing companies through environmental regulations and taxes.

As the ability to develop and operate environmentally friendly products and processes is becoming a competitive advantage, manufacturing companies are increasingly required to involve environmental considerations in their business strategies. Major strategic topics are:

- *Design for sustainable development.* Products are developed through an integrated design process, where environmental aspects are considered in all phases of the product lifecycle. The goal is environmentally friendly production and distribution, and refurbished and reused products. A great design challenge is the use of recyclable materials in new products, and finding application areas for recycled material. Today's garbage may become future products.
- *Product lifecycle management*. Manufacturing companies take responsibility for their products' total lifecycle. Systems and structures are developed to handle collection and reuse/recycling of waste products. This will enforce a stronger integration of supply and recovery chains, and requires technology for tracking and tracing of products.

The enabling information and communication technology (ICT)

ICT has been utilised in manufacturing since the 1970s. However, the application areas for the technology have been limited. This situation has now changed dramatically, the dramatic expansion of computing power and its application to an increasing range of tasks in the business environment is without doubt the single most powerful technological change affecting manufacturing today. Moore's law that computing power will double every 18 months, still prevails and is likely to continue for some time to come. Two major shifts have been identified in the use of ICT:

- A shift towards web-integrated sets of Enterprise Resource Planning systems
- A shift towards global, mobile, multimedia communication and control.

These shifts are creating new opportunities for manufacturing companies. The new technology enables efficient execution of operations and communication. And even more important, new business areas are enabled by the new technology.

The most important information systems for manufacturing are Enterprise Resource Planning systems (ERP). These systems have gone through an evolution in terms of functionality, scope, technology and sophistication. The main changes are summarised by Wortman (2000) as:

• *Registration*. ERP were hardware systems covering one function. The systems were used for data collection and registration <u>after</u> the fact had happened

- *Automation*. ERP were based on databases and allowed transactions between different functions in a single site. The systems were used to automate existing processes.
- *ICT-enabling*. ERP were based on client servers, and enabled multi-site interaction and re-engineering of processes
- *E-business.* ERP will utilise integrated portal technology to enable E-business, i.e. the utilisation of internet to create and operate new products and services in collaboration with other companies.

The growth in functionality, scope, technology and sophistication has enabled a shift towards ERP systems that integrate every site in a company, and that are integrated with a set of other ERP systems through the internet. The latest technology makes integration a less painstaking process than in the past. This enables short-term collaboration (in temporary networks or supply chains) for rapid and cost efficient supply of products and services.

Moreover, technology for communication, tracking, and surveillance is becoming better, cheaper, smaller and more mobile. ICT is connecting the globe and dissolving barriers caused by geographical distance. People are now able to communicate across the world and to run remote applications through mobile multimedia stations. The new multimedia terminals provide communicative freedom and will soon allow people to operate their ERP systems independent of their position. ICT also allows remote and mobile tracking, governance and control of manufacturing and logistics processes.

1.1.2 Practical effects on manufacturing companies

The general trends described in the previous section create comprehensive changes in most industries and will influence the competitive situation of manufacturing companies. Fiercer competition, dynamic markets, new consumer habits, stronger environmental regulations, and new technological possibilities enforce manufacturing companies to change. The practical effects for European manufacturers are:

- New and innovative products
- Global value chains
- Automation
- A shift from products to solutions

New products and innovative products

Innovation has become the central pillar for competitiveness. Manufacturing is evolving from local satisfaction of local needs to production patterns able to respond flexibly to global demands. In order to meet the evolving competitive, environmental, and social challenges, European manufacturing must become capable of achieving and maintaining technological and production leadership in the global market place.

- The time scale of product conception and development is shifting from the long to the short term and ultimately to a near real-time response.
- Planning tools, software and ICT are increasingly used to integrate new technologies into the design and operation of manufacturing processes. Planners and designers are using information from scalable virtual representations of

factories (virtual engineering in digital factories) to obtain dramatic time and cost savings in product development and implementations of new facilities.

- Processes are increasingly integrated into dynamic, co-operative manufacturing and value-adding networks of SMEs or "virtual enterprises".
- Knowledge is increasingly shared via knowledge platforms and competence networks, in conjunction with equitable intellectual property rights provisions.
- The development of new production processes may radically change both the scope and scale of manufacturing (metal printing, nano-technology etc.)

Global value chains

One effect of the new global environment on European manufacturers has been the increasing availability of new sources of low-cost labour and manufacturing capacity. In a global economy in which both goods and capital are mobile, but labour is not, the trend toward sourcing parts and components globally is here to stay. This effect is also confirmed by American trend studies: "Manufacturers now have the ability to manage global value chains effectively, which allows them to source from the lowest cost supplier globally and, as a competitive matter, forces them to do so in order to remain competitive themselves" (U.S. Secretary of Commerce, 2004).

In an increasingly global market for manufactured goods, competition will largely take place among value chains, rather than between individual manufacturers. This implies an entirely different concept of manufacturing. Rather than focusing on what has traditionally defined manufacturing – that is, the process of turning raw materials into components or finished products – manufacturers today think of manufacturing as a system designed to perform the activities required to deliver the end-product to the customer and meet the customer's needs, from design to finance, to production, to sales and marketing, to after-sales service.

Automation

Automation leaders have new opportunities to thrive in a global economy:

- European manufacturers are able to capitalise on their technologies to increase the already high level of factory automation and productivity, and thereby overcoming some of the labour cost disadvantage.
- Manufacturers will be increasingly looking for standardised solutions for operations located around the globe.
- Capital goods suppliers and automation providers will need new, advanced capabilities to design and deliver solutions tailored to their customers' strategy and tactics.
- Automating data and information flows is the main challenge for the next decade. Manufacturing companies need to get the right information to the right person (or machine) at the right time.
- Software systems that better connect manufacturing operations with the total value chain will be a competitive advantage.

A shift from products to solutions

The new competitive situation requires the ability to handle a continuously changing business environment, where markets consist of rapidly changing niches. Price, precision, and speed will still be major determinants of competitiveness, but competition for manufacturing companies will increasingly require offerings with more customisation and more service. The role of European manufacturers is shifting from a "production" to a "solutions" model.

- The market for products that improve living standards will continue to grow. To meet this demand companies will have to adopt more flexible production techniques.
- Value added will move from manufacturing to activities associated with the design, engineering, marketing, and organisation of products.
- The rapid development of information technology will create a new class of products for both consumer and industrial markets.
- Better use of information will radically transform value chains. Rather than producing products and then trying to sell them, companies will provide solutions to specific customer problems.

The enterprise change needed to take advantage of these trends is usually difficult to implement. Most successful efforts share common characteristics, and are based on new management and manufacturing approaches such as "lean manufacturing" techniques and quality assurance programs. Such approaches are adopted and synthesised to reengineer the enterprise and improve overall performance.

To adapt to this changing competitive environment, European manufacturers are forced to target a broad range of issues (technology development, global sourcing, automation, and customisation of products and services) in their operations strategy. The work in is thesis is mainly concerned with the last competitive issue, the shift from production to solutions, and how operations should be adapted to this shift. In a competitive situation characterised by fragmentation of markets and individualisation, success will increasingly require customer oriented enterprises to be able to align and extend operations capabilities and market requirements.

1.2 Research domain

This thesis is about manufacturing enterprises, and how they can improve their competitiveness through systematic reengineering of processes in manufacturing and office operations. To support this effort, enterprises are viewed not only from a process perspective but also from a resource, materials, information, organisations, and control perspective. Modelling and analysing enterprises from these perspectives can support their effort to implement "best practices", and ensure that the practices are combined in a way that supports the overall business strategy.

1.2.1 Research topic

The reengineering of operations processes in manufacturing enterprises, the main concern of this research, is seen as a means to realise operations strategy.

Operations strategy

The changing competitive situation is both a threat and an opportunity for manufacturing enterprise. Advances in product technology, globalisation of business and value chains, automation of processes and information flows, and customer demands for products that are better, faster, cheaper, and more customised, as well as other trends, "translate into opportunity for those who embrace it, and shrinking market share and potential difficulties for those that resist it" (Tersine et. al., 1997). Thus the need to compete though operations capabilities, and to align these capabilities with success factors in the market and the corporate strategy, has made operations strategy a widespread area of concern for manufacturing enterprises.

Over the past 20 years, operations strategy research has developed into the following four distinct research fields (Voss, 1995):

- *Competing through operations,* focusing on the identification and choice of performance objectives based on market requirements and operations capabilities.
- *Strategic choices in operations strategy*, focusing on strategic choices and the need for internal and external consistency. In order to create a consistent operations strategy, each strategic choice (such as the choice of manufacturing process, or manufacturing planning and control system), should be aligned with external factors (such as product volume and variety) and with choices in other decisions areas for operations.
- *Best practices*, focusing on the application of best practices (such as Materials Requirement Planning, Lean Manufacturing, Group Technology, and Flexible Manufacturing Systems) in order to improve performance.
- *The process of operations strategy development,* focusing on operations strategy formulation and realisation (Voss, 1995).

This thesis includes issues in all of the above-mentioned research fields, but is mainly concerned about operations processes and how these can be improved by implementing best practices. "Practice refers to the established processes which an organisation has put in place to improve the way it runs its business, ranging from organisational aspects such as teamwork and employee involvement to the use of techniques such as kanban" (Voss et. al. 1997). Enterprises with best practices usually perform better than those without (see for example Womack et. al., 1991). This is leading many manufacturing enterprises to seek best practice as the basis of their operations strategy.

Off course, reengineering of enterprises is not only about the choice and implementation of best practices. This research is also concerned about issues in the other three operations strategy research fields. The need to match best practice programmes to performance objectives is a issue in this research. So is also the consistency (or lack of it) between strategic choices about the best practices to apply. How best practices are targeted in operations strategy development is an important issue. How formulation and realisation of an operations strategy can be supported with models and methods is also an important issue.

Best practice programmes

Searching for and learning from best practices has been a topic for both industry and academia for decades. Within operations strategy research, this approach traces its roots to Hayes and Wheelwright (1984), who coined the term "world class manufacturing" as a set of practices that would lead to superior performance. This will in turn lead to increased competitiveness.

Leading manufacturers are implementing best practice programmes such as lean manufacturing, agile manufacturing, just in time, integrated teams, networked organisations, supply chain management, quality management, and extended enterprise (Rolstadås, 2000). Companies therefore face the challenge of choosing from a plethora of best practice programmes that all claim to effectively and efficiently reduce costs and improve service and value for customers.

Best practice programmes are a very hot management topic. For example, there have been more than 200 academic papers related to business process reengineering since 1999 (Maull et. al., 2003). Any manager browsing through the myriad of articles is likely to be bombarded with easy promises: "You too, can engineer values to increase loyalty, commitment, productivity, and even profits in your organisation" (De Cock and Rickards, 1996). Many authors promise that their improvement programme is "a revolution in management thinking" (Euske and Player, 1996), but in reality, few, if any, revolutionary methods exists. See for example Davenport (1994) who traces the roots of business process reengineering back to scientific management, total quality management, Porter's value chain concept (1985), and socio-technical systems design. The novelty of any given best practice strategy should therefore be doubted. Most of them could be viewed as "rather old hats, which just were never implemented" (Perlitz, 1993).

Many managers are seduced by the easy promises and slogans that include terms like quality, customer service, reengineering, and teamwork. They "fall victim to the most popular management fad and follow a 'copy' strategy with an almost religious fervour" (Tersine et. al., 1997). There is ample evidence that concepts such as total quality management and business process reengineering tend to be applied in an unreflective manner (De Cock and Rickards, 1996). It is, off course, a natural tendency to simplify thought and look for a simple solution. That is why companies keep looking for simpler recipes or cookbooks for successful management. "However, first-rate chefs innovate recipes for cookbooks and earn their gourmet ranking. Average cooks read cookbooks and follow their recipes" (Perlitz, 1993). There is no one best way to success.

The tendency to uncritically base improvement efforts on the latest fad might be one of the reasons for rather disappointing results. Several studies conclude that best practice programmes fail to provide the promised performance improvements. For example, a large scale study of the use and effectiveness of twelve manufacturing practises in the UK (business process reengineering, supply-chain partnering, outsourcing, learning culture, empowerment, team-based working, total productive maintenance, concurrent engineering, integrated computer-based technology, manufacturing cells, just-in-time production, and total quality management) concluded that "the overall levels of reported effectiveness are not impressive for any of the twelve manufacturing practices" (Waterson et. al., 1999). It is therefore no surprise that, in most enterprises, the prevailing employee reaction to any new management initiative is what management consultant Christ Hart calls BOHICA – Bend Over, Here It Comes Again (Rummler and Brache, 1995).

"Business" process orientation – a core element in several best practice programmes

The orientation of processes towards a set of end products has been a management topic of substantial importance in the last two decades, and an underlying assumption in several best practice programmes. One could argue about the true origin of the concept. Skinner introduced "the focused factory" as an operations concept in the early 1970s, and argued that there is a loss of focus and competitiveness if the same

process produces products with different performance objectives (Skinner, 1974). At the same time, Burbidge promoted group technology as a way to achieve process orientation (and thus effective flow) in job and batch manufacturing in the UK (Burbidge, 1975). However, it was through the introduction of business process reengineering (Hammer, 1990, Davenport and Short, 1990) that process orientation gained popularity.

A major reason for this popularity was the need in many enterprises to organise operations in processes rather than functions. The traditional functional organisation of enterprises is flexible and enables each department to optimise their resource utilisation. However, functionalised enterprises often demonstrate long lead times, poor quality, high manufacturing costs, fractionalised product responsibilities and low improvement opportunities - characteristics that became incompatible with a more customer-oriented market situation. Business process reengineering and several other best practice programmes, such as lean manufacturing (Womack and Jones, 1996), quick response manufacturing (Suri, 1998), and agile manufacturing, Kidd, 1994), therefore have process orientation as one of their core improvement elements. Although process orientation has been in focus for a number of years now in both academia and industry, enterprises have experienced difficulties in the transformation from functional orientation to process orientation. For example, some claim failure rates as high as 70 per cent for business process reengineering projects (Laudon and Laudon, 2000).

1.2.2 Research problem

Global trends and changes require enterprises to adapt to a competitive situation that is increasingly customer-oriented. Change is therefore inevitable (Henderson and McAdam, 1998) but the manner in which managers actually manage change can determine whether an enterprise is proactively pursuing business improvement or whether it is merely reacting to the inevitable set of changing circumstances surrounding it.

Unfortunately there is no easy answer to enterprise change. The approach targeted in this research is to reengineer operations by implementing best practices. Many such efforts fail to provide the promised results. Some enterprises manage to realise operations strategies that merge best practices into unique solutions that support the overall business strategy. Most enterprises, however, have not managed to adopt best practices in a way that fully exploit their operations resources and support the business strategy. The research problem addressed in this thesis is therefore:

The lack of success experienced by many manufacturing enterprises in their efforts to close the gap between market requirements and operations capabilities by implementing best practices.

The research in this thesis is focused on how this gap can be closed through a strategically aligned improvement approach, which combines different best practices into a unique solution for the enterprise. Enterprises are often implementing a variety of best practice programs, each with its own champions, gurus, and consultants, and each competing for managers' time, energy, and resources. However, managers find it difficult to integrate those diverse initiatives to achieve their strategic goals, "a

situation that leads to frequent disappointments with the programmes results" (Kaplan and Norton, 1996). Several studies of best practice programmes such as business process reengineering, continuous improvement, total quality management, teamworking, manufacturing resource planning, and computer integrated manufacturing, confirm that advanced implementation and full exploitation of best practices require adoption of a "strategic" approach (Maul et. al., 2003) It follows from this that managers who wish to exploit the full potential of best practices, and avoid the criticism for participating in yet another fad or fashion, should put considerable effort into developing strategically aligned projects.

The difficulties experienced in projects that aim to reengineer enterprises by implementing best practices are caused by several sub-problems which will be addressed in this thesis.

Disconnection from business strategy

The lack of connection to business strategy is an important explanation for the lack of positive results from improvement projects. Rummler and Bracke (1995) rank this as sin number one in improvement projects. This problem has at least two aspects. Firstly, a strategically aligned improvement project requires the existence of a useful operations strategy. This is not always the case. Operations strategy formulation processes often become decision-making without any significant implementation much talk, but little action. "Despite the best intentions of those at the top, lofty statements about becoming best in class, the number one suppliers, or an empowered organisation don't translate easily into operational terms that provide useful guides to action at the local level" (Kaplan and Norton, 1996). Instead, strategic goals are rather vaguely expressed in policies, vision, and mission statements and so forth (Kaplan and Norton, 1996). A vague operations strategy makes it difficult to choose between options in improvement projects. Secondly, each best practice method has its own focus area and performance objectives (Rolstadås, 2000; Euske and Player, 1996). Some best practice programmes are identified with problems limited to specific parts of the enterprise. For example, empowerment allows people to innovate and use their own judgement: thus it focuses on an individual employee's role, activity based costing identifies costs with outputs and thus focuses on the work that employees perform and the costs of performing it, and so forth (Euske and Player, 1996). Furthermore, different methods often require emphasis on different aspects of performance to which the specific improvement programme is directed. The piecemal application of best practices which are common in many enterprises - limited to specific parts or functional areas and with conflicting objectives - often lead to inefficiencies and disappointing results (Rummler and Bracke, 1995). Best practice programmes should therefore be aligned with the overall business strategy.

A lack of enterprise models that provide the big picture

The lack of understanding of the big picture is a second issue (Rummler and Bracke, 1995). Everything in an enterprise (resources, materials, processes, information, organisation, and control) is connected. To improve enterprise and individual performance, managers need to understand these connections. In this respect an enterprise model is useful (Rolstadås, 2000). The current "mosaic" may not present a pretty picture, but it is a picture.

A major means of extending the knowledge of enterprise operations is through an enterprise modelling architecture, which enables managers to systematically model all the different views of the enterprise. In the recent years a number of generic enterprise modelling architectures have been available. The unifying factor of these architectures has been the emphasis on enterprise integration (Smart et. al., 1999). However, these generic architectures are very formal and detail oriented, and the use of these architectures seems to be too cumbersome and resource intensive for many industrial problems. The industrial applications of these architectures have therefore been limited (Weston and Hodgson, 2001). An alternative approach is to create architectures for more enterprise-specific and coarse modelling. However, there is still a lack of architectures for such (more conceptual) modelling efforts.

A lack of understanding of human and organisational factors

A third issue is a lack of understanding of human and organisational factors. Such factors can be major obstacles to success. Thoroughly planned solutions might be rejected or only partly implemented. Stakeholders may resist new solutions and using new tools. The development process can suffer from lack of innovation, and the new enterprise model can provide solutions that inhibit, rather than enable, performance. Change management issues should therefore be addressed to ensure successful improvement projects. However, many best practice programmes such as enterprise modelling and integration (Vernadat, 1996), business process reengineering, (Hammer and Champy, 1993) and systems engineering (Blanchard and Fabrycky, 1998) overemphasise technical design aspects and lack concern for inherent social processes such as knowledge-creation and the exercise of power.

A lack of concrete and practical guidance in best practice concepts

A fourth issue is the lack of concrete and practical guidance in best practice concepts. Some best practice concepts are merely buzzwords with no practical use, and the lifecycle of buzz words are even shorter than most electronic products (Towill, 1999). Examples of best practice concepts that still lack practical guidance and detailed principles are agile manufacturing (see e.g. Kidd, 1994), mass customisation (see e.g. Zipkin, 2001), and extended enterprises (see e.g. Jagdev and Browne, 1998). Leading proponents of these concepts can give examples of agile behaviour, mass customisation, and extended enterprises, but they are still developing the core principles to implement them.

One could therefore conclude that - in order to guide and support enterprises in their effort to close this gap - there is a need for new theories, methods, models and techniques from several research fields.

1.2.3 Scope

The trend study in this chapter concluded that the global competition induced several practical effects on European manufacturers that should be targeted in their operations strategy: the demand for new and innovative products, the need to collaborate in global value chains, the need for automation, and the demand for more customised products and services.

This research addresses the changes needed for operations in single enterprises to take advantage of the new competitive situation. The new challenges require changes both in technology and practices. Each enterprise needs to achieve the performance levels that make its products competitive in a global market. Some enterprises achieve radical improvements through technology investments. Empirical and anecdotal evidence, however, suggest that investment in manufacturing technology alone cannot solve the performance dilemma, and the unsatisfactory pay-off from investment in manufacturing technology is often due to a lack of integration between technology and managerial practises (Sim, 2001).

The research scope encompasses:

Manufacturing and office operations in an enterprise (a group of departments, a plant, or a group of closely located plants), and how these operations can be improved by adopting and combining best practices.

The choice of scope is based on the assumption (which is in line with Porter, 1996) that operations activities is a major source for competitiveness. To reengineer operations activities in processes rather than functions, and to implement best practices wherever appropriate, can provide dramatic improvements in competitiveness. The research is limited to the operations in single enterprises, but this is still a very broad research scope that encompasses research fields such as operations strategy, enterprise engineering and change management. (See also chapter 1.2.5).

1.2.4 Objectives

Strategic decisions regarding operations are long term, high level decisions about resources and processes, and how they should be developed in order to provide sustainable competitive advantage. In contrast, operations management decisions are largely concerned with the way operations are run on a daily basis. However, there is still a set of broad and long-term decisions that must be made governing how operations are run. These are decisions within the area of enterprise reengineering, which concern the overall modelling and design of operations in manufacturing enterprises.

The overall objective of this research is:

To establish enterprise reengineering as an approach that enables manufacturing enterprises to achieve fit between market requirements and operations capabilities.

Enterprise reengineering is a sub-discipline of enterprise engineering that coins an "extended" process reengineering that also encompasses changes in plant layout design, logistics systems and information systems (Vernadat, 2002). However, the discipline has not been very well defined regarding terms, scope, models, methods etc. This research aims to establish enterprise reengineering as a strategy-driven and model-based approach to process reengineering. The total transformation process can be decomposed into a large collection of concurrent processes executed by a set of operations entities that contribute to business objectives. Enterprise reengineering is essentially a matter of modelling and improving these processes. The processes are viewed in the context of the resources, material flows, information flows, organisation, and control methods of the enterprise. An enterprise reengineering effort

encompasses changes in all these areas, and has a large impact on a range of strategic decisions for operations.

This research aims to establish enterprise reengineering as a way to realise the "soft" or infrastructural aspects of an operations strategy. Enterprise reengineering efforts can result in major competitive benefits by combining design elements, i.e. principles and solutions, from best practice approaches like flow manufacturing, lean manufacturing, business process reengineering, quick response manufacturing, and others, into a holistic solution that is aligned with the overall strategy. Enterprise reengineering should therefore be viewed as a way to close the gap between market requirements and operations capabilities. Note, however, that enterprise reengineering is not the only way to close this gap. Operations strategy in general covers all strategic decisions about the manufacturing enterprise and its value chain (such as make-or-buy decisions, capacity decisions, location of new plants, investments in new technology, and so on) that are not very well supported by enterprise reengineering.

This objective can be divided into more specific objectives:

1. To develop a strategic framework for enterprise reengineering.

The framework should describe the main issues in enterprise reengineering, both in a graphical and a narrative form.

- The framework should highlight that enterprise reengineering is a model-based approach guided by operations strategy.
- It should depict the reengineering effort as a transition from a current strategic position (in terms of costs, quality, time, precision, flexibility, and innovativeness) to a future strategic position.
- It should highlight that the design of a new operations model involves combining best practices into a unique solution.
- It should show that change managements issues such as participation and knowledge creation must be targeted in order to ensure success.

2. To develop a consistent and practical enterprise reengineering methodology to support the formulation and realisation of operations strategies.

The enterprise reengineering methodology should support a systems approach to operations mapping and design.

- It should provide guidance and tools for strategy formulation and analysis, and especially the evaluation of the performance objectives and decisions areas that are targeted by a strategic decision (such as the implementation of a best practice).
- It should provide procedural guidance for the mapping, analysis, design, and implementation of new processes in manufacturing and office operations.
- It should provide an audit sheet to rate operations performance and support strategic decisions by highlighting broad areas of strengths and weaknesses.
- It should also provide some change management principles that suggest how human and organisational factors can be targeted to ensure a successful project.

A core element in the methodology should be an architecture for enterprise modelling, which can be used to represent the AS-IS and TO-BE status for operations.

3. To develop an architecture for conceptual enterprise modelling that ensures a coherent, decomposed, and holistic picture of enterprise operations.

The operations model architecture should be used to generate a set of coarse description models (i.e. conceptual models) of the enterprise operations. Such an architecture should provide a systematic approach for modelling the most relevant views of the enterprise (resource view, materials view, process view, information view, organisation view, and control view). The architecture should propose:

- The different enterprise viewpoints that should be modelled
- How the views can be synthesised in an overall model of the control view (a control model). Such a synthesised representation can provide an overall picture that is useful for understanding and communication.

Each model in a model-set should represent a different view of the enterprise, and a template of symbols should be provided to support the modelling of each view. Furthermore, enterprise reengineering implies to break down the transformation process into managerial pieces for analysis and control. The models should therefore represent a decomposed view of the enterprise.

4. To establish "flow manufacturing" as a (optional) best practice programme for enterprise reengineering.

The programme should:

- Provide a procedural guidance and set of principles that support flow manufacturing reengineering.
- Represent a broad scope for flow manufacturing that not only encompasses traditional group technology design areas such as process design and layout design, but also job design and MPC design.
- Outline the major issues, models, and methods within each of these areas.

The role of flow manufacturing compared to some other process-oriented best practice programmes (such as group technology, socio-technical design, lean manufacturing, business process reengineering, quick response manufacturing, and agile manufacturing) should be defined.

Together, the strategic framework, the methodology, and the modelling architecture should enable enterprises to achieve their performance objectives through an enterprise reengineering effort. If the conclusion of a mapping and analysis of an enterprise is to perform improvements in manufacturing planning and control, order management, layout and flow, or inventory, the flow manufacturing programme should provide practical guidance and a set of principles to support reengineering.

1.2.5 Limitations

The research problem can be characterised as broad. This approach is chosen to provide managers and researchers with a holistic and practical methodology that enables effective and efficient reengineering of enterprises. This research encompasses several wide research fields. Operations strategy, enterprise engineering and modelling, change management, and best practice programmes, are each wide enough for a doctoral study on their own. Given this approach, limitations are crucial to explain and clarify the research:

• The field of operations strategy encompasses numerous strategic decisions that range from human resources programmes to localisation of new enterprises. This

research is restricted to strategic decisions that shape operations processes (such as the choice of best practices) and their contribution to business strategy.

- The research encompasses the decision areas and performance objectives for operations strategy, and how the strategy can be formulated and realised for the operations in an enterprise.
- Enterprise engineering is a discipline encompassing all types of engineering approaches that are concerned with the modelling and optimisation of enterprise operations. This research is limited to a sub-category, enterprise reengineering, which focuses on the improvement of operations processes.
- A major enterprise engineering concern is the development of generic architectures for operational models that are integrated in an enterprise-wide information system. This research is limited to architectures for conceptual enterprise models; models that can be used for human sense making and communication in enterprise reengineering efforts.
- Change management is a discipline that encompasses human and organisational issues, and how to make personnel embrace and support new solutions intellectually as well as emotionally. This research focuses on knowledge–creation and the exercise of power, and how the right conditions can enable participatory design and knowledge-creation in enterprise engineering projects.
- There are numerous best practices available for manufacturing. See for example Halevi (2001), who lists 110 different best practice methods for manufacturing. This research is limited to a few best practice programmes which are believed to support a process orientation of enterprises. One such approach, flow manufacturing, has proved to be very useful in obtaining effective flow and short throughput times. Flow manufacturing is therefore studied in detail.

1.3 Scientific approach

In this section, the assumptions and research approach for this thesis are described.

1.3.1 The issue of paradigm

For any type of research the perception of paradigm is be important. A paradigm can be defined as set of beliefs that guides action (Denzin and Lincoln, 1994). Before deciding on which research method to use, the underlying philosophical assumptions, the basic beliefs, should be clarified. These beliefs can be summarised by the answers given to three fundamental questions: the ontological question, the epistemological question, and the methodological question. These questions are interrelated. The answer to one question constrains how the other may be answered (Guba and Lincoln (1994).

- The ontological question. What is the form and nature of reality and, therefore, what is there that can be known about?
- The epistemological question. What is the nature of the relationship between the researcher and what can be known?
- The methodological question. How can the researcher go about finding out whatever he or she believes can be known?

The major point is that questions of method are secondary to questions of paradigm, which is the basic beliefs system that guides the researcher, not only in choices of method but in ontologically and epistemologically fundamental ways (Guba and Lincoln (1994). If, for example, a "real" world is assumed, then what can be known about it is "how things really are" and "how things really work". Then only those questions that relate to matters of real existence and real action should be investigated, while other questions, such as those concerning aesthetic or moral, fall outside the realm of legitimate scientific inquiry. Furthermore, the posture of the researcher must be one of objective detachment or value freedom in order to be able to discover "how things really are" and "how things really work". Finally, a "real" reality pursued by an "objective" researcher mandates methods, whether the methods are qualitative or quantitative, that reduce possible disturbing/uncontrolled factors. Thus, the methodological approach cannot be reduced to a question of methods. Methods must be fitted to a predetermined methodology.

1.3.2 Approaches by Arbnor and Bjerke

Research (formulating a problem, collecting data, and so on) is to a great extent shaped by the methodological approach chosen, and this in turn is arranged under a set of philosophical assumptions and concepts (a paradigm). Arbnor and Bjerke (1997) define a paradigm as "any set of general and ultimate ideas about the construction of reality, the structure of science, scientific ideals, and the like". They provide a list of six (social) science paradigms arranged on a scale according to how they perceive reality as well as other aspects of the paradigm. At one end of the scale there is a paradigm with objective-rationalist approach to reality. At the other end, they position the subjective-relativistic approach to reality.

In summary, the further one goes toward one end of the scale, the more (Abnor and Bjerke, 1997):

- Reality is considered to be objective and rational
- The relations to philosophy are decreased
- Knowledge as explanation is seen as the lodestar
- Results that are general and empirical are sought

On the other hand, the further one goes towards the other end of the scale, the more:

- Reality is considered as subjective and relative
- The relations to philosophy are increased
- Knowledge as understanding is seen as the lodestar
- Results that are specific and concrete, but eidetic, are looked for

This framework highlights the polarisation between positivism and anti-positivism in the science philosophy debate. This epistemological debate concerns issues such as whether it is possible or not to acquire objective knowledge, or if it is more subjective and has to be personally experienced. Typically, positivist search for regularities and causal relationships in order to *explain* the reality in their research (Arbnor and Bjerke, 1997). The positivism epistemology is essentially based on the traditional approaches in natural sciences. In this perspective, the growth of knowledge is a cumulative process in which new insights are added to existing ones and false hypothesis are eliminated. The anti-positivist (or hermeneutic) approach asserts that natural science methods, even if modified, are essentially unsuitable for social science domains. Every case in the socio-cultural world is unique and cannot be subordinated to an objective or quantifiable rule. Research based on anti-positivism will typically focus on *understanding* a phenomenon in its context. The research task is therefore to grasp objects and events as "life manifestations" of individuals. The process of understanding and the descriptions of manifestations can be described in "general" terms, as long one is aware of the fact that these are constructed forms for individual human actions (Arbnor and Bjerke, 1997).

Arbnor and Bjerke (1997) use this framework to propose three different methodological approaches: the analytical, the systems, and the actors approach. A methodological approach is defined as "a set of ultimate ideas about the constitution of reality, the structure of science, and so on, that is important to methods, that is, to the guiding principles for creating knowledge". The relation between paradigms and methodological approaches is intimate. Nevertheless, different methodological approaches may exist within one and the same paradigm, and vice versa, a methodological approache may take its inspiration from several different general paradigms. The methodological approaches proposed by Arbnor and Bjerke (1997) relate to their paradigmatic categories as shown in figure 1.



Figure 2 The three methodological approaches relate to paradigmatic categories

The analytical approach resembles positivist epistemology. The actors approach is anti-positivist, and the systems approach would fall somewhere in between.

The analytical approach is the oldest of the three. It has its origins in classics analytical philosophy and natural sciences, and assumes that an objective reality exists, and can be studied as such. Reality has a summative character, that is, the whole is the sum of its parts. This means that once a researcher gets to know the different parts of the whole, the parts can be added together to get the total picture.

Systems thinking emerged as a popularised discipline in the 1950s (Flood and Romm, 1997). The major reasons for the emergence of this approach were a dissatisfaction with the application of classical analytical methods in social science, a need for interdisciplinary approaches to solve increasingly complex social problems, and that several sciences became less technique oriented and more problem oriented (Arbnor and Bjerke, 1997). The assumption behind the systems approach, different from the assumption underlying the analytical approach, is that reality is arranged in such a way that the whole differs from the sum of its parts. This means that not only the parts

but also their relationships are essential, as the latter will lead to synergy¹ effects. Whether an objective reality exists or not, is not an extremely important issue in the systems approach. The goal is to define a particular system, its components and the relationships between them.

The actors approach is a reaction to both the analytical and the systems approach. The actors approach is directed at reproducing the meaning(s) that various actors associate with their acts and the surrounding context. The reality assumed by the actors approach (or at least the reality of interest to the social sciences) exists only as a social construction, which means that it is not independent of its observers. Systematic characteristics are therefore not relevant to understand businesses and organisations. A system is merely a concept that only exists in the mind of the actors. Interest is instead directed toward the finite provinces of meaning held by leading actors in a particular social context. The actors approach is therefore the least formalistic of the three (Arbnor and Bjerke, 1997).

The reality assumptions made by the three methodological approaches are listed in Table 1.

Methodological approach	Reality assumption			
Analytical approach	Assumes that reality is objective:			
	The whole is equal to the sum of its parts			
	 Knowledge does not depend on individuals 			
	 Parts are explained by verified judgements 			
Systems approach	Assumes that reality is objectively accessible, but:			
	The whole does not equal the sum of its parts			
	Knowledge depends on systems			
	• Parts are explained (sometimes understood) by the			
	characteristics of the whole			
Actors approach	Assumes that reality is a social construction:			
	• The whole exist only as meaning structures, which are			
	socially constructed			
	Knowledge depends on individuals			
	• The whole is understood via the actors' finite provinces			
	of meaning			

Table 1	Methodo	logical a	pproach and	d reality	assumption

The scientific approach adopted in this thesis is the system approach as defined by Arbnor and Bjerke (1997). The most common themes regarding this approach are briefly reviewed below (the reality assumption, the systems perspective, the role of theory, the use of methods, the judgment of research quality, and the research process). In many aspects, all of these issues also relate to the research in this thesis. The objectives are not based on hypothesis and the research does not strive to

20

¹ Effects in reality (or model) that mean that the total is not the same as the sum of the parts

determine formal cause and effects relationships. Rather, as the system approach suggest, it is to determine how components in systems relate to each other and influence each other as well as the totality, and to use this knowledge to guide efforts in real systems.

1.3.3 The systems approach

The term *system* is defined by Arbnor and Bjerke (1997) as a set of components and the relationships among them. This seemingly simple concept represents a reorientation of thinking compared to the analytical approach. This reorientation means studying components that are in inevitable interaction with each other instead of in potential cause-effect relations. In order to explain or to understand an individual component it is not enough to study the components itself or in isolation. The researcher must put the component in context.

Research based on the systems approach is based on certain presumptions (Arbnor and Bjerke, 1997):

- Reality is assumed to be constructed of "units". These units are called "systems", and consist in turn of components that are fairly intimately related to each other. These units are considered objectively accessible, in other words, it is possible to base systems models on them.
- Each unit usually has connections to other units, and is then called an "open" system. Open system has no natural boundaries. This means that the system under study must be placed in context in both time and space before they can be explained and understood.
- It makes no difference from the pragmatic methodological viewpoint of the systems approach whether reality is actually constituted in this way (as systems) or the researcher studies it as if this were the case.

A researcher working according to the systems approach may have several interests. Arbnor and Bjerke distinguish between *systems analysis, systems construction*, and *systems theory*. These interests are not usually independent of each other. It is usually advantageous to advance them simultaneously, and the boundaries between them are fluid. Analysis and construction of real systems are parts in developing new systems theories. These theories are also important sources of ideas for new analysis and construction.

1.3.4 The "Goal-Means" version of the system approach

Most of the work in this thesis is focused on developing new "system" theory. The theory development includes, among others, an enterprise reengineering methodology, which is useful for changing a particular type of systems (i.e. manufacturing enterprises) from the existing strategic position to a future strategic position. The stages outlined in the reengineering methodology (strategic planning, and operations mapping, analysis, design and implementation) resembles the "Goal-means version" of the systems approach. The thesis also provides a system modelling architecture for representing the existing and future state of manufacturing operations in an enterprise.

Simplified, the goal-means approach means that the researcher views the system as a goal-means mechanism. Usually, goals for both the study and for the system are stated at an early stage of the research process. Furthermore, the researcher usually makes a plan of the study as a whole, with the course of the study essentially following the order described in Figure 3.



Figure 3 The goals-means version (Arbnor and Bjerke, 1997)

In the goal-means version, there is a problem in the real system. The problem is defined in terms of lack of goal fulfilment. Using systems analysis, the researcher formulates the problem. System analysis includes modelling and describing the real system, and is conducted by traditional data collection methods such as using secondary material, direct observation, and interviews. After reproducing a system by means of an often very extensive system analysis, the researcher (often in close collaboration with the individuals in the real system) draws up a new systems proposal – makes a system construction. Then an implementation of the new proposal is attempted, which may or may not involve the researcher, and may or may not succeed in all respects.

1.3.5 Systems theory

General system theory was the first popularised approach to systems thinking. It was launched by a disparate group of scholars in the mid 1950s. Bertalanffy, whose interests were in the domain of biology, is considered to be the prime mover. He argued that it is necessary to prevent research from being carried out in an isolated fashion. The way forward was to identify a system of laws and generalised theories that unify all sciences, natural and social. To this end, Bertalaffy proposed a theory of universal principles – General systems theory. There were three main ones (Bertalanffy, 1955):

• Look for isomorphies² that demonstrate general system properties, and transfer these models across different fields (do not employ vague analogies)

² Isomorphic means exactly corresponding in form and relations.

- Employ a general theory of organisation that deals with organised complexity. The general systems theory includes concepts like organisation, wholeness, directiveness, teleology³, control, self-regulation, and differentiation.
- Physical systems, organisms, and societies, as examples of systems, are not at all the same the laws of behaviour are isomorphic but the essence of each system is different.

General system theory is a theory of systems in general – alternatively, theories of different classes of systems – that does not allude to a specific real system (e.g. an electric circuit, a manufacturing enterprise, or a political ideology). The structure of a system is seen as the essential producer to bring about certain effects or products.

Systems theory has developed strongly over the past 40 years. Modern systems theory is different from general systems approach in several respects (e.g. the allencompassing ambition, the revolutionary glow and the mathematical orientation have been abandoned), but the core ideas remain basically the same (Arbnor and Bjerke, 1997).

- Researchers still attach importance to the systems structures as a whole. Today however, the structure is rarely seen as the only producer of effects or products.
- Systems are still classified into groups, if not by type of structure, then on the basis of the application area (manufacturing system, information system, hospital system, educational system and so on)

Modern systems theory has generally become considerably more concrete, that is, the researchers make explicit what type of real system they create knowledge about. This is partly because the systems approach has for several decades been used by practically oriented researchers to develop theories for a particular type of systems (such as the manufacturing enterprise). These theories are (hopefully) more applicable, but less general.

Examples provided by Arbnor and Bjerke (1997) of theory results within the systems approach includes:

- *Systems models*⁴: to develop new systems models that are valid for more than one real case. These models (like for example the operations model of companies) represent a system, its components and the relationships between them, and may refer to a more or less well-defined class of systems.
- *Concept renewal*: to develop new concepts (such as Computer Integrated Manufacturing) for depicting new problems when earlier concepts are found inadequate
- *Classification mechanisms*: to find suitable mechanisms for separating real systems into different classes. (One example is Anthony (1965) who distinguished among strategic, administrative, and operative control systems).

³ Purposefulness

⁴ A system model is defined as the reproduction of a real system by Arbnor and Bjerke (1997)

• *Guidelines*: to develop guidelines for how to analyse, construct or change systems (Arbnor and Bjerke offers a five step change approach developed by Kanter (1983) as an example: 1. Break with tradition, 2. Crises or galvanising events, 3. Strategic decisions, 4. Individual efforts, 5. Action Instruments)

According to Arbnor and Bjerke (1997), such system theories are based on results from analysis and construction of real systems, and are also the major sources of ideas/concepts/models/guidelines for new system analysis and construction.

Note that every system approach study is based on certain presumptions, (the notion of *system* being the most important one), and it is not possible to approach a system totally free of expectations. At the beginning of a study and as it progress, researchers seem to find certain characteristics and specific behaviours that occur in real systems. These findings and the interpretation of them is usually based on system theory developed in earlier studies. The same characteristics and behaviours found in theory may also occur in the real system being studied. But existing theory may not satisfactorily cover what the study reveals, which can lead to development of new concepts, models etc.

1.3.6 Methodological aspects of the systems approach

In the system approach (as in the analytical approach) the overall purpose is to reproduce objective reality. However, the high level of formalism demanded in the analytical approach is not asked for here. The goals for a systems study can be to determine the type of system, to describe, to determine relations, to forecast, or to guide. This makes the formulation of the problem a more extensive job than for the analytical approach. A researcher cannot start a systems approach study by formulating hypothesis, as in the analytical situation. In analytical theory, hypotheses (possible causal relations) are deduced, and an explanatory study is conducted to attempt to verify or falsify them. Systems theory however, is a source of ideas about how certain characteristics and behaviours of real systems can be focused. It is not before the real systems are contacted (and initially analysed) that the concrete problem to study can be stated.

The system approach is typically a *historical description* or a *case study* (Arbnor and Bjerke, 1997). The more common of these two are the case study, which attempts to examine a contemporary phenomenon in its real life, especially when the boundaries between phenomenon and context are not clearly defined. A case study represents a research strategy "which focuses on understanding the dynamic present within single settings" (Eisenhart, 1989). Case studies have the following characteristics:

- They are typically qualitative studies, but can be based on both qualitative and quantitative evidence (see. e.g. Yin, 1981, Ellram, 1996).
- They are often used to develop new theory or to test particular aspects of existing theory (Meredith, 1998)
- They are particularly suitable when the research questions are "why" and "how" as opposed to the survey research questions of "who, what, where, how many, and how much" (Yin, 1981)
- The result found in a case study can only be seen as fully valid in the system that the researcher has actually studied.

Systems often have existed long before they are studied. It is therefore often essential to explain and understand the background of a real system in order to understand and explain what it is to day – and thereby also its ability to face the future. Historical studies of systems resemble case-studies, but involve some extra difficulties regarding the interpretative work. Documents (reports, minutes, statistics etc.) can be of highly differing quality and character, and the stories told in retrospective are always fragmented, open to interpretations (unless they are about certain facts), and often a matter of rationalisation. Regardless of the chosen approach, certain common methodological aspects still exists for the systems approach (Arbnor and Bjerke, 1997):

- Concentrating on the whole
- Believing that the parts can be explained and understood only in relations to the whole
- Reproducing the relations among the parts and between these and the environment of the real system
- Being prepared to revise the system model because the real system (necessarily) changes
- Accepting that the resulting systems models varies, depending on the researcher

System studies always contain aspect of induction (studies in the field of real individual cases with the intention of finding possible relations). The researchers using the system approach are not dependent on formal theory as researchers in the analytical approach. Using various techniques "correctly" does not guarantee success in the systems approach. Success is associated with imagination, alertness, and awareness when facing the complex reality postulated by this approach. From the assumptions behind the systems approach it also follows that real systems are not usually completely comparable with each other. The researcher cannot safely draw conclusions about any other real system, systems that are outside the selection of cases.

The main lesson learned from this review of the systems approach is that various paradigms will influence research methodology and the methods chosen. Different paradigmatic assumptions will lead to different results. Yet, performed in a structured manner, the results can be scientific. Obviously, results form e.g. the systems approach cannot be evaluated and judged with the same criteria used by proponents of a positivist paradigm. The objective of such research never had the intention of achieving results witch are objective in positivist sense, and which leads to cause and effect explanations.

1.3.7 Research approach in this thesis

The usefulness of the theoretical developments of this thesis for analysing and understanding enterprises is demonstrated in a historical "case" study of the reengineering process that took place at HÅG AS in 1991-1993. The problem at HÅG was a misfit between the operations performance of the enterprise and the market, which required more customisation, shorter delivery times, and higher delivery precision. This was solved by a collaborative reengineering effort carried out by SINTEF and company executives. The study of this process is organised according to the reengineering methodology, and the existing and future state of the system (the manufacturing enterprise) are represented by the operations model-set. However, the major reason for the choice of study is the remarkable effects that were achieved in this reengineering effort. The reengineering at HÅG has been one of the most successful in recent Norwegian history, and demonstrates how a company (through a reengineering for flow manufacturing) can alter the competitiveness radically. The data collection methods used in this study were:

- *Direct observation*. The author has visited HÅG at several occasions, and has gained a good insight in the current situation through direct observations at the plant floor. In addition, the author is currently leading a reengineering of HÅG's core supplier, Protex AS. This provides useful information about the ordering and procurement process, the use of ERP-system etc. at HÅG. The major impression is that, although HÅG has evolved both technically and organisational since 1993, the principal solutions are still the same, and a major source for HÅG's competitiveness.
- *Interviews*. Informal and semi-structured interviews were conducted with persons that were key actors at SINTEF and HÅG in the reengineering process in 1991 1993.
- *Documentation*. Several reports and slide shows that documents (fragments of) the reengineering has been accessed from different sources. In addition, layout drawings, organisational maps, financial reports etc. has been accessed.

Based on these sources, the author has developed a structured report of the major events in the reengineering process. This report provides a holistic and theory-based overview of the process, and should be a major source of inspiration for other manufacturing enterprises that face a competitive situation that requires more customisation, more service and lower prices.

The research of this thesis is also based on a range of *field studies*. The researcher has been involved in two reengineering projects: Mustad (Strandhagen and Alfnes, 1999) and Stabburet (Alfnes, 2000), which has been a major source of inspiration for this research. Furthermore, the enterprise reengineering method developed in this thesis has been used in several recent research projects. These are

- Raufoss Chassis Technology (RCT)
- Hydro Automotive Structures (HAST)
- Protex AS
- Hagen Treindustrier AS

The work carried out in these companies is only documented in SINTEF reports (see chapter 11), and are not included as full case studies in the thesis. The major experience from these field studies is that the enterprise reengineering methodology provides a very useful way to structure a reengineering effort, and also a very useful "toolbox" to support the activities in strategic planning, and operations mapping, analysis, design and implementation.
1.4 Outline



The outline of this thesis is illustrated in Figure 4.

Figure 4 Thesis outline

Figure 4 shows the chapters of this thesis, and is also a framework to understand how the core issues of this thesis are connected. Enterprise reengineering is an approach (Chapter 3) that aims to transform the enterprise from an existing operations model (and the strategic position induced by it), to a new operations model that contributes to an improved future strategic position. This transition is guided by operations strategy (Chapter 2), and supported by:

- Design elements from best practice programmes such as flow manufacturing and lean manufacturing (Chapter 4).
- A modelling architecture for conceptual enterprise modelling (Chapter 5).
- Change management principles (Chapter 6)

These issues are merged in a methodology for enterprise reengineering that encompasses strategic planning (Chapter 7), mapping and analysis (Chapter 8), and, design and implementation (Chapter 9).

Chapter 1 presents the context in which this research has been developed. It outlines manufacturing trends and challenges, the research domain (research topic, research problem, scope, objectives, and limitations), and the scientific approach.

Chapter 2 reviews the field of *operations strategy* as a basis for the developments and concepts presented in this thesis. Different perspectives and definitions of operations strategy are reviewed, and a framework is presented that defines the performance objectives and decisions areas in operations strategy. Operations strategy aims to align market requirement with operations resources, and the operations strategy checklist is presented as a useful device to support operations strategy formulation.

Chapter 3 introduces *enterprise reengineering* as a model-driven approach within enterprise engineering. The chapter has three themes. First, to propose the concept of enterprise reengineering. Second, define the role of enterprise reengineering in operations strategy. Third, to set out a framework to understand enterprise reengineering.

Chapter 4 introduces *flow manufacturing* as an optional design approach for enterprise reengineering. The chapter has four themes. First, to review the basic concepts of flow manufacturing. Second, to compare flow manufacturing with other performance improvement approaches. Third, to outline the design areas flow manufacturing, and, finally, to propose four principles for successful reengineering based on flow manufacturing.

Chapter 5 reviews the field of *enterprise modelling* in order to introduce an architecture for conceptual enterprise modelling. The chapter has three main themes. First, to review the notion of enterprise modelling and different types of enterprise models. Second, to develop an understanding of conceptual enterprise models and what type of problems they are most suited for. Finally, to set out a conceptual enterprise modelling framework termed "the operations model-set" as a support for analysis and design in enterprise reengineering.

Chapter 6 reviews the field of *change management* in enterprise engineering. The chapter has three themes. First, to develop an understanding of enterprise engineering projects as a change process that includes knowledge-creation and political processes. Second, to compare different engineering approaches and their view on change management (i.e. worker involvement and knowledge, political processes and conflicting interests). Finally, to propose seven principles for change management in enterprise engineering projects.

Chapter 7 - 9 proposes *the enterprise reengineering methodology*. The methodology is a procedural guide for strategic planning, mapping, analysis, design, and implementation, and aims to integrate the concepts and models developed in previous chapters.

Chapter 7 provides an overall description of the methodology and the first stage of the methodology: *strategic planning*. That is, how to understand and revise business strategy, how to translate market requirements into performance objectives, and how to evaluate and revise the operations strategy.

Chapter 8 outlines phases two and three of the methodology: *mapping and analysis*. Guidance are provided to the selection of data sources, initial data collection and analysis, and the mapping of the AS-IS operations model. Furthermore, an audit scheme is provided to guide the analysis of critical areas for operations performance and to identify improvement areas.

Chapter 9 outlines phases four and five: *design and implementation*. The basis for this work is the design of a operations model that shows the future solutions for operations. Although the operations model provides a generic representation of the enterprise, it is particularly useful for flow manufacturing reengineering efforts. A

five step approach for flow manufacturing is outlined that encompass to create product focused operations areas, to dimension each operations area in terms of equipment and people, to develop enterprise layout and flow, to design operations area teams, to modify MPC system and information flows. In addition, some guidance for implementing the new operations model is provided.

Chapter 10 presents a *case study of HÅG Fast*, a very successful enterprise reengineering project carried out in 1991-1992. The case study will primarily show how enterprise reengineering contributes to the realisation of strategic priorities. The study will also show the usefulness of the enterprise reengineering framework developed in this thesis, i.e. how it can support understanding and decisions making in a systematic way. Since 1992, elements of the framework has been tested in range of Norwegian companies, however this thesis is the first attempt to provide a complete theory founded and systematic approach to enterprise reengineering.

Chapter 11 concludes and discuss the work presented.

1.5 Abbreviations

AMBIT	Advanced Manufacturing Business ImplemenTation
ANT	Actor Network Theory
APS	Advanced Planning Systems
ARIS	ARchitecture of Integrated Information Systems
ATO	Assemble To Order
ATP	Available To Promise
BPR	Business Process Reengineering
С	Cost
CIM	Computer Integrated Manufacturing
CIMOSA	Computer Integrated Manufacturing Open System Architecture
CNC	Computer Numerical Control
CODP	Customer Order Decoupling Point
CONWIP	COnstant WIP
CPFR	Collaborative Planning Forecasting and Replenishment
DC	Daimler Chrysler
DSS	Decisions Support Systems
EDI	Electronic Data Interchange
EI	Enterprise Integration
ENAPS	European
	Network of Advanced Performance Studies
ERP	Enterprise Resource Planning
ETO	Engineer-To-Order
F	Flexibility
FMS	Flexible Manufacturing Systems
GERA	Generalised Enterprise Reference Architecture
GERAM	Generalised Enterprise Reference Architecture and
	Methodology
GIM	Groupe de Recherche Architecture et Infrastructures (GRAI)
	Integrated Methodology
GM	General Motors
GRAI	Groupe de Recherche Architecture et Infrastructures
GT	Group Technology
HAST	Hydro Aluminium STructures
Ι	Innovation
ICT	Information and Communication Technology
IDEF0	Integration DEFinition language 0
IT	Information Technology
JIT	Just In Time
MADI	Map, Analyse, Design, and Implement
MPC	Manufacturing Planning and Control
MRP	Materials Requirement Planning
MRPII	Manufacturing Resource Planning
MTO	Make-To-Order
MTS	Make-To-Stock
OA	Operations Area
OTED	One-Touch Exchange of Die
Р	Precision

PERA	Purdue Enterprise Reference Architecture
PEST	Political, Economic, Socio-cultural, and Technical analysis
POLCA	Paired cell Overlapping Loops of Cards with Authorisation
Q	Quality
QRM	Quick Response Manufacturing
RCT	Raufoss Chassis Technology
ROP	ReOrder Point
RPA	Rapid Plant Assessment
SLP	Systematic Layout Planning
SME	Small and Medium sized Enterprises
SMED	Single digit-Minute Exchange of Die
STS	Socio-Technical System design
SWOT	Strengths Weaknesses Opportunities Threats
Т	Time
TOP	Towards Optimal Performance
TOPP	Teknologiindustriens produktivitetsprogram
TPM	Total Preventive Maintenance
TPS	Toyota Production System
TQM	Total Quality Management
VMI	Vendor Managed Inventory
WIP	Work In Progress
XML	Extensible Markup Language

1.6 References

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2. Operations strategy

"In today's turbulent competitive environment, a company more than ever needs a strategy that specifies the kind of competitive advantage that it is seeking in the marketplace and articulates how that advantage is to be achieved" (Hayes and Pisano, 1994)

This chapter will briefly review the area of operations management and strategy literature in order to introduce and discuss the fundamentals of an operations strategy. This chapter has five main themes. First, to provide the reader with a clear appreciation of operations, its role in the organisation, and the differences between operations strategy and operations management. Second, to develop an understanding of the nature of operations strategy, and to discuss the various strategic viewpoints and different opinions that exist concerning the nature of operations strategy. Third, to assess what is meant by strategic positioning. Fourth, to set out a framework for operations strategy: its nature and context, its link with the broader business strategy, how it is formulated, and how it is deployed to support the competitive aims of the organisation. Fifth, to propose a strategy checklist to support strategic analysis and formulation.

2.1 Operations management

The value that is added by both operations management and operations strategy is fundamental to most enterprises. Every enterprise provides a product and service combination, and operational activities are central to the provision of those products and services. However, the boundary between what is regarded as operations strategy and what is regarded as operations management is often not clear. In fact, it can never be absolutely clear because an important element in operations strategy is the capabilities that resources and processes demonstrates on a routine day-to-day basis. Nevertheless, although operations management and operations strategy cannot be totally separated, they do have different characteristics.

2.1.1 The contribution of operations management

The term "production management" was predominately used in the past⁵. Indeed, in many manufacturing companies this title is still appropriately in use. However, the enlargement of the role to include responsibilities for other tasks in the value chain, such as procurement and despatch led to a change in title to that of "operations management". Furthermore, the extension of products from pure physical goods to

35

⁵ See Lowson (2002), or Fillipini (1997), or Amoako-Gyampah and Meredith (1989) for a review of the history of operations management and operations strategy.

include services has reinforced the change to using the term "operations management" as a more appropriate, general title.

The subject of operations management covers "the effective planning, organizing, and control of all the resources and activities necessary to provide the market with tangible goods and services" (Waller, 2003). Operations management is a concept that is defined in numerous ways. Virtually every textbook within operations management and strategy provides definitions that are slightly different from others. For example, Chase et al. (2004) define operations management as "the design, operation, and improvement of the systems that create and deliver the firm's primary products and services". Hanna and Newman (2001) define operations management as "the administration of processes that transform inputs of labor, capital, and materials into output bundles of products and services that are valued by customers". For other definitions on operations management, see for example (Reid and Sanders, 2002, Meredith and Shafer, 2002, Slack, Chambers, Johnston, 2004, Harrison, 1993, Hill, 2000, Lowson, 2002).

What is a common understanding in these definitions is that operations management is the management of the operations needed to produce an enterprise's products and services. The enterprise is usually viewed as a transformation process, where input such as material and information are transformed (altered, transported, stored, inspected) into outputs such as products and services (Reid and Sanders, 2002). A simple model of any enterprise is therefore the general input – transformation – output model shown in Figure 5.



Figure 5 The enterprise as a transformation process

Figure 5 shows the authors version of the well-known transformation process model, which is a generic way to describe operations in enterprises (see e.g. Russell and TaylorIII, 1998, or Meredith and Shafer, 2002) for similar models. In this model, the enterprise consists of a transformation process, transforming resources, and a control system. The enterprises take in a set of input resources (such as materials and information) and transform them (utilising transforming resources such as facilities, machines⁶, computers, and people) into outputs of products and services. This transformation process is monitored and coordinated through a control system that collects, process, store and disseminate information about the enterprise and the environment surrounding it.

Most authors also agree that operations management tries to ensure that the transformation process is performed efficiently so that the output is of greater value for the customer than the sum of inputs (see for example Meredith and Shafer, 2002). The type of value added through the transformation process is also defined in numerous ways in literature. From a manufacturing perspective, the transformation adds value to the inputs in (at least) four major ways. The input-resource can be changed directly (e.g. by physical materials into physical products). In addition value can be added through:

- the transportation of products from where they are to where the customer wants them to be;
- the storage of products so they are available for customers; and
- the inspection of products to verify quality and/or performance to a predetermined standard or specification (Meredith and Shafer, 2002).

Such value adding operations are all involved in the physical material flow, and includes inbound handling, production, assembly, packaging, outbound handling, internal transportation, stock keeping, quality control, outbound handling, distribution, and so on. The output is normally a combination of products and services that meets customer needs or expectations.

The products and services that are produced are generally seen as being different, in several ways. Pure goods are usually tangible, can be stored and transported, and the quality is evident. Production of goods normally precedes consumption, and involves low customer contact. Pure services are usually intangible, cannot be stored or transported, and the quality is difficult to judge. Production and consumption of services are simultaneous, and involves high customer contact. The current trend within manufacturing is that the core or tangible product is "layered" with additional services to make the overall package more attractive to the prospective customer. See Figure 6:

⁶ Machines include all types of equipment and vehicles that are used in the physical transformation process. Computers include all types of equipment that are used for information and communication.



Figure 6 The extended product (Jagdev et al, 2004)

This aggregation, which might be termed Extended Products, consists of a tangible (manufactured) product and additional intangible service-based components (Jagdev et. al, 2004). The distinction between products and services is therefore difficult to define and not particularly useful. It is however, important to notice that most products will contain service elements and some services contain tangible products. It is therefore possible to think of products and services in terms of a product-service continuum. Operations management is therefore relevant to all enterprises whether they see themselves as manufacturers or service providers.

2.1.2 Operations in the organisation

Initially, operations management can be considered as being a part of a distinct function producing a product or service combination. Enterprises have traditionally been organised on the basis of the type of work performed. Thus, enterprises were divided into marketing, finance, accounting, engineering, operations and other departments. This type of organisation is referred to as a functional organisation because work is organised on the basis of the function performed. In the functional view, all enterprises must perform a few core functions, in which one of them is operations. This view is adopted by many authors within operations management (see for example Hill 2000, Reid and Sanders, 2002, Hanna and Newman, 2001).

In the functional view, operations management can be considered as being a part of a distinct function producing a product or service combination. One example of the functional view is provided by Slack et.al. (2004), which defines operations as one of three core functions in any enterprise. These are:

- the marketing function (including sales) is responsible for communicating the organisation's products and services to its markets in order to generate customers requests for service;
- the product/service development function which is responsible for creating new and modified products and services in order to generate future customer request for service;
- the operations function which is responsible for fulfilling customer request for services throughout the production and delivery of products and services.

In addition, there are the support functions which enable the core functions to operate effectively. These include:

- the accounting and finance function which provide the information to help economic decision-making and manages the financial resources of the organisation.
- the human resources function which recruits and develops the organisation's staff as well as looking after their welfare.

- the information/technical (IT) function.
- the engineering/technical function.
- others.

This functional view tends to be rather narrow as it applies to core conversion processes (mostly manufacturing). Every organisation that offers goods or services has an operative activity. As far as the organisation structure concerned, some enterprises will have a discrete operations function. This might be called a manufacturing department, an operations systems, or have no identifiable name at all. It is important to stress that functional names, boundaries and responsibilities vary between enterprises, and also that there is no clear division between the operations activity and other activities like marketing and finance. This aspect has recently become increasingly valid as many enterprises have recognised the need for better methods for grouping and integrating organisational activities.

Authors like Lowson (2002), Waller (2003) and Slack and Lewis (2001) has therefore expanded the operations management concept beyond just internal production or operations. A more wide definition on operations management is for example provided by Slack and Lewis (2001), who define operations management as "the activity of managing the resources and processes that produce and deliver goods and services". This implies that the operations management concept encompasses other activities such as procurement, distribution, product and process design, etc. Further, it includes external management responsibilities at a value chain level, covering a number of interconnections between external firms. In this view, operations management covers operational activities throughout the enterprise and its value chain, whether performed by an individual, group, unit or department. These activities and their various interfaces can be best viewed as a number of processes. Operations management is concerned largely with the way in which these processes are managed. Typical tasks include designing processes, choosing and maintaining process technologies, designing the jobs of the operation's staff, planning and controlling activities, ensuring quality standards, improving operations performance, and so on.

2.1.3 Operations strategy versus operations management

If one accepts the previous definition of operations management, it becomes clear that operations has a strategic contribution to make in supporting the needs of customers and consumers. Operations strategy is concerned more or less with the same set of resources as operations management and has broadly similar objectives. However, there are some differences that are important, and that will be further elaborated in this chapter. Operations management is concerned with the operational efficiency of an enterprise, while the operations strategy is aimed at performing key operational activities better than rivals, and to create a sustainable competitive advantage. Or to put in another way, "whereas the operational role is to do things right, the strategic role is to do the right things" (Hill, 2000).

Another major difference is one of perspective. Where operations management deals with relatively immediate, narrow, specific and often tangible issues, operations strategy is more far reaching, broader, generalised, and treats the underlying principles. The differences between the operations management and operations strategy perspectives have been summarised by Slack and Lewis (2001). Operations

strategy operates on a longer time scale – years rather than days or months. The level of analysis is usually higher; it is concerned primarily with the whole enterprise rather than the constituent parts of the enterprise. Also, decisions are made with more aggregated data rather than with the detailed data used in operations management. Finally, operations strategy is concerned with a greater level of abstraction, dealing in overall concepts and approaches rather than the specific localised solutions.

The role of operations in the enterprise and its contribution to competitiveness should now be understood. The next section will review the notion of operations strategy, and its perspectives and definitions, in order to choose a good definition of operations strategy.

2.2 The nature of operations strategy

Competitive strategy is about difference, the choice of certain activities to deliver a unique value-mix to a selected market. Strategy, then is first about choices. Choices concerning markets, products and service combinations, resources in their widest sense and directions for the future.

2.2.1 What is strategy

The classical view is that strategy can be described as an enterprise's sense of purpose – a guiding purpose or policy, a focus statement, even a philosophy, for the achievement of an objective. It is the mapping of future directions that need to be adopted using the resources possessed. This view is held, among many others, by Bourgeois III (1980), who states that "the strategy concept has its main value, in determining how an enterprise defines its relationships to its environment⁷ in the pursuit of its objectives".

The study of competitive strategy is a relatively recent phenomenon, and the word strategy was first popularised in the business literature by Alfred Chandler in his 1962 book Strategy and Structure. Since then, the study of strategy has had a tremendous popularity. However, uniform treatment of the strategy concept is not evident in the definitions found in literature, and this lack of uniformity has led writers to point out that it is still not clear what strategy is (Bourgeois III, 1980). Mintzberg (1990) who has made extensive review of strategy literature has a similar view, and claims that "the starting point for research should increasingly be case and context as opposed to concept".

A general discussion about strategic management is outside the scope of this thesis. As far as the term "strategy" concerned, the author will assume that when an enterprise formulates its strategy, it is going to pursue this direction rather than

40

⁷ Markets, competitors, and so on.

another. Decisions have been made that commit the enterprise to a particular set of actions. The pattern of subsequent decisions then reflects the continuing commitment to this direction. Alternatively, if the pattern of its decisions changes, this indicates some change in its strategic direction. Strategic decisions usually mean those decisions which:

- are widespread in their effect on the enterprise to which the strategy refers
- define the position of the enterprise relative to its environment
- move the enterprise closer to its long-term goals.

Moreover, a strategy is more than a single decision; it is the total pattern of the decisions and actions that position the enterprise in its environment and that are intended to achieve its long-term goals.

2.2.2 The strategy hierarchy

Even though the lack of uniformity has hindered theoretical and empirical development of the concept, one can find a distinction between three levels of competitive strategy: corporate, business and functional. Most enterprises have a corporate strategy at the highest level. This seeks to determine the industries and markets in which the firm will compete. Investments, vertical integration, acquisitions, and allocation of resources to business units will all be the type of decisions made at this level. The business strategy is concerned with how each factory or business unit competes in a particular industry of market to establish competitive advantage (Bourgeois III, 1980). The next level of strategy concerns the functions and the so-called functional strategies, to support the achievement of the corporate and business strategies. Finally, the various strategies are deployed in the form of short-term tactics. The strategy hierarchy is illustrated in Figure 7.



Figure 7 The strategy hierarchy

Figure 7 shows the hierarchy for competitive strategy. Each company has several business strategies that support the corporate strategy, and each business strategy is supported by functional strategies such as a marketing strategy, an operations strategy, and a product strategy.

2.2.3 Operations strategy development

The more traditional view is that operations strategy is one of several functional strategies that are governed by decisions taken in corporate and business strategies. This view is based on the belief that senior managers can objectively appraise the enterprise, its resources and its environment, to formulate strategies that will maximise the chances to success in an uncertain future. After that, they can implement this strategy in a rational and logical way in order to achieve the desired consequences

(Mintzberg, 1990). This view is held by leading authors like Skinner (1969), Hill (2000), and Fine and Hax (1985) who state that the operations function should develop a task or mission in order to support the overall competitive strategy of the enterprise. Skinner (1969) for example, suggests that "a company's competitive strategy at a given time places particular demands on its manufacturing function, and conversely ...the manufacturer posture and operations should be specifically designed to fulfil the task demanded by strategic plans". In this view, the three levels of competitive strategy – corporate, business, and functional – form a hierarchy with business strategy forming the context of functional strategies and corporate strategy forming the context of business strategy. Everything about the operations, its technology, staff, systems, and procedures must be developed to support the overall competitive strategy.

Opponents of the traditional view will suggest this is largely a fiction. The process is less structured and more diffuse. The dichotomy between formulation and implementation is less apparent. Although the rational, logical and hierarchical perspective is a convenient way of thinking about strategy, this approach does not represent the way strategies are always realised (Mintzberg, 1990). Therefore, an alternative view is that many strategic ideas emerge over time from actual experiences. Mintzberg (1978, 1985, 1988) is one of the leading protagonists of this view, which is illustrated in Figure 8.



Figure 8 Types of strategy (Source: Mintzberg and Waters, 1985)

For Mintzberg, although senior management may have an intended strategy in mind, its development is far from rational as a process of negotiation, bargaining and compromise, involving individuals and groups, which will decide its final shape. However, and here is the real difference, the deliberate strategy (that reflects the strategy originally intended) will only constitute 10 - 30 per cent of the realised strategy. In other words, a strategy will emerge, incrementally, with patterns of decisions adapting to evolving external circumstances. Henry Mintzberg (1987) uses the term crafting strategy to contrast this view from the rational planning approach, and to highlight that the enterprise must learn from daily experiences and make adjustments in that light.

In reality, strategy development involves elements of both views described above. Business strategies will be evaluated in terms of how they make sense in the context of the corporate strategy, and operations strategies (especially because operations includes most of the enterprise's resources) can not afford to be in conflict with the overall strategy. Yet the strategic direction of any enterprise will be strongly influenced by day-to-day experiences. Operational issues set practical constraints for the business strategy (which in turn influences the corporate strategy), and moreover, the day-to-day experiences in operations can be exploited in the development of overall strategies. Thus, the most realistic view of strategy development is that there must be an alignment between higher and lower level strategies. A realistic approach to operations strategy development should incorporate that corporate objectives impact on business objectives, which in turn, influence operations strategy. Moreover, that day-to-day experience of providing products and services to the market reveals problems and potential solutions, which in turn become formalised into operations strategy.

2.2.4 The market perspective

Traditionally, the starting point for operations strategy analysis has been the market perspective. The operations should be specifically designed to fulfil the operations task or mission demanded by marketing strategic plans. Skinner (1969) for example, states that "Different marketing strategies and approaches to gaining a competitive advantage places different demands on the manufacturing arm of the company. Each strategy creates a unique manufacturing task".

The market perspective dominated strategic thinking in the 1970s and 1980s. See Lowson (2002) for an overview of the evolution of strategic management. This view in strategic thinking has an external orientation, and focuses on the environmental-based opportunities. The leading proponent of this view is Michael Porter (1980, 1985). In his book Competitive Strategy (1980), he introduced the five forces model and the concepts of generic strategies. Essentially, he postulates that there are five forces that typically shape the industrial structure:

- intensity of rivalry among competitors;
- threat of new entrants;
- threats of substitutes;
- bargaining power of buyers; and
- bargaining power of suppliers.

These five forces delimit prices, costs and investments requirements, which are the basic factors that explain long-term profitability prospects and henceforth, industry attractiveness.

Porter (1980) argues that it is not the type of industry that counts for competitiveness, but where the enterprise wants to position itself in the marketplace. He offers an enterprise three generic strategies to cope with the competitive forces and achieve sustainable competitive advantage: overall cost leadership (traditionally based on economics of scale); differentiation (offering a product or service perceived in the industry as unique); and focus (using the low cost or differentiation in a niche or narrow segment). These three strategies are illustrated in Figure 9.

Strategic Advantage



Figure 9 Porters generic strategies (Source: Michael Porter, 1980)

Porter presents cost leadership and differentiation as the only two ways to compete in the marketplace, and argues that an enterprise seldom can achieve these two capabilities simultaneously, because they imply conflicting trade-offs that cannot be overcome. Enterprises that engage in more than one are in danger of failing to achieve any of them – it is stuck in the middle, and will be much less profitable than rivals achieving one of the generic strategies (Porter, 1985). In the last two decades, however, there has been several cases where enterprises are "stuck in the middle", and still are able to be competitive⁸, for example by developing operations for mass production of individually customised products (see for example Alfnes and Strandhagen, 2000).

Despite that the market-driven view is still widely held (for example by Hill, 2000), there are those that reject many of the aspects of this approach. A major critique is that the market view primarily focuses on the external environment at competitors, markets, and trends in order to identify strategic opportunities, and then develop the internal capabilities to capitalise on those opportunities. Authors like Russell and TaylorIII (1998) argue that the trouble with this approach today is that by the time new capabilities are developed, the opportunity may have passed and the strategies become obsolete. Furthermore, that leading enterprises focus more on building basic internal capabilities than on achieving specific marketing or financial goals. They develop the capabilities first, then look for opportunities to use the capabilities.

2.2.5 The resource perspective

An alternative perspective to the market view is the resource based view. The market perspective focuses on the forces present in the environment, in order to design a strategy that aligns the enterprise to the environment. The resource-based explanation,

44

⁸ The general opinion has been that companies can be all things to all people, or most of them anyway. Positioning, in this view, is an effort to drive the largest possible wedge between cost and differentiation (or price).

by contrast, focuses on the role of the resources that are largely internal to the enterprise's operations. A resource can be defined as the basic element that an enterprise controls in order to best organise its operations process. A person, machine, raw material, knowledge, brand image and a patent can all be viewed as examples. The resource based view argues that competitiveness is more likely to be the result of the core capabilities (or competencies) inherent in an enterprise's resources than its competitive positioning in its industry. The leading proponents of this view are Prahalad and Hamel (1990, 1994). They introduced the notion of core competencies, a term that encompasses resources, skills and technologies in their analysis.

Although Prahalad and Hamel (1990) largely focus on production and product technology, the basic message in their viewpoints is still valid. The development of capabilities is a strategic issue that is crucial in order to gain a sustainable advantage in the marketplace. Prahalad and Hamel (1990) established three main ideas in their paper.

- First they state that the roots of competitive advantage "derives from an ability to build, at lower cost and more speedily than competitions, the core competencies that spawn unanticipated products. The real sources of advantage are to be found in management's ability to consolidate corporate wide technologies and production skills into competencies that empower individual business to adapt quickly to changing opportunities".
- Second, they postulate that "the tangible link between identified core competencies and end products is what they call core products the physical embodiment of one or more core competencies".
- Third, they state that "senior management should spend a significant amount of its time developing a corporate-wide strategic architecture that establishes objectives for competence building. Strategic architecture is a road map of the future that identifies which core competencies to build and their constituent technologies".

The essence of this view is its focus on the individual resources and capabilities of the enterprise, rather than on the strategies that are common to all competitors in the industry. Understanding the industrial environment is important but enterprises should seek their own individual solutions in that context. The term core capabilities (or competencies) is used to describe those unique aspects of operations through which the enterprise compete. They are usually built up over time and cannot be easily imitated (Prahalad and Hamel, 1990). The core capabilities can be related to a specific material (e.g. aluminium), a technology, a market segment etc. To be successful, companies must identify and prioritise capabilities that will be required even as products come and go, and devote manufacturing resources to acquiring them (Spring and Boaden, 1997). Many of the operations capabilities derive from the way resources are deployed to form processes and the fit that these resulting processes have with the enterprise's strategy within its markets. Capabilities can therefore be defined as those combinations of organisational resources and processes that together underpin sustainable competitive advantage for a specific enterprise competing in a particular product and service market (Slack and Lewis, 2001).

The market perspective and the resource perspective that are outlined represent two starting points for understanding the nature of operations strategy. Whether one adheres to the resources-based or market-driven viewpoint, the comments made earlier in this chapter still hold true: strategy is about difference, the choice of certain activities to deliver a unique value-mix to a selected market. Porter (1996) also suggests this in his later work, where he argues that "The essence of strategy is in the activities - choosing to perform activities differently or to perform different activities than rivals". Choices have to be made concerning strategic positioning and the use of particular resources, processes and capabilities. Therefore, the two perspectives on strategy need not necessarily conflict. The objective of operations strategy should be to align the capabilities of its operations resources with the requirements of its markets.

Operations strategy is clearly part of a company's competitive strategy, but most authors on the subject have slightly different views and definitions. Based on the review of this section, the author argues in line with Slack and Lewis (2001) that there are four important perspectives on operations strategy:

- The realised operations strategy is a reflection of a business strategy (a rational perspective)
- The realised operations strategy is the result of daily operations improvements and experiences (a process perspective)
- Operations strategy involves to translate market requirements into operations decisions (a market-driven perspective)
- Operations strategy involves to exploit competitive capabilities in chosen markets (a resource-based perspective)

Together these perspectives provide some understanding of the pressures that forms operations strategy. Next, some authors are represented in order to select a definition that encompasses these four perspectives.

2.2.6 A definition of operations strategy

Various researchers have interpreted operations strategy. To get an overview of different topics that are explored, see for example Dangayach and Deshmukh $(2001)^9$, which have made an comprehensive literature review of operations strategy in manufacturing, including 260 articles from 31 reputable journals and international conferences.

The term manufacturing strategy was predominantly used in the past, and many of the core ideas and concepts of operations strategy stems from the manufacturing strategy literature. The earliest work on manufacturing strategy was developed by pioneers like Skinner (1969), and Hayes and Wheelwright (1984). Skinner defined strategy as a set of plans and policies by which a company aims to gain advantage over its competitors, and saw manufacturing strategy as way of linking operations to corporate strategy. Hayes and Wheelwright (1984) have closely followed in Skinner's lead by defining manufacturing strategy as a consistent pattern of decision making in the

46

⁹ Even though their title is "Manufacturing strategy: literature review and some issues", manufacturing strategy and operations strategy articles are reviewed interchangeably

manufacturing function which is linked to the business strategy. Another important contributor is Hill (2000), who states that manufacturing strategy represents a coordinated approach, which strives to achieve consistency between functional capabilities and policies for success in the marketplace. The major concepts and ideas of these authors will be further elaborated in this thesis.

A more recent title to the strategic management of manufacturing operations is "operations strategy". The major reasons for this is, as argued earlier, to emphasis that the role of operations should be enlarged to include the responsibility for other tasks in the value chain, and also because many enterprises produce a mix of products and services. Operations strategy is therefore a more appropriate, general title.

Not many authors are prepared to give a definition of operations strategy, and there are several examples of books that are devoted to operations strategy aspects without defining what operations strategy is. See for example Harrison (1993), or Walters (2002). Some definitions can be found in operations management textbooks. Hanna and Newman (2001) states that "the set of decisions made in a firms's operations management function is its operations strategy". Reid and Sanders (2002) define operations management as "a long-range plan for the operations function that specifies the design and use of resources to support business strategy". However, these definitions provide a rather narrow and simplistic view on operations strategy. Neither of these definitions highlight the fact that operations strategy might encompass other activities throughout the enterprise or value chain, and they view strategy more as a single set of decisions, than a pattern of subsequent decisions that are developed over time.

A more comprehensive definition is provided by Lowson (2000), who define operations strategy as the "major decisions about, and strategic management of: core competencies, capabilities and processes, technologies, resources and key tactical activities necessary in any supply network, in order to create and deliver products and service combinations and the value demanded by a customer". This definition covers all activities that add value to the final customer, and highlights that operations strategy includes the management and modification of strategic decisions over time. However, the definition is unnecessary complex, especially since Lowson does not provide a clear description of the differences between core competencies, capabilities, processes, technologies, resources and key tactical activities.

The most suitable definition to underpin the strategic framework of this thesis is provided by Slack and Lewis (2001). They state that "Operations strategy can be defined as the total pattern of decisions that shape the long-term capabilities of any type of operation and their contribution to overall strategy through the alignment of market requirements with operations resources". The original definition uses the term reconciliation instead of alignment, but this change of terminology does not change the meaning of the definition. Namely that operations strategy is the pattern of strategic decisions that evolve over time regarding all types operations activities, both in the manufacturing and in the service sector, and also throughout the value chain. Furthermore, that operations strategy is contributing to the overall strategies regarding capabilities and market position through the alignment of market requirement and operations resources. In the author's opinion, their definition brings the different perspectives discussed earlier together in a single statement, which can be easily used as the fundament for a strategic framework of operations.

2.3 A framework to understand operations strategy

Operations strategy, like any strategy, revolves around a pattern of choices. The pattern of decisions tends to be of a medium to long-term nature, and should reflect the business in which the enterprise is embedded. When enterprises develop strategies they must consider two separate but overlapping sets of issues. The first is concerned with what is known as the content of the strategy. These are the specific strategies and actions which are the subject of the decisions-making, that is, the "what" questions of strategy. The second set of issues, is concerned with the process of how these decisions are actually determined and implemented in the enterprise. The strategy process governs the procedures and models which are used to make strategic decisions - the "how" questions of strategy. This section will largely focus on the content of operations strategy, which comprises the specific decisions and actions that set the operations role, objectives and activities. The process of formulating and revising the operations strategy will be elaborated in chapter 2.5.

2.3.1 Operations strategy framework

The operations strategy framework (adapted from Slack et. al., 2004) illustrates the different overall perspectives discussed in this thesis regarding operations strategy.



Figure 10 Operations strategy framework (Source: Slack et. al. 2004)

The framework in Figure 10 present operations strategy along two axis. The vertical axis illustrates its role as the link between overall strategy and daily operations, and the horizontal axis illustrates its role as an intermediator between market requirements and operations resources. The idea that underpins this framework is that operations strategy is an ongoing and iterative process that aims to align requirements and experience from the different sources in a consistent pattern of decisions.

The vertical axis in the framework illustrates operations strategy's link to the overall strategy. Corporate objectives impact on business objectives, which in turn governs the operations strategy. However, the framework also illustrates the major role of the day-to-day experience of providing products and services to the market, which reveals

problems and potential solutions. In real life, the daily operational experience has a strong influence on the strategic direction, or mission, of operations activities. The operations strategy should therefore be viewed as a pattern of subsequent decisions that seeks to deploy overall strategy and adapt to daily experience. The major contribution from this view is that overall strategies and operational experience must be aligned, and that the formulation of the operations mission, at least partly, should be shaped by the knowledge gained in day-to-day activities.

The horizontal axis in the framework illustrates operation strategy as an intermediator between operations resources and market requirements. An enterprise's market position defines how it wishes to attract customers relative to their competitors. Any operations strategy should reflect the intended market position of the enterprise. Enterprises compete in different ways, that is, their intended market position differ. Some may compete entirely on costs, others differentiate themselves from competitors by the quality of their products and services or by customising their products and services to individual customers need, and so on. The operations activity must respond to this by providing the ability to perform in a manner appropriate for the intended market position of the company. However, a successful operations strategy is not just a matter of selecting the current market position and then adjusting the operation's various resources and processes to fall in line. Operations resources are often complex to manage, and cannot easily be adapted to a new market position. The potential inherent in resources is realised largely in the way the enterprise arranges its resources into processes (what it does). Some resources and processes are particularly influential in determining a competitive advantage, and gives the enterprise a set of core capabilities with which it can establish, excel and protect itself in its market. In most enterprises, the capabilities of its operations resources are unlikely to be in perfect alignment with the requirements of its markets. The framework illustrates that the objective of operations strategy is to attempt this alignment over time through an ongoing and iterative process.

The next sections will review and discuss operations strategy in terms of performance objectives and decisions areas. The operations strategy framework of Slack et. al. is valid for all types of operations, both in manufacturing and service enterprises. However, the following review will mainly focus on objectives for manufacturing operations, which is the main concern of this thesis.

2.3.2 Performance objectives for manufacturing

Any operations strategy must aim to provide the performance objectives that are required for a certain market position. Developing and understanding markets are usually thought of as the domain of marketing, which aims to identify and anticipate customer requirements. Descriptions of market needs developed by marketing professionals then usually need to be translated in order to be useful for the development of the operation. This can be achieved by grouping competitive factors into clusters under the heading of generic performance objectives. Many authors have defined their own set of generic performance objectives, and no overall objectives exist on either the terminology to use when referring to these objectives or what they are. They are referred to as competitive criteria, competitive priorities, competitive capability, manufacturing objectives, and performance objectives (Spring and Boaden, 1997, Hayes and Schmenner, 1978, Miller and Roth, 1994, Fine and Hax, 1985, Slack and Lewis, 2001, among others).

Performance objectives can be viewed as a consistent set of goals for manufacturing operations (Leong et al, 1990). The performance objectives states how manufacturing operations will be developed to provide competitive advantage in the marketplace. The choice of competitive priorities in its simplest form is between seeking high profit margins or high output volumes (Hayes and Schmenner, 1978). This can be expanded and enriched however, since enterprises can compete in other ways than simply through the prices of their products. An enterprise may seek competitive advantage through generic strategies of cost leadership, differentiation, and focus (Porter, 1980). The operations activity translates these advantages into at least four groups of performance objectives; flexibility, quality, cost and time (Skinner, 1969, Hayes and Wheelwright, 1984, Fine and Hax, 1985, among others). Innovativeness is sometimes included as a fifth group.

The choice of performance objectives for the enterprise must be based on the market requirements in a certain market segment. Hill (2000) has developed the concept of "order qualifiers" and "order winners" that can be used to determine an operations strategy. These are the competitive criteria (or performance levels) that enable the products to qualify and win orders in the marketplace. The relevant order winners and qualifiers of differing levels of importance are market and time specific. One year a company might win orders by providing improved delivery times, the following year they will have to continue to provide this delivery time in order to qualify for the market. Each market/product combination requires a operations strategy that enables the product to win orders in the current market conditions (Hill, 2000).

One key to a successful operations strategy then, is to prioritise between different performance objectives that position the enterprise on the marketplace. The performance objectives have been thoroughly elaborated and defined in the literature. Each author has his own interpretation of which generic objectives that are important, and how they should be defined. For example, Hayes and Schmenner (1978) argue that most companies emphasise one of the following performance objectives - price, quality, dependability, product flexibility, and volume flexibility – and that managers have to make trade-offs¹⁰ between them. Hayes and Wheelwright (1984) argue that cost, quality, dependability, and flexibility are the most relevant performance objectives, while Miltenburg (1995) argue that it is cost, quality, product performance, delivery time and reliability, flexibility, and innovativeness.

Based on a recent review of manufacturing and business marketing literature, Spring and Boaden (1997) list the following performance objectives:

• Cost: production and distribution of products at low cost

50

¹⁰ The significance of the trade-off concept will be further discussed in chapter 2.3.4.

- Quality: manufacture of products that conform to specifications and critical customer expectations.
- Delivery precision¹¹: meet delivery schedules
- Delivery time: react quickly to customer orders for fast delivery
- Flexibility: react to changes in product, changes in product mix and volumes, modifications to design, fluctuations in materials, changes in sequence
- Innovativeness: Introduction of new products and processes

According to Spring and Boaden (1997), there is a considerable agreement in literature, particularly on price, quality and delivery. Hill (2000), however, has also defined a range of other competitive factors (such as colour range, product range etc.), but these can be understood as forms of flexibility, innovation and quality. This leaves Hill's criteria "technical support" as outside the criteria normally adopted in the operations and manufacturing strategy literature (Spring and Boaden, 1997).

In this operations strategy framework, the performance objectives developed by Spring and Boaden (1997) are adopted. The performance objectives are now examined in a more detail:

Cost

Competing on costs means offering a product at a low price relative to the prices of competing products, or to offer the same price and gain higher margins. Enterprises that compete on costs relentlessly pursue the elimination of all waste. Manufacturing enterprises in this category are traditionally producing standardised products for large markets. They improve profit by stabilising production processes, tightening productivity standards, and investing in automation (if automation is most cost efficient). However, today the entire cost structure is examined, not just direct labour cost. Cost saving efforts are also related to materials, machines and facilities, administration, inventory, distribution etc.

Quality

The concept of quality has been broadened to encompass many dimensions, and seems to embrace every aspect of the manufacturing enterprise. See for example Garvin, D.A. (1987), who identified eight dimensions of quality: performance, features, reliability, aesthetics, durability, conformance, serviceability, and perceived quality. In the context of manufacturing operations, quality should mainly be viewed as conformance – making a product to specifications (Hill, 2000). Another quality dimension that is included by some authors are product performance, which is related to the specifications of the product that affect the product's ability to do what other products cannot (see for example Miltenburg, 1995). Enterprises that compete on quality have to develop operations. The specified product performance therefore has a major impact on how equipment, workers, materials, and every other aspect of

51

¹¹ Spring and Boaden use the term *delivery dependability* for this priority

the operation should be designed in order to make sure it works the way it is supposed to.

Delivery time and precision

Enterprises in many industries (e.g. Dell computers) are competing to deliver highquality products in as short a time as possible. Delivery time is the amount of time a manufacturer requires from receipt of order to the product is delivered to the customer. Delivery speed is easily achieved in enterprises that can deliver standard products from a stock of final goods. However, for enterprises that make products to order, the delivery time may involve all processes in the order cycle. This includes inside sales, order entry, engineering and process planning (if product customisation is necessary), manufacturing planning, materials procurement and preparation, order scheduling, fabrication and assembly processes, testing, packaging, shipping, and distribution (Suri, 1998). When delivery time is a performance objective, the enterprise should be critically analysed, and processes should be combined or eliminated in order to save time. This can imply the use of technology (e.g bar codes) to speed up the processes, to rely on a flexible workforce to meet peak demand periods, and eliminate unnecessary steps in processes.

Often the delivery time is well known and used to give delivery promises to customers. Delivery precision is the amount of orders that are delivered according to the delivery schedule that was promised to the customer. In many businesses this criterion now constitutes a order qualifier (Hill, 2000). Enterprises that continue to miss due dates will not be seen as potential suppliers by customers, and will not be able to compete.

Flexibility and innovativeness

An enterprise with flexible operations can offer a range of products and customise them to the unique needs of the customer. However, flexibility is a concept that has been interpreted in many ways, and some of the definitions are so broad that the usefulness of the concept has greatly dismissed. See for example Browne et. al (1984), who made definitions for machine flexibility, process flexibility, product flexibility, routing flexibility, volume flexibility, expansion flexibility, operations flexibility, and production flexibility. A literature review by Suarez et al (1995) also points out that there exists many kind of flexibility whose definitions often overlap. Among the different flexibility types that are defined in literature, some types are more relevant for operations competitiveness, for example:

- Product flexibility the ability to customise products to the unique needs of customers
- Mix flexibility the ability to change the mix of products being produced within a given time period
- Volume flexibility the ability to adjust capacity rapidly
- Delivery flexibility the ability to change planned or assumed delivery dates

In an operations perspective, innovativeness can be perceived as the ability to introduce new products rapidly, or to rapidly make new design changes to existing products. Superior methods for developing, manufacturing and introducing new products can be a key to market dominance. Each of the other performance objectives (cost, quality, delivery time, delivery precision, and flexibility) also have potential benefits for market competitiveness (see Figure 11).



Figure 11 Competitive advantages through operations performance

Figure 11 shows some of the competitive advantages that can be achieved in the market through superior operations performance:

- Competing on cost enables low prices or higher margins.
- Competing on quality means offering a product that is error-free and reliable, and with high performance in the eyes of the customer. The potential benefits for operations are error-free processes, less disruption and complexity, less waste and rework, more reliability, and lower processing costs.
- Competing on delivery time means offering short delivery times, and fast response to requests. The potential benefits for operations are faster throughput times, less inventories, lower overheads, and lower processing costs.
- Competing on delivery precision means offering on-time delivery and arrival of products at a certain delivery time. The potential internal benefits are higher confidence in the operation, less safety inventory needed, fewer contingencies needed, more stability and lower processing costs.
- Competing on flexibility means offering a wide range of products or customise products to customers needs, and be able to adjust volumes and sequence of the deliveries to the demand situation. The potential benefits for operations are better response to unpredictable events and variations in the demand situation, and lower processing costs (Slack and Lewis, 2001).

2.3.3 Some typical performance measures

The six performance objectives – cost, quality, delivery time, delivery precision, flexibility and innovativeness – are really composites of many smaller measures. Some popular performance measurement systems are the TOPP approach, the TOP approach, the ECOGRAI approach, the "balanced scorecard" approach, the ENAPS approach, and the AMBIT approach. Each of these contains comprehensive lists of performance measures that cover some, if not all, business processes of an enterprise. See Jagdev et. al (2004) for a review of these approaches. Some work has been done to compile lists from literature of the most typical performance measures for operations. Table 2 shows some typical measures provided by the lists of Leong et. al. (1990), and Slack et al (2004).

Objective	Some typical measures
Cost	Cost per operation hour
	Total operation overhead cost
	Inventory turnover – work-in-process, raw materials, finished goods
	Capital productivity
	Capacity/resource utilisation
	Materials utilisation
	Labour productivity
Quality	Number of defects per unit
	Level of customer complaints
	Warranty claims
	Scrap level
	Mean time between failures
	Incoming supplier quality
Delivery	Percentage of on-time deliveries
precision	Proportion of products in stock
	Average delay of orders
	Mean deviation from promised arrival
	Accuracy of inventory status
	Schedule performance/stability
Delivery time	Customer query time
	Order lead time
	Throughput time
	Delivery cycle lead time
Flexibility	Number of products in the product line
	Number of available options
	Minimum order size
	Set-up time
	Average production batch size
	Time to change schedules
	Average capacity/capacity limit
	Time to increase activity rate
	Number of parts it is possible to produce on different machines (from invariable sequence to random
	processing)
Innovativeness	Number of new products introduced per year
	Time needed to develop new products
	Level of R&D investments
	Consistency of investments over time

Table 2 Some typical partial measures of performance

The list should be viewed as possible measures to quantify the degree to which an operation fulfils the six performance objectives. In order to support it's performance objectives, each enterprise needs to determine which performance measurements to use and the performance levels to acquire. However, operations strategy is not about measuring, but about choices. Performance objectives are the dimensions of an operation's performance, with which it will attempt to satisfy market requirements. An enterprise therefore needs to prioritise the performance objectives it aims to pursue in order to achieve a certain position in the market.

2.3.4 Positioning and trade-offs

Enterprises can outperform rivals only if they can establish a difference that they can preserve. Operations strategy is about being different. "Strategy is the creation of a unique and valuable position, involving a different set of activities. If there were only one ideal position, there would be no need for strategy" (Porter, 1996).

For operations strategy, strategic positioning means to prioritise the performance objectives to pursue in order to gain sustainable competitiveness. The earlier work on performance objectives by Skinner (1969) argued that manufacturers had to choose. One enterprise can not be best in everything at the same time (cost, quality, delivery time, delivery precision, flexibility and innovativeness), and is forced to compromise. There are *trade-offs* to be made, and these trade-offs are particular for the enterprise. "Like a building, a vehicle, or a boat, a production system can be designed to do some things well, but always at the expense of other abilities" (Skinner 1969). Operations trade-offs is one of the major concepts in operations strategy research, and the trade-offs between different performance objectives is often regarded as the key to a successful operations strategy. Spring and Boaden (1997) even claim that "the original big idea of manufacturing strategy was the trade-off".

The basic argument of Skinner (1969) is that manufacturing operations cannot be good at everything and so managers must decide which one or two performance objectives they want to be good at – the rest will have to suffer. "You can't have it both ways" (Skinner, 1969). However, when Japanese techniques and principles (like just-in-time production and total quality management) were introduced, it became clear that it is possible to pursue several priorities simultaneously. An alternative school of thought emerged. Some authors, like Schonberger (1986) questioned the whole idea of trade-offs, suggesting that "world class manufacturing" enterprises could outperform competitors in many areas simultaneously. Trade-offs were a "myth", which held back operations managers from addressing what should be their prime concern of improving operations.

The trade-off principle is now subject to a debate and revision (see for example Skinner, 1992). Skinner (1969) was happy enough to trade-off cost against quality: assuming he meant conformance quality, there is a good deal of evidence that these objectives, far from being mutually exclusive, can be mutually reinforcing, that is, improving conformance can reduce costs (Womack et. al., 1990). Similar debates are under way regarding other pairings of criteria, for example cost and product flexibility (Pine, 1993). Skinner however, although he has subsequently modified his original ideas, maintains their essential validity: "Trade-offs…are as real as ever but they are alive and dynamic" (Skinner,1992).

A review of the trade-off literature by Silveira and Slack (2001) suggested that there is still no consensus either to corroborate entirely or dismiss entirely the trade-offs concept. If some pair of competitive priorities trade-off and others do not, authors disagree as to which they might be. Silveria and Slack also tested the trade-off concept in a case study, and concluded that trade-offs still are a central concept to how managers approach the process of improvement. Furthermore, that trade-offs still are perceived to exist even if the performance of several priorities can be improved simultaneously. An empirical testing of the product-process matrix by Safizadeh et al. (1996) also supports the existence of trade-offs, and especially the trade-off between product flexibility and costs. See chapter 2.4 for a further elaboration on the product-process matrix.

Recent authors like Porter (1996) hold that trading off between performance objectives and overcoming trade-offs, are in fact, two different approaches, which may be adopted at different times by enterprises. Porter introduced the term

productivity frontier to distinguish between the two approaches. This constitutes the sum of all the best performances at any given time, and is constantly shifting outwards as new technologies and management approaches are developed and new inputs become available.



Figure 12 Operations effectiveness versus strategic positioning (Porter, 1996)

Porter argues that developing operational effectiveness (improving performance in multiple dimensions) is only possible for enterprises that are far behind the frontier, or when the frontier shifts outwards. He also argues that "at the frontier, where companies have achieved current best practice, the trade-offs between cost and differentiation is very real indeed" (Porter, 1996). Enterprises at the frontier must choose a unique position in order to develop a sustainable advantage. But a valuable position will attract imitation from competitors, and a strategic position is not sustainable unless there are trade-offs with other positions. Trade-offs occur when performance objectives are incompatible. That is, a trade-off means that more of one thing necessities less of another.

The position taken in this thesis is in line with Porter (1996). Trade-offs are real. Operations strategy is making trade-offs in order to align market requirements with operations resources. Without trade-offs there would be no need for choice and thus no need for strategy. Furthermore, improving effectiveness and strategic positioning are not mutually exclusive. There is a clear requirement for operations managers to position their operations in order to achieve the balance between performance objectives that are most appropriate for competitive advantage. There is also a requirement to find ways of overcoming trade-offs caused by constraints imposed by the operations resources.

2.3.5 Strategic decisions areas for manufacturing

No enterprise can merely choose which part of the market it wants to compete in without considering its ability to produce products and services in a way that satisfy that market. Both the constraints imposed by its operations, and the capabilities that

can be exploited in certain markets must be taken into account (Skinner, 1985). Operations strategy shapes these operations capabilities through a series of decisions over time. These decisions can be grouped in decisions categories.

Enterprises that does not properly align operations with the business in which the enterprise is embedded, usually commit at least one of three possible mistakes (Romano, 1983): incompatibility, multiplicity (or lack of focus), and inconsistency. These mistakes can be avoided by developing operations policies that are compatible with market requirements, are consistent internally, and reduce conflicting demands to a practical minimum. One key to successful operations strategy then, is to consider carefully how all areas of operations can contribute to its market objectives. It also needs to get an appropriate balance between the emphasis placed in each area and consider the sequence of all the decisions it will have to take. Overreliance on one area is usually an mistake.

The strategic decisions that directly concern operations can be grouped together under a number of headings. Different authors use different terminology and different groupings to describe these decisions. The strategic decisions are referred to as decisions areas (Spring and Boaden, 1997), manufacturing levers (Miltenburg, 1995), or decisions categories (Fine and Hax, 1985). This thesis will refer to them as decisions areas. The more conventional authors regarding manufacturing strategy limit themselves to decisions areas such as "plant and equipment, production planning and control, labour and staffing, product design/engineering, organisation and management" (Skinner, 1969). Such decisions have traditionally been the responsibility for the manufacturing function. Recent authors in operations management (for example Waller, 2003) however, claims that the operations management responsibility also encompass the value chain, and not just internal transformation processes. This thesis will adopt this view and expand the decisions areas to encompass responsibility to all operations activities that are involved in producing and delivering products to customers, including external management responsibilities at the value chain level.

Since Skinner (1969) proposed what he perceived as the most important decision areas in designing a manufacturing enterprise, many authors have developed comprehensive lists of strategic decisions for operations within manufacturing. Each list is supposed to contain all operations decisions, and determine completely the design of the manufacturing system, and how well the manufacturing system works (Miltenburg, 1995). A distinction is often drawn in these definitions between the strategic decisions which determine an operation's structure and those which determine the infrastructure, as suggested by Hayes and Wheelwright (1984). Structural decisions are primarily influencing design activities that are related to long term commitments and heavy investments. Infrastructural decisions are related to the work force organisation, production planning and control, and improvements, areas where changes may be incorporated in a shorter time perspective. Even though some authors, like Waller (2003) argue that only structural decisions (acquisitions, new clients, site selection, capital investments and so on) are principally strategic in nature, most authors recognise the strategic implications of the infrastructural decisions and include them as well (see for example the review on operations strategy by Anderson et al., 1989). Five well-known lists of decisions areas are shown in Table 3, which illustrates which decisions that are regarded as typical structural and infrastructural.

Type of Decision areas	Skinner (1974)	Hayes, Wheelwright, And Clarck (1984,1988)	Fine and Hax (1985)	Hill (2000)	Miltenburg (1995)
Structural	- Plant and equipment	 Capacity Facilities Technology Vertical integration 	 Capacity Facilities Processes and technologies 	- Capacity - Make or buy - Processes - choice - trade-offs - role of inventory	 Facilities Process technology Sourcing (suppliers and vertical integration)
Infra Structural	 Production planning and control Organisation and management Labor and staffing Product design and engineering 	 Production planning and control Quality Organisation Workforce New product development Performance measurement systems 	 Product quality Human resources Scope of new products 	 Manufacturing planning and control Function support Quality Systems engineering Clerical procedures Compensations Work structuring Organisational structure 	 Production planning and control Organisation structure and controls Human resources

Table 3 Conventional definitions of decision areas in operations strategy

The lists in Table 3 represent the conventional view of operations strategy, where decisions are regarded as structural and infrastructural as suggested by Hayes and Wheelwright (1984), and limited to the manufacturing function.

The decision areas in Table 3 somewhat differ from author to author, but there seems to be an essential agreement that capacity, facilities, technology, vertical integration, workforce, quality, production control and organisation are areas that really matters for operations strategy. Some authors also include product development as a decision area within operations strategy. Product development and operations are closely interrelated, and the product design has an major impact on the opportunity space for operations. However, although product design is a core function in any enterprise, operations managers do not have the direct responsibility for product development. Product development is therefore not treated as a decisions area within operations strategy in this framework.

The lists in Table 3 give a pretty good overview of areas that really matters for operations strategy. However, they all reflect a functional perspective on operations strategy, and do not encompass the wider responsibilities of operations in the value chain. Recent authors, like Lowson (2002) suggests that the type of judgements necessary for an operations strategy will vary from enterprise to enterprise, but they may cover the total value chain regarding:

- how to supply particular products and services
- what capabilities or competencies will be needed in the future
- what resources we will need to acquire
- what work flows are necessary

- what processes and technologies will be required
- the capacity needed and the level of flexibility involved
- human resource levels (skills, training, recruitment, selection and retention)
- quality levels
- what facilities are needed
- type of suppliers, relationships with them and sourcing and outsourcing
- decisions about the general operation systems and the resources needed long-term to maintain them

Lowson's (2002) list of possible strategic decisions encompasses all resources and processes that produce and deliver goods and services, including purchasing, distribution, and the collaboration with external firms in the value chain. To reflect this view, the definition of decisions areas should be familiar to the operations managers in a wider variety of operations. The author will therefore propose a more broad and generic list of decisions areas. These decisions areas are defined as:

- Resources
- Materials
- Information
- Processes
- Organisation
- Control

These decisions areas encompass all the strategic decisions that are listed in, and does also include most of the strategic decisions suggested by Lowson (2002). See section 2.3.8. First, a discussion on the notion of structural and infrastructural decisions that traditionally has been so important in operations strategy literature.

2.3.6 Infrastructural versus structural decisions

The author argues in line with Slack and Lewis (2001) that all decisions areas will involve both structural and infrastructural decisions. This view contradicts with the conventional definitions in operations strategy, outlined for example by Hayes and Wheelwright (1984). A distinction has often been drawn between strategic decisions areas that determine the enterprise structure and those that determine its infrastructure. Structural issues primarily influence the physical arrangement and configuration of the operations resources. Infrastructural decisions influence the activities that take place within the enterprise structure. However, a simple dichotomy between structural and infrastructural decisions is too much of a simplification. Not that the distinction itself is inappropriate. What is at fault is the tendency (as shown in Table 3) to categorise decisions areas as either entirely structural or entirely infrastructural. In reality, decisions in all decisions areas have both structural and infrastructural issues. (Slack and Lewis, 2002). Capacity and facility decisions for example, because they are mainly concerned with the physical size and location of operations resources, is mainly a structural issue. However, the type of activities that are carried out and how they are controlled can affect both size and location. Even decisions within the control and organisation category, while primarily being concerned with infrastructure, can have structural elements. The reporting mechanisms and control principles embedded within an organisational structure may reflect different locations and process technologies. Decisions areas should therefore be viewed as a spectrum where, at one

end, resource related decisions are largely structural, to at the other end, control and organisation is largely infrastructural.

2.3.7 Value chain decisions versus single enterprise decisions

Manufacturing operations are embedded in a total value chain. No single enterprise exists in isolation. All are part of an interconnected network of other enterprises. This network, which is usually referred to as the value chain, consist of suppliers, manufacturing plants, warehouses, distribution centres, and retail outlets, as well as raw materials, work-in-process inventory, and finished products that flow between the facilities (Simchi-Levi et al. 2003).

Usually, different value chain actors have different objectives. Even within one value chain stage, trade-offs have to be made between reducing inventory or transportation costs, or between increasing product variety or reducing inventory levels. Some potential conflicting objectives are summarised by Simchi-Levi et. al. (2003):

- Raw material suppliers might like stable volume requirements, with little variation in the mix of required materials. In addition, they prefer flexible delivery times, so that they can deliver efficiently to more that one customer. Finally, most suppliers would like to see large volume demands, so that they can take advantage of economics of scope and scale.
- Manufacturers might want to achieve high productivity through production efficiencies, leading in turn to low production costs. This requires a limited number of changeovers that causes expenses and quality problems. These goals are facilitated if the demand pattern is known far into the future and has little variability.
- Transporters and warehouses might want to minimise transport costs by taking advantage of quantity discounts, minimising inventory levels, and quickly replenishing stock.
- Retailers might want short order lead times and efficient and accurate order delivery
- The customers might demand in-stock items, enormous variety, and low prices

The operations strategy of the focal enterprise should be based on an awareness of such conflicting objectives, and should seek to align enterprise capabilities with the key actors in the value chain. This approach might be termed "global optimisation" in contrast to "local optimisation" where each actor of the value chain optimises its own operations without due respect to the impact of its policy on other actors in the value chain (Simchi-Levi et. al., 2003).

A complete operations strategy should encompass decisions regarding the focal enterprise (e.g. choice of production technology, type of layout, process design, choice of information system, etc.) in order to improve the capability of local operations. Furthermore, operations strategy should also encompass decisions such as the localisation of a plant, the choice of suppliers, make-or-buy decisions, or the level of inter-enterprise integration. Such decisions have a strong impact on the competitiveness of the total value chain. The author's view is therefore that decisions regarding local operations and decisions regarding the value chain should be regarded as two different decisions levels in operations strategy. This view is also supported by the major body of supply chain management literature, where strategic decisions regarding the value chain is a core issue. See for example Simchi-Levi et al. (2003), Schary and Skjøtt-Larsen (2001), and Christopher (1998).

2.3.8 A framework to structure operations strategy decisions

A proposed framework for operations strategy decisions areas is shown in Figure 13. This framework encompasses the conventional decisions areas listed in Table 3, and highlights that value chain decisions is a crucial part of operations strategy.

Scope							
Value chain	Capacity Facilities	Vertical integration Make or Buy	Value chain information systems	Value chain integration	Partnerships	Inventory and transp. policies KPIs	
Focal Enterprise	Production tech. People	Products Material flow and storage	Information systems (ERP)	Process design	Org. structure	Planning and control	
	Resources	Materials	Information	Processes	Organisation	Control	

Resource usage

Decisions areas

Figure 13 Decisions areas for operations strategy

Figure 13 shows the proposed framework for decisions areas in operations strategy. Each element of the framework is unique decisions area that should be analysed and optimised. All decisions areas are also interrelated and should be aligned.

Operations strategy aims to improve the competitiveness of an focal enterprise. This implies that decisions and choices are necessary about in-house operations, and also about the value chain that the focal enterprise is embedded in. The framework is (based on the scope of the decisions) divided into two decisions-levels:

- decisions about a single enterprise , and;
- decisions about the value chain

The major challenge is to optimise the competitiveness of the focal enterprise, and simultaneously make decisions at the value chain level that are aligned with other key actors.

The proposed decisions areas will now be explained in more detail.

Resources

Manufacturing operations are carried out by transforming resources such as facilities, machines, computers and people. At the value chain level, operations strategy should address overall capacity and facility decisions. That is, how much resources are needed, and where should the resources be located. Operations strategy should also

address the type of resources that are needed in each enterprise facility, and especially what type of production technology that are required to improve competitiveness (see chapter 2.4 for a further discussion on this issue).

Capacity and facilities

It often takes long time for a company to change capacity. If such a change requires a new or enlarged building, design and construction can take years. Capacity decisions includes the buildings and utilities for production, stocks, material handling, maintenance, and engineering, and have far reaching impacts on current and future strategy. Given a particular product mix and technology, operations managers have to decide:

- the capacity requirement and development (amount, acquisition time, increment size)
- the size and number of facilities (plants and warehouses)
- allocation of tasks (which process, or product group are the facility dedicated to)
- location of facilities

When a new plant or a new process line is necessary, the problem is to avoid oversimplification (i.e. simply selecting the least costly site). Schmenner (1979) outlines what the typical company ought to think about when deciding the location of a plant:

- the company's capacity needs
- the extent and quality of its present capacity
- the way existing plants fit together in a multi-plant operations strategy
- expected demands on manufacturing, apart from mere space requirements

Facility and task location should also be based on the level of technology required, where the product development support is located, what skills are available, how bulky the product is, the access to major transport routes, and so on.

Production technology

Production technology is the technology, which consists of the machines, equipment, and technology, used to produce and deliver a product. The strategic choices regarding production process technology has been widely elaborated in the operations strategy literature, and especially the choice of process type. "A pivotal decision for the operations function is process choice" (Safizadeh et al., 1996). Hayes and Wheelwright (1984), among others, argue that the emphasis given to flexibility and other performance objectives should agree with production process choice. The choice of production process technology is therefore a key decision that links operations to business strategy. Decisions that are made regarding production process technology include:

- the choice of process type and degree of equipment-integration
- the degree of specialisation of machines and equipment
- the amount of automation and flexibility

Materials

Materials are transformed through a series of stages from raw materials, parts, subassemblies, to final products in the hands of the customer. At the value chain level, operations strategy should address the vertical integration of the company. That is,
how much of the transformation process should be carried out by the company, and how much (and to whom, and in what way) should be sourced out to others actors. The physical material flow between and within facilities should be addressed, and especially what type of facility layout that are required to improve competitiveness.

Vertical integration

Decisions about vertical integration have a focus on the relationships with suppliers and distributors, the choice and contract with suppliers, in-/out sourcing of products and services, and delivery terms. Decisions regarding vertical integration may include:

- Choice of suppliers and transporters
- Type of collaboration (market, joint venture, partnership etc.)
- Scope of collaboration (what is the supplier/transporter responsible for)
- Contractual agreements (design, price, quality, delivery terms etc.)
- Make-or-buy decisions

Material flows

The material flow and level of product focus is determined by physical location of its transforming resources. Put simply, layout is deciding where to put all the facilities, machines, equipment and staff in the operation of. This determines the way in which the transformed resources (material and information) flow through the operation (Tompkins et. al. 1996). Key decisions are:

- What layout type should be used (fixed-position, process, cell, or product layout)
- Position of buffers and flow orientation in the enterprise

The choice of layout should be based on the type of production process technology that are chosen, and the strategic performance objectives for the enterprise. This often implies a mix of layout types. A mixed enterprise layout consists of smaller operations entities with different layout types, each organised according to local process characteristics and performance objectives.

Information

Information flows through the enterprise and provides representations of enterprise data, knowledge, and know-how. Information has two roles in enterprise operations. Information is an input-resource that can be processes by operations into an information-deliverable that provides value to the customer. A construction department do this by transforming some input data into a complete 3D product drawing. However, and even more important for operations strategy, information is also the mean to support the execution and integration of core transformation operations. Operations strategy should define the enterprise information system that acts to support the core transformation processes, and also the value chain information system that is used to communicate with other actors.

Value chain information systems

Technological developments such as data ware houses, web services, XML, portals etc. makes it possible to have increasingly more information available in the value chain. Having accurate information about inventory levels, orders, production, and delivery status throughout the value chain makes it possible to carry out operations (both in-house and towards other actors) more efficiently and effectively than before.

Quick Response, Efficient Consumer Response, and Vendor Managed Inventory are examples of such information sharing and integration initiatives (Simchi-Levi et al. 2003. Information exchange might include: business plans, sales promotion plans, new product introduction information, inventory data, point of sales data and forecasts, production and capacity plans, lead time information etc (Handfield and Nichols, 2002). Strategic decisions regarding value chain information systems should include:

- Type of business-to-business integration (EDI/XML etc) and customisation of the information platform. Even two XML platforms must be customised in order to communicate. The value chain information system should be customised towards key-partners (and their information systems).
- Integration with the ERP-system. Should the value chain information system be a stand alone application or an integrated ERP-module
- Information sharing. What type of information (for example sensitive sales forecasts) should be shared with each partner.

Enterprise information systems

In manufacturing enterprise information systems, the most important technology component is Enterprise Resource Planning (ERP) systems. Crucial information for operations are normally processed and stored in an ERP-system. The ERP-system is an information transaction system, "which enables a company to integrate the data used throughout its entire organisation" (Davenport, 1998). At the heart of the ERP-system is a central database that draws data from and feed data into a series of application supporting enterprise functions. By using a single database, the ERP system dramatically streamlines the flow of information throughout a business. The control of operations is normally handled in an manufacturing planning and control (MPC) system, which may or may not be closely integrated with the ERP-system. (see section 4.7 for a closer explanation of MPC systems). Strategic decisions that are made regarding the design of information systems include:

- How centralised and automated the information technology should be, and the level of connectivity with other technologies
- Degree of analytical content embodied in the information technology
- Type of applications and their functionality for sales and order management, materials management, procurement, economics, and so on.
- Information flows in the enterprise, especially the content, frequency and medium for information that supports core transformation operations.

Processes

Operations processes are groups of activities that add value to input-resources such as materials and information. A process can encompass the activities involved in a single production stage such as part production, or all activities in the total value chain that are involved in providing value to customers - the process scope is a matter of perspective. At the value chain level, the operations strategy should address the integration of processes (such as order management, planning, warehousing, transport etc) across enterprise boarders. The objective is to design processes in order to reduce resource consumption and improve performance. Similarly, in-house processes should be addressed in order to improve the way manufacturing and office operations are carried out within and across departmental boarders.

Integration across enterprise boarders

Decisions regarding inter-enterprise processes comprise the integration and collaboration with customers and suppliers in order to manage demand, stocks, and transport in the value chain. Decisions regarding process integration may include:

- The integration of administrative processes with partners
- Joint procurement, warehousing, and distribution

Process design

Design of manufacturing and office processes in order to achieve the enterprise performance objectives should be one of the core issues in operations strategy. The core objective is to design operations processes that improve performance levels in the desired strategic direction. Decisions regarding process design may include:

- Choice of criteria for product-grouping
- Product-orientation versus (production) process-orientation
- Value stream/business process integration and segmentation

The total transformation process can be decomposed in stages, each consisting of one or several "operations areas" ¹² that might contribute to one or several value streams/business processes. Depending on product characteristics, each operations area might have different performance objectives and resource capabilities. Operations strategy should address the overall activities and boundaries of each operations area in order to improve process performance.

Organisation

Almost all enterprises have organisational structures – groups of resources bounded together by set of shared responsibility with recognised relationships between the groups (Slack and Lewis, 2001. The way enterprises design their structure and thereby shape the internal organisation of resources and activities is a fundamental output of operations strategy. Operations strategy should also encompass how the partnership with key actors in the value chain are organised. It should be mentioned that the link between the formal design of an organisational structure and the effectiveness of that organisational structure is less clear than most operations strategy decisions. A major reason for this is the informal relationships that build up between groups, which largely influence the effectiveness of different structures in different circumstances.

Partnerships

Frequently, a company may find it effective to develop strategic alliances with other actors in the value chain. This type of collaboration might lead to long-term strategic benefits for both partners. Operations strategy includes decisions such as

65

¹² See chapter 3.2.3 for a description of operations areas and business processes/value streams.

- The distribution of roles and tasks (such as inventory management, transport management, order management etc.) in the partnership
- Performance criteria and sharing of success

The most important type of value chain related alliances for manufacturing enterprises are third-party logistics and retailer-supplier partnerships such as Vendor Management Inventory. A critical issue in such alliances is to agree on the responsibilities and the distribution of task between partners. One partner could be better suited to perform a task simply because of his position in the value chain, resources, or expertise. Another strategic issue is to agree on performance criteria for the partnership, and how to share benefits. A successful partnership require that both partners should work together in order to increase the total amount of joint benefit they receive, rather than manoeuvring to maximise their own individual contribution.

Organisation structure

Designing an organisation to achieve specific objectives will never guarantee that those objectives are achieved. Rather, the task of organisational design is to create the setting that encourages the desired performance (Slack and Lewis, 2001. Decisions regarding organisational structure include the following:

- The authority levels in the enterprise (from a traditional hierarchy to a more flat organisation), and the amount of authority at each level
- The grouping of resources and activities
- The specification of tasks and roles
- Reward systems and performance measures

From an operations perspective, the key issues regarding organisational structure evolve around the conflict between an efficient enterprise and a flexible enterprise. Hierarchical structures with centralised control and functional division of work have traditionally been applied in order to ensure the efficient usage of resources. This "mass production" approach was advocated by Fredric Taylor in the 1920s, and has been the dominant production form in the last century (Taylor, 1911). Since then, hierarchies have been blamed for all manners of organisational ills – slow decisions making, isolation from customers, inequality in compensation, and more. Yet, despite the barrage of criticism, hierarchies endure, and should be seen as "necessary, inevitable, and desirable fixtures of organisational life" (Ashkenas et al, 2002).

The goal is not to eliminate hierarchies, but make them work better through a redesign of enterprise boundaries, authority distribution, and control mechanisms in the enterprise. During the last decades, many enterprises have developed more decentralised and market oriented structures in order to increase the ability to respond flexibly (and efficiently) to market changes. Such alternative groupings of people (business processes, autonomous groups, manufacturing cells, and so on) are more market oriented, and the decisions-making is decentralised to the people that are performing the activity. The decentralised control structures should empower people (Malone, 1997) to make more decisions about the group of activities they are responsible for. This enables faster response to changes and unpredictable events. The development of such, more "healthy" hierarchical structures (Ashkenas et al, 2002), are often a prerequisite for, or a core element in, management philosophies such as process reengineering, lean manufacturing and quick response business manufacturing.

The major issue from an operational point of view then, is to develop a healthy organisational structure with the role clarity, specialisation and decisions structure that enables the required resource utilisation on one hand, and with the speed, integration and autonomy that enables the required flexibility on the other hand

Control

Operations (the flow of material and information-deliverables, the utilisation of people and equipment etc), are managed by a planning and control system in order to meet customer demand. A major strategic decision is to improve enterprise competitiveness by matching the manufacturing planning and control system with the ongoing needs of the markets, and enterprise manufacturing processes (Berry and Hill, 1992). At the value chain level, inventories and transport continue to represents major cost drivers. Strategic and coherent decisions regarding transport and inventories policies are crucial to lower costs and improve performance throughout the value chain. In addition, collaborative planning might be required to streamline production, transport, and inventories even further. Since 1995, new forms of value chain collaboration have taken regular information-sharing relations and their concepts one step further. These forms extend their focus on the value chain to include not only a passive exchange of information between partners, but also a more proactive approach through common planning and synchronisation of activities and business processes (Jagdev and Thoben, 2001).

Inventory and transport policies

Good inventory and transport control means keeping inventory and transport costs at the lowest possible level and still achieve the desired performance objectives. Strategic decisions regarding inventory policies include: (Ballou, R.H. 2004).

- location and levels of various items in the plant, regional warehouses, or field warehouses
- product availability (and hence, customer service)
- choice of inventory control methods (reorder point, periodic review etc)

The transport policy affects inventory levels through shipment sizes, replenishment times, and service levels. Strategic decisions include:

- mode selection
- carrier routing and scheduling
- shipment size/consolidation of shipments

These decisions are influenced by the proximity of warehouses to customer and plants, which in turn, should influence plant and warehouse locations.

Collaborative planning

The most known of the new collaborative planning concepts is Collaborative Planning Forecasting and Replenishment (www.CPFR.org). In addition to extensive information exchange and frequent co-ordination meetings, CPFR includes collaborative tasks such as joint business planning, joint sales forecasting, and joint order planning/forecasting. Furthermore, exception management is important in CPFR. Any change from any forecast beyond an agreed–upon threshold are defined as exceptions, and should generate collaborative actions by both parties to re-align the planning of the value chain. Strategic decision regarding this type of partnership includes:

- What products should be included in the collaboration
- Scope of collaboration: what collaborative planning tasks should be included
- Depth of collaboration: what level of integration (both technical and organisational) should be developed

A CPFR collaboration can range from a basic (simple data exchange programmes for a limited set of data) to advanced CPFR. Advanced CPFR deals with synchronising the dialogue between actors, and includes forecasting, replenishment and planning (i.e. production planning, product development, transport planning, and marketing activities). Generally, CPFR works best where the focus is on long-term relationships involving highly differentiated products with limited sources of supply (Skjoett-Larsen et al. 2003).

Key Performance Indicators (KPIs)

Based on the performance objectives of the enterprise, a set of overall performance measures (KPIs) should be determined. These KPIs should be aligned with the key partners in the value chain, and measured in a integrated value chain measuring system (Busi, 2005).

Planning and control

The choice of MPC-system is also a key decision in operations strategy, and Berry and Hill (1992), among others, argue that the choice of MPC-system should be matched with production processes and performance objectives. Berry and Hill (1992) present a by now well-established framework for MPC design options. It contains a number of alternative approaches for:

- Market interaction strategy
- Material planning approach
- Shop floor control approach

The framework differentiate between three forms of market interaction strategy, these are make-to-order (MTO), assemble-to-order (ATO) and make-to-stock (MTS). Material planning can be carried out using either a time-phased or a rate-based approach. Finally, the shop floor is controlled using either push- or pull-principles. (This framework will be further explained in chapter 4.7)

The decisions areas proposed here - resources, materials, processes, information, organisation, and control – define the scope and nature of the resource base of any manufacturing enterprise and its value chain. Once again though, the boundaries between operations strategy decisions in these areas are not clear. For example, decisions on capacity location are influenced by the choice of suppliers in the value chain, the extent of vertical integration is determined partly by the nature of the production technology involved, the organisation structure of the operation is influenced by the size of operations location, and so on. Furthermore, the exact nature of the decisions will depend on the nature of the enterprise. However, this relatively straightforward categorisation allows the examination of each set of decisions in turn, even if it is always necessary to be aware of the interconnectivity between them.

2.4 The product-process matrix

A pivotal decision in operations strategy is the choice of production process technology. Fit has to be achieved between production process capabilities and market requirements. This decision has implications for other important areas such as the choice of planning and control system, or choice of layout type. The production process choice has also traditionally been the focus in operations strategy literature. In this area, Hayes and Wheelwright have made one of their major contributions. It was Hayes and Wheelwright (1979) who originally proposed that many characteristics of production units varied with two primary dimensions – product structure and process structure. They also proposed that these two dimensions were related to each other as a consequence of shared lifecycles. On that basis, they outlined a relationship between the dimensions and some characteristics of production units. Their product-process matrix has proven to be useful and is now widely used for (at least) two purposes:

- To analyse which type of production processes that are most suitable for a homogenous product-group
- To analyse how the product mix that is currently produced, suits the manufacturing system. The product group should be as homogenous as possible (in volumes, variety etc) so that the process can be focused (Skinner, 1974).

Hayes and Wheelwright argue that each phase in a product's lifecycle, which are presumed to go through different phases, is strongly correlated to a similar process lifecycle. "Just as products go through a series of major stages, so does the production process used in the manufacture of that product" (Hayes and Wheelwright, 1979). This means that products should not always be manufactured by the same production processes during their entire lifecycle. Competitive advantages can be gained when processes are changed or adjusted to each product stage. Based on this assumption, they proposed a matrix of four fundamental product types, and four fundamental production processes that would be best suited for each product type. Their product-process matrix is shown in Figure 14.



Figure 14 The product/process matrix (Hayes and Wheelwright (1979)

The product types in the matrix are grouped according to increasing volumes, and process types are grouped according to an increasing flow. The product types constitute the stages in a product lifecycle from introduction until it becomes a standardised commodity product, and the process types constitutes the related stages in the process life cycle that evolve from a highly flexible process towards a automated and highly efficient process. Hayes and Wheelwright (1979) also follow Skinner (1974) in the assumption that; there is a loss of focus and competitiveness if the same process produces products for demands with different order winning criteria. Positions along the diagonal from top-left to bottom right are therefore considered appropriate.

The product types can be defined as:

- Very many different products that are customised to the customer in volumes of one or a few of each product.
- Multiple products produced in low volumes
- A few major products produced in high volumes
- Standard commodity products that are produced in very high volumes

The process types can be defined as:

- Job shop
- Flow shop/batch
- Line
- Continuous processing

Different positions in the matrix enable different competitive priorities, and one enterprise can have several manufacturing units with different product-process combinations. A job shop is typically highly flexible, but not very cost-effective, and will be best suited to manufacture many one-of-a-kind products that are customised to the customer. Continuous processing is highly automated and efficient, but not very flexible, and will be suited to manufacture standard commodity products. Enterprises should therefore position their manufacturing systems along the diagonal (Hayes and Wheelwright, 1979).

There are several issues regarding the original product-process matrix that should be considered before it can be adopted as a strategic framework for manufacturing operations. These are the assumptions of Hayes and Wheelwrights (1979,84) about:

- Product and process lifecycles
- Trade-offs
- Positions in the product-process

Lifecycles

Hayes and Wheelwrights (1979,84) view product and process lifecycles as sequential processes where new products and production processes are developed into mature, high-volume product and processes. Today, this sequential view of the lifecycle is not valid for many products and processes. Many newly introduced products will be removed from the marketplace if they do not rapidly achieve sufficient volumes for mass production processes, and many products and process will stay in approximately

the same area of the product-process matrix for their entire lifecycle. In addition, Hayes and Wheelwrights lifecycle perspective does not consider the decline phase of products, where volumes are reduced, and many variants are introduced in order to prolong the product's life.

Trade-offs

Different processes are assumed to have different capabilities regarding cost and delivery (time and precision) on the one hand, and quality and flexibility on the other hand. Manufacturing managers then have to make trade-offs between these capabilities in order to position their manufacturing system on the product/process. It has been argued however (see chapter 2.3.4) that quality and delivery precision are mere qualifiers in most industries to day, and that the real trade-offs are between flexibility and innovativeness on the one hand, and cost on the other hand.

Positions in the matrix

Hayes and Wheelwright (1979, 84) also assumed that two corners of the matrix were void because they represented a mismatch between products and processes that not could be found in industry, and argued that firms should position their manufacturing systems along the diagonal. This is no longer totally true. The upper right-hand corner characterises a commodity product produced by a job shop, which still is very uneconomical. Lower left-hand corner however, represents efficient and continuous processing of one-of-a-kind products. This is an ideal situation that many companies strive to achieve through developing their processes, products and operations for mass customisation (see e.g. Gilmore and Pine, 1997).

It is also evident that Hayes and Wheelwright (1979, 84) paid attention mainly to technology-based competencies and the choice of appropriate process technology. The product/process matrix still provides a useful insight, because it links products, processes and manufacturing performance and indicates how different process types and product types are related.

2.5 Operations strategy development

Operations strategy development should be understood as a repeating formulation process that aims to develop sustainable competitive advantage through an alignment of resource capabilities and market positioning. This process is difficult to manage. However, some simple strategic devices can support the strategic analysis and planning. First of all, this thesis proposes the "operations strategy checklist" as a useful device to support overall operations strategy analysis and formulation.

2.5.1 The operations strategy process

Markets change over time. Customer demographics and needs are not constant, so neither are market requirements. Nor are resource capabilities static, they are developed over time. This means that the alignment process and thereby the operations strategy change over time. The concept of operations strategy (as defined in this thesis) is based on the active process of alignment between operations resources and market requirement. This is essentially to achieve fit, which is one of the oldest ideas in strategy (Porter, 1996). The idea of operations strategy development as a process of achieving fit is illustrated in Figure 15.

Chapter 2



Figure 15 The operations strategy development process (based on Slack and Lewis, 2001)

Figure 15 illustrates the operations strategy process as a continuous effort of aligning and extending operations capabilities and market requirements. The vertical dimension represents the nature and level of market requirements either because they reflect the needs of customers or because their expectations have been shaped by the enterprise's marketing activity. Movement along the dimension indicates a broadly enhanced level of market performance or market capability. The horizontal scale represents the level and nature of the enterprise's operations resource and processes capabilities. Again, movement along the dimension indicates a broadly enhanced level of operations performance and operations capabilities. The purpose of fit is to achieve an approximate balance between market performance and operations performance (Slack and Lewis, 2001).The diagonal line in Figure 15 therefore represents a "line of fit" with market and operations in balance.

Operations strategy formulation is not a one-time event. Strategies will be formed repeatedly over time in order to take into account changes in both operations resources and market requirements. At each formulation episode (illustrated as bullets in Figure 15) a key objective is to achieve a sustainable competitive advantage through a fit (at an enhanced level) of market requirements and resource capabilities (Porter, 1996). Furthermore, the line of fit represents an idealised form of capability development exactly in line with evolving market requirements. More realistically, even the most successful long-run enterprise will experience differing degrees of fit between market requirement and their operations capabilities. For example, an investment in state-of-the art production technology might provide a capacity or a flexibility that not is coherent with the current sales volumes or product customisation levels. (see chapter 2.4 for a further discussion about process and product choices).

The ongoing process of fit is difficult to manage. The requirements of a market might change dramatically, and very few enterprises serve only one market. In addition, it is very difficult to predict the precise impact that operational change will have on the enterprise. As a result, very few enterprises have a tight fit with their external environments. One device to support the strategy process is the "operations strategy checklist", which is introduced as a useful device to support operations strategy analysis and formulation.

2.5.2 Operations strategy formulation procedures

Many consultant companies and academics have developed strategy formulation frameworks which are, or can be, used to formulate those operations strategies the enterprise should adopt. The most well-known of these frameworks is the "Hill methodology". Hill's (2000) follows a well-tried approach of providing a connection between different levels of strategy making. The methodology consists of five steps.

- 1. Understand corporate objectives
- 2. Understand marketing strategy
- 3. Translate market strategy to performance objectives how do products or services win orders
- 4. Process choice (this is similar, but not identical to the decisions areas of resources, materials, and information). The purpose is to define a set of structural characteristics of the enterprise that are coherent and correspond to the way the enterprise wish to compete.
- 5. Infrastructure choice (this is similar to the decisions areas of processes, organisation, and control). The purpose is to define, in the same manner, the infrastructural features of the enterprise.

Hill's framework is not intended to imply a sequential movement from step 1 to 5. Rather, Hill sees the process as an iterative one, where the operations manager cycle between an understanding of the long term–strategic requirements and the specific resource developments that are required to support strategy. In this approach, the identification of performance objectives in step 3 is seen as critical. It is at this stage that any gap between what is required by the market place and what the operations can provide becomes evident.

Although Hill's methodology has a market-based focus, and only encompasses some of the strategic decisions proposed in this thesis, the procedure still illustrates the basic elements in an operations strategy formulation. To understand corporate strategy, to determine and prioritise performance objectives based on the market strategy, to asses the current achieved performance (as compared to customers requirements and competitors performance), and to perform a gap analysis – what is required by the market place and what is the current performance.

Hill's approach, and especially the determination of order-winners and orderqualifiers is useful for analysing market requirements. In addition, operations capabilities should be analysed with one of the most widely applied strategy analysis tool – SWOT analysis. Strenghts, weaknesses, opportunities and threats can be analysed by this tool - see Power et al (1986) for a check list of environmental variables and strengths & weakness variables that could be assessed in a SWOT analysis. However, usefulness of a full SWOT analysis can be questioned. Empirical investigations on the use of SWOT analysis, e.g. by Hill and Westbrook (1997) has shown that the SWOT analysis is extremely difficult to incorporate in an effective planning process. Nevertheless, the strengths and weaknesses part of SWOT is a starting point for the analysis of operations resources.

There is a range of devices that can support strategy analysis and choices within a particular decisions area. The most well-known of such decisions-specific devices is the product-process matrix. However, the author will still argue that there is a need for a practical procedure for strategy development which encompasses both the market requirements and decisions areas, and which has a focus on how the decisions should actually be realised. A useful device for formulating the overall operations strategy is the strategy checklist.

2.5.3 The operations strategy checklist

Very few enterprises serve only one market. Different customer needs imply different objectives. If, as is likely, an enterprise produces goods and services for more than one customer group, it will be need to determine the order-winning, qualifying and less important performance objectives for each group. It is seldom possible to achieve perfect fit for all product groups at the same time. Each major product group might put forward conflicting performance objectives for the enterprise and the actors that are involved. The role of operation strategy then, is first to optimise the competitive position in the market by prioritising performance objectives and aligning them with enterprise resource capabilities. Second, to optimise the global performance of the value chain through a close collaboration with key actors. Hence, operations strategy formulations should include two phases:

- First to identify and analyse enterprise capabilities and performance objectives for the enterprise, i.e. how to develop tight fit with the enterprise's competitive position in a market. This involves a range of decisions about internal enterprise operations and its value chain.
- Second, to collaborate with key partners in order to improve the competitiveness of the total value chain for a certain market. This requires an alignment of the respective operations strategies in order to reduce the overall costs and improve performance in the value chain (transport and inventory policy, information sharing etc).

The resulting operations strategy should encompass decisions at the value chain level and at the single enterprise level (as proposed in chapter 2.3.8), and should aim to align market requirements with resource capabilities. The alignment process can be supported be a operations strategy checklist, which brings the market-based perspective and the resource-based perspective together. Table 4 shows one such checklist for Raufoss Chasiss Technology (RCT).

Decision areas				irea	IS	Tasks/events		Perf. Objectives				
х						Full-automatic & integrated prod. technology						
	х					Continuous material flow and minimum stock	х		х			
			х	Х		Supply chain centre for administrative processes	х		х			
		Х				Dashboard based on Man. Execution System	Х					
х						Establish new plant in Canada to serve US	Х		Х			
х			х			Production process up-time improvement			Х	Х		
		х			х	Information sharing with cust. and key-suppliers			х	х		
				Х		Value chain performance indicators			х	х		
					х	Make-To-Stock and constant rate-based prod.	х		Х			
Resources	Materials	Information	Processes	Organsation	Control		Costs	Quality	Del. time	Del. precision	Flexibility	Innovation

Table 4 The operations strategy checklist for RCT

The proposed checklist structure is based on the operations strategy matrix developed by Slack and Lewis (2001)¹³. The major difference from the original matrix is the type of decisions areas that are proposed. In contrast to the original matrix, the new matrix sets out generic decisions areas that can be applied in operations strategy formulation for most enterprises and their value chain. A second difference is that the checklist (in contrast to the original matrix) enables the decision-makers to fill in more than one performance objective and decisions area per. strategic choice. This list should be use to ensure that the strategy is coherent and that the decisions are aligned. Furthermore, identify the most important decisions areas. Some are particularly critical, and one of the key tasks it to decide which intersections between performance objectives and decision areas that need particular attention.

RCT develops, produces and supplies high quality, aluminium wheel suspension components to the global automotive industry. The matrix shows RCTs major strategic priorities in 2001, when the company had been nominated to sole supplier of wheel suspensions for the new GM Epsilon platform. The production was expected to be 500.000 cars per year in Europe, and 650.000 per year in US. The 7 years contract with GM was based on 100% delivery precision, 5 ppm defects, and 5% price reduction per year. Most of the strategic priorities therefore aimed to achieve cost improvements.

75

¹³ Slack and Lewis (2001) structures the decisions areas into: 1) capacity and facilities, 2) supply network, 3) process technology, 4) development and organisation, and performance objectives into: 1) quality, 2) speed, 3) dependability, 4) flexibility, 5) cost.

2.6 Summary

Operations strategy aims to align market requirements and operation resource capabilities. The most important lessons from this chapter is summarised below.

- Operations strategy implies choices. Trade-offs has to be carried out in order to position the enterprise at the market place.
- The major performance objectives for operations are costs, quality, time, delivery precision, flexibility, and innovativeness. Each can be measured by a set of measures that should be customised to the particular operation.
- The major decisions areas in operations strategy are resources, materials, information, processes, organisation, and control. Each area includes decisions at two levels, decisions about a single enterprise, and decisions about the value chain it is embedded in.
- A pivotal decision in operations strategy is the choice of production process technology, which influences decisions in a range of other areas, such as choice of MPC system and choice of layout type. This core decision is supported by the product-process matrix, which can be used to achieve fit between production process and product performance objectives.
- Operations strategy formulation is an iterative process that should include understanding corporate strategy, determining and prioritising performance objectives, assessing current achieved performance, and performing gap analysis.
- The strategy formulation can be supported by the operations strategy checklist. This checklist is a useful device to structure decisions in all decisions areas into a coherent whole that supports market competitiveness.

Operations strategy encompasses decisions in range of areas, both about internal operations and value chain operations. The next chapter will propose an approach to realise the strategic decisions through an enterprise reengineering. The approach is not suitable to accomplish all types of operations strategy decisions. Rather, the approach focuses on infrastructural aspects such as the implementation of best practices, and the scope is limited to operations in a single enterprise.

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3. Enterprise reengineering

This chapter will briefly review the enterprise engineering and business process reengineering literature in order to introduce and discuss the fundamentals of enterprise reengineering. This chapter has six main themes. First, to review the origins of the enterprise reengineering concept in enterprise engineering literature and to provide a new definition of the concept. Second, to compare enterprise reengineering with two related engineering approaches, namely business process reengineering and enterprise integration. Third, to outline the role of enterprise reengineering in operations strategy development. Fourth, to describe the major assumption of enterprise reengineering, namely that any enterprise can be decomposed into a network of operations entities that contribute to one or several operations processes. Fifth, to set out a conceptual framework for enterprise reengineering, and finally, to propose a methodology for enterprise reengineering.

3.1 Enterprise engineering and reengineering

In this thesis, enterprise reengineering is regarded as an approach within enterprise engineering. Enterprise engineering is "an life-cycle oriented discipline for identification, design and implementation of enterprises and their continuous evolution" (Kosanke et al, 1999). Enterprises models are "essential components in enterprise engineering" (IFIP-IFAC taskforce, 1999). Enterprise engineering encompasses hardware, software, communications protocols, information, and architectures, but also social and organisational issues that are relevant for enterprise modelling and improvement.

3.1.1 Historic roots - enterprise engineering

Enterprise reengineering is not a well defined term, but can be traced back to authors like Kosanke et. al (1999) and Vernadat (1999) that views enterprise reengineering as a sub-category of enterprise engineering. The term enterprise engineering has been used in the Computer Integrated Manufacturing (CIM) community since the early 1990s (Kosanke et. al,1999), and coins the modelling and design of enterprises and their core elements (people, machines and computers). The idea behind enterprise engineering is that enterprises may be engineered like any other complex systems. The enterprise is a system that must be engineered, implemented, and integrated in a systematic way very similar to approaches developed for software engineering. "This emerging discipline, embracing strategic planning, enterprise modelling, enterprise integration as well as traditional activities of industrial engineering is named enterprise engineering" (Vernadat, 1996).

An rather overall definition of enterprise engineering is a "discipline that organises all knowledge that is needed to identify the need for change in enterprises and to carry out that change expediently and professionally" (IFAC Taskforce, 1999). Another broad definition is provided by Kosanke et al, (1999), who define enterprise engineering as a discipline that are concerned "with intra and inter enterprise operations and with improving their efficiency and effectiveness". This thesis will adopt such broad definitions of the term. The chosen interpretation of these definitions is that enterprise engineering is a interdisciplinary and encompasses all types of engineering approaches (e.g. enterprise integration and enterprise reengineering) that are concerned with the modelling and optimisation of enterprise operations. The development of global information infrastructures is an enterprise engineering effort, but so are performance improvement projects that not necessarily are computer oriented. In this thesis, the term enterprise engineering therefore encompasses all enterprise modelling and optimisation efforts that are used to achieve the performance objectives of a company's operations strategy.

The term enterprise reengineering is viewed as a sub-category of enterprise engineering that coins an "extended" process reengineering that also encompasses changes in plant layout design, logistics systems and information systems (Vernadat, 1999). Vernadat (2002) states that enterprise reengineering is an impact of enterprise integration¹⁴, and mainly implies to use "modelling and analysis techniques such as BPR to eliminate unnecessary or non-productive operations". Kosanke et al (1999) use the term enterprise reengineering when they are reviewing the limited success of enterprise integration efforts in industry. They state that "the emphasis on enterprise modelling applications is still on enterprise reengineering", and they define enterprise reengineering as "the understanding and optimisation of the enterprise operations".

The author's interpretation of these statements is 1) that enterprise reengineering is targeting issues related to the operations management of enterprises and especially the modelling and design of day-to-day operations activities, and 2) that enterprise reengineering has adopted the process perspective of BPR, but represents an "extended" or system approach that focuses on the design and operations of the most effective *means* by which customer needs are transformed into customer satisfaction.

3.1.2 The link to operations strategy

The author will argue that enterprise reengineering is closely linked to the operations strategy of the enterprise. First of all, because the operations activities targeted in enterprise reengineering is a major source for competitive advantage. Two enterprises with the same facilities and same process technology can achieve radically different performance. The difference is in the way they perform their activities. In their research on high-performance manufacturing, Hayes and Wheelwright (1988) revealed that two factories with almost identical equipment may perform very differently. They suggest that "for all its sound and fury, the equipment or hardware, by itself is rarely the primary source of a factory's competitive advantage. What matters is how that hardware is used, and how it is integrated with materials, people, and information through software – the systems and procedures that direct and control the factory's activities".

81

¹⁴ The other impacts of EI are: Increased flexibility, Process management, integration and coordination, Heterarchic Organisation and holonic manufacturing systems, Networked enterprise, Electronic documents/information exchange, Legacy systems, Clean Manufacturing and recycling.

The perspective of this thesis, as outlined in chapter 2.3.8, is that operations strategy in general covers all strategic decisions about the manufacturing enterprise and its value chain. This includes a whole range of aspects, such as make-or-buy decisions, capacity decisions, location of new plants, investments in new technology, and so on. These decisions clearly have a great impact on the competitiveness of an enterprise, and should be included in any operations strategy development process. Any operations strategy should recognise that decisions regarding physical arrangement and configuration of the operations resources are important for competitiveness. But the way operations activities are organised and controlled has an even larger impact on the competitiveness, and thus, is the focus for this thesis. Authors like Michael Porter (1996), even describes activities as "the basis unit of competitive advantage". This might be a too bold statement, but the point is that the proper design of activities will provide a unique strategic position for manufacturing enterprises. The change of processes and other infrastructural elements provided by an enterprise reengineering may therefore result in major competitive benefits.

Enterprise reengineering will, even though most of the decisions concern processes, control and organisation, include infrastructural decisions in all strategic decisions areas. This view on infrastructural decisions contradicts with the conventional definitions in operations strategy, outlined for example by Hayes and Wheelwright (1984). Decisions areas contain both infrastructural and structural decisions, but the structural decisions often constitute the foundation for infrastructural decision (like computer hardware is the foundation for software development). The point is, as stated by Porter (1996), that "different positions (with their tailored activities) may require different product configurations, different equipment, different employee behaviour, different skills, and different management systems". Even though enterprise reengineering concerns with infrastructural decisions, the decisions regarding activities will affect the structure the activities take place in. Enterprise reengineering is not limited to decisions regarding processes, control methods, and organisation within an established structure. The design of processes, e.g. for lean manufacturing, may require changes in capacity, relocation of facilities, what type of products that are bought and where the supplier is located, and the type of process technology (both machines and control technology) that are required. This view on strategic decisions is illustrated in Figure 16.

			Infra	structural decis	sions
St	ructural decisio	ons			
Resources	Materials	Information	Processes	Organisation	Control



Figure 16 illustrates that the infrastructural decisions provided by enterprise reengineering projects will have implications for all decisions areas in a operations strategy. Strategic decisions regarding the enterprise infrastructure should be an integrated element in the total operations strategy development. Such decisions must be considered in all decisions areas, and should not be postponed to the capacity is configured, supply relationships settled and process technology installed. A successful operations strategy requires overall decisions about operations activities, and a clear

view on how they should be organised and controlled, before any major decisions regarding investments or structural changes.

3.1.3 The scope of Enterprise Reengineering

Enterprise reengineering is an model-based approach that aims to improve operations performance in the overall direction determined by the operations strategy. The main purpose of operations strategy is to make plans for how the enterprise can improve it's competitiveness. This encompasses numerous strategic decisions that range from human resources strategies to localisation of new enterprises, and is directing the work in research fields such as operations management and enterprise engineering. However, since these are research fields that cover many design issues, the scope of enterprise reengineering, as defined in this thesis, is restricted to the modelling and reengineering of operations processes. That is, how operations processes are logically and physically organised, and how they are controlled.

The scope of enterprise reengineering can therefore be envisioned as the intersection between the field of operations management, enterprise engineering, and operations strategy. See Figure 17.



Figure 17 The scope of enterprise reengineering

Operations management is the traditional field in which operations are studied. From an operations point of view, an enterprise can be perceived as an transformation process, consisting of a operations process, transforming resources, and a control centre as depicted in figure 5. The enterprises take in a set of input resources (such as materials and information) and transform them (utilising transforming resources such as facilities, machines, computers, and people) into outputs of products and services. The control of the operations process is supported by a manufacturing planning and control system, which, at least partly, is embedded in an information system that collects, process, stores and disseminate information about the enterprise and the environment surrounding it. Operations management is the management of all the operations activities and resources involved in this transformation process, and is directed by an operations strategy. However, operation management is broader than the scope of the enterprise reengineering, which are mainly concerned with operations activities.

Enterprise engineering is a field that focuses on the modelling of operations, and is also are directed by the operations strategy. Several approaches are possible in such a engineering effort, but the traditional approach to enterprise engineering has been to focus on the technological issues, i.e. how to build computer infrastructures that automate and integrates enterprise processes. Enterprise reengineering on the other hand, focus on how activities are carried out, and aims to find innovative solutions that improves the competitiveness of the enterprise.

3.1.4 A definition of enterprise reengineering

Enterprise reengineering focuses primarily on the operations activities, and how they should be modelled and designed. The total transformation process can be decomposed into a large collection of concurrent processes executed by a set of operations entities that contribute to business objectives. Each process consist of a group of operations activities that takes input, adds value to it and provides an output to internal or external customers. Enterprise reengineering is essentially a matter of modelling and improving these activities:

- how they are grouped in operations entities and processes,
- how resources are dedicated to the operations entities,
- how resources are laid out physically to create information and material flows,
- how operations entities activities are structured in the organisation, and,
- how processes are controlled.

Enterprise reengineering is therefore defined in the following manner:

Enterprise reengineering is the art of mapping, analysing, designing, and implementing operations processes so that the enterprise can achieve its performance objectives, and be competitive in its market environment

Enterprise reengineering is basically a strategy-driven and model-based approach that implies to map and analyse the existing operations processes of the enterprise, and to design and implement new solutions to how they are organised and controlled. The processes are viewed in the context of the resources, material flows, information flows, organisation and control methods involved, and the reengineering effort encompass changes in all these areas. As such, enterprise reengineering is a way to realise changes in all important decisions areas in operations strategy. However, the changes mainly affect the infrastructure of the enterprise. It can therefore be undertaken at relatively low cost and within relatively short period of time.

Any operations activity or group of activities can be viewed as a transformation process that uses resources to provide definite results on the behalf of the business. The size and scope of a enterprise is therefore not fixed, but should be defined by the business users. An enterprise should be viewed as the part of the company which

needs to be represented and improved (usually a group of departments, a plant, or a group of plants).

Finally, it cannot be emphasised too strongly that enterprise reengineering is an *engineering* discipline in the sense that it require all the established engineering skills of analysis, innovation/synthesis/design and implementation which are the hall mark of the engineering profession. However, the emphasis is on the way the enterprise achieves its goals simultaneously with maximising the value to the customer. Enterprise reengineering enables a company to regard the operation of an enterprise in a focused way in which objectives are met by design and not chance. In other words, the focus is more on the value delivery process than on technology improvements or product innovations.

3.1.5 Business process reengineering

The process perspective of enterprise reengineering stems from the business process reengineering (BPR) approach. BPR as an approach to performance improvement was established in 1990 (Hammer, 1990, Davenport and Short, 1990). It is a controversial approach for reorganising work into processes through information technology. A definition of BPR is "the fundamental rethinking and radical redesign of business processes to achieve dramatic improvements in critical contemporary measures of performance such as cost, quality, service, and speed" (Hammer and Champy, 1993).

BPR implies to take a process approach, and it is the prime focus on business process change which may be distinctive to BPR (Hammer, 1996, Maull et al, 2003). The approach "implies a horizontal view of the business that cuts across the organisation, with product inputs at the beginning and outputs and customers at the end, adopting a process-oriented structure generally means deemphasising the functional structure of the business" (Davenport, 1993). The term "business process" is used to highlight the customer focus of the processes involved. Business processes generally coins "the structure by which an organisation does what is necessary to produce value for its customers" (Davenport, 1993). Business processes are viewed as the complete end-toend set of activities that together create value for the customer. These activities are grouping employees from different specialities like sales, manufacturing and distribution to complete a piece of work.

BPR can be distinguished from mere process improvement by the radical way valueadding work is reinvented. Hammer (1990) and Davenport and Short, (1990) seem to agree on the proposition that all work activities in a process can be classified into three types:

- value adding work, or work for which the customer is willing to pay
- non-value-adding work, which creates no value for the customer but is required in order to get the value-adding work done
- waste, or work that neither adds nor enables value (Hammer, 1996)

"A firm that analyses its customer order-fulfilment process and then eliminates redundant or non-value-adding steps is practising process improvement" (Davenport, 1993). Business process reengineering on the other hand, "is the radical redesign of business processes for dramatic improvement" (Hammer, 1996).

One attempt to define the principles of BPR is provided by Hammer (1990). He defines the BPR principles as:

- Organise around outcomes, not tasks
- Have those who use the output of the process perform the process
- Subsume information-processing work into the real work that produces the information
- Treat geographically dispersed resources as though they were centralised
- Link parallel activities instead of integrating their results
- Put the decisions point where the work is performed, and build control into the process
- Capture information once and at the source

By such principles, non-value adding work is supposed to be designed out by reorganising the value-adding tasks into a new and more efficient process.

BPR provides a valuable perspective of processes and their role in creating value for the customer. The interest for BPR has therefore remained high in both academic and practitioner communities, and over 200 academic papers related to BPR are published since 1999 (Maull et al, 2003). However, several authors are highly critical of some of its methods and assumptions, and controversy surrounds whether or not BPR, as an approach to performance improvement has been successful. Some authors claim failure rates as high as 70 per cent (Laudon et al 2000). Other authors report about successful reengineering efforts that have significantly improved productivity and reduced staff (Teng et al, 1996). It should be noted, though, that the BPR approach is suspiciously void of tools and techniques by witch performance improvements can be accomplished.

The advantage of BPR is that BPR projects can (if they succeed) achieve dramatic performance improvements fast, and at relatively low costs. BPR, "although admittedly difficult to achieve because of the radical nature of the organizational change involved, is a highly appealing approach to business transformation. It can be undertaken at relatively low cost, and the redesign, if not the implementation, of new processes can be completed in a matter of months" (Davenport, 1993). The major reason for this is that reengineering efforts mainly concern processes and seldom require heavy investments in facilities and equipment. Although Hammer and Champy (1993) claim that BPR "ultimately changes practically everything about the company", the changes referred to is mainly job designs, organisational structures and management systems, i.e. the infrastructural dimensions of the company.

BPR provides a valuable perspective of processes and their role in creating value for the customer. However, business process reengineering only addresses parts of what is necessary for performance improvement in manufacturing enterprises, because (1) BPR is mainly targeting office operations, and (2) BPR has a prime focus on processes. The major differences of enterprise reengineering and business process reengineering are summarised below:

Er	nterprise reengineering	Business process reengineering				
•	aims to improve physical and office operations an enterprise approach that encompass decisions areas such as resources, materials, processes, information, organisation, and control	•	aims to improve office operations focus on information technology and processes			
•	based on existing processes and solutions model-based approach	•	"white sheet" approach models are beneficial but not required			

Table 5 A comparison of enterprise reengineering and BPR

Although BPR is presented as an "all-or-nothing proposition" for reengineering all core processes of the company (Hammer and Champy, 1993), business processes are mainly interpreted as office processes. The examples referred to are typically information intensive processes (such as credit issuance, procurement, order fulfilment etc) where information technology can act as an essential enabler for reengineering. All manufacturing companies have such office processes, but they also have manufacturing operations such as production, packaging, storage and distribution. A holistic approach to reengineering should target both these areas of the manufacturing enterprise.

BPR has the prime focus on processes. Davenport (1994) for example, states that "reengineering is not synonymous with total organisational transformation. It involves at best transformation of a few work processes at any given time, and there is much more within organisations that can be transformed". The process perspective is central for performance improvement, and reengineering of processes might provide dramatic results. However, the process perspective alone is to narrow to ensure success in manufacturing enterprises. The success of a reengineering project not only requires a thorough understanding of processes, but also a understanding of their material and information flows, the transforming resources involved (facilities, people, machines, and computers), how they are organised, and the methods used to control them.

Graphical representations are helpful for understanding process flows, but are not required in BPR. Enterprise reengineering on the other hand, is based on enterprise models as the mean to improve operations. Through the use of holistic enterprise models, enterprise reengineering is an approach to integrate and subsume many ideas which have been proposed (and very effectively used) to improve company competitiveness. (See chapter 4 for a description of some central improvement approaches that can constitute potential elements of an enterprise reengineering effort).

The major assumption advanced in this section is that a company which operates using an enterprise approach (as opposed to a pure process approach) delivers better reengineering throughout all its activities. When the enterprise approach is used to reengineer operations processes, the focus is on the design and operations of the most effective means by which customer needs are transformed into customer satisfaction. An enterprise approach demands that an uncoordinated approach is replaced by a framework in which the identities of the separate parts are subsumed by the identity of the total enterprise. There is therefore a need for models and methodological frameworks to support more extended processes reengineering efforts in a systematic way.

3.1.6 Enterprise integration

Enterprise reengineering can be viewed as an element of enterprise engineering that mainly focuses on the modelling and improvement of operations activities. In order to enhance the understanding of enterprise engineering, the reengineering approach is compared with the traditional approach in CIM, enterprise integration.

Enterprise integration

Already in 1955, demonstrations of the feasibility of numerical control of machine tools made many production engineering researchers consider the implications of computer-related technology for improving and optimising the performance of manufacturing activities in general (Merchant and Moehring, 2003). The growing appreciation of the need of a more systematic, overall approach to production engineering was reflected, for example in Dr. M. E. Merchant's paper "The Manufacturing-System Concept in Production Engineering research" from 1961. He outlined the concept of the systems approach to manufacturing, from design to finished product, and conceived the idea that the production engineering research should aim to automate, optimise and integrate manufacturing as a total system (Merchant, 1961). Dr. Merchant was one of the first in the world to visualise the potential impact of the use of computers in developing advanced manufacturing systems. Figure 18 shows the 1969 version of his concept of the computer integrated manufacturing system.



Figure 18 The concept of the Computer-Integrated Manufacturing Systems (Merchant, 2004)

His philosophy of the Computer Integrated Manufacturing system has been followed by people all around the world. In the 1970s and 1980s, several CIM projects were carried out with a focus on CIM technology. However, the potential benefits of computer technology was only realised by a few pioneering companies worldwide. To day, the CIM community is starting to realise that "the technology will only perform at its full potential if the utilisation of the system's human resources is also engineered – so engineered as to enable all personnel to communicate and cooperate fully with each other. Failure to meet this condition cripples the technology" (Merchant, 2004).

The focus in CIM is computerisation. However, the scope has extended from integration at the factory floor to integration of the whole enterprise. This approach is

termed enterprise integration, and aims to create a global information infrastructure that links people, machines and computers by the means of new information technologies. Three levels of enterprise integration are traditionally differentiated in CIM. These are physical or system integration, application integration and business integration (Vernadat, 2001). Integration at the physical and application level implies to develop a enterprise wide communication network, and is mainly a technical challenge. Integration at the business level requires multidisciplinary solutions that also recognise the role, place and involvement of people. It is this extended view on integration that differentiates EI projects from other IT-projects. EI projects aims to develop activities, decisions, resources and information flow in a joint system in such a way that everything behaves in a co-ordinated manner in order to satisfy global objectives and improve performance (Chalmeta et al. 2001).

However, integration in the enterprise "has been the main motivation in CIM projects over the last decade. Unfortunately, the results have been decidedly disappointing in many cases" (Vernadat, 1996). One reason for this might be that the CIM projects still focus too much on developing technology, and less on developing the operations processes that are enabled by the technology. Enterprise integration is to "provide the right information at the right place and at the right time and thereby enable communication between people, machines and computers and their efficient cooperation and coordination" (Kosanke et al, 1999). The underlying assumption is such a statement is that, if people only get the right information - they will do the right thing. Hence, integrated information technology is the means to improved performance.

Enterprise reengineering versus integration

Although enterprise reengineering can be carried out in all phases of a enterprise integration project, these two approaches can be regarded as two equal sub-categories of enterprise engineering. The major differences of enterprise reengineering and enterprise integration are summarised below:

En	terprise reengineering	Enterprise integration				
•	changes of operations activities	•	building of integrated computer infrastructures			
٠	short term, low investments	•	large scale, time consuming, and expensive			
٠	focus on products	•	focus on information and automation			
٠	require conceptual models	•	require executable models			

Table 6 A comparison of enterprise reengineering and enterprise integration

Enterprise reengineering is a extended reengineering of processes, and like BPR, the changes mainly affect the day-to-day operations activities in the enterprise. It can therefore be undertaken at relatively low cost and within relatively short period of time. In comparison, enterprise integration efforts are large scale computerisation and integration projects that are more time consuming and expensive.

The main objective for both approaches is improved performance, but they have different focus. Enterprise integration focuses on how to provide the right information at the right place and at the right time. Rather than focusing on the physical space of the enterprise, enterprise integration is occupied with the informational space between people, machines and computers. Enterprise reengineering on the other hand, also recognise the importance of information, but only as a mean to provide the "right product, in the right quantity, at the right condition, at the right place, on the right time, for the right customer, and at the right costs" (Coyle et al, 1996).

A major mean to achieve improve performance is integration in both approaches. But the term integration is interpreted differently. "Integration is a complex concept that is very difficult to oppose, because its logical opposite is disintegration and suboptimisation, which nobody favours" (Mouritsen et al, 2003). While enterprise integration programmes focuses on information integration, enterprise reengineering focuses on "organisational integration", i.e. the connectivity between activities. The integration objective in enterprise engineering carries practices to reduce the penalty in time, effort, cost or performance, which occurs in any two activities in a process or between processes (Mouritsen et al, 2003). They can be oriented towards sequentially, vertically or horizontally dependent activities (Lambert et al, 1998).

Both enterprise reengineering and enterprise integration are model driven approaches. Enterprise reengineering requires simple conceptual models to graphically visualise the current and future state of the enterprise. Computer-based tools that use a rigorously defined set of symbols to represent different process entities can be used for this type of modelling, but these are not essential. "The primary purpose of the graphical display is communication and recording, and any consistent set of easily understood symbols will suffice" (Davenport,1993). Enterprise integration on the other hand, requires very detailed enterprise models that are programmed in software, and support the transaction of information in the enterprise. (See chapter 3.1.6 for a further discussion of this topic) It should be noted, though, that enterprise reengineering can be carried out in all phases of a enterprise integration project, and models developed for enterprise reengineering can be useful in the initial stages of a enterprise integration project in order to understand the information flows.

3.2 Major assumptions for enterprise reengineering

Enterprise reengineering (as defined in this thesis) relies on the assumption that most enterprises are made up of several units or departments, which themselves act as smaller versions of the whole enterprise as they form a part. The traditional operations model depicted in figure 5, which represents the enterprise as a single process, is therefore to generic and superficial to provide real support in a reengineering effort. When modelling, it is therefore necessary to break down the enterprise into more managerial pieces for analysis and for control. The decomposition that is proposed for enterprise reengineering is inspired by holonic systems theory, proposed by Koestler (1967). The major concepts of this theory are outlined below.

3.2.1 Holonic systems as a source of inspiration

The term holonic is derived from the word "holon" which was introduced by Koestler (1967). The word holon is a combination from the Greek holos = whole, with the suffix –on which, as in proton or neutron, suggest a particle or part. Two observations impelled Koestler to propose this word. The first observation is from Herbert Simon (1962) who analyses a range of real-world complex systems in biology and society. Based on these analyses and "the parable of two watchmakers¹⁵", he states that complex systems will evolve from simple systems much more rapidly if there are stable intermediate forms than if there are not. Simons' analysis reveals why every complex adaptive system is hierarchic (in a loose sense).

The second observation, made by Koestler while analysing hierarchies and stable intermediate forms in living organisms and social organisation, is that – although it is easy to identify sub-wholes or parts – "wholes" and "parts" in an absolute sense do not exist anywhere. This made Koestler propose the word holon in order to describe the hybrid of sub-wholes/parts in real-life systems. Holons simultaneously are self-contained wholes to their subordinated parts, and dependents parts when seen from the inverse direction. Koestler also points out that holons are autonomous self-reliant units, which have a degree of independence and handle contingencies without asking higher authorities for instructions. Simultaneously, holons are subject to control from (multiple) higher authorities. The first property ensures that holons are stable forms, which survives disturbances. The latter property signifies that they are intermediate forms, which provide the proper functionality for the bigger whole.

Finally, Koestler defines a holarchy as a hierarchy of self-regulating holons which functions (1) as autonomous wholes in supra-ordination to their parts, (2) as dependents parts in sub-ordination to controls on higher levels, (3) in co-ordination with their local environment. According to Koestler, holarchies are often well-organised groups of people, where individuals exhibit a remarkable ability to autonomously react to disturbances.

3.2.2 The operations hierarchy

Koestler's concepts was developed for social organisations and living organisms, but is also a source of inspiration for operations. A major lesson of the holonic theory is that any manufacturing enterprise can be decomposed into a set of units that has some degree of autonomy, and that has some interaction with the local environment. These units are termed "operations entities" in this thesis, and act as smaller versions of the whole enterprise as they form a part.

91

91

¹⁵ The parable shows that watches based on modules will require more assembly work, but will require significantly less rework due to disturbances (the modularised watch don't have to be made all over again if the watchmaker is disturbed by customers).

At the general level, the operations process model depicted in figure 5 is also valid for each operations entity. A operations entity can be defined as a group of resources (people, machines, computers, facilities) responsible for executing tasks (processing centre) and for making decisions (decisions centre). It is important to notice that to "form a part" does not mean that operations entities are independent units. Even if each entity has some degree of independence and can handle contingencies without asking higher authorities for instruction, they also are subject for control from higher authorities. Examples of such operations entities are, among others:

- a order-handling department that transforms customer orders into work orders and product specifications, and;
- a manufacturing department that transforms parts (materials/components) into final products (see Figure 19).



Figure 19 All enterprises are made up of many small operations entities

Figure 19 illustrates the concept of enterprise decomposition. Each operations entity has inputs, some which will come from outside the enterprise but many of which will be supplied from other internal operations entities. Each operations entity will also produce outputs of products and services for the benefit of customers. Again, though, some of each operations entity's customers will be other operations entities. This decomposition can be extended further. Within each operations entity there might be sections and groups that which can also be considered as operations entities in their own right. In this way any enterprise can be considered as a hierarchy of operations (Slack et al. 2004).

An operations entity represents either a decisions centre consisting of a department, section, work centre, or one person. There must be someone responsible for it. The decisions in every operations entity are supported by some sort of control system. The control systems that are supporting decisions regarding operations in manufacturing enterprises, are known as manufacturing planning and control (MPC) systems. Furthermore, the operations entities represent (formal or informal) units in the organisational structure of an enterprise, and have organisational boundaries and responsibilities. The organisational structure determines the social organisation in terms of roles and jobs and their authority and responsibility over actors, or groups of

actors, in enterprises (Vernadat, 1996). Every operations entity is a part of a operations hierarchy, and has responsibilities and authorities on lower level units, and report to an upper level unit.

3.2.3 Core idea in enterprise reengineering – decomposed operations models

An enterprise could be viewed and represented as being composed of several smaller entities that are controlled and organised semi-autonomously. An enterprise modelling and reengineering effort based on this "decomposed" view enables differentiated solutions that are customised to the local requirements of each area of the enterprise.

In enterprise reengineering, it is especially the operations entities at the lowest organisational level (where some employees do the actual work) that needs to be mapped, analysed, and redesigned. Such operations entities, where productive resources are organized and work is completed, are termed work centres (Chase et. al. 2004), planning departments (Tompkins et. al. 1996), production units (Hyer and Wemmerlöv, 2002), value stream loops (Rother and Shook, 1999), or control areas (Alfnes and Strandhagen, 2000). These are the smallest organisational entities that control a set of resources, and are termed operations areas in this thesis.

Operations areas can involve both manufacturing and office operations, and is a collection of workstations that perform "like" activities. Depending on the situation, "like" could refer to workstations performing on similar products or information deliverables, or workstations performing similar processes. A work centre composed of a group of similar machines can be one type of operations area, a paint line another type, an assembly cell a third type, and so on. Thus, it is possible to view a complete enterprise as being composed of several smaller operations areas¹⁶ (as shown for manufacturing operations in Figure 20.

¹⁶ A decomposition at the single workstation level is also possible, but outside the scope of this thesis.



Figure 20 A decomposed operations model (adapted from Hyer and Wemmerløv, 2002)

Figure 20 shows a decomposed model of the manufacturing operations of a enterprise (in a similar manner, it is possible to decompose the office operations¹⁷). The top half of Figure 20 depicts an input-output model of an enterprise. Material flows from suppliers to customers via series of process stages. Within each such stage – reception, part production, sub assembly, final assembly and test, and shipment – there are one or more operations areas. A operations area is the smallest (in terms of span of control) type of decisions centre in the organisation, and is controlled by a particular control method¹⁸. It is also a physical distinct location where certain tasks are carried out, and to which resources (machines, personnel, and computers) can be assigned for a period of time.

A single operations area can be an entity in several business processes (or value streams) that has similar processing requirements, and is connected to other areas through flows (and buffers). The business process (or value stream) for product line X is indicated with a dotted line in Figure 20. Each operations area can be viewed as a

94

¹⁷ This is routine office work, i.e. a process that recycles relatively frequently, and where the tasks required to produce a particular type of deliverable are relatively stable

¹⁸ A manufacturing planning and control system can be decomposed into several control methods or sub-systems such as kanban, MRP, ROP etc. The control methods in use should suit the particular needs of each control area.

process that uses resources to convert inputs to outputs (see lower part of Figure 20). A operations area's production depends on the demand signals it receives (in the form of schedules and/or pull signals). In turn, the operations area requires materials to produce and therefore sends demand signals to the previous step in the business process. This could be another operations area or an external supplier.

In this thesis, such "decomposed" operations models as illustrated Figure 20 are regarded as the means for understanding, analyses and reengineering of enterprises. A enterprise decomposition make it possible to model the complete enterprise as a network of operations entities which are engaged in transforming materials and information for each other, each entity being at the same time both an internal supplier of products and services and an internal customer for the other entities' products and services. Each operations entity will contribute some part to the production of several products and services with which the enterprise attempts to satisfy the needs of its customers. The contribution from each operations entity will not occur in the same order for each product family. In fact, the flow of information and materials between two operations entities might be complex, involving delays and recycling. These collections of contributions from each operations entity to a line of end products are often called "end-to-end" business processes (Hammer and Champy, 1993) or "value streams" (Rother and Shock, 1999) and often cut across conventional organisational boundaries.

3.3 A conceptual framework for enterprise reengineering

Enterprise reengineering can be seen as a model-based way to implement strategic performance objectives, and the reengineering of a enterprise should be undertaken with a specific business vision and related objectives in mind. Developing a worthwhile operations strategy and performance objectives relies on a (1) clear understanding of the operations capabilities, coupled with an understanding of market structure and opportunity, and (2) knowledge about innovative activities undertaken by competitors and other organisations. However, "simply *formulating* strategy is no longer sufficient, it is also essential to *design* the processes to *implement* strategy effectively" (Davenport, 1993). Operations strategy implies to formulate performance objectives and improvement programmes that enable products to qualify and win in the market place. Enterprise reengineering is to model and design processes and other infrastructural elements such as control methods and the organisations structure in order to improve performance levels in the desired strategic direction.

3.3.1 The role of enterprise reengineering in operations strategy development

Figure 21 illustrates the operations strategy process as a continuous effort of aligning and extending operations capabilities and market requirements.

Chapter 3



Figure 21 The role of enterprise reengineering in operations strategy development

Enterprise reengineering is an model-based approach to streamline this process, i.e. how to effectively and efficiently transform the operations capabilities from a current strategic position to a new strategic position.

Enterprise reengineering focuses on the modelling and design of activities in production, procurement, order management, and other operations areas that are directly involved in processes that creates and delivers products and service to the customer. The most likely objectives for enterprise reengineering are cost reduction, time reduction, quality improvement and empowerment. The process is a especially suited unit for time reduction efforts, and to improve quality of products and work life. Cost reductions on the other hand, are regarded as effect of such improvements rather than a sufficient process redesign objective in itself. Cost should therefore be regarded in combination with the other objectives (Davenport,1993).

3.3.2 The strategic framework

Figure 22 shows a strategic framework for enterprise reengineering. Figure 22 shows the reengineering effort as a process from a current strategic position (in terms of costs, quality, time, precision, flexibility, and innovativeness) to a future strategic position. The reengineering is guided by the operations strategy and is based on a operations model which are transformed from a AS-IS status to a TO-BE status.



Figure 22 A strategic framework for enterprise reengineering

The transition of the operations model to a new state involves creativity and innovation, and should be based on a understanding of the business objectives. The process is supported by design elements from the most suitable improvement approaches. The reengineering also involves change managements issues, such as participation and knowledge creation, that should be targeted in order to ensure success.

Enterprise reengineering is about achieving excellence by combining design element, i.e. principles and solutions, from best practice approaches like flow manufacturing, lean manufacturing, business process reengineering, quick response manufacturing, and others, in order to develop a holistic solution that are aligned with overall strategy. Note that the reengineering of operations activities and how they are organised (in processes) and controlled, only covers some limited (infrastructural) aspects in an operations strategy. However, process changes may also affect a range of other strategic issues in an enterprise. For example, the compensation system might be altered, a new ICT-system or a new flexible machine might be required, or the supplier base might be altered in order to ensure rapid and responsive supply. A successful reengineering effort should therefore be based on a thorough understanding of all areas of the enterprise.

3.3.3 The enterprise reengineering methodology

The enterprise reengineering methodology is proposed to structure enterprise reengineering efforts. The methodology is based on an understanding of the company's business objectives, and includes an iterative and stepwise approach to improve competitiveness. The methodology consists of five parts that supports all phases of a enterprise reengineering project. These are strategic planning, and operations mapping, analysis, design and implementation. The methodology is further described in chapter 7-9.

3.4 Summary

In this thesis, enterprise reengineering is introduced as an approach that combines research within operations strategy, and particularly research regarding best practices, - with research within enterprise engineering, and particularly research regarding enterprise modelling architectures. Enterprise reengineering is established as a systematic and model-based approach for enterprises to effectively and efficiently create fit between market requirements and operations capabilities. Enterprise reengineering mainly targets the infrastructural aspects of operations strategy, and does not support all types of strategy developments equally well. The focus is on long term decisions regarding operations processes, and how they are organised and controlled. The process focus is adopted from BPR, but compared to BPR, enterprise reengineering represents a systematic and holistic approach to enterprise improvement. The total transformation process can be decomposed into a large collection of concurrent processes executed by a set of operations entities that contribute to business objectives. Enterprise reengineering is essentially a matter of modelling and improving these processes.

A strategic framework is provided that represents the main issues in enterprise reengineering and how they are connected. The framework depicts enterprise reengineering as an approach that aims to transform the enterprise from an existing operations model (and the strategic position induced by it), to a new operations model that contributes to an improved future strategic position. This transition should be guided by operations strategy, and supported by:

- Design elements from best practice programmes such as flow manufacturing and lean manufacturing.
- An architecture for conceptual enterprise modelling.
- Change management principles.

This strategic framework is the fundament for an enterprise reengineering methodology which is the major contribution of this thesis (chapter 7 - 9). The methodology provides an approach to improve competitiveness and is structured in five parts. These are strategic planning, and operations mapping, analysis, design and implementation.

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4. Flow manufacturing

An enterprise reengineering project can use a range of best practice manufacturing approaches (such as a lean manufacturing or quick response manufacturing) to improve performance. One such approach, flow manufacturing, is introduced in this chapter to improve how operations are organised and controlled in manufacturing enterprises. This chapter has three themes. First, to briefly review the history of flow manufacturing and to introduce the major concepts. Second, to compare the flow manufacturing approach with other existing improvement approaches. Third, to outline four crucial decisions areas in flow manufacturing, namely, process design, layout design, team design, and MPC design.

4.1 Historical roots and concepts

Flow manufacturing is a form of manufacturing where materials flow is balanced and runs rapidly through a set of operations areas in an enterprise. Flow manufacturing is an extension of the group technology (GT) layout approach that also encompasses team design and modification of the MPC system. This approach was initiated at NTNU/SINTEF in the 1980s (Quistgaard et. al 1984) and has been implemented in ca. twenty Norwegian companies.

4.1.1 Historical roots – group technology

Flow manufacturing has its origin in group technology (GT). Since the initiation in the USSR in the late 1950s, the group technology concept has been carried throughout the industrialised world, and has been used to reduce set-up times, batch sizes and material handling costs. The major facilitator for making group technology public was John Burbidge, who promoted and systematised this concept for 30 years (see for example, Burbidge, (1975, 1979, 1989). GT is now well rooted in Germany, the USSR, the UK and, especially Japan, where it is a "way of life" in many manufacturing enterprises (Black, 1987). GT provides a systems approach to the redesign and reorganisation of the functional shop, and group technology layouts are now widely used in metal fabricating, computer chip manufacturing, and assembly work.

GT was developed in order to create effective flow in job and batch manufacturing (Burbidge, 1975). GT was inspired by the efficiency and continuous flow in line manufacturing, typically built for mass production of high volume, standard products. The basic idea was to achieve effective flow, "not only in simple process industries and for single components in mass production quantities, but also for families of similar components" (Burbidge, 1975). GT is an improvement approach that "identifies and exploits the "sameness" of items and processes used in manufacturing industries" (Black, 1987). It groups units or components into families of parts which have similar design or manufacturing sequence. There are many ways to do this, but three popular ways are through:

- Tacit judgement, or eyeballing
- Analysis of the production flow
- Coding and classification

The eyeball methods is the easiest and least expensive, but do not work in large job shops where the number of components may approach 5000-1000, and the number of machines may be 300-500. The second method, product flow analysis (PFA), uses the information available on route cards to sort through all the components and group them by matrix analysis (Burbidge, 1979). The third method is to use a coding/classification method. There are design codes, manufacturing codes, and codes that cover both design and manufacture.

Over the years, the GT concept has been extended to create a variety of new improvement approaches, termed flow manufacturing (see e.g. Quistgaard et. al (1984), or Leone and Rahn (2002)), or cellular manufacturing (see eg. Hyer and Wemmerlöv (2002), or Kamrani and Logendran (1998)). However, the core building block in these approaches is still group formation, i.e. to assign parts and machines to operations areas in order to create flow.

4.1.2 Functional manufacturing

Flow manufacturing is believed to be crucial for a range of improvement efforts, and to yield large performance improvements. Burbidge for example, stated that "I believe that process [i.e. functional] organisation is obsolete, and I see group technology [i.e. flow manufacturing] coupled with just-in-time production control as essential for batch and jobbing production companies which want to survive in the future" (Burbidge, 1989).

Traditionally, many enterprises are organised in functions. The functions organised enterprise consist of a set of departments, each organised to handle a particular type of process such as grinding, welding, or testing. The focus is on productivity and resource-utilisation, and management is based on centralised hierarchical control and scientific management, principles developed by scholars like Frederic Taylor (1911) at the beginning of the 20th century. The principles of traditional functional manufacturing are (among others):

- Resources (machines, equipment, personnel etc) are organized in functional domains.
- Discipline and accuracy are vital. Work is rule based and follows a strictly hierarchical line of command. Activities must be carried out according to plans with fixed order sequence, and databases must always be updated.
- Planning and control are centralized and separated from value-adding activities. This principle creates jobs with a high degree of specialization and processes designed by these principles are characterized by an extensive number of separated activities, each representing a narrow area of responsibility.

Functionally organized enterprises are flexible and enable each department to optimise their resource utilisation. However, the problems that are commonly associated with such batch and queue system, are several. Functional manufacturing often involves unnecessary internal and external interfaces that create complexity, uncertainty and rigidity in the manufacturing enterprise. Such artificial barriers inhibit the performance necessary for a competitive supply of products, and may facilitate the Forrester-effect (Forrester, 1958). Moreover, hierarchical control, an extensive number of separated activities, and narrow areas of responsibility create systems that

are hard to coordinate (Dekker and Poutsma, 1999). Hyer and Wemmerlöv (2002) suggest some typical problems that are summarised in Table 7:

Table 7 Typical problems in functionally organised manufacturing enterprises:

Typical problems:
Materials moved long distances
Materials handled many times (in and out of storage)
Long setups
Large lot sizes
High defects rates
High rates of equipment breakdown
Unavailable tooling
Long manufacturing lead times
Part shortages in assembly
Large inventories
Divisiveness between operators, supervisors, and support
Problems with communication, coordination, and scheduling
Flow of material, and work content, are difficult to simplify and standardise
Difficulties in identifying cause of defects

In short, functionalised enterprises often demonstrate long lead times, poor quality, high manufacturing costs, fractionalised product responsibilities, and low improvement opportunities. Furthermore, few companies are solely in the business of performing operations with high efficiency. Rather, the overriding objective is to make complete products to sell and deliver to customers, rapidly and inexpensively, for problem free use. A major criticism of functionally organised enterprises, therefore, is that the principle of specialisation and division of labour has resulted in manufacturing systems that has lost it focus on the customer (Hyer and Wemmerlöv, 2002).

4.1.3 Performance improvement through flow manufacturing

A major cause of the poor performance of the functional manufacturing approach is the unnecessarily long throughput times associated with manufacturing processes designed using this model. A typical manufacturing process involves activities like production, assembly and transport. Such activities add value for a customer. However, value-adding activities often constitute a minor share of product throughput-time in functionally organised enterprises. This is illustrated in figure 23.



Figure 23 The time compression potential. Adapted from Quistgaard et al (1989)

Time-compression is a crucial competitiveness enabler. Unnecessarily long throughput-times are often created by delays in queues and stocks, and non-value-adding activities like planning, document handling and quality inspections.

Compression of throughput times provides lower Work-In-Process, shorter delivery time and improved customer service (Quistgaard et al, 1989). One way to compress time is to reengineer for flow manufacturing.

During the last decade, several Norwegian manufacturing companies has reengineered their manufacturing enterprises for flow manufacturing. Most of them have radically changed their routines, layout, product design, control methods and information technology, and improved their performance (Strandhagen and Skarlo, 1995). The shift to flow manufacturing is illustrated in Figure 24.



Figure 24 From functional to flow manufacturing

Figure 24 shows a enterprise that is a) organised in five functional departments, and b) reengineered into five product focused operations areas. The accompanying flows for two products are also illustrated. In a functional enterprise, similar equipment is grouped together in order to produce a variety of dissimilar products that may follow highly variable routings. The focus of this manufacturing form is to maximise the skills of the operators and the efficiency of each unit. In a flow oriented enterprise, on the other hand, dissimilar machines are grouped in order to produce similar parts using identical or closely related routings. The result, among others, is effective flow and shorter throughput time. In addition, flow manufacturing projects can provide the following performance improvements:

- inventory reduction;
- better capacity utilisation;
- fewer stock outs;
- reduced obsolescence costs;
- and improved customer service.

These are all performance objectives that are crucial in modern and customer oriented markets.

4.1.4 Flow building block - the operations area

A basic building block in flow manufacturing is the product focused operations area. An operations area is self-contained in the sense that it completes all operations in one or several processing stages in the manufacturing of one or several products. An operations area can be defined in the following way:

An operations area is a group of closely located work stations, which are dedicated to perform similar operations and managed by the same control method. The operations

area is a distinctive organisational unit within the enterprise, staffed by one or more employees, accountable for output performance, and delegated the responsibility of one or more control, support, and improvement tasks.

The term "operations area" above include both manufacturing and office operations, and is a group of workstations that performs "like" operations in the widest sense. "Like" could refer to similar equipment performing on a variety of dissimilar parts, or dissimilar equipment performing on a family of similar products. Figure 25 illustrates the concept of operations areas.



Figure 25 The operations area: a work centre, paint line, assembly cell etc.

A operations area is an operations entity where productive resources are dedicated to perform similar operations with similar processes or on similar products, resources are spatial close materials and information are transformed through operations performed on one or several product families, selected responsibilities are delegated to the operations area as an organisational unit, and that operations are managed by the same control method.

An operations area is an area of responsibility at the lowest organisational decisions level in the enterprise. That is, operations areas are operations entities where workers are under direct supervision of a manager or team leader. Typically, a reasonable span of control for such entities is on the order of 10 employees. Organizational units with many more workers than this will probably require intermediate levels of management (foremen, lead technicians, etc) (Hopp and Spearman, 2001). Of course, the number of employees will vary across enterprises. The appropriate span of control also depends on factors such as process and product characteristics, and physical location of equipment and personnel. If a set of processes is characterized by product and process differences, along with physical separation, it is logical to assign the responsibility to two managers. However, this rule of thumb still gives an idea of the entity size of a operations area.

A schematic view of an operations area is shown in Figure 26.



Figure 26 A schematic view of the operations area

There are two fundamental different ways to organise work, one is to group work stations that perform similar operations, the other is to group work stations that produce a certain product. Flow manufacturing has introduced a compromise, to group work stations in operations areas that perform operations on products with closely related routings. Depending on the product volume-variety, operations areas can be classified as product, product family, or process type.

- If the product is standardised and has a large stable demand, the type of operations area should be a *production line operations area* where multiple, sequential operations are performed on a single product.
- If the products is capable of being grouped into families of similar raw materials, parts, components, products, or information deliverables, the type of operations area should be a *product family operations area* where multiple, sequential operations are performed on one or more families
- If the product is none of the above, the type of operations area should be a *process* operations area where functionally specialised operations are performed on a variety of dissimilar products that may follow highly variable routings¹⁹.

Flow manufacturing aims to create product focused operations areas wherever possible in manufacturing and administration. Such operations areas (i.e. the production line or product family type) are characterised by (Suri, 1998):

106

¹⁹ The difference between a traditional functional department and an operations area that are organised around a particular type of production process might seem marginal. The most important difference is that operations areas are self-contained (the dependence of outside operations area minimised). A fullbreed operations area has distinct boundaries and do only allow unidirectional flow to other areas.

- The aim is to complete all operations one or more families of similar raw materials, parts, components, products within the operations area.
- Machines are dissimilar. This is in contrast to the traditional functional organisation where each operations area has similar machines.
- All resources dedicated to a product are located close to each other, again in contrast to a functionally organised enterprise where jobs need to go long distances from one operations area to the next.
- In contrast to the traditional efficiency principle of division of labour, the operations area is staffed with on or more multiskilled workers performing various operations.
- Instead of having a hierarchy of managers and tasks workers, the ownership of the operations area is given to a team of workers
- The operations area is dedicated to one or a set of products, which means that its resources are not diverted to making anything outside that family.

These principles may sound straight forward, but their application is more difficult than they may appear. Although, the ideas of flow manufacturing have been promoted for more than two decades, the application in industry of these ideas has not yet reached its full potential. Many industrialists don't understand that such drastically changes are necessary to create flow, and even if there is a desire to implement operations areas, managers still struggle with fundamental issues of how to properly implement them. A reengineering procedure for flow manufacturing is therefore proposed in this thesis as an (optional) element of the enterprise reengineering methodology.

4.2 The relationship to other performance improvement approaches

Flow manufacturing is based on product-oriented and interconnected operations areas in all stages of the enterprise. The objective of flow manufacturing is to change the organisation of tasks, procedures, equipment, and processes from a functional basis to a product-oriented basis. Operations areas are formed which complete all the set (or family) of products or components which they make, through one or a few processing stages, such as metal founding, machining, and assembly, and are equipped with all the machines and other processing equipment they need to do so. The role of flow manufacturing compared to some other performance improvement approaches is illustrated in Figure 27.



Figure 27 Relation to some other improvement approaches

Flow manufacturing is closely related to several different types of performance improvement approaches. Flow manufacturing has its origin in group technology, which mainly targeted technical issues like rearranging equipment on the factory floor. However, early industrial experience discovered that human side of work is equally important to the success of flow enterprises (see e.g. Burbidge, 1975). Flow manufacturing is therefore also closely connected to socio-technical system design described below. The operations area can potentially create a positive environment for work. John Burbidge said in this regard "I believe that group technology holds out the improvement in the quality of working life and that in the long run this will be its major contribution" (Burbidge, 1975).

Furthermore, flow manufacturing is related to lean manufacturing, which uses flow manufacturing concepts (such as flow-oriented layout, operations areas and teamwork) and pull control to create efficiency in repetitive manufacturing with somewhat stable demand. Flow manufacturing is also related to business process reengineering, which mainly is targeting office processes. Flow manufacturing provides principles and concepts that are more concrete in their application for office processes than the general principles of BPR, and should be used to support "BPR" improvement projects. Quick response manufacturing is an improvement approach that has its origins in time-based competition, and uses flow manufacturing as an foundation to create improvements in enterprises that operates in highly dynamic markets. Agile manufacturing also targets such dynamic markets, but is still an evolving concept. Examples of agile behaviour have been given, but core principles of how to implement are still being developed. Agile manufacturing may be viewed as an approach to take manufacturers beyond quick response manufacturing, but the principles to do so have to be better understood. These approaches are now described in more detail.

4.2.1 Socio-technical design

Socio-technical system design has traditionally focused on work-organisation in manufacturing systems, and has long traditions in Norway. Several breakthrough socio-technical projects were carried out in the 60s and 70s under the label "the Norwegian Industrial Democracy project" (Herbst, 1977). Since then, socio-technical system design has been developed and established as a comprehensive approach to design that meets the logistic requirements modern manufacturing companies have to cope with: i.e., flexibility, learning capacity and innovation (Dekker and Poutsma, 1999).

Socio-technical system design is an approach that attempts to develop jobs that adjust the needs of the production process technology to the needs of the worker and the work group (Pasmore, 1988). The term socio-technical systems (STS) was first used by Trist and Bamforth (1951) to describe the importance of finding a complementary match between technical and social systems, specially in cases where the technical system has been altered. The term was developed from studies of weaving mills in India and of coal mines in England. These studies revealed that that work groups could effectively handle many production problems better than management if they were permitted to make their own decisions on scheduling, work allocation among members, bonus sharing, and so forth. This was particularly true when there were variations in the production process requiring quick reactions by the group, or when the work of individuals were overlapping and interdependent. Socio-technical system design refers to this essential complementarity as "joint optimization" and suggest that really effective systems can only be generated when technology and people are properly matched (Trist, 1981). This is illustrated in Figure 28.



Figure 28 Joint optimisation of social and technical systems

Even in enterprises utilising the same technology, different work arrangements are possible. Socio-technical system approach attempts to develop arrangements that integrate the demands of both the production process technology and the workers. Various definitions are available for the components of socio-technical systems, but most follow similar themes. Pastmore et. al (1982) have integrated definitions from several sources to develop the following descriptions of the technical and social sub systems of enterprises. The technical subsystem system "consists of the tools, techniques, procedures, skills, knowledge, and devices used by members of the social system to accomplish the task of the organization". The social sub system is "comprised of the people who work in the organization and the relationships among them" (Pastmore, et. al., 1982). The major point in the socio-technical approach is that if the technical arrangement or layout of the enterprise is changed, the level of variety, challenge, feedback, control, decisions making and level of integration provided for people can be changed. These social changes will require careful attention because of their potential to influence employee attitudes, motivation, and performance.

Socio-technical system design has traditionally focused on work-organization in manufacturing systems, and especially the creation of autonomous groups. This research has long traditions in Norway. Several socio-technical projects were carried out in the 60's and 70's under the label "the Norwegian Industrial Democracy project" (Herbst, 1977). The Norwegian Industrial Democracy project was directed by Einar Thorsrud and the Tavistock institute and aimed to democratise work through what was called the "socio-technical" reorganisation of work. The objective of these projects (and also more recent socio-technical design projects) was to move away from the traditional functionally-oriented organizational structure through the design of autonomous groups. In a socio-technical system, activities are no longer separated into narrow areas of responsibility. Teams of multi-skilled and empowered workers replace the conventional hierarchy (Taylor and Felten, 1993). This is illustrated in Figure 29.



Figure 29 The creation of autonomous groups (Herbst, 1977)

Since those pioneering studies, the socio-technical approach has been applied in many countries – under headings such as "autonomous work groups", "self directed teams", or "self managed teams", see for example Heizer and Render (2004) or Chase et. al., (1998). Design of autonomous groups by socio-technical principles enables enterprises to handle variation and uncertainty, and provide solutions that improve peoples' work quality and performance. In flow manufacturing, these principles are used for effective job design in operations areas.

Even though Burbidge (1975) highlights the importance of teams, job design has not been central in flow manufacturing, which has mostly focused on the technical aspects of enterprise design. Principles for job design were not equally emphasised. However, the full potential of flow manufacturing is only achieved when both the social and the technical system is aligned. Sociotechnical design principles should therefore be considered in the design and staffing of operations areas. The socio-technical viewpoint can be summarised as follows. The majority of manufacturing companies still bears the characteristics of predominant division of labour: hierarchy, maximum break-down of tasks, narrow skills, external control and total specification. These principles do not meet the functional requirements of modern manufacturing systems. Competitive manufacturing systems require a structure that enables effective control and co-ordination of functionally differentiated processes. The core of socio-technical enquiry is therefore the analysis and identification of internal structural characteristics and market characteristics, which together determine the probability for disturbances and the flexibility to handle them. These characteristics are the basis for a new design, more capable to handle variation and provide stable supply.

Cherns (1976,1987) has developed nine principles for socio-technical design, which also are important in flow manufacturing (see Table 8). The first is that technology (tools, information, machines, procedures etc) should be designed for competent worker performance, rather than for automation or command and control. This requires extensive worker participation in design (Ehn, 1992). A second principle is that the degree of self-regulation should be maximised throughout the enterprise. This is enabled through a design guided by the minimum specification criteria (Trist, 1981), which is to specify no more than is absolutely necessary regarding tasks, jobs, roles etc. The more key variables that can be controlled by the group, the better the results, and the higher the member satisfaction (Herbst, 1977). A third principle is that variance that cannot be eliminated should be controlled as near the point of origin as possible. This is because the best decisions are based on the decision makers' practical

knowledge and insight in a specific situation. A fourth principle is that effective control relies on complete information and judgement, and information must be provided at the place where decision and actions will be taken. A fifth principle is that change and uncertainty require multi functionality: it is easier to achieve the necessary variety of responses when the workers/teams are multifunctional. A sixth principles is that boundaries should be designed around a complete flow of information, knowledge and material, so as to enable the sharing of all relevant data, information, knowledge and experience. The function of supervision is to manage the boundary conditions in the group's environment so that the group may be freed to manage its own activities (Trist, 1981). A seventh principle is that the teams should be supported by consistent reward systems, training policies, etc. An eight principle is that the design should aim for a high quality of work, and a ninth principle is that the design process is never complete, it is a continuing process.

Huber and Brown (1991) uses these STS principles to propose the core elements in flow manufacturing job design. The principles of STS and the core elements of flow manufacturing are listed in Table 8.

Table 8 Sociotechnical systems principles and	and flow manufacturing (adapted from
Huber and Brown, 1991)	

Socio-Technical Systems principles	Flow manufacturing parallel
1. Compatibility System design must be compatible with long term adaptive objectives. In order to adapt, the organization make full use of the creative capacities of its members through participation.	Work teams may emphasize planning and continuous improvement through joint problem-solving efforts.
2. Minimal Critical Specification Specify as little as possible about how jobs are to be performed in order to allow for the introduction of creative options	Work groups may be empowered to decide how to allocate tasks among members
3. The Socio-technical Criterion Variances should be controlled as closely as possible to their point of origin	The flow oriented layout permits immediate detection and response to variances in material quality, performance, equipment reliability.
4. Information flow Feedback about production quality or quantity should be made available first to those at the operating level. They are in the best position to act on the information.	The close clustering of machines and operators facilitates feedback about job performance and variances.
5. The Multifunctional Criterion Organisation should avoid fractioning the tasks of members; they should be capable of a range of functions.	Flow manufacturing work is less specialised. Job rotation and cross training characterise many operations area environments.
6. Boundary location Time-based boundaries between entities are likely to be more effective than functionally- based boundaries. Thus physically related machines that tend to operate in temporal sequence is preferred to a functional layout with similar machines located near each other.	Machines needed for a group of products are clustered together. These machines and the employees that operate them are dedicated to the production of these products.
7. Support congruence Support, including pay systems, selection,	Flow manufacturing does not inherently

training, conflict resolution, work	include these concepts. However, its
measurement, performance valuation, time	effectiveness requires consistent support
keeping, leave allocation, promotion, and	policies.
separation, must be congruent with	
objectives and design of the technical	
system.	
8. Design and Human values	
Quality of work life is an important	Flow manufacturing has been described as
responsibility of the organisation.	an approach that may improve quality of
	work life, however, there is little empirical
	evidence to support this position.
9. Incompletion	
Organisational design, involving	A flow manufacturing enterprise must be
simultaneous consideration of social and	adapted to changes in product mix, work
technical systems, is an ongoing process.	force, and production volume.

As indicated in Table 8, there are significant similarities between STS principles and core elements of flow manufacturing. The common themes point to a team-based design of operations areas, empowered operators, process control at the source, multifunctional operators, closely located resources, immediate feedback on process problems, potential job satisfaction, and enterprise design in constant evolution. Although there are great overlaps between STS and flow manufacturing, and STS-oriented redesign may not necessarily suggest the design of operations areas (Taylor and Felten, 1993). However, the STS principles are still central for job design in flow manufacturing.

4.2.2 Lean manufacturing

An emerging and related approach is lean manufacturing. During the last decade several enterprises have achieved flexibility and increased competitiveness by implementing the "lean" or "just-in-time" principles developed at Toyota (Raabe, 1999). Even though the "Toyota Production System" originally was developed for car production, the major principles frequently associated with lean manufacturing are not specifically automotive specific. They include time compression and reduction of inventories, product oriented layout, the pulling of production by demand, and product standardization and modularization (Raabe, 1999). Skorstad (1999) summarizes the logic behind lean manufacturing in Figure 30.



Figure 30: The logic behind lean manufacturing (Skorstad, 1999)

The two main principles in lean manufacturing are "the pull principle" and productoriented layout (Skorstad, 1999). The *pull principle* means that production is pulled through the factory by real demand. The pull principle is opposite to "the push principle", which often is utilized in mass production. The push principle means that production is pushed through the factory to meet expected demand calculated from forecasts (Andersen et. al., 1998). The pull principle ensures supply based on real demand, and will to a large extent eliminate the Forrester effect. However, certain requirements are necessary to enable the pull principle.

Supply on real demand require that Work in Progress (WIP) and throughput times are minimized to ensure responsiveness. Short throughput times are enabled through small batch sizes. Hence, set-up times are reduced to maintain productivity and efficient use of equipment. Techniques like OTED "One-Touch Exchange of Die" or SMED "Single digit-Minute Exchange of Die" are applied.

Demand-variation in volume and product mix is handled by variation in processes. Balancing techniques like multi-machine operation, U-shaped production-cells and training of multi-skilled operators ensures the required process variations.

The reduction of stocks, combined with a minimization of throughput times makes the manufacturing system vulnerable, so zero defects and stable equipment is a necessity in such systems. Techniques like Poka Yoke (a fail safe/equipment improvement process) and Jidoka (automatic halt of production if defects occur) aim at achieving zero defects. Preventive maintenance is applied to avoid machine breakdowns.

Simple, visible, flow-oriented order systems (Kanban) are applied to only make what is needed – in the smallest possible quantities. Kanban systems are simple pull-based systems where cards are circulated between workstations. Buffer levels are varied to meet the demand immediately, but most demand variation has to be handled by varying processes. The system principles are:

• Supply is based on real demand. Products can only be produced up to a predetermined maximum level.

- The demand of different products is visible. This enables workers to plan efficient order-sequences and to vary the Kanban stock-levels in order to meet demand variations
- Maximum levels of products (stocks + WIP) is continuously minimized

The second major principle is a product-oriented (or flow-oriented) layout, which means that functionally different resources are dedicated to one product or a product-family. The resources are organized in flow-oriented product lines, which provides shorter throughput times, and a simple and visible material flow. Another related principle is product standardization and modularization. A manufacturing system becomes harder to co-ordinate as product variety is increasing. A standardization and modularization of products can enable a more simple and controllable material flow and provide shorter lead times.

4.2.3 Business process reengineering

As described previously, BPR has mainly targeted office processes. All manufacturing companies have such office processes, and the examples referred to are typically information intensive processes (such as credit issuance, procurement, order fulfilment etc) where information technology can act as an essential enabler for reengineering. However, the principles are not clear, nor are there well stated implementation steps. In this thesis, projects termed "BPR" are therefore viewed as projects that implements flow manufacturing concepts (such as flow, operations areas and teamwork) in office processes.

4.2.4 Quick response manufacturing

Quick response manufacturing is an improvement approach that focuses specifically on lead time reduction (both in offices and at the factory floor) in manufacturing firms. QRM uses flow manufacturing as a foundation, and support process improvements in enterprises with mid- to high-variety product mix with a systematic approach. QRM is based on a shop floor system named POLCA, or "paired cell overlapping loops of cards with authorisation" (Suri, 1998). This is a push-pull system which allows different routings and job shop type operations. Planned release of jobs, bearing in mind capacity limitations, is done on a MRP/finite scheduling system. This determines the time before which jobs may not start, not when they are due to start. Each job has a card that travels with it through all work stations. This details all workstations to be visited. Each pair of work stations has a number of POLCA cards assigned to them. At all work stations except the first, there must be two cards available to authorise production; one from the first loop and one from the second loop. This ensures that no job is started on a work stations before there is available capacity also at the next work stations (Suri, 1998). QRM and POLCA can handle non-linear demand and changeover operations, and should be considered where the routings are irregular or repeat only at infrequent intervals (Bicheno, 2000)

4.2.5 Agile manufacturing

Agility may be defined as the ability of an organisation to thrive in a constantly changing, unpredictable business environment. Agility adds the idea of time-

compression to socio-technical systems design. Agile enterprises are capable of responding rapidly to changes in customers' demand (Kidd, 1994). The major principles of agility are outlined by Goldman et. al. (1995):

- Enriching the customer
- Co-operating to enhance competitiveness
- Mastering change and uncertainty
- Leveraging people and information

The agility approach strives for flexibility and responsiveness and is well suited to handle the dynamic and uncertainty of customised products.

Agile manufacturing is a concept that is a recently introduced and still is evolving. To quote Sharifi and Zhang (2001): "Until now, proposals for ways to become agile and characteristics defined for an agile manufacturer have been more or less expressed in an Utopian way" and "no businesses has been reported to possess all the required specifications of agility". Leading proponents of agility can give examples of agile behaviour, but they are still developing the core principles of how to implement it.

The vast majority of published work on agility is aimed at identifying and describing the various elements deemed necessary for agility. Examples of such work include Kidd (1994) and Goldman et. al. (1995). Many of these works recognise the critical role of the manufacturing system in establishing agility. Little discussion if any, however, is made of how to obtain such systems: most work simply note that processes, machines, and control hardware/software must be reconfigurable, programmable, modular, flexible etc (Hooper et. al., 2001). Adopting a manufacturing systems approach, Booth (1995) takes the view that agility is the synthesis of time compression and lean manufacturing techniques, while Cooke (1995) considers agile manufacturing as an evolution of FMS.

4.3 Design principles in flow manufacturing

Flow manufacturing aims to obtain effective flow, i.e. a progressive movement of materials and information through the entire manufacturing process of a product. Morris (1962) defines a principle as "simply a loose statement of something which has been noticed to be sometimes, but not always, true". The following principles have been observed to frequently result in effective flow and short throughput times:

- Create product-focused operations areas
- Create a flow oriented layout
- Create multiskilled and cross trained operations area teams
- Decentralise planning and control to operations areas

An flow manufacturing reengineering based on these principles should be viewed as one (optional) approach to improve competitiveness. The decisions areas that are affected and the major performance objective for a flow manufacturing project are outlined in Table 9.

Decision areas		as	Design principles		erf.	Objectives			S			
x			x			1. Create product-focused operations areas		x	x			
х	x					2. Create flow oriented layout			х	х		
				x		 Create multiskilled and cross trained teams 				x	x	x
		х			х	4. Decentralise planning and control	Х			Х		
Resources	Materials	Information	Processes	Organsation	Control		Costs	Quality	Del. time	Del. Precision	Flexibility	Innovation

Table 9 Flow manufacturing and the link to operations strategy

Table 9 shows the four major principles of flow manufacturing and the link to operations strategy. Each principle affects one or more decisions areas of the operations strategy and aims to support some performance objectives. In general, flow manufacturing aims to improve the flow (and thus reduce throughput times and lead times), but often result in a range improvements as indicated in Table 9.

Principle 1 Create product-focused operations areas

From a strategic perspective, this principle mainly affects processes, which are analysed and grouped in new ways, and resources, which are dedicated to a product family. The overall manufacturing process should be segmented into a set of productfocused and interconnected operations areas. Each operations area should contain a set of resources (equipment, people etc.) that are dedicated to a family of similar products (raw materials, parts, components, end-products) and grouped close together. Each operations area should be self-contained (in that it complete all operations for a family of similar products in one or several process stages), and connected to upstream and downstream areas through unidirectional flows. The effect of such reengineering is a simpler system that is easier to control and that may improve delivery time and quality.

Principle 2 Create flow-oriented layout

From a strategic perspective, this principle mainly affects resources (their physical location) and material flows, and is closely connected to principle 1. The operations areas should be laid out physically in a layout that reduces complexity and creates effective flow paths. Each operations area is a physical "space unit", equipped with machines and people, and organised according to a basic layout type (product, cell, or process). The layout should be segmented into a network of operations areas (each organised according to a basic layout type which preferably is product-oriented) in order to create effective flow and one-piece transfer batches. The effect of such a reengineering is mainly shorter throughput times and improved delivery time and precision.

Principle 3 Create multiskilled and cross trained teams

From a strategic perspective, this principle mainly affects the organisation which should be rearranged into a more process oriented and team-based structure. Each operations area should be organised as a semi-autonomous unit, which is staffed with a team of multiskilled and cross trained operators. Operators should be trained in several operations and be able exchange one another. They should also be responsible for some managerial activities such as planning or quality inspections. The effect of such a reengineering is (among others) higher flexibility and innovation, and improved delivery service.

Principle 4 Decentralise planning and control

From a strategic perspective, this principle mainly affects control issues (planning and control methods) and information issues (information system design and information flows). It is primarily at the shop floor control levels that manufacturing planning and control is changed in flow manufacturing. Detailed planning and control activities should be decentralised to each operations area. With operations areas, the order release point should be changed from the machine level to the operations area level. By delegating planning and control tasks to the operations area, the centralised MPC efforts can be reduced. The effect of such a reengineering is mainly simplified and improved control and thus, lower costs and higher delivery precision.

Off course, these principles do not stand alone. Each of these principles reflects a broader design area in flow manufacturing and are supported by an reengineering procedure for flow manufacturing that is presented in chapter 9. The proposed design areas for flow manufacturing are:

- 1. Process design
- 2. Layout design
- 3. Job design
- 4. MPC design

These design areas are described in more detail below.

4.4 Process design

Flow manufacturing aims to create product-focused manufacturing and office processes in order to improve flow and performance. The total manufacturing process is therefore decomposed into several operations areas that contribute to the production of one or a family of end products. Nine different ways to group end products are described, and the advantages and disadvantages with different levels of end-product focus is discussed in this section.

4.4.1 Product grouping

Flow manufacturing is based on the assumption that enterprises should adopt a product focus unless it can be demonstrated that this type of organisation has clear disadvantages. There are many ways to build product families. Whether products are similar depends on the purpose of the improvement project. For example, the purpose may be to achieve efficiency in manufacturing or to satisfy the needs of marketing and sales. Nine different ways to group products are shown in Table 10.

Table 10 Nine different ways to group end-products (Adapted from Hyer andWemmerlöv, 2002)

	1			
Criteria for identifying product families	Examples			
Product type. Group products of the same type or	Motors and generators.			
function into families				
Market. Group all products sold in a certain	North America, Europe; market			
geographical market in one family	segmentation can alos be based on			
	type of user, e.g. commercial vs. residential user.			
Customers. Group all products sold to one or more	The products for two dominant			
customers in the same family.	customers make up two families, the			
	rest of the products a third family.			
Degree of customer contact. Group products	Group all stocked items in one family,			
according to the degree of influence the customer	all made-to-order in another, etc.			
has on the final product.				
Volume range. Group products with similar volume	High-volume vs. low-volume products.			
ranges into the same families.				
Demand variation. Group products with similar	Large and repetitive orders in one			
customer order patterns in the same families	family, small and irregular placed			
	orders in another.			
Competitive basis. Allocate all products that	Those competing on cost and speed to			
compete on the basis to the same family.	one family, those competing on			
	customised design to another.			
Process type. Group products or parts requiring	All assembled product in one family, all			
similar processes in the same families	non-assembled products in another,			
	etc.; within each group, products with			
	similar routings form a family.			
Product characteristics. Group products with the	Large vs. small, light vs. heavy, etc.			
same physical features or raw materials into				
tamilies				

The first three categories in Table 10 reflect the way marketing and sales personnel view the products. Such sales families can be purposeful for segmenting manufacturing if there are only a few dominant customers or markets to be served. The fourth category reflects the market interaction strategy and thus, the positioning of the customer order decoupling points (CODPs) in an enterprise. All make-to-stock products can be grouped in one family, all assembly-to-order in another group, and so on. The characteristics of make-to-stock, assemble-to-order, and make-to-order are strongly related to both volume (category five) and order stream (category six). The volume determines capacity needs, and if the volume of certain products is high enough, it is possible to dedicate operations areas to those products. The order stream (or the demand variation) influences processing stability, and might influence the grouping of products. Mixing products with large and small batch sizes can be disruptive to manufacturing efficient due to varying setup, processing and material handling requirements. Category seven reflects segmentation based on a competitive basis. Product with distinctively different performance objectives should be grouped in different families. Category eight reflects segmentation based on process types. This can be meaning full if products use processes that differs in radical or exclusive ways (such as assembled versus non assembled products). The final category is product characteristics, and covers key aspects of product design and manufacturing features such as physical size, weight, key shapes or features, major sub assemblies, key components or raw materials. Typically, these characteristics are used to gain efficiency in manufacturing, e.g., by separating products based on steel from those made of aluminium, or large products from small products and so on.

4.4.2 Levels of product focus in flow manufacturing

The goal in flow manufacturing is to find families of similar products. A natural way of partitioning a manufacturing system is to start at the endpoint, for example, the assembly processes for the final products. Figure 31 shows the overall manufacturing process in enterprises at different levels of product focus. The complete manufacturing process for a set of assembled products is segmented into stages based on (1) part production, (2) sub-assembly, and (3) final assembly and testing operations.

In enterprises with the lowest level of product focus, as shown in Figure 31a, different areas of the enterprise perform different segments of the total process. Each segment is organised in self contained operations areas with unidirectional flow between them. None of the operations areas are dedicated to particular end-products, and there is not a great deal of difference in the physical structure of the operations areas from a functionally organised enterprise. A machining department, for example, will probably complete most of the parts it makes already. A few parts may, however, have intermediate operations in other departments. Only a small numbers of machines and other facilities will have to be transferred from these departments into the new machining operations area to make it self contained so that it can complete all the parts it makes (Burbidge, 1989).



Figure 31 Separating process stages based on product families (Hyer and Wemmerlöv, 2002)

If the final products can be grouped into families based on one or more similarity criteria (see Table 10), it is possible to separate the final assembly into smaller operations areas, each dedicated to the assembly of one product family (see Figure 31b). Taking this one step further, it is also possible to split the sub-assembly department so that all sub-assemblies used by a particular product family are manufactured in their own dedicated areas (see Figure 31c.). Or, it is possible to go all the way and create operations areas where all parts that are components of a product family are produced separately from all other parts (Figure 31d). The alternatives a-d in Figure 31 represents different levels of product focus. Thus, an enterprise where all

parts, subassemblies and final product operations are dedicated to the same end products has the largest products focus.

There are both advantages and disadvantages with product focus. Hyer and Wemmerlöv (2002) suggest that the advantages are:

- Increased control of the product line
- Less risk of disturbances and delays due to other parts and products
- Greater employee identification with the product
- A more direct link to the market

These benefits should, according to Hyer and Wemmerlöv (2002), lead to a stronger customer orientation and service, greater employee identification and product loyalty, easier process improvement, higher quality, and a more nimble, responsive system. The most obvious disadvantage with splitting a enterprise according to products is the risk of resource and task duplications. That is, a company may end up using more people and equipment to perform possibly identical tasks. This risk gets larger the deeper the focus. Splitting parts production according to end product, as in Figure 31d, means that parts common to different products will be made in different operations areas, each dedicated to a product family. This leads to a duplication of equipment and people, and potentially insufficient or unbalanced resource utilisation. Low utilisation is of particular concern when capital-intensive equipment is involved.

In brief, the trade-off in achieving product focus is between market orientation, customer satisfaction, employee involvement, and product control on the one hand, and manufacturing efficiency and resource utilisation on the other (Hyer and Wemmerlöv, 2002). This conflict is complex, and the decision regarding product focus should be based on a strategic analysis and the type of performance objectives that are pursued for a market.

4.5 Layout design

The layout of an enterprise determines the physical location of its resources. Layout design is to decide where to put all the facilities, machines, equipment, and staff in the enterprise. The design of layout is a critical step in a flow manufacturing projects, because the layout selected will serve to establish the physical relationships between operations. If the goal is to reconfigure a large part of the plant, a formalised layout planning such as systematic layout planning is required (see chapter 9). However, unless a new enterprise is built from scratch, it is highly unlikely that the whole enterprise will be affected by the flow manufacturing project. In fact, only one or a few viable new operations areas may have been identified. In such cases, the layout planning may be greatly simplified. Much of the work usually consist of making minor changes in existing layout, locating new machines, revising a section of the enterprise, and improving the flow.

It is especially the flow that is targeted in flow manufacturing layout design. Based on the logical operations areas that have been identified, (each organised according to a basic layout type) the layout designer aims to create a network of effective flows.

4.5.1 The basic layout types

In chapter 4.1.4, three types of operations areas were identified:

- Production line operations area
- Product family operations area
- Process operations area

Figure 32 illustrates the material flows for each type of operations area. Also provided in Figure 32 are the associated layouts common to each type of operations area.

The layout for a product line operations area is based on the processing sequence for the part(s) being produced on the line. Materials typically flow from one work station directly to the next adjacent one. Nice, well planned flow paths generally results in this high volume environment. Such layouts will be referred to as product layouts.



Figure 32 Alternative types of layout for flow manufacturing

The layout for a product family operations area is based on the grouping of parts to form product families. Non-identical parts may be grouped into families based on common processing sequences, shapes, material composition, tooling requirements, handling/storage/control requirements, and so on. The processing equipment required for this family is grouped together and placed in a manufacturing cell. The resulting layout typically has a high degree of intra-area flow and unidirectional flow to other operations areas, and will be referred to as cell layouts.

The layout for a process operations area is obtained by grouping like processes together. Typically there exist little intra-area flow and a high degree of two ways flow to other operations areas. Such a layout will be referred to as process layout and is used when the volume of activity for individual parts or groups of parts is not sufficient to justify a product layout or group layout. Product layout, cell layout, and process layout is compared in Table 11, which is based on the work of Thompkins et. al. (1996), and Slack et. al. (2001). Typically, one will find that a particular situation has some products that fit each of the layout types. Hence the layout can consist of operations areas that are based on different basic types. This is termed a hybrid or modularised layout (Benjafaar et. al., 2002).

	Advantages	Limitations		
Product	Low unit costs for high volume	Can have low mix flexibility		
	Smooth, simple, logical and direct flow	Machine stoppage stop the line		
	Low work-in-process inventory and short	Product design changes are difficult		
	throughput time	Slowest station paces the line		
	Material handling are reduced	Work can be very repetitive		
	Simple control methods are possible.	High equipment investments		
	Special purpose equipment can be used			
Cell	Can give a compromise between cost	Grouping products can provide lower		
	and flexibility for relatively high-variety	machine utilisation		
	operations	Multiskilled operators required		
	Smoother flow lines and shorter travel	Some form of control is required to		
	distances than for process layouts	balance the flow through operations		
	Ideal for teamwork	areas.		
	More general purpose equipment can	Less specialised equipment can be		
	be used	used		
Process	High mix and volume flexibility	Complex flow		
	Increased machine utilisation	Increased work-in-process		
	General purpose equipment can be	Throughput time is long		
	used	Material handling requirements are		
	Can provide a diversity of tasks for	increased		
	personnel	More complicated control methods are		
	Robust in the case of disruptions	required		

Table 11 Advantages and limitations of three basic layout types

4.5.2 Material flow patterns inside and between operations areas

Flow manufacturing aims to obtain effective flow, i.e. a progressive movement of materials and information through the entire manufacturing process of a product. The manufacturing is therefore physically separated into a network of operations areas in order to reduce systems complexity and improve flow. Each operations area is a group of work stations organised according to a basic layout type and is connected by a material flow network with a well understood flow-pattern.

Tompkins et. al. (1996) suggests the following principles to create effective flow in the enterprise:

- maximise directed flow paths
- minimise flow
- minimise the cost of flow

A directed flow path is an uninterrupted flow path progressing directly from origination to destination. An uninterrupted flow path is a flow path that does not intersect with other paths. A directed flow path is also a flow path with no back-tracking. Backtracking increases the length of the flow path, and when flow paths are interrupted, congestion and undesirable intersection occur. Figure 33 illustrates the congestion and undesirable intersections that may occur when flow paths are interrupted between operations areas. Furthermore, the principle of minimising flow includes eliminating intermediate steps, minimising backflows between consecutive point of use, and combine processing steps into larger tasks. Finally, the principle of minimising walking, manual travel distances, and motions, and also to eliminate manual handling by mechanising or automating flows (Tompkins et. al., 1996).



Figure 33 The impact of interruptions on flow paths (Tompkins et. al. 1996)

Figure 33a) shows a layout with uninterrupted flow paths between operations areas, and Figure 33b) shows a layout with interrupted flow paths between operations areas.

Effective flow between operations areas depends on effective flow within operations areas. The flow pattern inside an operations area depends on the layout type. A pure line flow (i.e. a product layout) should be created in an operations area if possible. This is a pattern where all parts or products follow the same routings throughout the operations area and are processed at each of the work stations. More hybrid versions allow backtracking to previously visited work stations for further processing, and by passing of workstations. Finally at the very opposite end of a flow line pattern is process operations areas. This is operations areas where parts can enter and leave at multiple stations and where there is no unidirectional flow pattern. This latter type of complex flow patterns should be avoided if possible because it affects productivity, scheduling complexity, and ease of control.

The most effective inter-area flow is achieved when an operations area starts with raw materials and ends with finished products, with all operations being completed in the operations area. However, a complete standalone operations area often is neither practical nor economical feasible. The reality is that most operations areas supply, or are supplied by, other production units inside or outside the enterprise. Several flow patterns between operations areas are therefore possible. The most typical flow pattern is that products begins their processing in one operations area and are transferred to other operations areas for further processing. Another pattern, which should be avoided if possible, is when products begin their processing in one operations area, are partly processed by other units (which could be shared resources like heat treatment), and then return to the original operations area for completion.

4.5.3 One-piece flow

Flow manufacturing aims to create one-piece transfer batches wherever possible in order to minimise lead time. Traditionally, the assumption has been that when a batch arrives at a work station it remains there until all items in the batch are processed. This is the typical situation when work stations are placed far apart, as in traditional job shops or when materials is sent to subcontractors for processing. This implies that all parts in a batch have to wait at the workstation until the last one is processed. The way to minimise waiting time, therefore, is to process an item and immediately send it to the next station. This is the typical situation in standard line production, and should

also be adopted for job shops and batch production through group technology (Burbidge, 1975).

One piece flow is only the best solution if some basic requirements are fulfilled. One piece flow requires small lot production with short set-up time between successive batches. If set up times are too large, small lot production can have a negative effect on lead time. Further, one piece flow requires a material handling that minimises the cost of flow between work stations, and makes it is easy to keep track of batches moving in the system. Otherwise, small batches could become too expensive and also a coordination problem (Hyer and Wemmerlöv, 2002).

Regular batch production, for set up, move time, and tracking reasons, therefore requires large transfer batches. Flow manufacturing, on the other hand, aims to create smaller transfer batches by creating operations areas. Operations areas where closely located work stations produce a small number of similar products are ideal to create one-piece flow. When an operations area produces one model at the time, the changeover time between individual items within a product family are small or nonexistent. (If the operations area produces several product models simultaneously, transfer lots must be carefully sequenced to avoid excessive setup time). When work stations are placed next to each other, operators can move products easily. Alternatively, if the material handling is mechanised the effort to move products is inconsequential. And because production take place within the confined space of an operations area, the tracking problem is insignificant. These factors make it ideal to use very small move batches inside each operations area, while the batch sizes by witch the material is moved to and from the operations area typically is larger due to material handling efforts and the problem of tracking small lots throughout the entire enterprise.

In general, manufacturers' layouts have been traditionally designed for high worker and machine utilisation, whereas modern (flow oriented) layouts are designed for quality and flexibility, the ability to quickly shift to different product models or to different production rates. According to Gaither and Frazier (2002), the traditional layout has very large floors plans, extensive areas reserved for inventory, much space used for long conveyors and other materials-handling devices, large production machines requiring much floor space, L-shaped or linear production lines, and generally underutilised floor space. The modern layout, on the other hand, has relatively small floor plans, compact and tightly packed layouts, large percentage of floor space used for production, less floor space occupied by inventory or material handling devices, and U-shaped production lines. Gaither and Frazier (2002) vision of the modern layout seems to support the flow manufacturing approach, namely to build the layout for effective flow.

4.6 Job design

Flow manufacturing requires both a physical and organisational restructuring of the enterprise. Operations areas can have significant impact on operator and supervisory work, and often mean different responsibilities, more tasks, and more teamwork. But these changes are not automatic. Jobs don't change on their own just because the physical layout changes. It is management that determines whether and to what degree

jobs will change. In flow manufacturing, job design usually involves to create some sort of operations area teams.

It should be noted that an operations area and a team is two distinct concepts. It is possible to have operations areas without teamwork (for example single-operator operations areas) or team-work without operations areas. However, the most powerful combination is often operations areas with teamwork. In this thesis, the following definition of a team is adopted:

"A team is a collection of individuals who exist within a larger social system such as a organisation, who can be identified by themselves and others as a team, who are interdependent, and who perform tasks that affect other individuals and groups" (Stewart et. al. 1999).

From the definition of an operations area and the definition of a team, it should clear that operations areas and teams share many common features. A group of workers is a team when they perceive themselves as a unique group within the enterprise, when they and others clearly identify who is a team member, when their work tasks require them to work closely with one another, and when they produce a whole and distinct part of a product or service that is used by others. Almost all operations areas working groups fulfils these criteria: they are collection of individuals, they can be identified as belonging to a particular team, and they work together with the shared goal of producing a family of outputs. However, not all operations area teams are alike. Such teams can work together in different ways and have widely varying responsibilities.

4.6.1 Core issues in job design

Job design may be defined as the function of specifying the work activities of an individual or group in an organisational setting (Chase et.al. 2004). Its objective is to develop job structures that meet the requirements of the company and its technology and that satisfy the job holder's personal and individual requirements. Job design includes (1) to determine work methods, i.e., the procedures and processes used in executing a job; (2) the overall design of workplace, tools and equipment (including the levels of noise, dirt, temperature, lighting, ergonomics and so forth) to account for the physical and mental considerations of people, 3) to take into account the social and physiological work environment, i.e. what makes work meaningful and satisfying (Vonderembse and White, 1996).

Some basic concepts regarding the behavioural aspects of job design is now explained: specialisation, job enlargement, job rotation, and job enrichment.

The term *specialisation* describes jobs that have a very narrow scope (Stevenson, 2005). The main rationale for specialisation is the ability to concentrate one's efforts and thereby become proficient at that type of work. Sometimes the amount of knowledge or training required of a specialist and the complexity of the work suggests that individuals who choose such work are very happy with their jobs. At the other end of the scale are extreme specialised jobs that are monotonous and boring (such as much assembly-line work). These lower-level jobs are the source of much dissatisfaction among workers, but are also the source to high productivity due to simple repetitive work. On one hand, specialisation has made possible high speed,

low-cost production. On the other hand, extreme specialisation (as in mass production industries) often has serious adverse effects on workers, which in turn is passed on to management. In essence, the problem is to determine how much specialisation is enough. The advantages and disadvantages of extreme specialisation are summarised in Table 12.

 Table 12 Major advantages and disadvantages of specialisation of labour (Chase et. al (2004)

Advantages	
For management:	For labour:
1. Simplifies training	1. Low education and skill requirements
2. High productivity	2. Minimum responsibilities
3. Low wage costs	3. Little mental effort needed
Disadvantages	
For management:	For labour:
 Difficult to motivate quality 	1. Monotonous work
2. Worker dissatisfaction, possibly resulting	2. Limited opportunities for advancement
in absenteeism, high turnover, disruptive	3. Little control over work
tactics, poor attention to quality	Little opportunity for self-fulfilment

In recent years, there has been an effort to overcome some of the problems of specialisation by moving to more varied job design. Driving this effort is the theory that certain "job characteristics" are closely related to employee motivation, satisfaction, and as a result, employee performance (Hackman, J. Oldham, G., 1980). These are:

- skill and task variety, i.e., to what extent a variety of skills are required to carry out a job,
- autonomy, i.e. to what degree an individual can influence the way work is conducted,
- task significance, i.e. to what extent the job is important compared to other jobs in the enterprise,
- tasks identity, i.e. to what degree a job completes a "whole" and identifiable piece of work from beginning to end,
- feedback, i.e., to what extent a person receives clear and direct information about how well a job is done.

These job characteristics determines the motivating potential in a job, and when jobs are designed with high levels of these characteristics, employees should be more motivated, more satisfied, and more productive. To day, job designers frequently consider job enlargement, job rotation, job enrichment, and increased use of mechanisation to make jobs more interesting and meaningful (Stevenson, 2005).

Job *enlargement* means to add tasks requiring similar skills to an existing job. Job *rotation* is a version of job enlargement where the employee is allowed to move from one specialised job to another. Variety has been added to the employee's perspective of the job. Job *enrichment* adds more decisions making authority (such as planning and control) to the job, and improves the workers autonomy. Figure 34 illustrates these job design concepts.



Figure 34 Job specialisation, rotation, enlargement, and enrichment (Vonderembse and White, 1996)

For most workers, job enrichment and enlargement has a positive effect on job satisfaction, and reduces worker turnover, tardiness, and absenteeism (Heizer and Render, 2004). However, the key question is whether these approaches also have a positive effect on performance. Chase et. al. (1998) suggests that the benefits of enrichment and enlargement occur both in quality and productivity. Quality in particular improves dramatically because when individuals are personal responsible for their work output, they take ownership of it and simply do a better job. Also, because they have a broader understanding of the work process, they are more likely to catch errors and make corrections than if the job is narrowly focused. Multiskilled and autonomous workers can identify and fix errors at the source before work is passed on to downstream operations. This can increase output quality, eliminate extra work to fix mistakes, and reduce lead times. Productivity improvements also occur from broadly scoped jobs, but they are not as predictable or as large as the improvements in quality. For example, both enriched and enlarged jobs will almost always include a mix of tasks that for production workers may cause "interruptions in rhythm and different motions when switching from one task to the next" Chase et. al (1998). This can reduce output and decrease productivity.

The level of specialisation is an important issue in job design. Job enlargement has a lot of positive effects, and especially where process steps are easy to learn. But sometimes the amount of knowledge or training required, and the complexity of the work, implies that job should be done by a specialist. For example, in a precision machining environment, where equipment is difficult to operate and the required skills can take years to develop, the amount of multi-functionality and cross-training should be limited. In such situations, training costs and skill availability is so high that workers should specialise in a limited set of tasks.

Another important issue in job design is workers autonomy and standardisation of work. Autonomy is the degree to which the job permits freedom and independence in the work place. Standardisation on the other hand, refers to developing and using the one best way to perform a work task or execute a step in the process. Standardisation

seeks to drive out variation in methods and procedures and, as a result, to create a repeatable reliable, process that yields high quality, output consistently and at low costs (Hyer and Wemmerlöv, 2002). Standardised labour tasks, which are essential for a repeatable, consistent process, provides little opportunities for operator autonomy. Thus, the focus for autonomy must be put elsewhere. One alternative is to involve workers in the standardisation of work. Formal work standards developed by industrial engineers and imposed on workers are alienating. But procedures that are designed by the workers themselves in an effort "to improve productivity, quality, skills, and understanding, can humanise even the most disciplined forms of bureaucracy" (Adler, 1993). Autonomy could also be enhanced by involving workers in other decisions that affect their work place, such as planning and control, or monitoring quality.

A major issue in job design is whether the nine principles of STS is an integrated package or consists of selectable components (Badham and Couchman, 1996). Semiautonomous groups based on socio-technical principles have been seen as a solution of jointly optimizing both technical efficiency and work motivation. The bundle of characteristics or principles that made up a work group has been represented as an integrated package. But Japanese forms of work organizations have challenged this. The STS package actually consists of a number of distinctive elements, only some of which have been introduced by management in Japan. For example, in the case of lean manufacturing, a form of teamwork has been created which emphasizes multiskilling as a necessary prerequisite for job rotation; and quality circles as a means for extracting operator knowledge about processes and applying that knowledge to incrementally improve production systems. This approach does not, however, include traditional STS principles of team autonomy and removal of authoritarian supervision (Klein, 1991). One can therefore conclude that the STS principles should be applied in order to create teams that supports the overall strategy and is adapted to the particular manufacturing environment.

4.6.2 Advantages and disadvantages of operations area teams

Burbidge (1975) listed a set of dedicated workers as a key principle of operations area autonomy (or independence), which in turn is an essential aspect of successful operations areas in practice. The conversion to flow manufacturing therefore often implies that workers with process oriented skills are divided into part or product oriented teams and assigned to operations areas with heterogeneous processes.

The creation of teams in operations areas is an effective way to provide job enlargement and enrichment, and also the performance improvements connected with wider job content. The creation of such teams is especially beneficial:

- When the work is interdependent (they are linked sequentially or there is a lot of back and forth among tasks)
- When breath of skill and workforce flexibility would make a difference in performance
- When increased communication and information exchange could improve performance
- When increased worker motivation and interest in work would make a difference in performance

An operations area that completes all operations in a manufacturing stage on one or more product families usually fulfils all these criteria. Note that some exceptions exist where the current technology in an operations area doesn't make it possible for a group of people to perform the work in a collaborative and efficient way. The disassembly jobs at a slaughterhouse are a example of such exceptions.

The benefits of teamwork are advocated by several authors, such as Slack et. al. (2001), Stenvenson (2005), and Hyer and Wemmerlöv (2002). The positive effect of team work on performance is also well documented. For example, Waterson et.al. (1999) performed a survey of the use and effectiveness of modern manufacturing practices in 564 UK manufacturing companies. In this survey, team work was reported to be one of the most common and growing manufacturing practices with a high effectiveness in terms of quality improvement and responsiveness, and a medium effectiveness in terms of costs. The reason for this success might be that the creation of teams compensate for many of the disadvantages of specialisation that were listed in Table 12. Jobs in teams often will be enriched and enlarged, characteristics that have a positive effect on job satisfaction, quality, flexibility and improvement. Improved communication about tasks can improve quality and responsiveness even further. Workers also tend to develop a team identity and a commitment to fulfil the team's performance objectives. This can improve productivity and reduce absenteeism. Furthermore, the creation of teams reduces the need for supervisors, because one supervisor can attend several autonomous teams. The disadvantages of teams (under the conditions outlined above) are few. A major disadvantage for management is the loss of flexibility to freely allocate workers, because they are dedicated to a team. For some workers, team work might imply new tasks that are less attractive.

Table 13 summarises the advantages and disadvantages of team work when the conditions listed above (interdependent work, need for work force flexibility, and so on) are prevailing.

Ad	vantages		
Foi	management:	For	labour:
1.	Fewer supervisors are necessary	1.	Job enlargement and variety
2.	Improved responsiveness and problem	2.	Job enrichment and control of work
	solving	3.	Enhanced problem solving, decisions
3.	Continuous improvement		making, and administrative skills
4.	Higher quality and productivity	4.	Broad responsibilities
5.	Less turnover and absenteeism	5.	Belonging to a team
Dis	advantages		
Foi	management:	For	labour:
1.	Less flexibility in the allocation of	1.	Possible group conflicts and internal
	workers		competition
2.	Larger selection and training costs	2.	Possibility that some of the team jobs are
3.	Possibility of free riders in the team		less rewarding
4.	More time spent on "coaching"		
5.	Possibility for higher labour costs		

Tabla	12	Advantages or	d die	advantages	with toom	work in a	norations (roog
Lanc	13	Auvantages al	iu uis	auvantages	with team	WOLK III (operations a	ai cas

4.7 Manufacturing planning and control system design

A flow manufacturing reengineering project aims to improve efficiency and response times to orders and order changes. Although well designed operations areas represent essential building blocks in efficient enterprises, they are incomplete without a system that supports decisions regarding the material flow. Each operations areas is also a decisions centre, and has some degree of autonomy to make decisions about how to run operations, i.e. manufacturing planning and control decisions. In flow manufacturing projects, an important question is therefore whether to replace or adapt the MPC system, and if so, how.

The essential task of manufacturing planning and control is to manage efficiently the flow of material, the utilisation of people and equipment, and to respond to customer requirements by utilising the capacity of suppliers and internal resources in order to meet customer demand (Vollman et al. 2004). The manufacturing planning and control (MPC) system assist the decision-maker in managing enterprise operations. A MPC system supports decisions regarding when, and in what quantities:

- parts and components should be ordered from suppliers,
- manufacturing or product assembly orders should be issued
- parts should be moved from one work area or plant to another.

It also involves resource-related decisions, such as determining the number of operators that should be assigned to a operations area per day or week, when to buy new equipment, how to allocate incoming orders to various control areas, and when an operator should begin on a new job or move to another work station or control area. In a manufacturing enterprise, this implies a multitude of decisions that put requirements on the design of the decisions support system (the manufacturing planning and control system). Furthermore, an assortment of MPC systems is available to manufacturers: ERP/MRP, reorder point systems (ROP), pull/kanban systems, and finite/constraint-based schedulers (see Andersen et al. (1998) for a detailed overview of MPC systems). All manufacturing enterprises have some form of MPC system in place - whether sophisticated, formal, and computerised, or simple, informal, and manual. Thus, the manufacturing planning and control system way.

4.7.1 The decisions hierarchy

Every enterprise can be decomposed into set of decisions centres. This can be done explicitly, through the systematic development of a control model (see the next section). Or it can be done implicitely by addressing various decisions piecemeal with different models and assumptions. Regardless of the level of foresight, some decomposition will be done. Since all real-world manufacturing enterprises are complex, it is frequently impossible to consider the enterprise as a whole when one is making decisions. It is necessary to decompose the decisions problems into manageable sub-problems.

One of the most important dimensions along which manufacturing organisations are decomposed is time. The primary reason for this is that manufacturing decisions differ greatly with regard to the length of time over which their consequences persist. For example, the construction of a new plant will affect the company's position for years, while the effects of selecting a particular part to work on at a particular workstation may evaporate within hours. Clearly, the decisions about a new plant require a longer planning horizon than the planning of the work on a work station. This makes it essential to use different planning horizons in the decisions making process.

The basic idea behind the time-based decomposition is that strategic decisions (long horizon and long period) cannot be based on the same level of detailed information as is the case for operational information (short horizon and short periods). The volume of absorbable information should be held constant (Chen and Doumeingts, 1996). It is therefore essential to decompose the enterprise in smaller, more manageable entities in order to avoid overloading individual manufacturing managers. Planning and control decisions made at a high hierarchical level are therefore normally based on aggregated information (in terms of product families, factories, etc.) and aggregated time periods. These high level decisions form the context for the decision-making process at the lower level decisions centres, where information is disaggregated into more detailed information and time periods, and the considered horizon is shorter.

Many frameworks that models manufacturing planning and control decisions therefore represent the decisions processes as a planning hierarchy, where long term decisions form the context for short term decisions. The most common structure is to divide the planning horizon into long, intermediate and short time (see eg. Hopp and Spearman, 2001, Vernadat, 1996, Volmann et. al. 2004). This structure is compliant with hierarchical taxonomy proposed by Anthony (1965) for organisational decisions levels: (1) strategic, (2) tactical, and (3) operational²⁰. However, a complete analysis and design of the manufacturing planning and control system should also include other dimensions than time. The author therefore argues in line with Chen and Doumeingts (1996), who propose that the domain of decisions making also should be expressed in terms of space (the limit on the size of the part of the operations process where it is most suitable. A complete analysis of the manufacturing planning and control system should donly be used on the parts of the operations process where it is most suitable. A complete analysis of the manufacturing planning and control system should therefore include a representation of how the control methods are distributed in different operations areas.

4.7.2 The control model²¹ for analysing MPC applications

In order to provide a complete model of the manufacturing and control system, a detailed analysis of each operations area is required. The GRAI-grid proposed by Chen and Doumeingts (1996) implies a two dimensional decomposition of the decisions making process in enterprises:

• a hierarchical decomposition in accordance with planning horizon (e.g. long term, intermediate, and short term)

131

131

²⁰ Anthony's original terms were Strategic planning, Management Control, and Operational Control.

²¹ See chapter 5 for a more elaborate discussion on models and modelling

• a functional decomposition, defining the various functions of such a system for each major part

In addition to a hierarchical decomposition of the decisions-making process, where the next upper level coordinates each lower level, the GRAI-grid suggests a decomposition in to coarse planning and control functions such as: to manage products, to plan, to manage resources (Chen and Doumeingts, 1996).

In flow manufacturing, however, a much more refined functional decomposition is required, and especially at the operative level. As explained in chapter 4.1.4, the operations process can be decomposed into many small operations areas, each consisting of workstations that perform "like" functions. Reengineering for flow manufacturing is basically to decompose the complete operations process into operations areas, and then redesign the operations areas and their interaction in order to streamline the flow of material or information deliverables. Thus, the shop floor control of an enterprise should not be considered a "black box" that includes a single control method. Each operations area is a decisions centre ruled by a control method. They all have local characteristics that should be identified and reflected in the manufacturing planning and control system.

SINTEF has developed a mapping tool termed the "control model" that can support a more detailed functional analysis of MPC applications (see for example Alfnes and Strandhagen, 2000). Figure 35 shows an example of an control model for Hagen, an Norwegian staircase manufacturer. The figure focuses on the shop floor level.



Figure 35 The control model at Hagen Treindustrier

A control model is a representation of how operations are organised and controlled in manufacturing (see Quistgaard et. al, 1989, Andersen et. al, 1998, Alfnes and

Strandhagen, 2000). A control model is normally developed by the following building blocks:

- main operations processes (operations and buffers)
- operations areas (specifying which operations that is one area of responsibility)
- material flow (specifying different routes through the operations processes)
- information flow (specifying the flow of customers orders and work orders)
- control methods (specifying the decisions rules of each operations area)
- customer order decoupling point (specifying which parts of the operations processes that is controlled by customer orders)

To develop a suitable control model is the core activity in any flow manufacturing project. One of the application areas of the control model is to decompose the decisions-making process into operations areas, and thereby specify how different parts of the operations process are supported by different control methods. In addition, the control model specifies the planning hierarchy (e.g. the master production schedule, material planning schedule) for the enterprise. A hierarchical framework for analysing manufacturing planning and control systems is presented in the next section.

4.7.3 A schematic MPC system framework

A framework is provided to understand the decisions and activities that are supported by the MPC system, and how they are integrated. Given that most enterprises use ERP/MRP as a foundation for their MPC activities, the framework is (as most other models of MPC systems, see e.g. Browne et. al., (1996), Vollman et.al. (2005) based on the so-called MRPII (manufacturing resource planning) structure. See Sheikh (2003) for a detailed overview of MRPII systems.



Figure 36 The planning hierarchy

Figure 36 is a hierarchical model of the general MPC system that would be used within an enterprise for planning and controlling its manufacturing operations. Each rectangular box represents a separate decisions problem and hence a planning and control module²² supported by the MPC system. The major independencies between modules are represented by arrows.

The figure is based on the MPC system framework developed by Vollmann et al (2005), and structure MPC modules into three parts or phases based on time horizons. The time aspects changes at the different levels. Specifically, the planning horizon (the length of time for the plan), the planning period (the smallest unit of time used for planning), and the replanning frequency (the frequency at which plans are revised) will change:

- The planning horizon gets shorter from a year or more at the aggregate planning level to a week or a day at the shop floor control level.
- The planning period gets smaller from at quarter or a month at the aggregate planning level to a day or an hour at the shop floor control level.
- The replanning frequency gets higher from monthly or quarterly at the aggregate level to daily or weekly at the shop floor control level.

The top third is the modules that set the overall direction for manufacturing planning and control. Demand management encompasses forecasting and order entry. Sales and operations planning balance the sales/marketing plans with available production resources. The master production schedule (MPS) is the disaggregated version of the sales and operations plan. That is, it states which end items or products options manufacturing will build in the future. Resource planning determines the capacity necessary to produce the required products now and in the future. In the long run this means equipment, buildings, suppliers etc., while in the short run it means labour and machine hours.

The middle third encompasses the set of modules for detailed material and capacity planning. The master production schedule is disaggregated into orders for parts and components. Enterprises with limited product range can specify rates of production for developing these plans. However, for enterprises producing a wide variety of products with many parts per product, detailed material planning can involve a material requirement planning (MRP) process. MRP determines (explodes) the period-by-period (time phased) plans for all parts and raw-materials required to produce all the products in the MPS. This material plan can thereafter be utilised in the detailed capacity planning system to compute labour or machine centre capacity required to manufacture all parts and components. The result of the detailed planning

134

²² The term module is used to represent the combination of analytic models, computer tools, and human judgment used to address the individual planning and control problems. As such, they are never fully automated, nor should they be.
is order schedules for purchased items (for the supplier system), and order schedules for manufactured parts (for the internal shop floor system).

The bottom third depicts the MPC execution systems. The suppliers systems provide detailed information to enterprise's suppliers. The shop floor system controls how the operations processes are performed at the plant floor. The final assembly schedule activity is also part of the shop floor system, but is represented as an individual module that is directly connected to the demand management. The idea is to position the final assembly scheduling as a short horizon planning activity (normally one to four weeks) and to indicate that the schedule is mainly based on accepted customer orders. As such, this is an improvement of Vollman's original framework, which includes final assembly scheduling in the master production scheduling²³.

Most enterprises have some form of short term, final assembly schedule. For enterprises producing for inventory, there are relatively small differences between the master production schedule and the final assembly schedule. But for enterprises operating in an assembly-to-order or make-to-order mode, the end items are not specified. The master production schedule is limited to ensuring that raw materials or components are available. The final assembly schedule then takes over and schedules the final product configurations based on customer specifications. Although the same scheduling system can be used for final assemblies, sub-assemblies, and components, (this is usually the case for make-to-order manufacturing) there are many shop floor systems for witch detailed scheduling of components and sub-assemblies never take place. Rather, the planned orders from MRP are sent directly to the order release function. Or, if the operations processes are controlled by pull systems, there may or may not be any MRP schedules for lower-level items.

For the shop floor control of components and sub-assembly, there are two major types of manufacturing execution systems available. For enterprises that are product focused, pull systems are suitable for execution. This requires that operations are organised in operations areas that produce a similar set of parts (i.e. cells). See chapter 4.7.6 and chapter 9.2.5 for a further explanation of pull systems. The second type of execution system is traditional shop floor scheduling based on MRP order schedules. This type is suitable for more process focused enterprises. That is, for operations that are organised in control areas with similar processes, producing a large variety of parts. The scheduling system relies on planned orders from the MPS or the MRP, and is planning the operations required by each order. The system establishes priorities for all shop order at each work station. Operations are processed at various workstations, and the job status is monitored by the system until orders are completed.

135

²³ This implies a logical error. The master production schedule is a long term product-build schedule based on forecasts and customer orders. It represents an anticipated build schedule for end items, options, or groups of items. The final assembly schedule, on the other hand, represents the actual build schedule for exact end items, and is mainly based on customer orders.

The three-phased framework provides a good overview of the typical decisions and schedules that are involved in manufacturing planning and control, and is supported by a wide array of MPC systems and software. This framework is therefore a crucial element of the control model, and is used to structure the analysis of enterprise-specific planning and control hierarchies. As mentioned above, the framework is based on a MRP-II structure, which implies that some of the proposed planning and control modules will be present in the manufacturing enterprise, others will not. However, each module in use should be specified in terms of:

- planning horizons, periods and replanning frequency
- planning objects (end items, sub-assemblies, parts, raw materials etc.)
- control method (Kanban, MRP, ROP etc)
- interaction with other modules

Based on the existing control model for an enterprise, the individual modules of the MPC system should be evaluated and aligned to the overall strategy and manufacturing environment. The next sections illustrate the variety of options for master production scheduling, material planning, and manufacturing execution systems.

4.7.4 Market interaction strategies

The market interaction strategy encompasses the manufacturing approach used, the variety of products produced, and the market served by the enterprise, and has a large impact on the MPC system design. The market interaction strategy can range from providing unique products, to providing standard products from a final stock. For any segment of its product lines, an enterprise can operate in four different manufacturing "modes" depending on the market interaction strategy: engineer-to-order (ETO), make-to-order (MTO), assemble-to-order (ATO), and make-to-stock (MTS). The major difference between these market interaction strategies is the positioning of the customer order decoupling point. This is illustrated in Figure 37.





Figure 37 shows how four different positions of the customer order decoupling point implies four different market interaction strategies. The decoupling point separates the part of the enterprise where manufacturing is based on customers' orders from the part that is based on planning and level control. Customer specific manufacturing is often

time-critical and characterised by uncertainty and a high degree of demand variety. This kind of manufacturing requires fast and flexible processes that focus on duedates. Manufacturing processes upstream from a decoupling point are not time-critical to the same extent. Such processes have smoother demand and allow for costefficiency and standardisation.

The decoupling point is also a point to stock components as a buffer that smooth demand variety. In order to reduce number of components, such stocks should coincide with product T-points. T-points are points in product structures where a few standard components can be configured into a range of different products (Strandhagen and Skarlo, 1995). The decoupling point is often associated with the concept of postponement. It is better to postpone the decoupling point as close to product completion as possible. Postponing the variant explosion enables shorter delivery times and higher delivery precision.

Engineer-to-order products are designed, produced and delivered to customer specifications in response to customer orders, while MTO products are built and delivered in response to the customer. Critical operations issues relate to satisfying the customer (since each customer wants something different) and minimising the time required to complete the order. Make-to-stock products are designed and produced for "standard" customers in anticipation of demand. Customers choose from the range of pre-stocked products that are available for purchase. Critical operations issues are forecasting future demand and maintaining inventory levels that meet customer service goals. Assemble-to-order products are produced in standard modules to which options are added according to customer specifications. Thus, components are made-to-stock, then assembled-to-order after customer order has received. Critical operations issues are the minimising of inventory levels of standard components, as well as the delivery time of the finished product (Russell and Taylor III, 1998).

The market interaction strategy is strongly related to the degree of customer contact and the type of performance required, and therefore should have a high influence on the design of the MPC system. The overall design of the manufacturing control system depends on the position of the customer order decoupling point, which is the point where a product is earmarked for a particular customer. Typically, firms with high-volume standardised products would choose a make-to-stock (MTS) strategy. The market characteristics for a typical MTS design are; make-to-stock products, delivery speed supported by finished goods, low product variety, and high production volume. Firms with low-volume customised products would choose a make-to-order (MTO) strategy. The characteristics for MTO design are; make-to-order products, delivery speed achieved through rescheduling; high product variety, and low production volumes.

4.7.5 MPC features for different market interaction strategies

Four major types of market interaction have been identified that has a large impact on the MPC design. For the MPS, the market interaction strategy primarily affects the choice of unit that is used for stating the MPS. That is, whether the MPS is stated in end item terms (MTS), product modules (ATO), or prototype products (MTO/ETO). The material planning approach and the shop floor approach will also be affected. Some key features of the MPC system for the different market interaction strategies are listed in Table 14.

Features	MTO (or ETO)	ΑΤΟ	MTS	
Basis for planning	Confirmed order backlog	Module forecast/backlog	Product forecast	
MPS unit	Prototype products	Modules	Products	
Forecast accuracy	Low	Medium	Medium	
Schedule variability	High	Medium	Low (i.e. level schedules)	
Bills of material	Created for order	Planning bills	Standard bills	
Final assembly schedule	Based on orders	Based on orders	Based on forecast and orders	
Order promising	Capacity checks	ATP via module MPS	ATP via product MPS	
Material planning	Time phased planning	lanning Time and/or rate based Rate base		
Shop floor and	Schedules or pull with	Pull system, with	Pure pull or with	
supplier control schedules		schedules schedules		

 Table 14 MPC features for different market interaction strategies

Table 14 lists the major MPC features associated with different market interaction strategies. These features are now described in more detail (except material planning and execution systems, which are described in the next section).

The **make-to-stock** enterprise produces in batches, carrying finished goods inventories for most, if not all, of its end items. The MPS is the production statement of how and when each end item is to be produced. Enterprises that make to stock are often producing consumer products as opposed to industrial goods, but many industrial goods, such as supply items to automotive manufacturers, are also made to stock (Vollman et. al. 2005). Under MTS, the MPS is stated in end items, and these end products are produced to forecast demand. Customer orders are filled directly from stock in order to provide short delivery time for standardised products. Manufacturing plans is mostly based on forecast information and standard bills of materials, and order promising records are usually not required for planning. Even if forecast accuracy is unreliable at the product level, the schedule variation is often low, because many tend to group end products in model groupings until the latest possible time in the final assembly schedule. The final assembly schedule (which states the finishing date of end products) is a more detailed version of the MPS, and is also based mostly on forecasts.

The **assemble-to-order** enterprise is characterised by a large number of possible end item configurations, all made from combinations of basic modules (components and subassemblies). Customer delivery time requirements are often shorter than total manufacturing lead times, so production must be started in anticipation of customer orders. The large number of end item possibilities makes forecasting end item configurations difficult, and stocking end items very risky. As a result, the assembleto-order firm tries to maintain stability, starting basic components and subassemblies into production, but, in general, not starting final assembly until a customer order is received (Vollman et. al. 2005). The Norwegian swivel chair manufacturer HÅG, for example, offers millions of product variants composed of a limited number of components differing in colour, shape, size and material. Under ATO, the MPS is stated in modules or "options". Bills of materials are based on average products and modules, and reflect how products are sold rather than how they are manufactured. It is the final assembly schedule that converts "average" products into unique products in response to actual customer orders. Order promising is based on available modules and capacity checks in the final assembly.

The **make-to-order** (or **engineer-to-order**) enterprise carries no finished-goods inventory and each customer order is built as needed. This form of production is often used when there is a very large number of possible production configurations, and, thus, a small probability of anticipating a customer's exact needs. With this market interaction strategy, customers are expected to wait for a large portion of the entire design and manufacturing lead time. Examples include a tugboat manufacturer or refinery builder (Vollman et. al. 2005). Under MTO, the MPS unit is typically defined as the particular end item or set of items composing a customer order, and the backlog of customer orders form part of the overall product lead time. These end items are usually "prototypes", since a part of the job is to define the product and the bill of material. The order backlog is a critical measure for estimating capacity and materials requirements, and is the basis for the final assembly schedule and for order promising.

4.7.6 Material planning and shop floor options

Detailed material planning specifies how much of each product component is required. Material planning can be accomplished in several ways, but are normally performed by an ERP system. Two popular alternatives are time-phased (MRP) and rate-based material planning. In time-phased planning, detailed requirements are established for each individual time period; in rate-based planning, an average requirement per period is determined and fixed over several time periods (Vollman et. al., 2005).

There also exist a wide variety of manual and computer-based manufacturing execution systems. The two basic approaches are push systems and pull systems. Pull systems initiate material movement or production activities through the removal or depletion of inventory. In essence, consumption triggers replenishment (use one, make one). This is in contrast to push systems where materials is sent along to the next stage in the manufacturing system once it has been processed, and where orders are initiated not based on actual usage but on a schedule (Hyer amd Wemmerlöv, 2002). The newest innovations are push-pull systems, which combines schedules and generic pull signal to control the production activities (Suri, 1998). The features of different options are listed in Table 15.

Features	Time phased/ Push	Time phased/ push-pull	Rate based/ Pull	
Material explosion	MRP	MRP	Rate based requirements	
Central/decentr. Planning	Centralised	Centralised	Decentralised Kanbans, containers, etc.	
Basis for control	Work orders	Work orders		
Control of material	MRP & priority lists, or	Generic pull systems	Product specific pull	

flow	detailed finite schedules	with schedules	systems
Supplier material control	MRP	MRP and/or Pull	Pull supplier material
Reporting unit	Per machine and/or operator	Per operations area	Per operations area

Table 15 illustrates that the choice of material planning approach and shop floor approach are closely linked. Through net requirement calculations, time phased planning (MRP) determines when to release orders to suppliers and the internal enterprise. The MRP approach supports push systems where work orders are released against a schedule developed by a centralised planning function. Rate based material planning were developed to support pull systems. This combination is especially suited for repetitive environments where it is sufficient to determine rates of production in different parts of the enterprise, and where simpler mechanisms (such as standardised containers in which materials are moved and stored) are more suitable to control the material flow. Pull systems "are inherently rate driven in that we fix the level of WIP and let them run" (Hopp and Spearman, 2001). A third option is to combine MRP with some sort of push-pull system, where work orders and generic pull signals are used in combination to control the flow (Suri, 1998). The different options are now described in more detail.

Time-phased material planning

Time-phased planning for individual product components is typically carried out with MRP. The production process is usually based on batch manufacturing and materials are also purchased in batch orders. Preparation of time-phased plans requires a large manufacturing data base in order to establish detailed plans. The data base must include information on: master production schedule quantities stated as bill of materials to determine gross requirements; on-hand inventory balances and open work (or purchase) orders to determine net requirements; production lead times, supplier lead times, and safety order quantities to determine order release dates; and lot size formulas to determine order quantities. Under MRP, plans are typically updated on a periodic (daily or weekly) basis to develop priorities for scheduling manufacturing and supplier operations (Vollman et. al. 2005).

Rate-based material planning

The primary intent in rate-based scheduling is to establish rates of production (a rate of production specifies the number of items to be produced in any time period) for each part in the factory. Realizing these rates allows the company to move material through the manufacturing system without stopping, in the shortest time possible. Examples of firms using rate-based planning include repetitive manufacturing, assembly lines and other flow systems. Typically single level planning bill of materials is used to convert master production schedules into detailed material plans that specify the appropriate daily or hourly flow rates for individual component items (Vollman et. al. 2005).

Push-based shop floor control

In a push-based shop-floor system, work orders are released against a schedule developed through time-phased material planning. The shop-floor scheduling system's objective is to coordinate the sequencing of orders at individual work stations with

customer delivery requirements. A large centralised data base requiring a substantial volume of shop transactions is needed to provide control reports for order tracking, dispatching, and work station monitoring. One objective is to utilize each work station's capacity effectively. The approach is based on scheduling work orders that dictate the set of detailed steps or operations necessary to make each component (Vollman, et.al. 2005).

Pull-based shop floor control

The basic pull system idea has been around for a long time in the form of reorder point systems, but became popular world wide as an important element in lean manufacturing. The pull system is based on minimal flow times for the entire product. Group technology techniques are typically employed to create continuous flow, and detailed scheduling is decentralised to each operations area. Where continuous flow systems cannot be achieved, processes are linked using Kanban/CONWIP cards, containers, and other signals of downstream need as the authorization to produce, typically in small lot sizes (Vollman et. al., 2005). Customers pull what they need, and signals (cards, containers etc.) triggers replenishments.

Push-pull shop floor control

It is possible to combine pull signals and schedules into a hybrid push/pull control system. Many pull systems are in fact controlled by at least one schedule, the final assembly schedule. To avoid automatic replenishment at other stages of the manufacturing process, schedules can be used for each operations area. Schedules are calculated based on MRP work orders. The role of the schedules is to indicate to each area the items that are needed for the coming time period (an hour, a shift, a day, a week, etc.), and the order in which they should be made. The role of the pull signal, on the other hand, is to indicate when production of the next item can begin. Since the operations area has a schedule telling it what items to make, it is not necessary to use Kanban cards that are product specific. Rather, the pull system is "generic" in that the cards or containers don't include product information (Suri, 1998).

A comparison of approaches

Time phased material planning (i.e. MRP) were developed to be work order driven planning and control systems in manufacturing environment with long lead times and varying demands. Time phased (MRP) planning and push is appropriate for custom products produced in wide variety and low volumes. It also facilitates schedule changes and revisions in customer delivery dates as well as changes in product mix. MRP supports push systems where orders are released against a centralised planning function. Such an approach becomes cumbersome and impractical when manufacturing is repetitive and rapid, and output levels are high and stable. The emergence of lean manufacturing and the accompanying focus on pull systems led software vendors to modify MRP to be rate based rather than work order driven. Pull systems "are inherently rate driven in that we fix the level of WIP and let them run" (Hopp and Spearman, 2001). In repetitive environments, it is sufficient to determine rates of production in different parts of the enterprise. Furthermore, simpler mechanisms such as pull systems (based on standardised containers in which materials are moved and stored) are more suitable to control the material flow.

Pull systems, through their tight WIP control, offers many potential benefits over push systems, such as reduced inventory and stabilised lead times (Hopp and Spearman

(2001). They also have the advantage of being simple to use, require relatively low maintenance, and can be operated without computers. The complexity of MRP-based order schedules, coupled with their poor performance has led many companies to disconnect the traditional shop floor system in favour for a pull system. Pull systems however, can have clear disadvantages. For example, that they require discipline to operate successfully. Missing cards or disrespect for WIP limits will lower performance. The most obvious disadvantage, as pointed out by Suri (1998), is the philosophy of "ship one, make one" (Womack and Jones, 1996). Pure pull systems replenishes each container that has been removed form a storage location and pulls the materials through all stages of the manufacturing process for all items controlled by the system. This prevents product specific pull systems from being applied effectively in situations with greatly shifting production volumes and product mixes. Such situations can be handled by push-pull systems such as POLCA, where the pull system is combined with a job schedule at each manufacturing stage (Suri, 1998). However, systems such as POLCA are fairly complex compared with traditional Kanban, and should not be used when there is linear repetitive production (Bicheno, 2000).

4.8 Experience from Norwegian flow manufacturing projects

Since 1997, the author has been involved in several flow manufacturing projects that are used as illustrative examples in this thesis. The most well-known example of the "Norwegian" approach to flow manufacturing was carried out in 91-93 at Håg, and is documented in the case study in chapter 10. Inspired by the success at Håg, several Norwegian companies have reengineered their enterprises for flow manufacturing. These flow manufacturing projects has varied in scope and focus. What they have in common is that they all have resulted in a proposal for a new control model for the company. Håg and some more recent flow manufacturing case companies are listed below:

	Process design	Layout design	Job design	MPC design
Håg	Х	x	x	x
Hagen	Х	x		x
Hast	Х			x
RCT	Х			x
Protex	Х	x	x	x

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Table	16	Targeted	design	areas in	flow	manufac	furing	projects
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HÅG is one of the leading manufacturers of office chairs in Scandinavia. They produce approximately 1000 chairs each day with an average order quantity of two products, indicating the demand for variety. HÅG has been the market leader in Norway from the end of the 70s with approximately 40 percentage market share. Most of the customers are located in northern and central Europe, and in US, and the export share constitutes 80 percentages of the total sales. All operations are centralised at the factory in Røros, and based on assembly-to-order production and direct distribution. In the period 1991 – 1993, a reengineering project was carried that targeted all design areas of flow manufacturing. The processes was analysed and grouped in operations areas, the layout was flow oriented, the operations areas (especially in final assembly) was staffed with multiskilled operators that could handle several operations on several

product families, and a control model was implemented that was based on assemblyto-order market interaction strategy and kanban shop-floor control (see chapter 10).

Hagen is one of the 10 largest manufacturers of staircases in Europe. They construct and produce ca. 30 customer-specific stairs each day to construction companies and personal consumers. The market is mainly in Norway where Hagen is market leader with an a market share of ca. 35-40 percentage. Hagen is also exporting 9% of its volume to Germany and Denmark. The operations are performed on four plants in Norway and distributed directly to customers. The main factory is located at Stryn, which produces all components, and completes the fabrication of "industrial" stairs. For stairs that require handicraft operations, components are distributed to the three other plants for completion. In the period August 2003 – May 2005, a reengineering project for flow manufacturing was initiated by SINTEF. The project resulted in a more streamlined order and construction process, a flow-oriented layout, a new control model based on push-pull for the fabrication of customer-specific parts and kanban for the fabrication and procurement of standard parts. The new layout and order process was implemented in January 2004 - August 2004. Since August 2004, SINTEF has supported the implementation of the new control model, and this work is still not completed.

Hydro Automotive Structures (HAST) is the global leader in crash management systems in aluminium. In 2004, they delivered ca 5 million bumper beams as single parts or as part of a crash management system to their customers worldwide, the majority of them to Western Europe. Hydro Aluminium Structure's plants dedicated to Crash Management are located in Raufoss, Norway (termed HARA), Louviers, France, Skultuna, Sweden, and Holland, USA. In the period January – April 2005, a reengineering project was initiated by SINTEF that focused on the M24 production line at Raufoss. A complete enterprise mapping and analysis was performed, and a new (more integrated and more frequently updated) control model was proposed. The further development of this project is still not decided upon.

Raufoss Chassis Technology (RCT) has since 1981 developed and produced aluminium chassis components to the European OEM car industry. In 1999, RCT was nominated as sole supplier of complete aluminium control arms for the new GM European Epsilon platform to be introduced in the spring 2002. A new plant was established at Raufoss to serve an expected sales volume 500.000 cars per year in Europe. In 2000, RCT was again nominated as sole supplier for GM North America Epsilon platform to be introduced in 2003, and a similar plant was set up in Montreal, Canada to serve an expected sales volume of 650 000 cars per year. In the period January 2002 – January 2003, SINTEF was involved in the design and implementation of a control model for the Raufoss factory based on a make-to-stock market interaction strategy and a rate-based material and capacity planning. In addition, order management, production planning, and procurement was streamlined and collocated in a "Supply Chain Center".

Protex is a small textile manufacturer with seat covers as their core product. Protex is the sole supplier of seat covers to HÅG, and has two plants for cover production which are located in Ålen, Norway, and in Baltikum. Standard covers (ca 100 variants) are produced in Baltikum (ca. 600 per day) and more special covers (ca 3000 variants) are produced in Ålen (ca 400 per day). In the period January 2005 – April

2005, a reengineering project for flow manufacturing was initiated by SINTEF. The project has the potential for a more streamlined order process, a more flow oriented layout, and a new control model (more integrated and more frequently updated).

These are some of the flow manufacturing projects that the author has been involved in. The preliminary conclusions from these project are (as already experienced in earlier flow manufacturing projects such as the HÅG project), that product-oriented and streamlined processes, a flow-oriented layouts, more multiskilled and teamorganised operators, and more decentralised control results in shorter throughput times and improved performance.

4.9 Summary

This chapter has introduced flow manufacturing as an (optional) reengineering approach. The historical roots of flow manufacturing are briefly reviewed, and especially it's origins from group technology which was developed to improve performance in job and batch manufacturing. Flow manufacturing is presented as an alternative to traditional functional manufacturing that aims to improve flow and reduce throughput times.

The basic flow building block is the operations area, which contains a group of dedicated equipment and people that perform "like" operations. Three types of operations areas are defined, the production line type, the product family type and the process type. Usually "like" is understood as performing all operations on a product or family of similar products, and flow manufacturing aims for product focus wherever possible. But an enterprise will also contain some operations areas that are organised to handle a particular type of production process. The major point is that, regardless of product focus level, each operations area should be self-contained and only allow unidirectional flow.

Some well-known improvement approaches are discussed in order to position flow manufacturing in the management literature landscape. Flow manufacturing is based on group technology and uses elements of socio-technical system design to reengineer enterprises for flow. It is argued that the basic flow building block, the operations area, is also used as a fundament for approaches such as lean manufacturing, business process reengineering, quick response manufacturing, and agile manufacturing. An reengineering for flow in manufacturing and office processes can therefore be viewed as the starting point for these approaches.

Four flow reengineering principles are proposed, each representing a broader design area in flow manufacturing. These are:

- Process design: Create product focused operations areas
- Layout design: Create flow oriented layouts
- Job design: Create multiskilled and cross trained operations area teams
- MPC design: Decentralise planning and control to operations areas

The principles are supported by an flow manufacturing reengineering procedure that is outlined in chapter 9. Of course, the level of flow orientation depends on the operations strategy and the manufacturing environment. Each of these design areas are therefore briefly reviewed in order to provide some major design concepts, and to discuss the major advantages and limitations of the proposed principles. A range of improvement approaches termed cellular manufacturing or flow manufacturing has their origins in group technology. What makes this "Norwegian" flow manufacturing approach different is the main focus on shop floor control, and the use of "control models" that, in addition to the traditional planning hierarchy, also includes the operations areas and how they are controlled.

The international experience is that flow manufacturing has contributed significantly to increase the productivity in manufacturing and especially for batch manufacturing (manufacturing of relatively large variety of parts or products with repetitive demand in batch sizes) (Kamrani and Logendran, 1998). This is also the major experience from a range of Norwegian companies, and partly demonstrated in the case study in chapter 10. In these companies, the introduction of flow manufacturing has resulted in a reduction of move distances/move times, a reduction of throughput time, a reduction of response time to customer orders, a reduction in WIP inventory, a reduction in finished goods inventory, improvement in product quality, and a reduction in unit costs.

4.10 References

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5. Enterprise modelling

The transition from a current state to a future state in a enterprise reengineering project include a whole range of aspects that should be analysed and decided upon. Such a transition process is best supported by a set of enterprise models that represent the operations processes and resources involved. Enterprise models are used for a range of purposes and can differ from some coarse sketches to detailed numerical models. Some modelling approaches are more suitable for enterprise reengineering efforts and strategy development.

This chapter will briefly review the enterprise modelling literature in order to introduce a architecture for conceptual enterprise modelling. The chapter has three main themes. First, to review the notion of enterprise modelling and different types of enterprise models. Second, to develop an understanding of conceptual enterprise models and what type of problems they are most suited for. Finally, to set out a modelling architecture for enterprise reengineering, a model-set that shows different views and how they are related.

5.1 Modelling in general

A human's model of the world depends on its knowledge and guides the way we perceive, classify and react to our environment. The act of building (external) models explores alternative ways to represent and analyse this knowledge, and is essential for the way we understand the world around us. Modelling has a long history in science and everyday life, and different aspects of modelling are used in a range of scientific disciplines such as system theory, mathematics, philosophy, psychology and linguistics (Wolfgang Kreutser, 1986).

Models are useful representations of reality. Well-known models are those used for the solar system, the atoms, product geometry or road maps. "A is a model of reality B for an observer C, if C can use A to obtain information on B" (Vernadat, 1996). In principle, models can range from a few symbols on the back of an envelope to a oneto-one image of reality. However, any useful model has to simplify and idealise, and the level of detail should not exceed the necessity of practical application and insight. Wolfgang Kreutser (1986) define a model as "an appropriate representation of structures and processes of a miniworld, instantiating some aspects of theory". There is no single best model of a phenomenon. The way a phenomenon is represented depends on the theoretical framework of the problem solver, and the usefulness always depends on the purpose for the application of the model (Alan and Pritsker, 1998).

Models can be categorised in a number of ways. Alan and Pritsker (1998) view models as either scaled physical objects (iconic) models, mathematical equations and relations (abstract models), or graphical representations (visual models). Kreutser (1986) has a slightly different view, and view models as:

- iconic, e.g. a wooden model that describes the shape of an aircraft wing
- analogue, e.g. a hydraulic system that mirrors the flows of goods, money service and information of a economy in a different medium.

• symbolical, e.g. Newtons physics, which offers a mathematical model of the solar system.

A symbolical model is always expressed in terms of a system (or language) of symbols or constructs. This thesis adopts Kreutser's (1986) definition, and view mathematical models and graphical models as two categories of symbolical models.

5.2 Enterprise models

Enterprises are normally represented by symbolical models. Vernadat (1996) defines (symbolical) models as "a (more or less formal) abstraction of a reality (or universe of discourse) expressed in terms of some formalism (or language) defined by the modelling constructs for the purpose of the user".

Enterprise modelling is a generic term which covers the set of activities, methods and tools related to developing models for various aspects of an enterprise (Vernadat, 1996). Some kind of enterprise description already exists in any company. The problem is that in nearly all cases it is poorly documented. It exists in the form of organisation charts, documented operational procedures, regulation texts, and in enterprise data. A large part of the knowledge remains in the mind of people, and is not documented at all. Methods and tool are required to capture and represent this information in a coherent enterprise model (or model-set) that are useful for analysis and engineering of the enterprise.

An enterprise model can be defined as "a consistent set of special-purpose and complementary models describing the various facet of an enterprise to satisfy some purpose of some business users" (Vernadat, 1996). Overall consistency among these models must be enforced, but is not always guaranteed. Many types of enterprise models exist. Enterprise models may have different representations, be expressed in different formalisms, be more or less formal, be processable or not, be human-oriented or machine-oriented, be strictly deterministic or not, and may incorporate more or less common sense. A number of criteria have been proposed to characterise such models, see for example Vernadat (1996) and Szegheo (2000). An adapted version of Szegho's criteria is presented below. Enterprise models might be characterized by:

- the purpose of the model
- the content of the model
- the level of abstraction
- the quality of formalism
- the manifestation of the model

All these criteria represent important characteristics of enterprise models. However, an overall and crucial criteria is the *purpose* of the model. Each enterprise model serves one or a family of purposes. The design of an all-embracing model of an enterprise is not possible. Due to its complexity and size, an enterprise model must be made of a set of models. Furthermore, there are several viewpoints or angels from which one can look at an enterprise resulting in a variety of models suited for different purposes. An enterprise is therefore described or represented by a collection of more or less interrelated, special purpose models.

Several efforts in the development of 1) enterprise models and 2) enterprise analysis and design methodologies are being carried out. Most of these modelling frameworks and reference architectures are developed for CIM enterprises in supporting their enterprise integration efforts (Delen and Benjamin, 2003). However, enterprise models are also developed for other purposes, such as human sense making or computer assisted analysis. This author argues in line with Christensen et al. (1995) that enterprise models, dependent on their purpose, can be divided into three categories:

- Conceptual models
- Operational models
- Analytical models

It should be noted that this categorisation does not claim to be complete, it is rather intended to be pragmatic. Each of these modelling categories serves different purposes, but they also differs in a range of other aspects.

5.2.1 Conceptual models

Conceptual models are developed for human sense making and communication, where the main purpose of enterprise modelling is to make sense of aspects of an enterprise and communicate with other actors. In enterprise engineering, conceptual models are normally descriptive, visual, and built on high level modelling entities. These models are very good for understanding and communications among people "because of their informal, easy-to-grasp, syntax or formalism. Usually, they make the use of diagrams comprising boxes, circles, and arrows" Vernadat (1996). In some cases, the use of computer based tools for design display and simulation might be required, "but less technological approaches can also be very useful" (Davenport, 1993). Conceptual models can be developed by the use of formal modelling languages that allows computerised design, or just by drawing informal sketches of the enterprise. This type of models are further explained in chapter 5.5.

5.2.2 Operational models

The main purpose of developing operational models is to integrate the model in an enterprise-wide information system and thereby actively take part in the work performed by the organisation. Such computer enactable enterprise models are necessary both in the development and the operations of an integrated enterprise. Vernadat (1996) states this clearly: "Things to be integrated and coordinated need to be modelled. Thus, enterprise modelling is clearly a prerequisite for enterprise integration".

The development of operational models implies the modelling of "relevant business processes and enterprise objects concerned by business integration, and execution of which needs to be computer controlled" (Vernadat, 1996). The level of detail is high, and the modelling of precise enterprise details concerning enterprise procedures, know-how, and knowledge is required. However, an object will only be modelled if it has to be exchanged by at least two components of the integrated system. Otherwise, it is local to an application and does not need to be part of the enterprise model. The complete enterprise model represent all the parts of the enterprise operations that need to be integrated, including its manufacturing or service tasks, its organisation and management, and its control and information systems (Vernadat, 1996).

The representation of the enterprise in an operational model goes through different levels of details, "starting from requirement descriptions in a user oriented language and ending with a complex set of software modules running on a modelling tool with an underlying information technology platform" Kosanke et al. (1999). The complete enterprise model provides a data-driven and model-driven enterprise with several capabilities. "Whether or not the integrated enterprise operates in a hierarchical, deterministic mode or in a distributed chaotic mode, the enterprise model provide the operator or executive, human or machine, with a map of the enterprise and some knowledge of what functions the enterprise comprises, in what state they are, and what capabilities exist at any moment to accomplish an output" (Kosanke and Nell, 1999).

Several architectures have been developed in academia to assist the construction of integrated operational models. The top three architectures are (Open System Architecture for Computer Integrated Manufacturing - CIMOSA, Purdue Enterprise Reference Architecture - PERA, and GRAI integrated Methodology - GIM) (Vernadat, 2001). Such architectures promise to provide industry with improved means of handling complexity and uncertainty and thereby enabling the development of large-scale models that are change capable. Primarily this is because they provide a semi-formal, yet customisable structure that can facilitate the reuse of information coded by multi-perspective models of the enterprise. Potentially therefore, these architectures can drive down the cost and lead-time for large-scale system engineering projects. "However, to-date this potential has been realised in very few manufacturing enterprises" (Weston and Hodgson, 2001). Today, a complete enterprise modelling project, supported by such a framework has the following characteristics (Ortiz et al, 1999):

- It includes the detailed construction of the models of the processes to be restructured and designed
- it is data centred, i.e. a considerable amount of data has to be introduced in the process models
- the processes are modelled with the required (high) level of details and then built and operated
- the cost (human, economic, etc.) is high

One successful exception is ARIS (Architecture for Integrated Information Systems), which was used to create the graphical models that describe the functionality and integration of the SAP R/3 system (Wall, B., 2004). Still, operational models are only suitable to represent tasks that can be defined formally for computer exploitation and automation. Many tasks in the engineering and operation of an enterprise include social and human aspects, and may not be possible to model formally and still obtain a desired level of accuracy.

5.2.3 Analytical models

The main purpose of developing analytical models is to gain knowledge about the enterprise through computer assisted analysis. Sophisticated methods for enterprise modelling and analysis are developed. The information systems that integrate these tools and methods are commonly called Decisions Support Systems (DSS). The most

common DSS tools are optimisation and simulation (Delen and Benjamin, 2003). Other tools include statistical analysis, data mining, on-line analytical processing tools, calculators, and artificial intelligence (Simchi-Levi et. al. 2003).

An analytical model is typically a hybrid of many of the tools described above. The problems that are modelled are usually complex, and the model can provide efficient solutions. These are solutions that minimize costs and satisfy performance requirements. There are many factors that dictate the appropriate analytical tools to use for a particular analytical model. These include (Simchi-Levi et. al. 2003):

- The type of problem being considered.
- The required accuracy of the solution there may not be a need to find the optimal solution.
- Problem complexity some tools may not be appropriate for very complex problems
- The number and type of quantifiable output measures
- The required calculation speed. For "operational" analytical models such as leadtime quotations and vehicle routing, speed may be essential.
- The number of objectives or goals of the decision-makers.

Analytical models are suitable for well-structured problems, and especially the complex ones that involve a number of interdependent parameters and variables that can be expressed formally. However, the modelling methods are generally very elaborate and require acute expertise to be used efficiently. The development of analytical models is therefore often regarded as to complex, time-consuming, and prohibitively expensive (Delen and Benjamin, 2003).

This thesis will focus on conceptual enterprise models, which the author believes are especially supportive for human innovative and human oriented engineering approaches such as enterprise reengineering. To underpin this view, the two following sections will explain a generalised modelling framework for enterprise engineering, and some central concepts regarding the human role in enterprise engineering.

5.3 A generalised modelling framework for enterprise engineering

A range of modelling architectures and frameworks are developed to support enterprise engineering. These architectures guides during the project of design and implementation of an integrated enterprise system by means of a structured methodology, the formalisation of operations and the support tools (Chalmeta et al. 2001). Starting in 1989, a Task Force carried out jointly by members of the IFAC and IFIP organisations has analysed the state of the art in enterprise integration architectures and methodologies and has developed GERAM, a generic framework for enterprise architectures and methodologies (Bernus et.al., 1995). GERAM views enterprise models as an essential component of enterprise engineering and integration; this includes various formal (and less formal) forms of design descriptions utilised in the course of design, such as computer models, and text and graphics based design representations. The most important component is GERA, a generic modelling framework that is represented as a three-dimensional structure exhibiting seven lifecycle phases, three levels of instantiation and the identification of model views. (see Figure 38)



Figure 38 GERA

The GERA framework is mainly a generalisation of the top three architectures (Open System Architecture for Computer Integrated Manufacturing - CIMOSA, Purdue Enterprise Reference Architecture - PERA, and GRAI integrated Methodology - GIM) (Vernadat, 2001). The GERA modelling framework organises enterprise models according to the life cycle phases in which these models are used. Subdivisions in the framework, called views define the target of modelling (i.e. what does or does not fall into the scope of any particular view). For example, the software and hardware subdivision highlights the fact that the scope of modelling extends to both. The "management and control" versus "customer service" subdivision requires that both control system and mission support are covered. The CIMOSA-inspired subdivision into function, information, resource and organisation likewise propose what need not to be forgotten. Finally, the PERA inspired human versus machine subdivision requires that not only the automated part of the enterprise is covered in models.

The GERA framework²⁴ identifies a set of components that are essential for enterprise modelling and integration architectures. The components are presented in a structure with three dimensions:

• The *life cycle* axis defines the various phases for completely engineer and then operate an integrated enterprise (Identification, Concept, Requirements, Design, Implementation, Operation and Decommission)

155

155

²⁴ Appendix to the ISO TC 184/SC5/WG1 draft international standard on Requirements for Enterprise Reference Architectures and methodologies (ISO DIS 15704)

- The *instantiation* axis defines three layers, namely a generic layer (in which generic modelling constructs and engineering rules are provided), a partial layer (in which partial models of data, processes, organisation or resources structures are provided to be freely reused), and a particular layer representing the models of a particular enterprise
- The *view* axis suggest that at least four fundamental aspects of the enterprise must be taken into account in the models: function, information, resource and organisation aspects.

GERA aims to be a generalised modelling framework for enterprise engineering, and cover the life cycle of any entity type. As, such it can be used to characterise modelling requirements of entity types as e.g. networks of companies, projects, virtual or incorporated enterprises, products of various kind (any type of system, software or hardware, human organisation or a combination thereof) (Bernus, 2001).

5.4 The minimum formalism challenge

The involvement of people is an important success factor in enterprise engineering projects. The GERAM architecture has therefore adopted concepts from PERA to describe the place of humans in enterprises, and thereby ensure that both humanoriented design and technology-oriented design is facilitated by the models and tools involved in the project.

PERA provides concepts to define the place of the human in the computer integrated plant or enterprise. PERA argues that there are only two kinds of requirements developed from management pronouncements (e.g. from operations strategy) – those defining information type tasks and those defining physical manufacturing tasks. These tasks can be described as functions in a manufacturing or customer service architecture, or in an information and control systems architecture. Many tasks and functions require human innovation etc. and cannot be automated with the presently available technology. Humans will therefore constitute a large "component" of the enterprise, and the role of humans (i.e. what task they perform) can be illustrated by the "extent of automation line". See Figure 39



Figure 39 The relations between automatability, humanizability and extent of automation (adapted from Williams, 1994)

Figure 39 shows how the human role can be defined in terms of the "humanizability line", which shows the extent to which humans can be used to actually implement the tasks and functions defined in a enterprise architecture. The "automatability line" does

the same to show the limits of technology in achieving automation, and will always be outside of the "extent of automation line" which shows the automation actually installed (Williams, T.J., 1994)

One implication of PERAs human-oriented view of the enterprise is that the level of automation involved in a enterprise engineering project will effect the type of models and tools that are most suitable. Li and Williams (2003) terms this "the challenge of minimum formalism". They argue that the degree of mathematical or information technology based formality should be severely limited in models for human innovative work. "On the other hand, where computer interpretability of the information concerned is involved, a high degree of formality may be necessary". Furthermore, that in a enterprise engineering project, "the degree of formality to be used must be phase specific, and must involve the minimum complexity of expression needed to assure a nonambiguity of interpretation and understanding of the information transferred across the phase-to-phase interface" (Li and Williams, 2003). The use of models and tools in an enterprise engineering project is illustrated in Figure 40.



Figure 40 Types of models and tools involved in an enterprise engineering project (adapted from Li and Williams, 2003)

Figure 40 shows the use of some typical models and tools in different phases of a enterprise engineering project, and the level of formalism involved. All functions (strategy development, conceptualisation etc) in first phases of an enterprise engineering project are human innovative. Some may be defined formally for computer exploitation, but according to Li and Williams, this is probably not possible. In the succeeding phases, the degree of mathematical or information technology based formality which may be imposed will depend on the extent of automation involved in the project. All automatable functions defined in the next phases can be defined by formal or computer interpretable means if appropriate for needs of the succeeding phases. However, informal models and text description are often sufficient in the design of human tasks or work process (Li and Williams, 2003).

In reengineering projects, which mainly focuses on the design of human tasks, the "minimum formalism" perspective implies that there is a limited need for detailed and

computerised models such as CIMOSA. This author therefore argues that a faster and less resource intensive modelling approach in enterprise reengineering is to develop a set of coarse conceptual models that represent different perspectives of the enterprise. Coarse enterprise modelling is "to perform quickly a top down analysis producing a synthetic view of the overall enterprise structure" (Vernadat, 1996). Such macroscopic models are used in the first steps of a enterprise engineering project to identify problems quickly. They are then updated and refined during the analysis and design of the enterprise as more information is obtained from the enterprise studied or when corrections to problems are being proposed (Vernadat, 1996). This view is also supported by Davenport (1993) who argues that "firms have successfully employed large whiteboards and large pieces of colored paper and string affixed to walls. Most computer-based tools use a rigorously defined set of symbols to represent different process entities, but these are not essential. The primary purpose of the graphical display is communication and recording, and any consistent set of easily understood symbols will suffice (Davenport, 1993).

5.5 Conceptual enterprise models

This author argues in line with Boman et al (1997), who "believe that conceptual modelling will play an essential role in the development of enterprises and information systems of the future". This is especially true for enterprise reengineering. The reengineering of enterprises is best accomplished in a series of work-shops, and conceptual modelling is an effective means of surfacing creative enterprise designs. The objective of such sessions is to develop creative, but pragmatic new enterprise designs, taking as input the knowledge developed in earlier phases about performance objectives and resource capabilities. "Graphic representation of a process design can be extremely helpful in understanding process flows" (Davenport, 1993).

5.5.1 Modelling domain: the wicked problems

Enterprise reengineering is to a large extent a problem-solving process. There are many different kinds of problems, and consequently, many different ways in which solutions can be sought. The simplest way of categorizing problems is to partition them into well-structured problems, which can be formally defined and ill-structured, wicked problems, where a formal representation does not exist (Boman et al, 1997). Examples of well-structured problems are "solve this set of linear equations", or "find the shortest driving path between these two addresses in this city". These types of problems are often easy to recognize, and formal models and methods are available.

Wicked problems lack all these nice features. In the case of a wicked problem people often cannot even agree upon what the problem really is about. This is generally due to the fact that wicked problems often cannot be formulated at any desired level of accuracy. Formal models are often used in the physical sciences, where models can be formulated based on theoretical laws and principles. However, modelling a complex large-scale enterprise is usually more difficult than modelling a strictly physical system, for one or more of the following reasons: (1) few fundamental laws are available, (2) many procedural elements are involved which are difficult to describe and represent, (3) policy inputs are required which are hard to quantify, (4) random components are significant elements, and (5) human decisions making is an integral part of the enterprise (Alan and Pritsker, 1998).

In the process of developing enterprises, many kinds of wicked problems evolve. Many kinds of stakeholders exist. Requirements are unclear and conflicting. Different needs and views exist. In addition, enterprise operations are difficult to illustrate and describe in terms which are easily understandable to non-specialists. Communication problems are more the rule than the exception. However, in the same way as good illustration skills in architecture facilitate communication between a architect and the stakeholders involved in a building project, adequate concepts and a clear notion are essential in enterprise engineering. A good conceptual model, when describing enterprise operations at the conceptualization and problem formulation level, can significantly improve the dialogue and co-operation between stakeholders and enterprise engineers.

5.5.2 Epistemological meaning

A concept in epistemology is "something conceived in the mind: thought, notion" or an "abstract or generic idea generalized from particular instances" (Merriam-Webster, 2004). A concept is a general notion related to cognitive knowledge, and can be understood as an abstract or generalised idea (a individual unit of reasoning), a representation of a mental image, or a draft or proposal for something new. The term is closely associated with the term conception. Conception is "the capacity, function, or process of forming or understanding ideas or abstractions or their symbols" (Merriam-Webster, 2004). In other words, conception is beginning of a process of existence, or deriving or forming of an idea of something. The conceptualisation of an existing or new solution is therefore the starting point for any enterprise engineering effort. Conceptualisation is a creative composition driven by human intuitions, conjectures, experiences, and reasoning (Horváth, 2000). Conceptualisation is to imagine new ideas, and to compose, adapt, and validate these ideas by common sense reasoning (based on intuitive and learnt design concepts), and the conversion of the results into conceptual models.

5.5.3 A definition of conceptual models

Conceptual modelling has been put to use in many different contexts to support human creativity, understanding, reasoning, and sense making. "It has been used for enterprise engineering, e.g. for clarifying and developing the missions and goals of an enterprise. It has been used for building requirements specifications for information systems. It has been used for reverse modelling of existing systems as a step in legacy systems migration. And there are many other applications of conceptual modelling, ranging from product data models to natural language systems" (Boman et al, 1997).

The definitions of conceptual models depend to a large extent on the field of application. In an enterprise integration perspective, a conceptual model can be defined as "a simple model which is used to communicate the ideal which one is attempting to achieve when building some system" (Mills et al, 1995). In an enterprise analysis perspective, "representations that lie between a decision-maker's perception and an analyst's model of the same enterprise is often called conceptual models in recognition of their basic conceptual nature" (Delen and Benjamin, 2003). In this thesis, conceptual enterprise models have the following definition:

Conceptual enterprise models are coarse symbolical representations that serve as the means for sense making, understanding and imagination. They are the manifestation and representation of a cognitive process, and represent some knowledge about the enterprise at an abstract level.

Conceptual enterprise models can be viewed as any visual abstractions of the enterprise that are expressed using some modelling constructs. However, conceptual enterprise models can be distinguished from other types of enterprise models by the simple representation of knowledge. Just by looking briefly at the contents of the conceptual model, every decision-maker should gain a good overview of the problem domain. The models can be informal or formal, but are always closer to the human conceptualisation of a problem domain than, for instance, operational models or analytical models.

5.5.4 Conceptual enterprise models requirements

Conceptual models can have many different types of applications. Different applications may require different levels of detail and precision of a conceptual model. For instance, initial conceptual models in enterprise integration will typically be incomplete and contain only the most important concepts and relationships, while models for developing a software system must be more complete and precise.

One of the simplest, least formal methods of concept modelling is concept mapping (Novak, J.D., 2004). Concept maps are completely informal graphs usually used during the very first stage of modelling. Concept maps do not compare very easily with other concept maps, not least because they have no uniform notation. This implies that modelling based on concept maps can not guarantee that the model becomes a adequate mirror representation of the enterprise. (There is no way of verifying or validating the model). Furthermore, because of the individual design, such informal models are not easy to communicate to others. More formal conceptual models are therefore required in most enterprise reengineering efforts.

Conceptual enterprise models should be expressed using special-purpose modelling constructs. Typically part of a modelling language's syntax, these constructs include simple graphical elements such as circle, boxes and arrows. These graphical elements are combined into easy to understand diagrams that can generally be augmented using annotations (Delen and Benjamin, 2003). The models can be formal or informal. Note that the use of diagrams or graphical means to represent and enterprise does not imply a lack of formality. Some of the IDEF methods for example, have precise syntax and semantics. The constructs are used to represent different perspectives or "views" of the enterprise.

The term "view" is used to describe a "selective perception of an enterprise that emphasises some particular aspects and disregards others" (Vernadat, 1996). A core idea in enterprise engineering is that the enterprise, like any complex system, should be described from different perspectives depending upon the problems recognised and the improvement strategy chosen. All such perspectives reflect dimensions of enterprise analysis and ask for different modelling methods (Trienekens and Hvolbye, 2001). For example, lead time analysis asks for different models than analysis of organisational structures. In the strictest sense, views are like different pairs of glasses which would give a different view of the same model. This implies (Vernadat, 1996):

- the number of views are not fixed, and it can be expanded if there is a need for it
- the views are not separate models, but different perspectives or angles used to look at a model at a given modelling level.

A more broad interpretation is that a modelling view defines a target of modelling (i.e. what does or does not fall into the scope of a particular representation of the enterprise) (Bernus, 2001).

Delen and Benjamin (2003), use the term "enterprise model-set" to refer to a group of conceptual models built to obtain a coherent and comprehensive picture of an enterprise. This set includes visual description models of various types, and each type of model define a "perspective or viewpoint from which the system is considered for a given purpose, concentrating on some aspects and hiding irrelevant ones to reduce complexity" (Vernadat, 1996).

A fully developed enterprise model-set has three critical characteristics (Delen and Benjamin (2003): First, each type of model is different in nature from any other model type in a set. The difference lies in the semantic categories (the kinds of things taken as primitive - processes, activities, classes, attributes etc) and the logical relations those categories can maintain with one another. Second, each model is necessary to capture different aspects of the enterprise, and ideally all types of models should be developed to provide a comprehensible and coherent description of the enterprise. Finally, the models constituting a set are not independent of each other. The dependability and relationships across models enables the projection of a consistent and coherent enterprise view.

The use of such conceptual model-sets benefits enterprise reengineering in several important ways. First, conceptual models provide decision-makers with a consistent and coherent view of the current and future state of the enterprise, and enable managers to design and analyse operations at the macro level. Second, they can be used to transfer enterprise-specific knowledge among domain experts, system analysts, and other stakeholders. The time and associated costs of knowledge transfer activities is significantly reduced. Third, high-level enterprise models can be reused by a number of analysis methods specialists to build a variety of analysis models.

Based on this brief review of enterprise modelling, the author proposes a model-set termed "the operations model-set" to support enterprise reengineering. The model-set indicates the different enterprise viewpoints that should be modelled, and how the core concepts from each model can be synthesised in an overall control model. The control model provides a holistic representation of how operations processes are organised and controlled.

5.6 The operations model-set

The operations model-set can be used to generate coarse description models of the enterprise operations. The description models enable managers to design and analyse operations without a high level of detail, but linking them with the strategy of the enterprise, and the parameters they must use to measure performance. They are not committed to a low-level representation language (such as a particular simulation

language), and might provide the foundation from which a variety of analysis models can be built. The model-set proposes that six perspectives should be covered in a coarse enterprise modelling effort, and shows how core concepts from several perspectives could be synthesised in an overall control model.

5.6.1 Six enterprise perspectives

The transformation process model presented in Figure 5 focuses on the functional aspects of the enterprise, i.e. what the enterprise do, and highlights that the main purpose of the enterprise is to produce value for customers. Such a high-level model provides valuable understanding of the enterprise. However, models that represent more details and perspectives are often required to support real enterprise engineering projects.

Several frameworks or architectures have been developed to provide a way of viewing the enterprise from different perspectives and showing how they are related. A well known reference architecture of perspectives/views in enterprise engineering is the meta model of GERAM suggesting that at least four fundamental aspects of enterprise must be described: function, information, resource and organisation aspects (Bernus, 2001). Other well recognised aspects to describe are the material, information, and control flow (Berio and Vernadat, 2001).

These views reflect distinct, though complementary, perspectives of the enterprise. In spite of the fact that the models involved are describing the same enterprise, each of them is unique and stands alone because each serves quite different purposes (Zachman, 1987). For example, a resource layout drawing exists independently of, and is clearly different from, a process model diagram. Looking at a layout drawing tells very little about the work flows. Only assumptions can be made about the processes, depending upon how descriptively named the resources are in the layout model (and vice versa for the process model). The type of models and modelling methods used depends on the purpose of the enterprise engineering effort, and the targeted decisions area (supply network, process technology, layout, job design, planning and control). For some purposes, a synthesis of the different views can useful. Even though the same concepts are modelled twice in such a model-set, the synthesised representation can provide a overall picture that are useful for understanding and communication.

5.6.2 The operations model-set

The operations model-set proposes six views that should be modelled, and provide examples of models that can be used to represent each view. These views are:

- resource view
- material view
- information view
- process view
- organisation view
- control view

A framework that illustrates the relationships between these different views are shown in Figure 41.



Figure 41 The operations model-set

Figure 41 shows the different views in a operations model-set and examples of models that can represent each view. Furthermore, it illustrates that the core concepts from each view should be synthesized in an overall control model. The interpretation of the different views in this thesis is described below. Each view is illustrated with examples of enterprise models from Raufoss Chassis Technology (RCT). RCT is a manufacturer of wheel suspensions (rear arms and front arms) for GMs Epsilon platform. See Figure 42.



Figure 42 Products: wheel suspensions

The resource view

From a resource perspective, an enterprise is a group of resources – human and technical – dedicated to the processing of a set of objects (products, components,

documents etc.). The resource view describes the physical attributes of resources and facilities and how they are located in space. An example of a model that represents the resource view at RCT is shown in Figure 43.



Figure 43 Example of resource view model: Plant layout at RCT

Figure 43 shows the RCT plant layout and resources (ovens, forging lines, machining lines, assembly lines etc) for the production of front and rear control arms.

The material view

From a material perspective, an enterprise is a group of nodes (either resources or tasks) connected by material flows. The material view shows how resources are connected in space (e.g. through material flow diagram), and how tasks are linked in processes. An example of a model that represents the material view at RCT is shown in Figure 44.



Figure 44 Example of the material view: Material flow diagram at RCT

Figure 44 shows the material flow for front arms and rear arms at RCT.

The organisational view

From an organisational perspective, an enterprise is a structural framework of human beings that carry out various activities. An organisation view describes the responsibilities and authorities of employees and organisational entities at different decisions levels. An organisational entity is an administrative unit within the firm. As such, it is allocated resources, supplied with material, used as a planning and control point, and accountable for performance and improvement. An example of a model that represents the organisational view at RCT is shown in Figure 45.



Figure 45 Example of the organisational view: Team organisation at RCT

Figure 45 shows how the plant is organised in six teams, each responsible for a part of the production process at RCT.

The process view

From a process perspective, an enterprise is a group of activities that transforms raw materials into products and perform managerial transactions. The process view describes how the activities are related in terms of process stages and flows. In a macro level, the process view describes the enterprise functionalities. An example of a model that represents the process view at RCT is shown in Figure 46.



Figure 46 Example of the process view: Delivery process at RCT

Figure 46 shows the delivery process at RCT, from customer call-off to the customer receives his goods.

The information view

From an information perspective, an enterprise is a group of function executions (transforming an input state into an output state) supported by information flows. The information view generally describes the way in which data are accessed, stored, processed, and transferred. An example of a model that represents the information view at RCT is shown in Figure 47.

Chapter 5



Figure 47 Example of the information view: Information flow at RCT

A model of the information flow in RCTs ICT-system is shown in Figure 47.

The control view

From a control perspective, an enterprise is a set of decisions centres that controls the dynamic behaviour of the enterprise. Decisions must be coordinated and timely sent to the concerned organisation entities of the enterprise. The control view describes the enterprise in terms of decisions centres and their connected control methods. An example of a model that represents the control view at RCT is shown in Figure 48.



Figure 48 Example of the control view: Control model at RCT

Figure 48 shows the control model for RCT. The control model represents a synthesis of the other models of RCT, and shows the processes, operations areas, and the material and information flow that links the processes together. The model is valid for all RCT manufacturing processes, i.e. both for the production of front and rear control arms. Call offs are received weekly from all customers except Saab, which send call offs daily. The production plan is updated weekly, but is fixed for a four week planning horizon.

The control model provides an overall view of the three operations areas in the RCT plant: 1) reception, 2) production, 3) shipment. An operations area represents the smallest organisational entity that is considered for planning and control purposes. Note that, because every organisational unit in the production is controlled by the same method, they all represent a single operations area. This makes the model very simple. A more decomposed model of the enterprise is often required.

5.6.3 Some advantages and limitations

The development of control models as a support for analysis and design of enterprises has been tested in several case studies (se e.g. Alfnes and Strandhagen, 2001). The experience from these projects is that conceptual enterprise models are especially suited to support strategic decisions and reengineering of operations processes. This type of engineering is typically at the "macro level" (Ortiz et al, 1999) in contrast to engineering at the "detailed level" that is required to develop executable models. At a macro level, coarse enterprise models such as the operations model-set has the following characteristics:

- They can be developed in a short period of time, and with a moderated consumption of resources
- They use a language and tools comprehensible by managers and decision-makers, because the main objective is that managers design and analyse the business processes without a high level of detail, but linking them with the strategy of the enterprise, and the parameters they must use to measure performance.

- They can be used to generate the AS-IS and TO-BE coarse models of the business processes of the enterprise.
- They can support the establishment of the overall action plans to go from one model to the other, both at the technical and human level.
- They are mainly developed in interaction with managers and support a common understanding of the enterprise.

Conceptual enterprise models can be developed in a range of different ways and with more or less formality. The positive aspects of the proposed operations model-set are:

- it provides a systematic approach for modelling the most relevant views of the enterprise, and enable decision-makers to develop a holistic picture of the enterprise.
- it has introduced the control model as a tool for enterprise analysis and design.

However, some practical limitations can be mentioned. The operations model-set has the following limitations: (which are valid also for the GIM methodology - see Vernadat, 1996, p.101):

- It only provides support for requirements definitions and analysis of inforamtion systems. It is not a design and implementation tool in the systems engineering sense; for instance system simulation and information system design are not supported
- It makes use of redundant models, i.e. the same concepts are modelled twice (for instance, resources are modelled in resource view and in the material view)
- It produces a "paper model"; i.e. a static model which is not computer processable and is, therefore, of limited value to support the management of continuous change
- It does not support detailed system design and implementation description at an engineering level

5.7 Summary

Enterprise models are used for a range of purposes and can differ from some coarse sketches to detailed numerical models. Enterprise models, dependent on their purpose, can be divided into three categories 1) conceptual models, 2) operational models, 3) analytical models. This chapter focuses on the conceptual type of models, which usually are developed to make sense of aspects of an enterprise and communicate with other actors. Such models are normally descriptive, visual, and built on high level modelling entities.

A range of modelling architectures and frameworks are developed to support enterprise engineering. GERAM, a generic framework for enterprise architectures and methodologies, has been developed to identify the essential components in such architectures. GERAM suggest at least four fundamental aspects of the enterprise that must be taken into account in the models: function (i.e. processes), information, resource, and organisation aspects. Furthermore, it highlights that human-oriented design (depending on the level of automation involved in the enterprise engineering project) should be facilitated by enterprise models and tools. This is termed "the minimum formalism challenge" and means that the degree of mathematical or information technology based formality should be severely limited in models for
human innovative work. It follows that in enterprise reengineering projects, which mainly focus on the design of human activities, it is limited need for detailed and computerised models such as CIMOSA.

The application areas and requirements for conceptual modelling are briefly reviewed. Based on this review, a architecture termed "the operations model-set" for modelling enterprise operations are proposed. The operations model-set proposes six views that should be modelled, and provide examples of models that can be used to represent each view. These views are 1) resource view, 2) material view, 3) process view, 4) information view, 5) organisation view, and 6) control view.

The operations model-set aims to be a generic architecture with a special focus on control. The control view therefore has a special role in this architecture. The core aspects of each model is synthesised in an overall control model that illustrates how operations processes are organised and controlled.

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6. Change management in enterprise engineering

This chapter develops a conceptual framework to understand social processes in enterprise engineering, and how such processes may impact new designs. Based on this framework, a set of change management principles is proposed.

6.1 Introduction

In most companies there is a potential to improve operations performance. Exploiting this potential is the goal of many enterprise engineering projects, which attempts to create business processes that give companies a competitive advantage. However, this is unfortunately not the outcome of every enterprise engineering project. Thoroughly planned solutions might be rejected or only partly implemented. Stakeholders may resist new solutions and they may resist using new tools. The development process can suffer from lack of innovation, and the new enterprise models can provide solutions that inhibit, rather than enable performance.

The main assumption in this chapter is that traditional design principles advocated by scholars as Vernadat (1996), Hammer and Champy (1995), and Blanchard (1998) are insufficient to ensure the successful outcome of development projects. These scholars over-emphasize technical design aspects and lack a concern for inherent social processes as knowledge-creation and the exercise of power.

The point of departure is that enterprise modelling, design, implementation, and use should be considered as interwoven aspects of enterprise engineering. Real change does only occur when new solutions are accepted and learned by the stakeholders in an enterprise. Every phase, from problem definition to analysis, modelling, design, and implementation, involves choices and knowledge-creation by stakeholders that influence the use of new models. Moreover, good solutions require users' knowledge of a specific enterprise. New processes are developed in enterprises consisting of social groups with different knowledge bases and interests. Some of this knowledge and interests can be conceptualized by a designer through analysis, while other aspects are hard or even impossible for a designer to grasp. Two aspects are of major importance; essential parts of practitioners' knowledge are embodied in their involved and unreflected performance, both as performers and in their relation to the environment. Second, stakeholders' interests must be related to a specific situation or problem, and cannot be completely conceptualized by a designer in beforehand. Thus, effective enterprise engineering requires collaborative knowledge-creation by designers and users/practitioners.

The understanding of enterprise engineering as a collaborative *knowledge-creation* process forms one of two theoretical pillars for this chapter. The second pillar is an understanding of enterprise engineering as a *political process* that includes exercise of power and conflicting interests. Based on these pillars, an alternative approach to enterprise engineering is proposed. This alternative highlights the obstacles of enterprise engineering and proposes enabling conditions and design principles that may lead to successful results.

6.2 Knowledge: a core aspect of enterprise engineering

What is knowledge? Philosophers, since the ancient Greeks have tried to answer this question and have in spite of big differences generally agreed upon knowledge as "justified true beliefs" (Nonaka and Takeuchi, 1995). The problem is; what does "justified true beliefs" actually mean? This has been the theme for a more than two thousand years' disagreement between two epistemological traditions, the rational tradition and the empirical tradition.

Rationalism (Plato, Descartes, etc) has dominated the western philosophical tradition. Rational philosophers argued that there existed a priori knowledge that was independent of sensory experience, and tried to attain knowledge by deducing a whole system of theoretical, objective principles from some basic universal ideas. This knowledge was general, explicit, law-like rules that, like the truths of geometry, could be defended in rational arguments. Hence, this was the meaning of "justified true beliefs" (Nonaka and Takeuchi, 1995). Any problem could be analyzed into basic elements, and explained by those explicit rules (Dreyfus and Dreyfus, 1991). This perspective is still dominating the technology-based approach to design, which view human intention as "noise" in enterprise engineering.

Empirism (Locke, Hume, etc) claimed that there exist no a priory knowledge and that the only source of knowledge was sensory experience. Locke compared the human mind to a tabula raca, "or white paper, void of all characters" which has no a priori ideas. Knowledge was derived inductively from an objective world by sensory perception and experience. Knowledge was not universal, but beliefs justified by individuals limited perception and reflection on the world.

Kant continued the rationalistic tradition, but integrated elements from empirism. He agreed that the basis of knowledge is experience, but claimed that one could still find basic principles that applied to our world by understanding the rational human mind. He held that the mind is active in ordering sensory experiences in time and space and supplying concepts as tools for understanding them. All concepts were really rules, and the mind was rule-following. E.g., the concept of a dog is the rule that if it has four legs, barks, and wags it tail, then it is a dog (Dreyfus and Dreyfus, 1991). Thus, knowledge could be attained both inductively from experience, and deductively by basic principles.

Modern philosophers as Heidegger and Wittgenstein have contradicted the western philosophical tradition's focus on the objectivity of knowledge. These thinkers set themselves against both traditions, and emphasized the practice- and action-oriented character of human knowledge. They concluded that perception can not be explained by the application of rules to basic features. Human understanding was a skill akin to knowing how to find one's way around the world, rather than knowing a lot of facts and rules for relating them. Human understanding was thus a knowing how, rather than a knowing that (Dreyfus and Dreyfus, 1991). This is the perspective adopted by the emerging socio-technical approach, which view human intention and competent performance as vital in enterprise engineering.

6.2.1 Knowledge and its connection to action

The philosophical "review" shows that modern philosophers emphasis a practice and action oriented approach to knowledge. Flyvbjerg continues this approach, and argues in line with (Dreyfus and Dreyfus, 1991) that one should emphasize context dependent, action oriented "intuition" more than analytical rationality to develop high performance in concrete and practical situations (Flyvbjerg, 1991). This perspective has neither been adopted in the traditions of western management theory, from Taylor (1911) to Simon (1976), nor by scholars as Vernadat (1996), Blanchard (1998), etc. In these schools, knowledge is viewed as rational and explicit. But knowledge is more than the explicit, formal, and systematic knowledge that can be expressed in words and numbers, and communicated in the form of hard data, scientific formulae, codified procedures, or universal principles.

Explicit knowledge does only represent the tip of the iceberg, because our knowledge is implicit in our patterns of actions (Schön, 1983). Much of human knowledge is value-loaded, context bounded, specific and oriented towards action. This has been proven in several studies of the human learning process by Dreyfus and Dreyfus, (1991), which show that proficient and virtuous performers in chess, car driving, nursing, etc. identify problems and acts on an experience-based and context-specific intuition or *tacit knowledge*. We know a great deal more than we can tell, and that "unspoken" tacit knowledge (Polaniy, 1967) is a key component in competent human action. Expertise is knowing how to do something appropriately. Beginners act according to explicit rules, but skilled performers don't act with calculated analytical rationality, and explicit rules can actually be a hindrance for high performance. This doesn't mean that one should reject analysis and rationality as elements in human knowledge, but rather consider them equal to context-specific and practice-oriented experience, common sense and intuition (Dreyfus and Dreyfus, 1991).

Moreover, knowledge is not only context-specific, but also relational. Knowledge depends on the situation and is created dynamically in social interaction among people. Berger and Luckmann argue that people in interaction construct a social knowledge through actions and language etc. The social knowledge is constructed into a reality, which in turn influences peoples' judgement, behavior and attitude (Berger and Luckmann, 1967).

In summary, knowledge can be perceived as the personal "justified true belief" the individual employs in his dealing with the world. Knowledge is primarily tacit and includes both cognitive and technical elements. The cognitive elements center on mental models in which we create models of the world by making and manipulating analogies in our mind. The technical element includes concrete know-how, crafts, and skills (Nonaka and Takeuchi, 1995).

6.2.2 Knowledge creation: a core process in enterprise engineering

Enterprise engineering involves knowledge creation. New concepts, models, and routines are all the result of a project's knowledge-creation, but new knowledge is not only created from words, numbers, concepts, or general principles. Creating new knowledge is also not simply a matter of learning from others or acquiring knowledge from the outside. The key to knowledge creation in a engineering project lies in the mobilization and conversion of individuals' tacit knowledge in the company. In fact,

only individuals create knowledge, but individuals create knowledge in interaction with others. Organizations can only mobilize the tacit knowledge created and accumulated at the individual level by supporting creative individuals or providing the proper contexts for knowledge creation. The mobilized tacit knowledge can be "organizationally" amplified through a knowledge conversion process and crystallized into new routines and norms at higher organizational levels. The main driving force in enterprise engineering is the organization's ability to facilitate processes where knowledge conversion may take place. If the conversion process, starting at the individual level and moving up through expanding "communities of interaction" that go across sectional, divisional and organizational boundaries (Nonaka and Takeuchi, 1995).

6.2.3 Knowledge conversion: Interaction between tacit and explicit knowledge

Nonaka and Takeuchi's main assumption about knowledge creation is that individuals create knowledge through the social interaction between tacit and explicit knowledge, this is called "knowledge conversion". Managers, workers, and designers share and crystallize knowledge in a conversion process, through dialogue, discussion, experience sharing, and observation in "communities of interaction". This knowledge conversion is not easy, because tacit knowledge is not easily visible and expressible.

Tacit knowledge is highly personal and hard to formalize, making it difficult to communicate or to share with others. Subjective insights, intuitions, and hunches fall into this category of knowledge. Furthermore, tacit knowledge is deeply rooted in an individual's action and experience, as well as in the ideals, values, or emotions he or she embraces (Nonaka and Takeuchi, 1995).

Tacit knowledge is mobilized through the articulation of tacit mental models, while explicit knowledge is incorporated as new routines and mental models through learning and involvement with objects, procedures, concepts, etc. Nonaka and Takeuchi have postulated four different modes of knowledge conversion (see Figure 49). The four modes of knowledge conversion are as follows:

- Socialization, from tacit to tacit. Socialization is a process of sharing experience and thereby creating tacit knowledge such as shared mental models and technical skills. Individuals can acquire such tacit knowledge, which can be called "sympathized knowledge" from others without using language, but through observation, imitation, and practice. Thus, an individual needs experience to become a skilful practitioner.
- *Externalization, from tacit to explicit.* Externalization is a process of articulating tacit knowledge into explicit concepts. Through externalization, tacit knowledge is expressed as "conceptual knowledge" taking the shape of metaphors, analogies, concepts, hypothesis, or models.
- *Combination, from explicit to explicit.* Combination is a process of systemising concepts into a knowledge system. Individuals exchange explicit knowledge through documents, meetings, e-mail, etc, or reconfigure explicit knowledge from existing information in textbooks, documents, or databases. The acquired explicit knowledge is combined into new "systemic knowledge" such as models, prototypes, and ICT tools.

• *Internalization, from explicit to tacit.* Internalization is a process of embodying explicit knowledge into tacit "operational knowledge". Conceptual and systemic knowledge is incorporated and becomes a part of an individuals tacit knowledge in the form of mental models or technical know-how.



Figure 49: Four modes of knowledge conversion and four contents of knowledge (Nonaka and Takeuchi, 1995)

6.2.4 The organizational knowledge spiral

According to Nonaka and Takeuchi (1995), mere socialization (from tacit to tacit) or mere combination (from explicit to explicit) does not really contribute to enterprise engineering if the created knowledge is not shared by larger organizational communities. Major innovations or changes will only develop when tacit and explicit knowledge interact in a conversion process. Unless shared experience in a design group becomes explicit, it can not easily be leveraged by the organization as a whole. Further, a designer's model has no importance for the enterprise engineering unless it is justified and internalized by the organizational members. Organizational knowledge creation is a continuous and dynamic interaction between tacit and explicit knowledge, which develop as a spiral in expanding organizational communities. The interaction between tacit and explicit knowledge is shaped by shifts between different modes of knowledge conversions, which in turn are induced by several triggers (see Figure 50).



Learning by Doing

Figure 50: The knowledge creation spiral (Nonaka and Takeuchi, 1995)

The triggers for knowledge conversion are as follows:

- *Field building*. The organizational knowledge creation spiral starts in the socialization mode by building a "field of interaction" for designers and practitioners. This field facilitates the sharing of peoples' experiences, mental models, and technical skills. Interaction and sharing of experience is essential to acquire sympathized knowledge, because this type of knowledge is embedded in associated emotions and specific contexts.
- *Dialogue and collective reflection*. The externalization mode is triggered by meaningful dialogue and collective reflection in which practitioners and designers articulate hidden tacit knowledge that is otherwise hard to communicate. They attempt to express their conceptualized images through language, but expressions are often inadequate, inconsistent, and insufficient. Models and analogies trigger articulation of knowledge, and the emerging expressions are developed into shared conceptual knowledge through dialogue and collective reflection.
- *Linking explicit knowledge*. The combination mode is triggered by "networking" newly created and existing explicit knowledge. The combination of explicit knowledge gives rise to systemic knowledge like models, prototypes, tools, or procedures.
- *Learning by doing*. The internalization mode is triggered by "learning by doing". Operational knowledge is converted from explicit knowledge through bodily experience, and the conversion is eased if the knowledge is verbalized or diagrammed into documents, manuals, or oral stories. Documents or stories help to internalize what people have experienced, and facilitate the transfer of explicit knowledge so that others can re-experience a situation (Nonaka and Takeuchi, 1995).
- *Practice*. An additional aspect of learning by is practice. Nonaka and Takeuchi do not emphasize this. Individuals acquire practice through action, and trial and error. Tacit knowledge is emerging from practice and is shared among people in a collective of practice. Through action, people share experience with specific tools, materials, and products, and a collective of practice emerges. A collective of

practice denotes people that share a set of experiences, goals, and interest through a common practice as described by (Brown and Duguid, 1991). Through action, individuals get bodily experience and become competent performers by involving themselves with the environment (Dreyfus and Dreyfus, 1991). Through action, and trial and error, people can test and judge the value of new knowledge (Greenwood and Levin, 1998).

In summary, enterprise engineering implies that tacit knowledge crystallizes as new concepts and technology, and that explicit knowledge internalizes as new mental models and technical skills. Nonaka and Takeuchi's model provides a dynamic explanation to the knowledge creation as a driving force in development projects.

They identify a knowledge transfer process through which individuals' knowledge creation taking place in groups, may be shared by the whole organization through the mobilization of individuals' tacit knowledge. They also present a knowledge conversion process that goes through different modes. Each mode is creating different forms of knowledge and is initiated by different triggers. Finally, they hold the interaction between tacit and explicit knowledge as crucial for organizational knowledge creation.

Although their model captures the knowledge creation process quite nicely, it lacks some important aspects in enterprise engineering. Firstly, their model assumes harmony. Conflicting interests and worldviews and power-differences are nonexisting or only perceived positively. The individuals are viewed as friendly and harmonic persons that enjoy creating knowledge. Secondly, they do not consider the power of knowledge, knowledge can be utilized, intentionally or unintentionally, to influence other stakeholders. Thirdly, constraints that are inscribed in routines, artifacts and norms of the existing infrastructure are not emphasized.

6.3 The political process of enterprise engineering

This section will explore the Actor Network Theory (ANT) perspective on technology development to provide a deeper understanding of the political processes involved in enterprise engineering.

6.3.1 The enterprise viewed as an Actor Network

The Actor Network Theory (ANT) provides a fruitful perspective on enterprises as actor networks. Companies and other institutions are viewed as networks of people and objects (texts, machines, money, etc.) that interact, effect, and shape each other (Williams and Edge, 1996).

Knowledge is considered a social product rather than something generated through scientific methods. Knowledge is inherent in every aspect of the network, and takes material form as talks, texts, machines, models, concepts, routines, skills, etc. (Law, 1992). Moreover, we are always actors in political processes. An actor is constantly involved with others, and tries to realize his interests, as he perceives them. Every action we make influences others, and the actions of others influence us (Law, 1992). People do constantly participate in several actor networks, and are trying to realize own interests in involvement with other actors that influence them, and are influenced

by them. Thus, technological development and change will always imply power exercise and knowledge-creation for persons that participate.

6.3.2 Technological development

According to ANT, knowledge and power are inherent in every aspect of technological development. Technological development is understood as a political process, where the designer starts in his "laboratory" and develops technology by building alliances with other actors. He develops technology by mobilizing a network of human and non-human actors, by enrolling local players in a broader network. Every relevant actor will participate in the development project at one time or another, but they are not necessarily enrolled in the project. They will resist if the project does not serve their interests, as they perceive them. Enrolment or active participation requires that actors can relate the fact or artifact to their own situation and interests. The designer enrolls actors in the network by aligning the technology to their interests, or by translating their interest (Latour, 1987). Whose interests that actually are promoted depend on the actors' power. Powerful actors have the ability to align other actors to their own interests.

The technological development will continue until *closure* occurs. Closure is the stabilization of technology and occurs when consensus emerges (Pinch and Bijker, 1987). Closure will only occur when the interests of different social groups are embedded in the technology. Thus, to stabilize a technology, one has to close a technological controversy and obtain consensus. This requires that stakeholders' expectations are aligned around realizable objectives (Latour, 1987).

6.3.3 Resistance to change

Resistance to change is not only a question of workforce motivation. An enterprise consists of several social groups with conflicting interest and norms, and of technology and routines that have emerged over time. Enterprise engineering projects meet resistance from both stakeholders that defend their interests and from existing technology.

Stabilized technical choices and routines have a tendency to become irreversible over time (Callon, 1991). Change have to be negotiated against the conservative forces of economical, technical, and organizational investments in the existing infrastructure, and the accumulated resistance against change will depend on the number of irreversibilities in the infrastructure (Monteiro and Hepsø, 1998).

Enterprise engineering will also be resisted by stakeholders. A design project is a social process where every stage in the design and implementation of new technology involves a set of choices between different technical options. Stakeholders will resist if their interests are not considered in the new model. If the cleft between the interests of different social groups is too large, e.g., between managers and workers, the engineering project can fail or only lead to minor changes.

The resistance to change can be reduced by active participation of stakeholders through all phases of a design project. Active participation gives stakeholders the opportunity to influence technical choices and ensures that their interests are embedded in the new model. This increases the possibility for a good solution and a smooth implementation. But stakeholders will only be motivated to active participation in a design project if this serves their interests, as they perceive them. It may also be that participation in a design project initiated by other social groups is not socially acceptable. This is well illustrated in Lysgård's study of worker collectives, where an involvement with management is considered disloyalty to other workers (Lysgård, 1961). Active participation in a design project requires incentives, either personal or for a specific group.

6.3.4 Obstacles to innovation

In enterprise engineering, there is always a risk for single loop learning instead of innovation. Single loop learning refers to a situation where people or enterprises alter their behavior but do nothing to change the behavioral strategies that gave rise to the problematic situation initially. Since the underlying causes are not confronted, the problem returns (Argyris and Schön, 1996). Single loop learning is learning that only affects conceptual knowledge, and not the tacit knowledge, which is double loop learning. Real knowledge-creation and innovation involve challenging deeply rooted assumptions, norms, or organizational routines that have previously been inaccessible through a sharing of tacit knowledge. The creation of innovative knowledge may be hindered by rejection of new knowledge or by the communicative power of certain stakeholders.

Knowledge creation is a process where stakeholders align themselves toward a truth (justified true beliefs) or social fact. Real knowledge-creation implies that knowledge must be judged and found credible by the stakeholder. The credibility of knowledge depends on the arguments and the processes necessary for having someone trust new knowledge and is tested through practice or collective reflection. The first credibility test is *workability*. Workability means whether or not a solution resolves the initial problem, and is a matter of collective social judgement about the outcomes of an action (Greenwood and Levin, 1998). The second test is collective social judgement or *sense making*. A chain of arguments that can not be overstated in a collective dialogue and reflection process, i.e., a line of arguments that make sense for the stakeholders, is credible knowledge.

There are several conditions that might be a hindrance for innovative knowledgecreation, and valuable knowledge might be rejected. Knowledge might be rejected if a few individuals carry out the creation of knowledge in isolation. When knowledge is created in this way, a truth might be established before it is dispersed to the rest of the organization. The knowledge can therefore represent a black box for others that they find hard to access. Black-boxing inhibits the "interpretative flexibility" of knowledge (Pinch and Bijker, 1987), and constrains the disputation, negotiation, and reinterpretation necessary to enroll other actors and to achieve closure in technology development. Moreover, participants are unlikely to accept as credible the "objective" theories of designers if they cannot recognize the connection to the local situation or because they find the frameworks too abstract for the specific context. Credibility depends on the arguments and the processes necessary for having someone trust new knowledge (Greenwood and Levin, 1998). An innovative knowledge creation process requires sharing of every participant's knowledge. But the conventional training of academic designers and managers generally makes them experienced debaters with lot of practice in managing conceptual models. This can create a situation of communicative domination that undermines the knowledge creation process. This situation was called "model monopoly" by (Bråthen, 1973). He identified situations where one side dominates, and through skills in communication and handling of certain kinds of conceptual models constantly increases the influence on others. In addition, designers' and managers' social prestige and years of formal training may convince people to accept a particular point of view to easily, and thereby translate their interests toward own objectives (Latour, 1987).

In summary, enterprise engineering involves alignment of interests, knowledge creation, and the exercise of power. In order to create the "best" solution, a design project must be based on an understanding of these aspects and processes, and provide conditions that facilitate knowledge creation and judgement, inhibit the exercise of power, enable negotiations between stakeholders, and align solutions to the existing infrastructure.

6.3.5 Comparison of design approaches

Competitive business processes are designed by enabling the competent performance of workers. This implies that an effective design strategy needs to include new principles for active worker participation. In our view, participation does not only mean the involvement of workers in minor and narrow design details. Active participation is to influence the decision making in work and design. Participation is crucial in enterprise engineering, and will be the focus in this section.

6.3.6 Technology-based and socio-technical design

This section explores different design schools' view on workers. The design schools are divided into two basic approaches, the technology-based and modern socio-technical design, to contrast their view on worker involvement and knowledge. See Table 1 for the main differences

Technology-based design	Modern socio-technical design				
Humans are noise	Humans are competent				
Eliminate or deskill	Empower and reskill				
Design by experts	Participatory design				

Table 17: Two opposite views on knowledge and worker involvement

Traditional *technology-based design*, which includes scholars in systems engineering, production planning and control, and much of the traditional management theory, does not emphasize the worker role in production and logistic processes. In technology-based design, worker participation is non-existing or marginal. This approach proceeds with the same basic understanding of the human role in production and logistics as articulated by (Taylor, 1911) at the beginning of this century. Workers' activity are assumed to be typically limited to the exercise of a few manual skills, and the enterprise is understood as mechanical interactions of these limited

skills with installed technology. Since workers' activity is assumed to be limited to the exercise of simple manual skills based on limited production knowledge, workers' participation in production problem solving, or workers' performance of skilled work is not valued. On the contrary, workers' involvement is seen as an unquantifiable risk to enterprise performance (Salzman, 1992). The technology-based design will therefore aim to eliminate human intention. For example, the primary personnel objective in systems engineering is to eliminate people. And when people are required, "skill level requirements should normally be minimized" and jobs should be designed under the assumption that workers are "able to follow clearly presented instructions where interpretation and decision making are not necessary [and] will normally require close supervision" (Blanchard and Fabrycky, 1981). Worker participation is therefore insignificant in system engineering. The conceptual and preliminary phase of the design process is carried out by a team of systems engineering experts, and which involves other engineering experts when so needed (Blancard and Fabrycky, 1998).

Socio-technical design is now emerging as a more effective approach to enterprise engineering. The "socio-technical" concept reflects a focus on joint optimisation of technology and social systems, indicating that really effective systems only can be generated when technology and people are properly matched. The basic assumption of socio-technical design is that manufacturing processes rely on the skills and knowledge of workers and their ability to handle daily variety in demands and the production environment (Herbst, 1977). In socio-technical design the designer sees the elimination or simplification of routines and tasks as an opportunity for the worker to assume a broader role in the production process, i.e., to participate more in the operative decision making, although it may involve a shift in types of skills used.

Socio-technical design concepts like "autonomous groups" or "teams", and "empowerment" are now common management concepts and acknowledged by management schools like Toyota Production System (Monden, 1983), Total Quality Management (Aune, 1999), Business Process Reengineering, (Hammer and Champy, 1995), and Enterprise Modelling and Integration (Vernadat, 1996). These schools acknowledge that effective performance requires more, not less worker skill and judgement, and aims to empower workers.

However, most management schools have kept the technology-based strategy for design, and typically recommend that a team of experts carry out the design process. Participation in the design process is often considered as unnecessary, and workers should only be involved in implementation and minor design decisions. This view can be illustrated by Vernadat's (1996) process improvement strategy:

- 1. Get management commitment to redesign the process
- 2. Form a cross-functional team
- 3. Model the existing AS-IS process in detail (simplification based on cost and time analysis)
- 4. Identify areas for improvement
- 5. Design an "ideal" TO-BE-process
- 6. Determine how much of the TO-BE process can actually be implemented with parts of the AS-IS that must be kept.
- 7. Validate and test the TO-BE process (on the basis of simulation and cost analysis)

- 8. Propose an implementation plan that will disrupt the organization as little as possible, involves the people affected, and will get changes in place as quickly as possible.
- 9. Get management commitment for the implementation plan and install the new process
- 10. Monitor the new process for future changes as needed.

In Vernadat's improvement strategy, the process is carried out by a cross-functional team of experts, "Usually, four or five experts are enough" (Vernadat, 1996). They will carry out information collection, modelling of AS-IS processes, and design of TO-BE processes. Practitioners are only involved as objects for information collection through interviews. The information collection will not involve e.g., group meetings because "Experience shows that [information collection by interviews] provides results of the same quality as [information collection by group meetings] in a much shorter period of time" (Vernadat, 1996).

In modern socio-technical design, empowerment means participation in the major decisions as well as in their implementation. This differs from management fads such as "job enrichment" or "quality circles" or "management by objectives" which provide a clearly structured solution for implementation (Taylor and Felten, 1993).

Participatory or co-operative design is viewed as a method to create effective and productive solutions and to empower workers. This approach argues that new technologies will be more effective when designed to augment, rather than replace the skills of users (Winograd and Adler, 1992). To design usable technology, designers and users must develop a common understanding through dialogue and practice. According to (Bødker, Greenbaum, and Kyng, 1991), designers learn about work conditions and workers' needs through dialogue and practice. Moreover, through dialogue and supported by prototypes, scenarios, etc, users experience the possibilities and consequences of new model, and can play an active role in determining the design of it.

6.3.7 Enterprise engineering – conflicts or harmony

The design schools explored also have distinctly different views on the political processes involved in enterprise design. The main differences between these views are listed in Figure 50.

Harmony	Conflict
There is a best solution	A solution represents interests
Humans are neutral and/or friendly	Humans are stakeholders
A enterprise is developed without resistance	A design meets resistance and is developed
	through negotiations

Table 18: Two opposite views on political processes

The harmonic view

• *Systems engineering* assume that people are neutral decision-makers (experts) or neutral collections of operations (workers). The experts calculate neutral

"optimal" solutions that will be implemented without resistance. (Blanchard, 1998)

- *Vernadat* assumes that only technical aspects cause user resistance. Models are used if they are "simple to understand, easy to use, computer supported, and if they provide a realistic image of the reality" (Vernadat, 1996)
- *Winograd* assumes harmony, and argues that through a design process based on dialogue and learning, users and designers will finally develop a solution that increases productivity (Winograd and Adler, 1992).

A problem with these approaches is the underlying assumption that managers and workers share the same desire, i.e., to increase productivity.

The traditional socio-technical design acknowledges the conflicting interests in a company, but focuses on specific design principles, e.g., semi-autonomous groups that will provide productivity and good jobs. This approach is less concerned about the design process and is not sensitive to the asymmetric distribution of power in organizations. The actual planning and design in traditional socio-technical design was therefore carried out by management and socio-technical experts (Ehn, 1992).

The conflicting view

- *Traditional management theory* recognizes the conflicting interests in a company and support worker participation as a means to achieve higher work moral and higher commitment to new systems and technologies (Greenberg, 1975). Managers often involve workers in narrow design problems and minor decisions to ensure their goodwill to new solutions. The basic relationship between labor and managers are not altered, and worker participation is often limited to local and unimportant decisions.
- *Business process reengineering* acknowledge that people resist radical changes of their jobs (changes that are determined by experts), and claims that overcoming resistance mainly is a selling job (Hammer and Champy, 1995).
- *Modern socio-technical design* criticizes the lack of focus on the design process in traditional socio-technical design. This approach adds the political dimension in their approach to participatory design. Modern socio-technical approach recognizes the conflicting interests in a company, and views participatory design as a method to democratize work. They argue that the participation of skilled users in the design will not only contribute to successful and high quality products. Participatory design will also raise questions of democracy, power, and control. Through participatory and work-oriented design managed by the trade union, one will create jobs that liberate workers from owners' control of resources, technologies, production systems etc., and enhance the individuals' autonomy at work (Ehn, 1992).
- *Nyhlen*, another socio-technical scholar, criticizes the view that democratization and full participation is achievable in organizations (Nyhlen, 1992). He distinguishes between representative participation, participation, and co-determination, and assumes that the only "real" participation is co-determination. For Nyhlen, "real" participation is democratic in nature and only occurs when workers fully realize their interests. Thus, he claims that "real" participation only is possible to a limited degree and in narrow areas in organizations, because control of individuals is inherent in any organization (Nyhlen, 1992).

Enterprise engineering is a dynamic process that involves people, technology and knowledge. Every step in this process, from problem definition to the use of new technology, is carried out under conditions that constrain or enable knowledge creation and the realization of stakeholders' interests. This comparison of design approaches has shown that non of the existing approaches has fully considered the conditions that are triggers or obstacles for the success of a engineering project. There are many reasons for a project to fail, but the effect of constraining conditions can be reduced or overcome if a engineering project provides the proper context for participation, negotiation, and knowledge creation. The next section will propose, based on earlier outlined models and concepts, conditions that can enable knowledge creation and smoothen the political processes in enterprise engineering.

6.4 Change management principles

Participation as a concept has not been scrutinized by many scholars, the most recently definition was provided by (Nyhlen, 1992) as outlined above. Nyhlen's definition of real participation as the full realization of workers interests implies that participatory design is not a suitable concept to describe enterprise engineering, because enterprise engineering implies alignment of interests and not that every stakeholder can realize all interests. However, a more fruitful definition is that real participation is to be active and influential in the decision making in work and design of work-organization and technology. Moreover, the design and implementation of new solutions implies technological changes in which knowledge creation is inherent. Thus, participatory design is to acknowledge the interests and knowledge of the stakeholders, and to provide conditions that facilitate negotiations and knowledge creation. Participatory design demands strategies for distribution of authority, power, and responsibility, and arenas for communication and negotiation. Relevant practitioners in production, purchasing, order fulfillment etc. should be involved in the design process, and enabled to create new knowledge and to inscribe own interests in the technology. Clear-cut rules should be defined for political processes and participants' interaction, and renegotiated during the engineering process. Further, knowledge is inherent in every aspect of an enterprise, in procedures, in ICT-tools, in machines etc. In order to carry out a successful design project, one should acknowledge that changes in business processes require knowledge creation, and apply strategies that facilitate this knowledge creation.

The core principle for effective enterprise engineering is *participatory design*. Participation is, as already defined, to be active and influential in the decision making in work and design of work-organization and technology. Stakeholders that have strategic importance and who are important for the knowledge creation should be identified and become active participants early in an enterprise engineering process. This is important for two reasons; to reduce potential conflicts in implementation and use, and to achieve requisite variety in the design project. Firstly, to reduce potential conflicts, it is important that all relevant social groups are represented and promote their interests in the early phase of the knowledge creation process, before closure occurs. Secondly, a design project's composition of participants should provide a knowledge base that matches the variety and complexity of the environment, in order to create knowledge that deals with challenges posed by the environment.

The core process in enterprise design is co-operative *knowledge creation*. The process of knowledge creation should be understood, and the triggers for knowledge creation facilitated in the design project. These triggers, field building, dialogue, linking explicit knowledge, learning by doing, and practice, should be acknowledge and facilitated in a design project.

The following conditions are proposed to enable participatory design and knowledge creation in enterprise engineering:

- *Clearly stated objectives and ground rules.* The knowledge spiral is driven by the project intention, which is defined as the project's aspirations to its goals. Efforts to achieve the intention usually take the form of strategy (Nonaka and Takeuchi, 1995). In a project strategy, the most critical element is to conceptualize the objectives for the project, which should be aligned with corporate strategies. Conceptualized objectives make it easier for stakeholders to judge if the project serves their interest. Further, objectives make it easier for individuals to judge the value of information, or knowledge, that is perceived or created toward project goals. The knowledge spiral will be governed by ground rules for participation, which can be interpreted differently by different stakeholders. It is important that these rules are conceptualized, and that every stakeholder commits themselves to the conceptualized rules. These rules should concern the composition, authority, goals and areas of responsibilities for groups.
- Arenas for negotiations and knowledge judgement Arenas for negotiations are arenas where different interest are articulated and negotiated. Such arenas should be arranged both in initial phases and when choices are made in later phases, to ensure that the interests of all stakeholders are embedded in the new enterprise. In addition, the creation or transfer of knowledge requires that knowledge is credible to the individual to become "justified true beliefs". New knowledge should be tested through practice and sense making conferences.
- *Autonomy*. A condition for knowledge creation is autonomy or self-organizing teams. The design groups should be put together as cross-functional teams, and organized with "minimum specification criteria" (Trist, 1981) in order to increase the chance of introducing unexpected opportunities and the possibility that individuals will motivate themselves to create new knowledge (Nonaka and Takeuchi, 1995).
- *Fluctuation and creative chaos.* Fluctuation and creative chaos stimulate the interaction between design project or organization and the external environment. Fluctuation is "order without recursiveness". An environmental fluctuation, e.g., in the market, often triggers a breakdown of routines, habits or cognitive frameworks within the organization, out of which new knowledge can be created through dialogue and social interaction. Fluctuation may trigger creative chaos, where members sense a crisis and focus their attention on defining the problem and resolving the crisis situation. Managers or project leaders can also, to some extent, evoke creative chaos by setting challenging goals.
- *Redundancy*. Redundancy may be defined as the existence of information and shared experience that go beyond the immediate operational requirements of project participants. Sharing experience and sharing redundant information promotes the expression and sharing of tacit knowledge, because individuals can sense what others are trying to articulate, and thereby offer advice or provide new information from different perspectives. Redundancy can be built into an

organization or design project by creating competitive design groups, by "strategic rotation of personnel", by frequent meetings, (Nonaka and Takeuchi, 1995), by building arenas for formal and informal interaction and communication, and finally, by building arenas for shared experience.

- *Experiencing the future.* The explicit concepts of designers can be too abstract to grasp for practitioners. To facilitate knowledge creation, situations should be created that have familiar resemblance with their work, this can be done e.g., by real life experiments, or through simulation games where practitioners can experience present and future solutions. Moreover, often the existing technical solutions at a specific workplace severely limit the creativity of practitioners. Visiting workplaces is a simple and powerful way of getting to understand that a broad spectrum of possibilities exists (Bødker, Greenbaum, and Kyng, 1991)
- *Iterative design*. An iterative design approach where uncompleted solutions are tested in practice ensures alignment to the existing infrastructure.

6.5 Summary

Enterprise engineering is more than the analysis and design of a "best" model by an expert. Interests and knowledge are embedded in every solution, and even thoroughly planned solutions will meet resistance, both from stakeholders and the existing infrastructure. Enterprise engineering is a political process that involves stakeholders with conflicting interests, and the conservative forces of economical, technological, and organizational investments in the existing infrastructure. Enterprise engineering is a knowledge-creation process, which relies on practitioners' and designers' experience and their ability to create new solutions.

Effective enterprise engineering is to acknowledge the interests and knowledge of the stakeholders, and to provide conditions that facilitate negotiations and knowledge creation. Through a well-organized knowledge-creation, sense making, and negotiation process, conceptual and operational knowledge can be shared and crystallized as good solutions. Effective enterprise engineering enhances the probability for good models that facilitate competent performance, and that are aligned to stakeholders' interests and the existing infrastructure.

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7. The enterprise reengineering methodology – strategic planning

This chapter outlines the overall process model for the enterprise reengineering methodology, which includes strategic planning, and operations mapping, analysis, design and implementation. The chapter focuses on strategic planning and proposes a procedure with four parts. First, to understand and revise business objectives; second, to determine the current operation strategy (performance objectives and major decisions); third, to perform an analysis of the gap between operations capabilities and market requirements; and fourth, to formulate a revised operations strategy that specifies some targets and actions for operations.

7.1 Introduction

The objective of this methodology is to reengineer the operations processes so that the enterprise can achieve its performance objectives. The methodology is based on Porter's (1996) distinction between operational effectiveness and strategy. Operations effectiveness is the ability to perform operations tasks more efficiently than competitors. Strategy on the other hand, is a plan for competing in the market place. Every enterprise can improve their operational effectiveness through an operational focus, this is Skinner's "focused factory" or "plants within a plant" principle (Skinner, 1969). Strategy is defining what the enterprise or enterprise entity should focus on.

Operations effectiveness and strategy must be aligned; otherwise the enterprise may be very efficiently performing the wrong task. An operations strategy set the course for a broad product group, which often constitute the entire product range for a manufacturing enterprise. The role of enterprise reengineering is to realise operations strategy through an improvement of operations in a targeted direction. This is achieved by decomposing the total operations process of the enterprise (and thereby the operations strategy), into a set of operations areas that are linked by material and information flows. The reengineering is then to redefine the boundaries and focus of the operations areas in the enterprise, and align them, based on each area's particular characteristics, to the overall performance objective of the enterprise. The process model for enterprise reengineering is shown in Figure 51.



Figure 51 The enterprise reengineering methodology

The methodology consist of 5 parts, strategic planning (which includes the choice of best practices such as flow manufacturing), mapping (which includes to develop a AS-IS operations model), analysis, design (which includes to develop a TO-BE operations model) and implementation of the operations model. Each of these parts is described in the following chapters. It should be noted, however, that the process is iterative. Both operations strategy and the operations model should be repeatedly updated to include changes in the market or resource situation.

7.2 Strategic planning

Operations strategy formulation aims to align market requirements and resource capabilities in order to achieve competitiveness in a certain market. The main stages of the strategic planning are:

- Part 1. Understand and revise business objectives
- Part 2. Determine the current operation strategy
- Part 3. Gap analysis of market requirements and current capabilities:
 - Alt. 1 A coarse review of options within each decision areas, and a identification of options that will potentially enable a closing of the gap.
 - Alt. 2 Identification of options based on a thorough mapping and analysis of enterprise operations (chapter 8).
- Part 4. Revise the operations strategy, and formulate actions to meet objectives and to develop new capabilities.

Each stage of this process is carried out by a group of managers operating in a workshop environment and supported by a facilitator who guides them through the process. Worksheets are used to capture information, and various visualisations tools (mainly the operations strategy checklist, the operations model-set, and the operations audit sheet) can be used to facilitate discussion.

An important aspect of the enterprise reengineering methodology is that strategic planning, both at the functional and business level, is a repetitive process (Mills et al, 1998). The relationship is mainly hierarchical, i.e. the operations strategy designs a plan to take the business strategy from concept to reality. However, in order to ensure

competitiveness, the strategy process should also include revising the business strategy based on a review of operations capabilities.

7.3 Part 1 Understand and revise business objectives

The corporate strategy applies at the level of a company involved in different business segments. It essentially defines the portfolio of business in which the corporation wants to be and the resource allocation pattern among those businesses (Lasserre, 2003). The corporate strategy informs all stakeholders (shareholders, employees, customers, suppliers etc.) of the firm's main purpose, and of its products, markets, competitive emphasis, and values. The corporate strategy usually provides the corporate goals, although often in a vague and rather opaque form, and not very useful for guiding operations. The corporate strategy also includes performance measures that tend to be financial or market oriented. Typical metrics include annual profit, return on assessment, sales per employee, and market shares for key product lines.

It is the business strategy that determines how the manufacturing operations should perform. The business strategy applies at the level of a business operating in a particular industry segment. It defines the way this business wants and is able to compete in this segment (Lasserre, 2003). In smaller corporations, this means that business strategy and corporate strategy is coincident. The formulation of a business strategy includes a range of assessments and decisions. These include developing an understanding of what business the company is in (the company's mission), analysing the market (environmental analysis), and identifying the company's strengths (core capabilities).

7.3.1 Mission

The first decision a company needs to make is to identify its mission. The mission statement usually expresses the primary task of the company. The mission may be accompanied by a vision statement that describes what the company sees itself becoming. The mission statement should answer three overriding questions:

- What business will the company be in?
- Who will the customers be, and what are expected customer attributes
- How will the company's basic beliefs define the business

For example, Dells mission is to "be the most successful computer company in the world at delivering the best customer experience in the markets we serve". The mission basically defines the company. In order to develop a long term plan for a business, one must know exactly what business the company is in, what customers the company is serving, and what the company's values are.

The two remaining issues are usually treated through an SWOT analysis that scrutinises Strengths and Weaknesses (resource capabilities), and Opportunities and Threats (external factors).

7.3.2 External environment

A second factor that must be considered when developing a business strategy is the external environment in which the business is operating. This environment includes trends in the market, in the economic and political environment, in the society, and so on. These trends must be analysed to determine business opportunities and threats. A checklist for environmental analysis is provided by Power et. al. (1986):

Table 19 Environmental variables checklist (Source: Power et. al. 1986)

Societal Changes
Changing customer preferences – Impacting product demand or design
Population trends – Impacting distribution, product demand or design
Governmental Changes
New legislation – Impacting product costs
New enforcement priorities – Impacting investments, products, demand
Economic changes
Interests rates – Impacting expansion, debt costs
Exchange rates – Impacting domestic and overseas demand, profits
Real personal income changes – Impacting demand
Competitive changes
Adoption of new technologies – Impacting cost position, product quality
New Competitors – Impacting prices, market share, contribution margin
New products - Impacting demand, advertising expenditures
Supplier changes
Changes in input costs – Impacting prices, demand, contribution margin
Supply changes – Impacting production processes, investment requirements
Changes in number of suppliers – Impacting costs, availability
Market changes
New use of products - Impacting demand, capacity utilisation
Product obsolescence – Impacting prices, demand, capacity utilisation

Market place trends might include changes in customer wants and expectations, and ways in which competitors are meeting those expectations. For example, in the computer industry customers are demanding speed of delivery, high quality and low price. A competitive trend might be the use of new technology, such as point-of-scale scanners, automation, computer assisted processing, electronic purchasing, and electronic order tracking. Another competitive trend is e-commerce, for many companies, e-commerce has become a significant part of their business. In addition to market trends and competitive trends, environmental analysis should look at economic, political, and social trends that can affect business. Economic trends include recession, inflation, interests rates and general economic conditions. Political trends include changes in political climate – local, national, and international – that could affect the company. Social trends are changes in society that can have an impact on a business, and so on.

There exists a range of tools and framework to support environmental analysis, such as the PEST (Political, Economic, Socio-cultural, and Technical) analysis, portfolio analysis, or Porter's Five Forces analysis. For a more comprehensive overview of environmental analysis, see Lynch (1997).

7.3.3 Core capabilities

The business strategy aims to take advantage of an opportunity in the market. However, the business strategy should also be based on, and take advantage of, it's core capabilities. A good starting point for analysing capabilities is the strength and weaknesses part of SWOT. A company could have core capabilities (i.e. strengths) in areas such as (Power et al, 1986):

- Marketing
- Research and development
- Management information systems
- Management team
- Operations
- Finance
- Human resources

A major source for competitiveness is operations, and the business strategy should also be based on an analysis of the contribution of operations resources. Table 20 lists some possible operations factors that might be included in such an analysis. It should be noted that many of the listed weaknesses are simply a lack of a particular strength. What are strengths in one set of circumstances could be a weakness in another. It is important therefore to clarify the assumptions under which such lists are derived.

Table 20 Strengths and weaknesses checklist (source: Slack and Lewis, 2001)

STRENGHTS	WEAKNESSES
 Economics of scale Ability to adjust capacity Reserve capacity Appropriate locations Long-term supplier relationships Supply market knowledge Supply chain control Advanced process technology knowledge In-house process technology development capability Flexible organisational structure In-house operations expertise Continuous improvement culture Effective product and service 	 Uneconomic volume Underutilisation of capacity Insufficient capacity Inappropriate locations Lack of power in supply market No long-term supply relationships Old process technology with poor performance No capability to improve "off the shelf" process technology Rigid organisation or decision-making structure No in-house operations expertise Static levels of operations performance Poor product and service development
 Continuous improvement culture Effective product and service development process 	 Poor product and service development skills

Lynch (1997) gives the following hints to enhance the quality of the analysis: Keep it brief, statements should be specific and avoid blandness. Relate strengths and weaknesses, wherever possible, to key factors for success. Strengths and weaknesses should also be stated in completive terms, where is the enterprise better than competitors? It is important to be realistic about the strengths and weakness of one's own and competitive enterprises.

7.3.4 Business strategy formulation

The mission, environmental analysis and core capability analysis constitute the basis for a business strategy. However, it should now be clear that the business strategy analysis needs to consider every part of the company and the environment, and most importantly, do so with limited recourses. Potentially, this raises a major strategic problem: business strategy analysis could be overwhelmed by the size of the task. The Japanese strategist Kenichi Ohmae (1983) has suggested a way of tackling this matter by identifying the key factors for success that are likely to deliver the company's objectives. Three principle areas should be analysed in order to determine the critical success factors - Ohmae's three Cs:

- *Customers* (environment). What do the customers really want? What are the segments in the market place? Can we direct our strategy towards a group?
- *Competition* (environment). How can the company beat or at least survive against competition? What resources and customers do they have that make them particularly successful? How does the company compare on price, quality, etc? Does company have a stronger distributive network than its competitors?
- *Corporation* (core capabilities). What special resources does the company itself possess and how do they compare with competitors? How does the company compare on costs with its rivals? Technologies? Skills? Organisational ability? Marketing?

Potential factors for success in an industry could be price, service, product or service reliability, quality, technical specifications, branding etc. Whether a potential factor is a key factor or not, should be based on the company's mission and objectives. Ohmae's approach limits the scope of the strategic analysis to three areas (customers, competitors and core capabilities), and the objective to the identification of key factors for success. Such a limitation makes the strategic task more manageable.

Based on the analyses and decisions outlined above, it should be possible to formulate a business strategy that positions the company in the market place. The business strategy is essentially a framework that assists a company in achieving its vision while allowing it the flexibility to deal with unforeseen changes in the business environment. The elements of the strategy can be summarised to (Summers, 2005):

- 1. Vision: the company's strategic direction for the foreseeable future
- 2. Mission: the translation of the company's vision into strategic actions.
- 3. Critical success factors: the 3 to 10 things, as identified by customers, that a company absolutely must do well if the company is going to thrive
- 4. Goals: what must be achieved in order to support the critical success factors
- 5. Objectives: the specific and quantitative actions that the company must take in order to support the accomplishment of the goals and ultimately the mission and vision (profitability, market shares, return on investments, etc.)

The business strategy summaries the company's decisions regarding the products it will make, the technology it will deploy, the markets it wish to penetrate, and the performance goals it plans to accomplish. The formulation of a business strategy should therefore precede, and be the basis for, the development of an operations strategy for a specific enterprise.

Part 2 of the strategic planning process is to analyse the market in order to understand and prioritise performance objectives for operations. This is described in the next section.

7.4 Part 2 Determine the current operations strategy

It is likely that the business strategy will encompass several different product groups that compete in different ways and impose different requirements on a manufacturing enterprise. The main objectives of operations strategy formulation are therefore a) to translate required competitive dimensions (typically obtained from marketing) into specific performance objectives for an enterprise and b) to make necessary plans to ensure that the operations capabilities of that enterprise are sufficient to accomplish them. The steps for prioritising these performance objectives are (Chase et al. 2004):

- 1. Segment the market according to product group, and identify the product requirements, demand patterns, and profit margins for each group
- 2. Determine the order winners and order qualifiers for each group
- 3. Convert order winners into prioritised performance objectives for operations

7.4.1 Grouping products

The first step in determining performance objectives is to divide the product range into groups of products that have distinct competitive requirements. One group is chosen for the first run-through of the operations formulation process and other groups are dealt with in turn. The segmentation should result in product groups that fit together in the sense that they have similar market characteristics and/or operations requirements (product characteristics, type of customers, product range, designchange frequency, product performance, quality requirements, demand variation, volumes, margins etc).

7.4.2 Determine order-winners and qualifiers

Based on the market requirements and business objectives, order winning and order qualifying criteria should be identified for each group (Hill, 2005). Such order winning criteria (those criteria that differentiate the enterprise from competitors and drive increased sales) could be:

- price,
- brand name,
- product performance,
- product range,
- introduction of innovative new products
- etc.

The order winning and qualifying criteria's must reflect the market characteristics in which the product is to be sold. Hill (2005) suggests a framework to support such an analysis based on the products' non-repeat or repeat nature. At one extreme a product may comprise an offering that is not repeated, that is, it is designed specifically to one customer. This is termed a special product, referring to its unique, non-repeat nature. However, most products are of repeat nature (provided more than once and to more than one customer) and at the extreme will be high volume. With this fundamental change of nature, dimensions of a product such as volumes, order size, level of change required and typical order-winners and qualifiers will also differ, as shown in Table 21.

Aspects	Non-repeat	Repeat					
		Low-volume High-volume					
Product type	Special	Standard					
Product range	Wide	Narrow					
Customer order size	Low	High					
Level of product change required in the process	High	Low					
Design predominantly determined by	Customer	Provider					
Orientation of innovation	Product	Process					
What does the company sell?	Capability or skill	Standard offering					
Order winners	Unique capability, repeat business or recommendations	Price					
Order qualifiers	Price, delivery precision, quality conformance	Delivery precision, quality conformance					

Table 21 The implications of the non-repeat and repeat nature of a product(Source: Hill, 2005)

Table 21 illustrates some of the aspects of a product group that will have implications for operations. The special (non-repeat) or standard (repeat) nature of the product is reflected in the width of the range offered, and the volumes involved. In non-repeat markets, product design are predominately determined by the customer, while repeat product designs (including options available) are determined by the provider -a customer's choice is limited to what is on the option list. The way a company wins orders should reflect these non-repeat/repeat and volume dimensions.

7.4.3 Performance objectives

The criteria should then be translated to performance objectives for operations (cost, quality, range flexibility, innovativeness, delivery precision etc). See Table 22 for an example of how this can be carried out, and Table 2 in chapter 2 for a overview of potential measures within each performance dimension.

objectives (sources in Stuck, 1772)							
External performance dimensions	Product group 1	Product group 2					
Product	Standard medical equipment	Electronic measuring devices					
Order winners	Price Product reliability	Product specification Product range					
Qualifiers	Delivery lead time Product specification Quality conformance	Delivery precision Delivery lead time Price					
Main performance objectives	Cost Quality	New product flexibility Range flexibility Delivery precision					

Table 22 A comparison of how two product groups differ in their performance objectives (source: N. Slack, 1992)

If the performance objectives is very different, (as in the above example), these groups will almost certainly require two separate focused units within the enterprise, each devoted to providing the things that are important in their separate markets. In such cases, each unit needs a separate operations strategy that direct changes in the targeted direction.

7.4.4 Formulate the current operations strategy

This part involves an analysis of the strategic decisions and actions taken in each decision areas. This "history review" should be based on an understanding of what type of operations the manufacturing enterprise is involved in. The first step in analysing the operations strategy is therefore to check the current degree of fit between market requirements and operations capability.

Hill (2005) proposes a framework for such a check, which he terms product profiling. The purpose of a product profiling is to asses the fit between the requirements from the market and the type of process technology used to provide them. Although the scope of the check is limited, it is a good starting point for an assessment of the current strategy, because investment in process technology is a pivotal decision that has major influence on other decisions, such as capacity decisions, layout decisions, planning and control decisions. Figure 52 is an example of the outcome of a product profiling, and shows the basic principle:

		Typical characteristics of process choice					
A	spects	jobshop	line				
	Product type	Special	0	Standard			
	Product range	Wide C		Narrow			
Products	Customer order size	Small)	Large			
markets	Level of product change required	High)	Low			
	Rate of new product introductions	High		Low			
	Order winner	Delivery speed/ unique capability	0	Price			
	Process nature	Generalpurpose		Dedicated			
Operations	Process flexibility	High	•	Low			
Operations	Operations volumes	Low		High			
	Operations key strategic task	Meet specification/ delivery speed		Low cost operations			
Investments	Level of investement	Low		High			
Position of product group Y Position of enterprise X							

Figure 52 Profile of enterprise x and product group y (Source: Hill, 2005)

The procedure to follow is first, to choose the characteristics of markets and operations pertinent to this business. Next, the characteristics that reflect the change between job shop, batch production, and line production are described. On the one hand, the product range associated with job shop is wide and becomes increasingly narrow as it moves to line. On the other, customer order size is small in job shops and becomes increasingly large as it moves through to line and so on. These dimensions represents the classic characteristics of the trade-offs embodied in choosing a process, as described in the product – process matrix, chapter 2. Figure 52 shows that there is a mismatch between market characteristics and operations capabilities at enterprise x. The enterprise manufactures a large range of products with small volumes and order sizes. Such a situation can occur because the investments in process technology did not relate to the requirements of the market, or because the market has changed since the enterprise invested in process technology (Hill, 2005).

The next step involves analysis of the decisions and actions taken in a number of decisions areas. The decisions areas and some possible strategic decisions (or events) are listed in Table 23.

	Strategic changes	Performance objective
Resources		
Resources	Increase production capacity in order to fulfil requirements for a new long-term contract	Cost
	Establish new plant that is near the market Establish new production line to enable simultaneous	Delivery time Flexibility
	Centralisation of all production to one site in order to reduce	Costs
	Automation of equipment resulting in manpower reductions with increased capacity, better quality,	Cost
	Reliability program in order to improve up-time	Delivery precision
Motoriala		
Materials	Acquisition of core supplier to reduce costs Outsourcing of component production to low-cost country Flow orientation of layout Product standardisation and modularisation	Costs Costs Delivery precision Costs
Information	EDI system for ordering Internet (XML) solution for transparency in the value chain Quality monitoring equipment ERP system that automates information transactions and work flows.	Costs Costs Quality Delivery precision
Processes	VMI collaboration with supplier 5S programme to improve work place organisation SMED programme resulting in radically reduction of changeover times	Costs Quality Flexibility
Organisation		1
	Team organisation to improve flexibility Performance monitoring system that give early notice of missed deadlines	Flexibility Delivery precision
Control	Collaborative planning with supplier in order to allow urgent orders to be given priority New market interaction strategy – from MTS to ATO to enable mass customication	Delivery time Delivery time
	Just-in-time procurement Replace MRP orders with kanban system	Costs Delivery precision

 Table 23 Examples of strategic changes or events

Current strategy is composed of what has already been implemented (or realised) and what is planned (or intended) to be implemented. Realised strategy can be identified from past decisions and actions. The analysis should identify past decisions and their primary performance objectives, and group the decisions according to decisions areas. Such an analysis provides a summary of realised strategy which can surface the sources and implicit choices of the operations strategy, and provide a history which may guide future development.

A key requirement for an ongoing strategy process is an easily updated representation of a company's strategy (Mills et al. 1998). The operations strategy checklist provides such a representation. The final step in analysing the current strategy is to populate an operations strategy checklist with past and present strategic decisions. See example in Table 25. The operations checklist describes operations strategy as a set of decisions that affect both the decisions areas and performance objectives. It emphasis what is required from the operations function (i.e. performance objectives) and how the operations tries to achieve this through a set of choices that affect one or several decisions areas.

7.5 Part 3 Gap analysis

This stage is an assessment of whether the current strategy is likely to achieve the performance objectives. Gap analysis should be used to asses the enterprise's performance relative to the market requirements for a certain competitive position. If it is a match, there is no immediate need to form new strategies. However, if gaps are identified then new strategies have to be investigated. An example is shown in Figure 53.



Figure 53 Gap analysis

The example shows that there is a major gap between actual and desired performance on delivery precision. This area should therefore be targeted in the enterprise's operations strategy.

The gap analysis includes a review of options within each decision areas, and a identification of options that will potentially enable a closing of the gap. At a minimum, this strategic analysis is carried out by a group of managers in a workshop environment. However, in some cases it can be necessary to base such analysis on facts rather than assumptions and overall performance indicators. The procedure outlined in chapter 8 for mapping and analysis of enterprise operations should then be carried out.

7.6 Part 4 The revised operations strategy

This is the design stage and requires managers to review their potential options within the strategic decisions areas and identify those that which will potentially enable a closing of the gaps identified in stage 4. A willingness to search for new ideas, to question assumptions and constrain and employ creativity will largely determine the quality of the new strategies formed. The operations strategy checklist, built earlier in the process, can help avoid past problems and may suggest themes to pursue. In cases where the problems are complex, and no clear solutions can be found at the first glance, an mapping and analysis (as depicted in chapter 8) should be carried out to create a sufficient decisions basis.

Strategy formulation is an iterative affair. Operation's strategic options are tested against their ability to achieve the performance objectives and their consistency with the enterprise and environmental constrains. It should also be noted that operations strategy must be developed in concert with business strategy and other functional strategies. Some strategic operations options may offer new capabilities that the company should consider at the business level. New operational strengths may even change the total business strategy for the company. Alternatively, strategies to achieve the performance objectives may not be found within the resource and environmental constraints, and this should also be fed back to the business strategy level.

Formulating an operations strategy is to translate relevant performance objectives for which the operations function is solely or jointly responsible for into relevant actions. Table 24 gives an overview of some courses of actions than might be required (based on Hill, 2005):

Relevant performance objectives	Typical areas for review and improvement
Cost	Reduce costs in all areas particularly regarding materials and overheads, which typically make up a major share of total costs.
Quality conformance	Provide services or make products to specification. Build quality into process and delivery system rather than checking conformance after the event. Also, improvements have impact on costs.
Delivery precision	Assess on-time delivery performance by service/product and customer. Review current approaches to meeting orders – involves discussions on the extent to which services and products can be or are made to order and the role of activities and investments such as scheduling and inventory in meeting these requirements
Delivery time	Review the elements of the operation process with the purpose of reducing the lead time in the various steps comprising the service delivery system or manufacturing process
Range flexibility	Review the process capability and skill base in relation to current and future service/product range requirements. Identify and supplement capabilities in line with proposed needs
Volume flexibility	Assess current capacity provision in terms of the ability to rapidly increase in line with known or anticipate changes in demand. Approaches include short term capacity and inventory holding alternatives.
Innovativeness - time to market	Identify the elements of the lead time of the development process. Assess the work involved in order to reduce task content, and do tasks in parallel

 Table 24 Translating relevant performance objectives into actions

The operations strategy formulation should result in a populated operations checklist. Any operations strategy should be able to tell how each choice will affect costs, delivery time etc. The operations checklist should be used to assess the issues that are required in an operations strategy, and should be used to explore some of the basic aspects of operations strategy formulation:

- Exploring what it means for an operations strategy to be comprehensive.
- Ensuring there is internal coherence between the different decisions areas.
- Ensuring that decisions taken as part of the operation strategy process corresponds to the appropriate priority for each performance objective.
- Highlighting which resource/requirements intersections are most critical with respect to the broader financial and competitive priorities of the enterprise.

In other words, the checklist helps operations strategies to be comprehensive, and to highlight which actions that is more critical than others.

Example: the HAST strategy matrix

Hydro Automotive Structures (HAST) delivers aluminium extrusion-based applications within crash management, body structures and sub frames to the automotive industry. In 1999, HAST won several large contracts (with Renault, GM, Daimler-Chrysler, etc.), which increased the sales volume from 3 million to 6 million bumpers per year. An investment in new production lines was therefore required to increase the production capacity. The following strategic events have happened since then:

Year	Strategic event					
2001	Consignment stocks (final goods) were established in England, Germany, and					
	Spain to reduce delivery time.					
2001	A Health, Security and Environment improvement programme was introduced.					
2002	A bumper factory was built in Louviers, France, and a crash-box factory was built in Skultuna, Sweden to increase capacity.					
2002	A new production line (M-24) and a new automatic CNC factory for product					
	completion (drilling, cutting, welding, and assembly) were built at Raufoss,					
	Norway to produce bumpers for GM and DC.					
2002	The Hydro Automotive Production System (HAPS) programme was initiated to					
	improve performance in all dimensions. The programme has included the					
	following events:					
	2002: Team organisation, 5S, and involvement of people to improve safety and					
	work place organisation.					
	2002: Total productive maintenance programme for reliable and stable equipment					
	2003: Quality programme and training in problem solving tools					
	2003: Flow orientation of layout (rearrangement and investment in equipment) in extrusion plant, profile plant and CNC plant.					
	2003: Pull manufacturing control (Kanban) in CNC factory					
	2004: SMED programme to reduce change-over-time, batch sizes and lead					
	time.					
	2004: Cyclic production (to reduce lead-time and large weekly fluctuations) in the					
	extrusion plant.					
2004	EDI collaboration with major customers was established to improve delivery					
	precision.					
2004	Implementation of SAP on all factories to reduce costs.					

Table 25 Operations strategy events at HAST for 2001 - 2004

In 2004 and 2005 the sales volume for HAST is reduced. Several of the major customers (GM and others) have a sales decline, and in 2005, the contract for the BMW 3-series is completed. Furthermore, HAST did not win enough contracts in 2001-2003 to uphold the sales volume for 2004-2005. In order to adjust to a reduced

sales volume, HAST has reduced the workforce with 150 man-labour year, and plans to reduce costs even further through a reduction of lead-times and inventory levels, and a improvement of production stability, reliability and quality.

Through their operations strategy, HAST has managed to improve their performance (production costs, customer rejects, delivery precision, work-in-progress), and has recently won new contracts that will increase the sales volumes from 2006. The operations strategy can be structured in the following manner:

Decision areas		as	Tasks/events	Perf. Objective		es						
	v					Establishement of consignement	v					
	^					stocks	×					
Х						Bumper factory in France	Х					
х						Crashbox factory in Sweden	х					
х						New production line and CNC factory						
				Х		Team organisation					Х	
				Х		5S Programme		Х				
			Х			TPM programme			х	Х		
			Х			Quality programme		х				
	х					Flow orientation of layout			х	х		
					х	Pull (Kanban) control in CNC factory				Х		
			Х			SMED programme					Х	
					х	Cyclic production in extrusion plant			х			
		Х				EDI collaboration with customers	Х			Х		
		Х				Implementation of SAP	Х			Х		
Resources	Materials	Information	Processes	Organsation	Control		Costs	Quality	Del. time	Del. precision	Flexibility	Innovation

 Table 26 The strategy checklist for HAST

The major strategic events for HAST are structured in the operations checklist in Table 26. The checklist illustrates that HAST has carried out a rather broad improvement program that aims to improve performance in many competitive dimensions simultaneously. However, even though many of the activities are targeting delivery time, delivery precision, and flexibility, the improvements that are achieved also has large effect on waste (overproduction, unnecessary transport, unnecessary inventory, defects, etc.), and hence costs, which is the critical performance objective in the automotive industry.

Strategy development is an ongoing activity which needs to be institutionalised within an enterprise. The process described here allows operations strategy to evolve over time as it responds to new market opportunities and new manufacturing process options. Much strategy emerges imperceptibly and may only be recognised in
retrospect. However, operations managers need to be attuned to a strategic view of operations, and operations contribution to competitiveness. The adoption and repeated revisiting of this process can provide useful assistance in this task.

7.7 A detailed overview of the enterprise reengineering process

The reengineering methodology provided by this thesis supports the formulation and realisation of an operations strategy. First of all, by enabling managers to develop an operations model that represents the enterprise from six different perspectives that coincides with the overall decisions areas in the operations strategy. This provides the decision-makers with firsthand decisions support for identifying options and making choices in each decisions area. In addition, the operations model reveals the segmented nature of the enterprise. The enterprise is represented as a set of more or less focused operations areas with distinct characteristics and distinct needs, and enables the manager to differentiate the strategy. Rather than treating the enterprise as one uniform unit and a set of general decisions areas, the manager is enabled to target each operations area and its individual needs.

The reengineering method supports the implementation of a range of strategic decisions. The main objective is to provide operational effectiveness by improving the enterprise infrastructure. This means that the method can be used a) to improve enterprise infrastructure in order to close the gap between actual and required performance, and b) to adopt the infrastructure to a structural change (such as the implementation of new technology, or the establishment of a new production line or a new production facility). Moreover, the author will argue that the operations model developed through such a process, even when no changes of the infrastructure seems to be needed, provides an overview of the enterprise that is useful input for further strategy formulation and realisation. The main elements of the method are shown in Figure 54.



Figure 54 Enterprise reengineering elements

An enterprise reengineering is initiated when some problem is identified in how operations meet market requirements. There is some lack of goal fulfilment, either in the form of decreasing market shares or by insufficient performance levels. The enterprise reengineering is a strategy-driven effort and should be based on a clear operations strategy that is aligned with business objectives. If no such strategy is in place, the existing operations strategy should be mapped and evaluated in a strategy checklist that highlights the effects on decision areas and performance objectives. The problems, and the possible options for improvement, are identified by mapping and analysing the gap between market requirements and operations capabilities.

In cases where it is necessary to base such analysis on a detailed understanding of the current situation, a mapping and analysis of enterprise operations are carried out. The mapping includes developing a dataset with data regarding resources, processes, material flows, information, organisation, and control. Based on this dataset, an operations model-set is developed that represents the AS-IS state of the enterprise. Furthermore, the insights and understanding gained from the mapping is structured

and analysed in an operations performance audit, which aims to evaluate broad areas of strengths and weaknesses.

The operations model and the audit should provide the decision-makers with sufficient input to identify improvement targets and revise the operations strategy. The revised operations strategy can result in a range of outcomes that should be reflected in an operations model of the TO-BE state in the enterprise. A design and implementation procedure is provided to guide the realisation of the strategic targets. If one of the targets is to implement flow manufacturing, a five-step programme is provided to guide such an effort.

The mapping, analysis, design and implementation of operations are described in the next two chapters, starting with the mapping and analysis.

7.8 Summary

An overall process model for the enterprise reengineering methodology is proposed in this chapter. The major steps of this strategy-driven and model-based methodology include strategic planning, and operations mapping, analysis, design and implementation. An enterprise reengineering should align operations capabilities with overall business objectives. A procedure for strategic planning are proposed that includes: 1) understanding and revising business objectives, 2) determining the current operation strategy, 3) gap analysis of market requirements and current capabilities (which may include a thorough mapping and analysis of enterprise operations), 4) revising the operations strategy and specifying some targets for operations. These targets imply changes that should be realised through the design and implementation of new solutions, and represented in a TO-BE operations model.

A tool, the strategy checklist, is provided to support the formulation and evaluation of the operations strategy. The checklist structures the operations strategy as a set of decisions that affect both the decisions areas and performance objectives. This helps decision-makers to specify the performance objective that are targeted and the decisions areas that are affected for each choice. Hopefully, this enables the decisionmakers to formulate a coherent operations strategy that that targets the right performance objectives and is aligned across decisions areas.

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The enterprise reengineering methodology - strategic planning

8. The enterprise reengineering methodology - mapping and analysis

This chapter will outline the mapping and analysis phases of the enterprise reengineering methodology. Mapping and analysis is the phases where the current reality in operations is revealed, and some improvement areas and problems are identified. The chapter has two themes, first to propose a procedure for enterprise mapping. This procedure includes developing a mapping dataset with data regarding resources, processes, material flows, information, organisation, and control. Based on this dataset, an operations model-set is developed that represents the AS-IS state of the enterprise. Second, to provide an operations audit scheme to support the analysis that should be carried out based on the insights and understanding gained from the mapping. Together, the operations model and the audit should provide the decision-makers with sufficient input to identify improvement targets and revise the current operations strategy.

8.1 Mapping

Mapping is an indispensable tool in documenting and understanding the enterprise prior to analysis and design. What is needed is a graphical representation in a format suitable for further investigation, debate and redesign. Examples of such representations are process maps, material flow charts, organisations charts etc. But enterprise mapping can only be achieved by fully understanding the behaviour of the operations processes in the enterprise, their inputs and outputs, operating constraints, control mechanisms etc. A data collection and initial data analysis is therefore required in order to develop a working and agreed map of the current state of the enterprise.

The data collection procedure proposed in this chapter aims to encompass all important areas regarding operations. However, it is not necessary to map every aspect of enterprise operations equally well. This will be to time consuming. In most cases, some overall problems are already identified in the current operation strategy. Even though all areas should be covered to some extent, the mapping should focus on these problems.

8.1.1 Selection of data sources

In order to avoid a very excessive data collection, one should use all available data in a considered and structured way. This includes 'weighing' the evidence obtained from the four major data categories that are grouped together in table 27.

Possible information sources		Usage score for HAST case				
		low		high		
People contact Methods	interviews			X		
	brainstorming					
	cross-functional groups		x			
Written Documents	accounts	X				
	procedures	X				
	minutes	X				
	publications			X		
	drawings					
Numerical Techniques	ERP data analysis	ERP data analysis				
	statistical analysis	X				
	time series analysis			X		
Investigative Methods	questionnaires	X				
	walking the process		x			
	activity sampling	X				

 Table 27 The relative importance of sources used in enterprise mapping (adapted from Towill, 1997)

The four categories are via people contact, documentation sources, numerical techniques, and investigative methods. The extent to which these data sources were utilised in the construction of an operations model for an aluminium bumper factory (HAST) is also shown table 27.

The table indicates that the data collection mainly was based on interviews, publications (reports, organisational charts, strategy documents etc.), and time series analysis (demand variations, inventory variations, production volume variations etc.)

It is an important skill on the part of the enterprise modeller to seek out and sift these sources to obtain a reliable map of the enterprise and which fully document the 'handovers' between the enterprise and its suppliers and customers. People contact methods are potentially the most rewarding of all sources but equally likely to provoke frustration. According to Towill (1996), it is not unreasonable to assume that at the start of an interview both sender and receiver bias may be as high as 50 per cent. This means that initially only about 25 per cent of the information is of reasonable high fidelity. In addition, each "player" has a "rich picture" of their own business, let alone a full understanding of the complete enterprise. So effective mapping must proceed in a recursive manner and include the proper combination of people-based, documentation based, numerical-methods-based, and investigation based methods.

In many cases, a lot of the available numerical data has poor quality and reliability, and the data is rarely in a form suitable for mapping and analysis purposes. In addition, industrial data are often difficult to interpret. Any need for "second

guessing" the meaning of data usually turns them into a liability. The extraction of useful information can therefore be cumbersome and expensive. This is especially the case for dynamic data such as demand patterns, stock-level variations and performance data. Structural data regarding products, equipment, and personnel are often more reliable, and easier to access from the ERP-system.

Although the investigative sources also are time consuming and expensive to pursue, they are often the only way to fully understand (and thereby reengineer) the enterprise. The processes involved are often complex and poorly documented. Consequently, it should be a normal practice not to accept the validity of a enterprise map unless there is supporting evidence either from activity sampling or alternative process flow analysis. Activity sampling involves a large number of instantaneous observations of one or more workers or equipment items in a representative period of time. The study enables an estimate of the proportion of total time spent in a activity. "Walking the processes" is often an easier approach, and can result in the most amazing insight into the real cause of poor performance.

8.1.2 The mapping dataset

Without a clear understanding and definition of the customer requirements, and the operations capabilities involved in the reengineering project, an enterprise can not be effectively constructed. To gain this understanding requires the capture of data from the enterprise IT-systems (basically the ERP-systems), interviews with key personnel, the gathering of documents, and so on. Both requirements and capabilities must be thoroughly understood and must be the basis for the design of the enterprise. A mapping dataset with information regarding resources, products, material flows, etc. should therefore be constructed. This dataset should contain the necessary facts for the enterprise mapping. If possible, dynamic data regarding volumes, demand variations and performance should also be collected from the ERP-system. A specification of the data needed is provided in Figure 55.



Figure 55 Initial data collection – creating a mapping dataset

Figure 55 specifies the major categories of data that should be collected, and illustrates how the data will be used to develop a operations model-set for the existing situation.

The initial data collection should limit itself to data that are easily available, and not dwell in too many details. The rule of thumb is to collect enough data to get an understanding of the situation, and not use too much effort in an excessive data analysis.

Resource data

From a resource perspective, an enterprise is a group of resources – human and technical – dedicated to the processing of a set of objects (products, components, documents etc.). The following should be mapped regarding resources:

- Equipment²⁵ (name, capabilities, capacity, set up times, reliability, utility levels)
- Personnel (name and position)
- Facilities (buildings, warehouses, etc.)
- Suppliers, transporters, and customers (name, products, localisation)

Material (and product) data

A material and product dataset should be created. This should identify the quantities of finished parts to be dispatched and demand variations. For all products within the project, the dataset should list:

- volume (historical data and projected demand in a one-year time frame)
- demand variation (time series graphs of demand can illustrate this)
- a part list or a bill of material

The part list allows the specification of every part which must be produced, and the volume level that are required to produce the products within the project. In order to provide a correct picture, the volumes that are delivered to external units should also be specified in the part list. In addition, the physical material flow should be mapped regarding:

- Distances
- Batch sizes
- Frequencies
- Inventory levels
- Volumes
- Throughput time

In some cases it is possible to extract detailed product routings from the ERP-system. Identification of process plans for each part in might be available in the ERP-system. This allows the detailed routings of each product to be identified. However, such

215

²⁵ If a group of items always operate together, they should be considered as a single item of plant.

routing data is often unreliable. The validity of a material flow diagram based on such input should therefore be supported by evidence either from sampling or alternative "walking the processes". More detailed routing information might be necessary to design the actual factory layout.

Information

The dataset should list the following regarding information systems:

- Name and functionality
- Functions in actual use
- Dataflow and integration to other systems

Process data

All major processes in manufacturing and office operations should be listed with major process steps, cycle times and lead-times:

- Order management
- Planning
- Procurement
- Production
- Stock holding
- Distribution

Organisation

The following information is required regarding the organisation:

- Organisation structure and existing operations areas
- Task allocation (direct tasks versus indirect tasks)
- Number of employees per skill level
- Number of shifts and number of effective hours per shift

New ways of work often demands operators that are skilled in multiple processes. The existing skill base is therefore important in the design phase.

Control data

The control dataset should contain the following information:

- Customer requirements
- Customer order decoupling point (MTS, ATO, MTO, DTO).
- Control methods (Kanban, MRP, periodic control systems etc.)
- Plans (horizon, time buckets, update frequency,)
- Performance measures (cost, quality, delivery time, delivery precision, flexibility, innovativeness).

Note that the mapping should provide a clear understanding and definition of customer requirements. Without such an understanding, an enterprise can not be effectively constructed. The requirements of the enterprise will vary by customer, by product, by locations etc. The mapping should provide a clear statement of due date expectations, service requirements, method of acquisition and delivery etc. for each customer.

Furthermore, the performance measures for the project must be defined and measured. In many cases, performance data can be extracted from the ERP-system. However, firms often do not record the information vital to their own improvement activities. In other cases, a system has to be put in place to measure the current performance. For example, if the ERP-system keeps track of order releases and completion dates, then lead time can be constructed. Another way is to use a paper trail, such as a tagging sheet that accompanies the job throughout the process. At each stage an employee records start and completion time (or arrival and departure time) at the workstation. After a reasonable time period, the average lead times can be determined.

8.1.3 Initial data analysis

If an enterprise makes many products, it may be difficult to get a good understanding of the situation. To simplify analysis, products should be grouped into larger families of similar items, and products that can serve as representatives for these families should be identified. This rule applies to parts and components as well. The products could be grouped according to customer, product type, locations etc. Ideally, these families should also be useful for segmenting production processes. However, in this early analysis stage, any established product families might be used to simplify the analysis, especially in terms of understanding demand volumes and load pictures.

Product-Volume analysis

Production volume is possible the single most important factor determining the design of manufacturing systems. If product families are established, the nature of the demand process for *each* product family can be examined by a product-volume analysis. A further refinement of this product-volume analysis is to include the volume variation of each product. The product-volume data can be presented in:

- descending order of volume, in a Product-Quantity chart,
- in cumulative volume form, in an ABC graph
- in ascending order of demand variation, in an XYZ graph.

Based on these charts, it is possible to concentrate on products that represents different requirement for manufacturing operations. For example, products with the highest volume usually create the largest load on operations and will therefore shape material flow. High volume products within a family should be further examined, while other products can be ignored in this "big-picture mapping".

Practical guidelines for ABC-XYZ analysis

The following input data is required in order to carry out an ABC-XYZ analysis for a product:

- A time series indicating how many items have been consumed per period
- The product's value.

The appropriate length of a time period depends on the problem investigated, but will normally be equal the time period used in production planning. If the enterprise has, for example, daily production planning, the demand variation per day is relevant.

Let $x_1, x_2, ..., x_n$ be the product's *consumption value for n periods* (i.e., for each period, the number of items consumed times the product's value).

1) The ABC-analysis is carried out by calculating

average consumption value:
$$\overline{x} = \frac{1}{n} \sum_{i=1}^{n} x_i$$
.

Products with high average consumption value will be called A-products, products with medium average consumption value B-products, and products with low average consumption value C-products.

2) The XYZ-analysis is carried out by calculating 26

variability in consumption:
$$\frac{\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_{i}-\overline{x})^{2}}}{\overline{x}}.$$

Products with low variability in consumption will be called X-products, products with medium variability in consumption Y-products, and products with high variability in consumption Z-products.

This analysis makes it possible to group the enterprise's product spectre into 9 families as indicated in the table below.

	Α	В	С
x	High volume	Medium volume	Low volume
	Stable demand	Stable demand	Stable demand
Y	High volume	Medium volume	Low volume
	Medium variation in	Medium variation in	Medium variation in
	demand	demand	demand
Z	High volume	Medium volume	Low volume
	Large variation in	Large variation in	Large variation in
	demand	demand	demand

Table 28 The ABC-XYZ matrix

218

²⁶ Note that other measures of variability are possible.

Based on this matrix, it should be possible to pick out representative products of each family for the further enterprise mapping.

8.1.4 The AS-IS operations model

The mapping aims to create high-level, graphical representations of the enterprise (the AS-IS operations model) that can support understanding, debate and redesign. The AS-IS operations model should be based on facts that are gained from the initial data collection and analysis, and provide the graphical representations shown in Figure 56.



Figure 56 The AS-IS operations model-set

The resulting model-set contains six types of maps, each representing a distinct dimension in order to provide a more or less complete picture of the enterprise. To simplify the work in material and process mapping, products or product families picked out in the initial data analysis should be used.

Resources

A map of the current layout of all equipment should be included. An overall layout shows the current allocation and utilisation of factory space (how much space that is devoted to different operations, inventories etc). A more detailed layout, that shows the location of all equipment and each process in the plant, is some times required for further analysis of the material flow.

Material flow

Moving material over great distances and with many stops contributes to manufacturing inefficiency. Material flow mapping emphasise move distances and showing flow pattern - to scale – with a facility layout as a background. To do a high level material flow mapping, take some representative samples of high volume products or parts and trace their movement through the manufacturing system. In some cases this might include to track materials between different buildings and to/from other plants. Some template symbols for material flow mapping are proposed in Figure 57.



Figure 57 Template symbols for material flow modelling

The high level mapping is sufficient to provide an overall picture of the material flow and highlight material handling inefficiencies. A more detailed mapping of the product routings is often necessary to design the actual factory layout.

Processes

From a process perspective, an enterprise is a group of activities that transforms raw materials into products and perform managerial transactions. Process mapping means to document the activities and how they are related in terms of process stages and flows. The goal is to understand how work is performed and how work flow problems originate.

The process mapping should result in process maps that illustrate the processing steps for each targeted product family in manufacturing and office operations. Unlike the material flow diagram, the process map does not show distances and locations of resources. The process map is schematic and shows the logical relations between activities. The term stage (or task) is used to indicate that multiple activities have been pulled together for analysis purposes. The activities involved in a enterprise entity can be represented as:

- a single stage operations process (all activities involved in the enterprise entity are viewed as a simple black box).
- a multiple stage operations process, where multiple groups of activities are linked through flows.

• a collection of concurrent multi-stage processes that perform activities in parallel. (Chase et al, 2004). In some cases, a multiple-stage process representation can include buffers to indicate that the output of a stage is stored prior to being used in a downstream stage. Several standard graphical formats exist, for example flow charts, input/output diagrams, and IDEFO diagrams, but any consistent presentation of the processes will do. In the process mapping effort it is often beneficial to make a distinction between manufacturing processes and office processes²⁷. This is because the object that is processed on the factory floor is material. In the office, on the other hand, the object is information. Some template symbols for process mapping in office and manufacturing operations are proposed in Figure 58.



Figure 58 Template symbols for manufacturing and office process mapping

The mapping of *manufacturing processes* includes all process steps from reception, part production, subassembly, final assembly and shipment. In many cases it is preferable to start with the final product. Take some high volume product families and map their process steps backwards through the manufacturing system. It is also preferable to start by mapping high-level processes. This ensures that the overall picture is provided in a reasonable amount of time. Details can be added later if needed. The mapping of office processes includes the whole order processing cycle from order entry, credit checking, quote writing, design engineering, production and inventory allocation, shipment, and invoicing. Use customer and market information to identify families of "information deliverables" or office processing "outcomes". Such a deliverable might be a quotation, a production plan, an invoice, or a folder containing production specifications for a physical item. A family of deliverables require similar processing steps through the office. For example, it might be preferable to group standard orders and special orders (that require detailed construction and specification) in two distinct families. Start with the customer and map the processing steps (on a high-level) backwards through the order-cycle for each targeted family.

Information flow

221

221

²⁷ This is routine office work, i.e. a process that recycles relatively frequently, and where the tasks required to produce a particular type of deliverable are relatively stable

From an information perspective, an enterprise is a group of function executions (transforming an input state into an output state) supported by information flows. Some of the functions and flows in this "information system" are automated, and a array of techniques can be used by systems analysts to model the IT-infrastructure. Common examples are IDEF0, Data Flow Diagrams, and Entity Relation Diagrams (Kubeck, 1995) However, such techniques are meant for detailed modelling and programming, and are not very suited to provide an overall picture of the total information system. A combination of a "rich picture" (Checkland and Scholes, 2004) and a Data Flow Diagram (a "rich Data Flow Diagram") should therefore be developed in order to model systems, functions, databases, users and dataflow.

- A rich picture is cartoon-like representation of the primary stakeholders, their interrelationships, their concerns, and some of the structure underlying the work processes (Checkland and Scholes, 2004). This type of graphical representation provides a broad, high-grained and human-oriented view of the information system
- A data flow diagram is a standardised diagram that models the flow of information within an information system or a business process. A data flow diagram is very stringent and uses only four symbols (data store, data flow, process (system), and external entity) to model a information system. This allows a decomposition of the diagram into an elementary level of detail that is required to generate programming logic (Kubeck, 1995).

A Data Flow Diagram provides many benefits, but it does not provide a complete picture of any information system. For reengineering purposes, the diagrams should be a tool for reasoning about work context of the computer system, rather than a tool for programming. The standard Data Flow Diagram should therefore be enriched with details regarding physical characteristics, system functionality, users etc. Some template symbols for information flow mapping are proposed in Figure 59.



Figure 59 Some template symbols for information flow modelling

The result of an information flow mapping is an informal representation that allows the user to understand the existing IT-infrastructure and how the technology affect work processes and information flows.

Organisation

The personnel should be mapped in an organisational chart, which shows the distribution of responsibilities and authorities in the work organisation.

Control

From a control view, the enterprise can be seen as a network of organizational entities (decisions and operations centres), each having some degree of autonomy and intelligence to solve problems in its area of competence, and communicating with other enterprise entities. A control model should therefore show a "decomposed" view of the enterprise that highlights local requirements. When defining the control system of any manufacturing system, Chen and Doumeingts (1996) propose a two dimensional decomposition.

- a functional decomposition, defining the various functions of such a system for each major part
- a hierarchical decomposition in accordance with decisions levels (e.g. operational, tactical and strategic)

The organisational entities at the lowest decision level in such decisions hierarchies are directly involved in the operations processees. Such entities are termed operations areas, and are the smallest organizational entities that are considered for planning and control purposes. A work centre composed of a group of similar machines can be one type of operations area, a paint line another type, an assembly cell a third type, and so on. Each area normally has a person responsible for it.

It is possible to model the complete enterprise (both manufacturing and office operations), as being composed of several smaller operations areas with workstations that perform "like" functions. Such a "control model" represents a holistic synthesis (with a special focus on control issues) of the other models that are developed in the mapping. An example of the overall control model for the M-24 production line at HAST is shown in Figure 60.



Figure 60 Control model for HAST

Control models are developed through the following steps:

- Decompose the enterprise into a set of production areas (e.g. receiving, parts production, sub-assembly, final assembly and shipping).
- Identify one or more operations areas in each production area. A operations area is a collection of work stations that perform operations on similar product or with similar processes. It can also constitute a stage in the operations process for a

product or product family, and might be a natural stock-holding point in that operations process.

- Identify the control methods that are used in each operations area for each operations process.
- Model the interaction between operations areas as material and information flows (the route of each product family should be indicated). If the complexity is to high, decompose the model into several sheets, one sheet for each operations process.

Some template symbols for developing control models are proposed in Figure 61.



Figure 61 Template symbols for developing control models

In facilities that are organised in a systematic manner, the existing operations areas should be possible to identify.

- In process-oriented layouts, work stations involved in one type of operation, e.g. a grinding department, might constitute a operations area.
- In a product (or product family) oriented layout, work stations that perform operations on one product or product family might constitute a operations area.
- If the detailed placement of work stations within a process-oriented layout (e.g. a grinding department) is product oriented, each product-oriented group might constitute a operations area.

However, if the layout is not organised systematically, it might not be possible to create a clear control model for the existing enterprise.

8.2 Analysis - operations performance audit

In this section, an audit scheme for analysis of operations performance is provided. This audit scheme encompasses 15 areas within operations that should be analysed and evaluated in order improve the competitive performance of the enterprise. Several other approaches for assessment exist (see Fagerhaug, 1999). However, the audit scheme provided here is based on three audit schemes that are more specific to manufacturing operations, and lean operations in particularly.

8.2.1 Purpose

The audit sheet embraces world-class philosophies and criteria within a predefined framework to assess operations excellence. The sheet defines the meaning of excellence in fifteen areas that have a major impact on operations performance (costs,

quality, time, precision, and so on), and allows companies to assess whether they use best practices in all crucial areas, or if further improvements are necessary. The purpose is to assist a team of managers and consultants to:

- Perform an audit of the state of a manufacturing enterprise.
- Judge the operations performance of a manufacturing enterprise.
- Prioritize the targets of opportunity for improvements

The rating should be based on the experiences and observations of the team members, and supported by performance measures and models developed in the mapping.

8.2.2 Point of departure – lean manufacturing

The audit sheet aims to be a generic and neutral tool to assess operations excellence for all types of manufacturing. However, the audit sheet is based on tools developed within the lean paradigm, tools that equalise operations excellence and lean performance. The major reason for this limited, and rather biased point of departure, is the significant role of lean concepts for improving and describing manufacturing operations.

The lean manufacturing approach developed at Toyota provides a set of concepts, methods, and techniques that are more detailed and interrelated than any other approach available, and has led to significant improvements during the last two decades. To quote Godson (2002) "A revolution in operations has occurred over the last fifteen years as a result of world competition and the implementation of best practices. This revolution is largely based on the Toyota Production System (TPS), and the concepts from this system have spread from Toyota to the rest of the world". Lean concepts (such as 5S, SMED, TPM, and so on) are therefore essential building blocks for enterprises that aims to develop best-in-class operations. (See Bicheno (2000) for a comprehensive overview of lean concepts and techniques).

Lean concepts were developed for repetitive manufacturing of automobiles. The lean vision of excellent operations therefore refers to the type of repetitive operations found in batch or line production. The lean vision of operation excellence can be described by the following quotation from Kobayashi (1990).

"In the level five factory the entire factory has become a single line with zero internal inventory. The plant uses quick changeover technology and runs a fully mixed production schedule, leading to ultimate adaptability".

This vision of the excellent enterprise, as a single line that can produce a mixed set of products, is clearly most suited for batch or line type of operations. Lean manufacturing requires standardised work and minimum variation, and is most suited for standard products with minor customizations, or customisation that involves choosing from a set of predefined options, and for markets with relatively stable demand. (See Suri, 2002 for a discussion about the suitability of lean concepts for high variety operations). All lean concepts is therefore not applicable for job shop type of operations (which typically compete on customisation and high level of craft work), or continuous processing type of operations (which typically compete on efficiency and resource utilisation).

The audit sheet aims to provide a generic definition of operations excellence. However, the lean roots of the audit sheet make the 15 areas most suitable to describe excellence for batch or line type of operations. For other types of operations, it might be necessary to add other areas of excellence, and it might not be possible to achieve the defined excellence objectives in all 15 areas. Furthermore, no enterprise can be excellent in every dimension, trade-offs has to be made. The audit sheet is therefore a useful tool to assess the gap between operations capability and operations strategy, and to prioritize the targets for improvements.

8.2.3 An overview of critical areas for operations excellence

The audit sheet is based on three audit schemes for lean manufacturing: by Godson (2002), Kobayashi (1990), and Schonberger (1996). Godson has developed the Rapid Plant Assessment (RPA) tool to assess the state of an operation based on a brief plant tour. The RPA tool focuses on powerful visual cues and key data generally available, and enables visitors and managers to assess the operations performance of the plant. The two other schemes are not only assessment tools, but are also guides for implementing lean manufacturing. Kobayashi's scheme is classic Japanese, concentrating on shop floor management. Schonberger's goes wider in bringing in customers, benchmarking and perhaps a more western view of employees.

The main structure of the audit sheet is based on the RPA tool. However, the original scheme has been altered both in scope and depth to encompass elements from Kobayashi (1990), and Schonberger (1996). The audit sheet and the related factors/principles in each of the three evaluation schemes are given in Table 29. For each scheme, the number of the principle is shown in brackets. The detailed rating systems are not given, and the reader is referred to the original schemes for details.

Table 29 The audit sheet and related areas in three other assessment schemes

	ALFNES	GODSON	KOBAYASHI	SCHONBERGER	
1	Customer Satisfaction	Customer Satisfaction (1)	Mgment of objectives (2) Effiency control (17)	Team up with customers (1) Use customer information (2), Align measures with customers wants (13) Promote every improv. (16)	
2	Leading technology	-	Leading technology (20) Zero Monitoring (7)	Seek simple, flexible, movable equipment (15)	
3	Safety, environment, cleanliness, & order	Safety, environment, cleanliness, & order (2)	Cleaning and organising (1)	-	
4	Visual Management Deployment	Visual Management Deployment (3)	-	-	
5	Manufacturing planning and control system	Scheduling system (4)	Production scheduling (16)	Operate close to customers' rate of use or demand (7)	
6	Order management	-	-	Cut internal transactions and reporting (12)	
7	Information system	-	Using micro processors (18)	-	
8	Layout, product flow, space, material movement	Product flow, space, material movement (5)	Coupled manufacturing (8)	(part) "organise by product family" (1)	
9	Inventory & WIP Levels	Inventory & WIP Levels (6)	Reducing inventory and WIP (4)	Cut flow time and changeover (6)	
10	Teamwork, skill level, & motivation	Teamwork, skill level, & motivation (7)	Small group activities (3) Work. empowerment (14) Kaizen (6) Cross func. work (15) Conserv energy/matr. (19)	Continual improvment (3), Frontliners invol. in strategy & change (4), Train everbody for new roles (8), Expand reward variety (9), Teams records (11),	
11	Equipment & tooling state & maintenance	Equipment & tooling state & maintenance (8)	Maintenance (9)	Improve present capacity before new equipment (14)	
12	Quick changeover	-	Quick changeover technology (5)	Cut flow time and changeover (6)	
13	Value chain integration	Supply chain integration (10)	Developing suppliers (12)	Cut to best components, operators, suppliers (5)	
14	Commonality of work and components	Mgmt. of complexity and variability (9)	Work floor time policies (10)	Cut to best components, operators, suppliers (5)	
15	Quality System Deployment	Quality System Deployment (11)	Quality assurance (11) Waste elimination (13)	Reduce variation and mishaps (10)	

Table 29 shows the major areas in the proposed audit sheet and the related factors/principles in Godson's, Kobayashi's, and Schonberger's schemes. The audit sheet differs from Godson's scheme in the following manner:

- Leading technology, order management, information systems, and quick changeover technology is new factors to assess.
- Godson's area no. 9 "Management of complexity and variability" is rather diffuse. This area of excellence is therefore simplified and limited to "Commonality of work and components", which is a key lean success factor according to Spear and Bowen (1999).

Table 29 also shows the related factors in Kobayashi and Schonberger's schemes. As a generalisation, Godson's scheme covers the major aspects of plant floor operations, but lacks the assessment of "borderline" factors (such as order management performance) that may have dramatic influence on manufacturing performance. The strongest aspects of Kobayashi's scheme are related to management at the workplace and waste or muda. The strongest aspects of Schonberger's scheme are the links with the customer, on worker involvement in continuous improvement, on design, and simplicity of process. These three schemes are combined and enhanced in the audit sheet, which enables a comprehensive assessment of a manufacturing enterprise.

8.2.4 A description of each area of excellence

This section provides a description of each area in the audit sheet, and the major elements to consider in conjunction with each of them. The list aims to be generic and cover all important areas of operations excellence for a manufacturing enterprise, but of course it still does not include everything. A first practical exercise is therefore to evaluate the list, ensuring people understand it all, and add to it other areas that are needed for a particular enterprise.

Customer satisfaction

From no measurement and understanding of customer satisfaction to fully displayed ratings and interactive, cross-functional involvement at all levels

In the best enterprises, customer information and understanding is mutually shared by marketing and operations. Workers in such enterprises clearly know who their customers are – both internal and external – and make customer satisfaction their primary goal. Customers are served individually and rapidly, and experiences that their need for personalisation, high quality, and efficient deliveries are satisfied.

Important factors to consider are:

- The display of ratings for customer satisfaction and product quality
- Employees knowledge of external and internal customer requirements
- Customer ratings, and also quality certifications and ratings
- Product range and product introduction rate

Leading technology

From low awareness to full awareness and utilisation of leading technology to provide a competitive advantage

In the best enterprises, the use of leading manufacturing technology provides a competitive leverage. Manufacturing technology is the set of skills, know-how, and devices that a particular enterprise has acquired during the development of manufacturing processes and enhancement activities. Technology does not improve simply by the introduction of new equipment. In the best enterprises, manufacturing technology enables the enterprise to do the right things exceptionally well (low costs, high quality, quick response etc.), and all investments and improvements are in line with the overall operations strategy.

Important factors to consider are:

- The key equipment characteristics of the different stage of the manufacturing process. Level of automation, use of robots, use of CNC-machines etc.
- The distinctive equipment-elements that might contribute (or diminish) the operations competitive effectiveness, and especially the use of monumental equipment that may restrict operational flexibility.
- The last capital investments and their effects on operations competitive effectiveness

Safety, environment, cleanliness and order

From untidy to 100% organised, 100% of the time

In a clean and orderly enterprise, parts are easy to find, inventory is easy to estimate, and products move safely and efficiently. Everything is labelled and everything is in place. The facility is safe, clean, orderly and well lit. The air quality is good and the noise levels are low.

Factors to consider are:

- Safety & environment records
- Labelling and order of inventory, tools, equipment, and flow
- The cleanliness of machinery, equipment, personnel, and facilities
- The use of instructions and standards at work stations

Visual management deployment

From informal, infrequent, and fragmented, to 100% updated and 100% visualised information about objectives, status and performance

The best enterprises are able to gain all operating information and control without having to go off the shop floor. Tools that provide visual cues and directions are readily apparent to guide workers to appropriate locations and tasks. Organisational boundaries are clearly labelled, and interaction between operations areas is supported by visual tools such as Kanban. The status of the total operations can be viewed from a central control room, a status board or a computer screen.

Important factors to consider are:

- The amount of information on display and how it is kept up to date (regarding business objectives, customer requirements, ratings, performance, safety, quality, productivity, preventive maintenance, skill levels, vacation schedules and so on)
- Labelling and coding of operations areas, product lines, inventory, equipment, tooling, and products
- The display of product flows, inventories, layouts, plans, productions rates, and other key information, and to what extent this information is visualised on a single display that shows the current state of the operation

Manufacturing planning and control system

From poor delivery performance often with high inventory, to excellent performance in delivery, quality, cost, and schedules being achieved 100% of the time

The best enterprises use a MPC system that integrates and simplifies planning and control at long, intermediate, and short term level. Most enterprises have some form of long term and intermediate term planning system. However, the best enterprises have adapted the MPC system to their particular resource and demand situation, and they also uses efficient execution systems to control final assembly, sub-assemblies, components and supply. In addition, the planning situation in the best enterprises is dramatically simplified by achievements in other areas, such as layout and flows.

Three major types of manufacturing execution systems are available. Pull systems (such as the use of tact time, level scheduling, and Kanban), push systems (such as traditional shop floor scheduling based on MRP orders), and push-pull systems such as POLCA (Suri, 2002). Regardless of the type, the best manufacturing execution systems are easy and effortless to use. Furthermore, they provide rapid and smooth

flows through predetermined or flexible routings, and enables enterprises to satisfy demand with sufficient utilisation rates.

Important factors to consider in the assessment of MPC systems are:

- Key characteristics of manufacturing processes and demand situation
- Overall sales and operations planning, overall resource planning, and master production schedule,
- Detailed material planning and capacity planning
- Supplier execution systems and delivery
- Manufacturing execution systems for final assembly, sub-assembly, and part production, and performance.
 - Degree of scheduling to customer order
 - o Scheduling buckets (each order, hourly, daily, weekly, or monthly),
 - o Computer scheduling versus kanban
 - The use of tracking systems
 - Flow time efficiencies
- MRP costs and backroom costs of scheduling

Order management

From functionally oriented, manual, and cumbersome, to customer-oriented, responsive, and automated order management

The order management cycle typically consist of 10 steps, some of which may overlap: order planning, order generation, cost estimating and pricing, order receipt and entry, order selection and prioritisation, scheduling, fulfilment, billings, returns and claims, and post sales service (Shapiro et. al., 1992). The best enterprises have reorganised and streamlined their order management, and are able to provide a single point of contact and immediate response to customers. Work (cost estimating, quoting, order processing, etc.) is carried out in a closed-loop²⁸, collocated, multifunctional, cross-trained team. The team is responsible for a family of products, and is integrated with shop floor operations. All types of work that does not require human judgement or intuition are automated by information technology.

Important factors to consider are:

- Unnecessary waiting time, transport, storage, duplication, inspections, and defects
- Forms, procedures, communication, technology, and flows that can be simplified
- Small jobs that can be combined, and the use of specialists
- Boundaries between administrative functions, and between administration and manufacturing
- The use of IT to automate data capturing, transfer, and analysis.

230

²⁸ Closed-loop means that all the required steps can be done within the team.

Information system

From low awareness of the potential of IT to 100% computer integrated and enabled manufacturing

The best enterprises use information systems that integrate equipment and subsystems, are user-friendly, and easy to adapt to new requirements. IT is used to automate all tasks that do not need human intervention, and to support all types of routine decisions-making in operations. In other, less successful enterprises, manufacturing based computer systems are very complex. Sub-systems are added over time, and, as a result, systems cannot communicate well with another. Furthermore, the software grows so complicated and interdependent that it often is just as difficult to change as the physical equipment.

Important factors to consider are:

- Level of IT automation in office and manufacturing operations
- Level of integration a single system, a integrated IT-infrastructure, or many independent sub-systems
- Adaptivity to changing requirements
- Decisions support and accessibility of day-to-day information needed by operators
- Level of data entering, and operators understanding of why the information is needed and who uses it once it is entered
- Commonality and user-friendliness of support software and applications across the operation.

Layout, product flow, space use & material movement means

From functional to 100% interconnected and flow-oriented layout

The best enterprises have interconnected and rapid flows through operations. Space is used efficiently. Materials and products are moved only once, over as short distance as possible, in efficient containers. Production materials are stored at each operations area, not in separate inventory storage areas. Tools and set-up equipment are kept near the machines. The enterprise is laid out in product-oriented operations areas or lines, rather than in "shops" dedicated to a particular type of machines. Operations areas are interconnected so that orders can proceed continuously without any backflows or stoppages. These interconnections are not necessarily physical, though there can be a physical aspect to them. The flow follows unidirectional and predetermined routes between operations areas, and is controlled by planning boards, replenishment boards, or inventory levels.

Important factors to consider are:

- Product focused operations areas or product lines, versus shop layout
- Transport modes (conveyers, forklifts, rolling carts) and travel distances between processes.
- Material movement responsibility process owned or separate material staff
- The use of planning or replenishment boards to link the flow between operations areas
- Container and batch sizes
- Single versus multiple docks to minimize material travel

Levels of inventory and work-in-progress

From no recognition of the waste of overproduction to mixed model production with low inventory and high customer service

Internal operations seldom require high inventories, so the observable number of any component part is a good measure of operations performance. The best enterprises have minimum work-in-process and can respond instantly to the many demands of the customers. If necessary, the enterprise can run fully mixed custom orders without slowing down, and freely adjust its mix in response to the needs of the customers. Such enterprises have no overproduction and only produce what the customers want.

Reducing inventory makes overproduction and all other types of waste (such as unnecessary transport, defects, motion) easier to discover. The best enterprises reduces inventory (and thus the lead time) through efficient manufacturing execution systems, reduction of batch sizes, flow-orientation of layout, simplification and integration of processes, quick changeover technology, cross training and teamwork, and standardisation of work. Moreover, by keeping equipment reliability high and prevent the need for buffer inventories.

Important factors to consider are:

- WIP levels at each process and WIP in transit in the enterprise
- separate stores versus buffers at each operations area
- number of inventory storage areas and finished product levels
- key numbers such as total inventory to sales ratio, and process cycle time to flow time ratios, theoretical versus actual flow times

Team work, skill levels and motivation

From strict hierarchy to a highly empowered, flexible and team based organisation

In the best enterprises, people consistently focus on the enterprise's goals for productivity and quality, and knows their jobs well. Workers are not only caretakers of equipment, but craftspeople involved in improving the overall process. The workorganisation is segmented in closed-loop, collocated, multifunctional, cross-trained teams responsible for a product-focused operations area, and empowered to make necessary decisions. The flexibility is further enhanced through education, training programmes, and job rotation that enables the enterprise to deploy its employ to any position at will.

Important factors to consider are:

- Key organisational characteristics.
 - A "clockwork style" hierarchical organisation where clear instructions are coming down from the top, with rational division of responsibilities.
 - A "team-style" organisation managed by objectives rather than instructions. Everyone is headed in the same direction. The organisation is clearly defined, and based on cooperation and teamwork.
- Team problem solving capability & history
- Task type allocation: types of indirect labour tasks performed by workers or by supervisors:
 - o material management activities (ordering parts, scheduling work etc.)
 - maintenance and housekeeping activities

- manufacturing support (designing tools, NC machine programming etc.)
- o quality assurance activities (inspections, analysing quality data etc.)
- o training activities
- improvement activities (identifying improvement opportunities, developing and implementing solutions etc.)
- Multi-functionality (average no of tasks per employee in each operations area) and the use of a formal job-rotation programme
- Cross-training and task overlap. Degree of overlap in direct tasks and in indirect tasks, and the use of a formal training programme.

Condition and maintenance of equipment and tools

From no maintenance, or expert maintenance, to full participative TPM

In the best enterprises, equipment is clean and well maintained, and the total equipment efficiency is greater than 90 percent. A thorough program for participative maintenance control is used to repair vital equipment before it breaks down.

Important factors to consider are:

- Use of preventive maintenance techniques
- Operator routine maintenance and machine performance data availability
- Pool-proofing and integrated go-no go quality checks
- Process control capability
- Tool and fixture orderliness, cleanliness, and storage location
- Equipment improvement policy

Quick changeover

From belief that the way to reduce total set up time is via increased batch size to full *SMED*

The best enterprises have developed their quick changeover technology to the point where it is economically viable to have very frequent changeovers. This enables the enterprise to produce small volumes of a large variety of goods while still maintaining the competitive advantages of single-product mass production. According to Kobayashi (1990), it is possible to shorten changeover time to less than 10 minutes in almost any enterprise. The Single Minute Exchange Of Die (SMED) methodology developed by Shingo (1985), or investments in flexible equipment can contribute to reduce set-up times. The best enterprises are capable of Single Minute (or less) Exchange of Die and one piece flow.

Important factors to consider are:

- Measurements and records of setup times and batch sizes
- The existence and current improvements of a SMED programme.
- The repeatability of set-ups. To what extent it is possible to return to the same setup without having to make adjustments.
- The availability of tools and equipment at the changeover machine
- The use of optimal sequences for changeover times, and the use of mixed model production schedules (ABABAB instead of AAABBB)

Value chain integration

From adversarial, guarded to full partnership with information sharing and value chain co-operation.

The best enterprises keep costs low and quality high by working closely with a relatively small numbers of dedicated and supportive partners. The best partnerships aim at zero receiving inspection, and delivery directly to the point of use. Packaging and part orientation are designed to reduce waste. Delivery is based on Kanban or Vendor Managed Inventory. Communication and information transfer is based on EDI or XML. Both sides work toward schedule stability, the customer to not change his mind at the last moment, the supplier to provide reliable delivery. Order management operations are streamlined and automated.

Important factors to consider are:

- Number of suppliers and sourcing policies, short-term or long-term
- Level of collaboration and shared IT-investments, and suppliers/customers costsaving ideas implemented
- Supply release system (from inventory levels or customer order), and schedule stability.
- Waste in terms of multiple quotes, order acknowledgment, remittance advices, invoices, counting, repackaging, checking, returns, expediting, double handling, and storage.
- Delivery performance in the chain

Commonality of routines, equipment and components

From complex, varied, and unspecified, to simple and 100% standardised operations.

In the best enterprises, every activity is simplified, specified, and standardised in order to reduce variability and complexity. Every operator follow a well defined sequence of steps for a particular job, and it is instantly clear when they deviate from specification. By commonality in designs, materials, sizes, capacities, machines, tooling, and operating procedures, the best enterprises are able to standardise the jobs so they can be performed efficiently by multiple operators, and to use the same types of parts in the manufacture of different products. The result is repetitiveness and economic of scales, less quality errors, and flexibility to handle variable demand.

Important factors to consider are:

- Use of common parts, processes, and procedures
- Commonality of tooling and fixturing, and of equipment and tools
- Commonality of support software and applications programs across the operation
- Ability to handle variable demand in volume and product mix
- Ability to smooth demand through manufacturing planning and control
- Number of suppliers

Quality system deployment

From supervisors being responsible for inspections to total quality management based on process control, prevention, operator responsibility and failsafing

The best enterprises are always striving to improve quality and productivity. Employees are proud of their quality programme, and the commitment to continuous improvement is highly visible. Procedures and measurements are developed for processes and products. Workers are organised in quality improvement teams, and use problems solving tools and techniques to improve operations. Most machines have some sort of failsafing system. Equipment has been improved and is reliable. Rawmaterial quality is assured through supplier partnerships. Statistical quality control methods are being used. The final inspection is done automatically, and the abnormality rate (including scrap, rework, and special adjustments) is less than 0.1 percent, despite a stringent final inspection.

Important factors to consider are:

- Quality certification and ratings
- Product and customer quality data
- Quality process and measurement at each process and for each product
- Scrap and rework levels
- Formalised problem solving process and new product start-up process
- Total quality programme, well developed and deployed
- The display of customer requirements, production schedules, work instructions, productivity levels, incoming and outgoing quality, scrap and rework levels, attendance, vacation schedules, safety, and levels of employee training.

8.2.5 The use of the audit sheet for assessment and analysis

The rating of an enterprise is an important input for operations strategy development, and should be carried out in a meeting where managers and consultants are sharing their observations and impressions. The result of this meeting is a short report, assessing the operations performance and suggesting improvement areas.

The team should use the audit sheet to rate operations performance. Rate each of the 15 areas on a scale from "poor" (1) to "excellent" (5) to "best in class" (6). Best in class is meant literately. Only one enterprise in each industry, worldwide, deserves this rating. The enterprises total score on the audit sheet, and the current performance ratings gives an fairly accurate assessment of the enterprise capability. This kind of assessment is particular useful because the 15 areas highlight broad areas of strengths and weaknesses. Areas with low ratings are instantly visible opportunities for improvements and should be the first steps on a company's journey to operations excellence.

	Ratings>		Poor	Below Average	Average	Above Average	Excellent	Best in Class	
No	Measure Score	Related dec. areas	1	2	3	4	5	6	Scores
1	Customer Satisfaction	Organsation Processes							
2	Leading technology	Resources							
3	Safety, environment, cleanliness, & order	Organsation Resources							
4	Visual Management Deployment	Information							
5	Manufacturing planning and control system	Control							
6	Order management	Processes Information							
7	Information system	Information							
8	Layout, product flow, space, material movement	Resources Materials							
9	Inventory & WIP Levels	Materials							
10	Teamwork, skill level, & motivation	Organisation							
11	Equipment & tooling state & maintenance	Resources Organisation							
12	Quick changeover	Resources Organisation							
13	Value chain integration	Materials Organisation							
14	Commonality of work and components	Processes Materials							
15	Quality System Deployment	Organsation Resources							
	Totals								

Figure 62 The audit sheet

The audit sheet in Figure 62 supports management in the assessment of operations performance. The total score of all areas will fall between 15 (poor in all areas) and 90 (the best in the world in all areas), with an average score of 45. The rating should be based on the factors and definitions of excellence that were described in the section above. The audit sheet also guides the management to address operations strategy decisions areas (resources, materials, information, processes, organisation, and control) that relate specifically to each area of excellence.

For each area of excellence, the related decisions areas in operations strategy are listed. Operations strategy provides the premises for any improvement programme. The sheet should therefore be used to identify the particular profile of an enterprise, and to identify areas to improve in order to align capabilities with strategy. An important aspect to consider is the process characteristics of the enterprise. Enterprises with repetitive batch or line type of operations have a larger potential for high score in all areas. Job shop manufacturing is typically very flexible and involves a large element of craft work. This type of manufacturing is most suited for the production of one-of-a-kind-products that are customised to the customer. It could therefore be very difficult to achieve:

(7) Information system: 100% computer integrated and enabled manufacturing

(8) Layout and flow: 100% interconnected and flow-oriented layout

(9) Inventory: mixed model production with low inventory and high customer service

(14) Commonality: 100% standardised operations.

Continuous processing is typically highly automated and efficient, but not very flexible, and is best suited for standard commodity products in high volumes. It could therefore be very difficult to achieve:

(1) Customer satisfaction: fully displayed ratings and interactive, cross-functional involvement at all levels.

(9) Inventory: mixed model production with low inventory and high customer service (12) Quick changeover: full SMED

It is also important to notice that some areas generally have a higher potential for improvement. The author's experience from several projects is that the potential for improvement is especially high in (5) manufacturing planning and control, (8) layout and flow, and (9) inventory. These observations are also supported by Goodson's (2002) dataset, which shows that these three areas consistently receive the lowest ratings. Moreover, management often focus too much on shop floor activities, and underestimate the impact of poor office processes. Many manufacturing enterprises therefore can achieve large improvements by addressing their order management process.

8.2.6 Choice of improvement area

The audit sheet defines 15 characteristics that companies require to achieve operational excellence. Many companies have made considerable efforts in certain areas, however, no company is yet to be excellent in all areas. Trade-offs has to be made. The analysis carried out through the audit is an input to the overall operations strategy development, and should result in a path of improvement for a particular enterprise. Improvement programmes should be formulated that improves capabilities in one or several of the 15 areas of excellence (5S, TPM, TQM, SMED, CIM, Visual management, and so on).

The current status and planned future can be illustrated in a spider diagram. An example is provided in Figure 63, where the enterprise mainly wants to target manufacturing planning and control, IT, order management, and inventory in the nearest future. Some initiatives should also be carried out to improve the commonality of products, and to improve the integration with customers and suppliers. Together, these initiatives will hopefully improve customer satisfaction.



Figure 63 Current reality and planned future for an enterprise

Improvement programmes in any of the 15 directions should be supported by a TO-BE operations model that shows how the intertwined efforts from all programmes will affect the future design. The TO-BE model-set should visualise the future enterprise from a resource, material, information, process, organisation, and control perspective, and be supported by a textual/numerical description of the future operations and their performance objectives.

Together the operations model and the operations audit should provide the decisionmakers with sufficient knowledge and understanding to identify the most crucial improvement areas and problems, and to formulate the targets for one or several improvement initiatives in a revised operations strategy. If the strategy is to perform improvements in (5) manufacturing planning and control, (6) order management, (8) layout and flow, and (9) inventory, a reengineering method is provided to guide the improvement effort. A major assumption of this thesis is that the potential for improvement is especially high in these areas, and that many enterprises should start their improvement work by some radical changes in these areas. A flow manufacturing programme that targets improvements in these areas is therefore provided in chapter 9.

8.2.7 Summary

An approach for mapping and analysing enterprise operations is proposed in this chapter. The purpose of this exercise is to provide sufficient knowledge to identify problems in the existing operations that could be targeted by a revised operations strategy.

The mapping procedure consists of two parts 1) to collect information in order to populate a mapping dataset, and 2) to develop an AS-IS operations model. The dataset should encompass resources, processes, material, information, organisation, and control, and can therefore be very time consuming. However, the mapping and

analysis is not an end in it self, and the collection of data should limit itself to data that are easily available. Furthermore, some initial product-volume analysis should be carried out to identify product groups that can be targeted in the mapping. Based on the mapping dataset and the knowledge gained in this effort, a operations model-set is constructed that represents the enterprise graphically from a resource-, process-, material-, information-, organisation-, and control perspective. An overall control model is developed that represents the major processes, material flows, and information flows, and control methods. This model represents a synthesis (with a special focus on control issues) of the other models, and provides a holistic and decomposed picture of the enterprise.

The operations model and dataset should be analysed in order to identify improvement areas and formulate problems that should be targeted by a revised operations strategy. One tool is provided to support this effort, the operations performance audit sheet, which should be used to identify 15 broad areas of strengths and weaknesses regarding infrastructural aspects of an operations strategy. The areas are: 1) customer satisfaction, 2) leading technology, 3) safety, environment, cleanliness, and order, 4) visual management deployment, 5) manufacturing, planning and control, 6) order management, 7) information systems, 8) layout, product flow, space, material movement, 9) inventory and WIP levels, 10) teamwork, skill levels, and motivation, 11) equipment and tooling state and maintenance, 12) quick change over, 13) value chain integration, 14) commonality of work and components, and 15) quality system deployment. Each of these areas should be rated against an ideal state. This enables the decision-maker to identify gaps between the existing state and the state that would support the overall business strategy.

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9. The enterprise reengineering methodology - design and implementation

This chapter will outline the design and implementation phases of the enterprise reengineering method. Design and implementation is the phases where changes identified in the TO-BE operations strategy should be realised in terms of the day-today operations of the enterprise, in other words altering structures, methods, practices, and attitudes in order to produce the anticipated quantitative and qualitative results. The chapter has two themes. First, to outline a procedure for design and implementation of improvement initiatives. The procedure is based on the principle of participatory design, and supported by the operations model architecture for illustration of new solutions. Secondly, to propose a flow manufacturing programme that could be the "engine" in such an improvement initiative. The programme consists of a five step procedure and four principles for flow manufacturing, and should be regarded one optional programme in an enterprise reengineering project.

9.1 Design and implementation in general

The point of departure is that design, implementation, and use should be considered as interwoven phases. Real change does only occur when new solutions are accepted and learned by the stakeholders in an enterprise. The targets defined in the operations strategy formulation should continue to provide guidance throughout the design and implementation phase. The operations strategy will in turn be enhanced during design and implementation by new inputs from the design teams.

9.1.1 Underlying change management principles for design and implementation

According to Pendelbury, et. al., (1998), the prime cause for the high rate of failure in improvement programmes is the insufficient attention to human factors, for if such projects are to be successful, they require marked changes in behaviour. Design and implementation should therefore be processes that allow individuals to understand how they can play a practical part in the reengineering, and help ensure that change, once achieved is lasting.

The overall principle to achieve effective, lasting and rapid realisation is participatory design (see chapter 6). Participation is to be active and influential in the decision making in work and design of work-organization and technology. Widespread participation in the early stages of a reengineering project can create a range of ideas which enables the enterprise to take advantage of both the pool of skills at its disposal and the creative power represented by each individual employee. By obtaining their participation, potential resistance is reduced and the risk of failure is minimised, while the likelihood that the changes achieved will be lasting is increased.

The design and implementation process should therefore be based on the following underlying principles:

- *Clearly stated objectives and ground rules for participation.* The objective of a improvement initiative should be clearly stated and the roles of different groups of participants should be defined. These rules should concern the composition, authority, goals and areas of responsibilities.
- *Fluctuation and creative chaos.* Managers or project leaders can to some extent, evoke creative chaos by setting challenging goals.
- Arenas for negotiations and knowledge judgement. Such arenas should be arranged to ensure that the interests of all stakeholders are embedded in the new enterprise.
- *Autonomy*. Realising the operations strategy will require the active participation of all staff. It is inconceivable to attempt to control every employee's every action during the change process. Managers should instead focus on channelling the vast number of activities into the initiatives defined by the strategy.
- *Redundancy*. Sharing experience and sharing redundant information promotes the expression and sharing of tacit knowledge, because individuals can sense what others are trying to articulate, and thereby offer advice or provide new information from different perspectives.
- *Experiencing the future*. The explicit concepts of designers can be too abstract to grasp for practitioners. To facilitate knowledge creation, the understanding of the future situation could be enhanced by the development of enterprise models, through simulation games, or by real life experiments.
- *Iterative design.* An iterative design approach where uncompleted solutions are tested in practice ensures alignment to the existing infrastructure.

A very important tool to support some of these underlying principles is the operations model. This tool described below.

9.1.2 The TO-BE operations model

The operations model-set can be used to represent the current and future operations from six different perspectives (i.e. resource, material, information, process, organisation, and control) with a special focus on control issues. The AS-IS operations model should be used as an input to the detailed analysis carried out in each improvement initiatives. The design of the TO-BE operations model should capture planned changes in all the key improvement areas. Examples of such changes and their most related decisions areas are:

- Investments in new production technology may change resource layout and material flows.
- The deployment of a 5S programme, a quality system program, or a total maintenance program, may change organisational structure and processes.
- A successful quick changeover programme may affect manufacturing control
- Investment in new information technology or deployment of a visual management programme may affect information flows

The planned changes should be reflected visually in the TO-BE operations model, and specified by text and numbers. The TO-BE model is an excellent device to understand enterprise operations conceptually, and should be used in the early phases of all types of improvement efforts to communicate and improve planned changes.
It should be noted that the TO-BE operations model goes through several iterations. Assuming that the targeted enterprise is at an existing facility with existing products and processes, some of the problems will be the result of the product's design, the processing machinery already bought, and the remote location of some activities. These features of the future state probably can't be changed immediately. Unless the enterprise is involved in a new product or technology introduction, the first iteration of a TO-BE operations model should take product designs, process technologies, and enterprise location as given and seek improvement as quickly as possible without changing these features. Subsequent iterations can address product design, technology, and locations issues.

Furthermore, although the operations model provides a generic representation of the enterprise, it is particularly useful for representing manufacturing planning and control systems, and is developed to support the design and creation of flow manufacturing.

9.1.3 The initiation of improvement initiatives

On the basis of the conclusions of the operations strategy, a set of improvements initiatives are set out. The overall plan for these each improvement initiatives should include a description of the following elements (Upton and Macadam, 1997):

- Context why should the enterprise need to improve operations, and what are the primary changes in the competitive environment?
- Goals what are the objectives of the improvement effort (lower costs, faster response, and so on)?
- Focus what decisions areas (resources, materials, information, processes, organisation, and control), and what entity of the enterprise are currently the primary focus of the improvement effort?
- Methods and techniques what methods are being used to build improvement, for example, SMED or flow manufacturing?
- Resources which type of people (internal, consultants etc.) and how many is involved in improvement process
- Organisation and timing how many improvement initiatives are there, how are the design teams organised? (cross-functional teams, teams that span different departments and organisational levels) Furthermore, what will the sequence of projects be, and over what time frame will they take place?
- Learning how is new knowledge captured and used in future projects?, and how does each team involve others that may have similar relevant experiences?

In addition, each initiative should be established and planned. For each initiative a change organisation must be established. This entails to specify the project leader, the design teams, the role of each group, how they should function, and the relationships between them and senior management. A project management system should also be established that keeps the process on right track, predicting dysfunctions and discrepancies, and uses resources effectively (for further details, se for example Baca, 2005).

The teams should be prepared to work productively toward an agreed-upon set of project goals. Each design team should draw or fill in a detailed plan for its own improvement initiative. The following elements should be included in the plan:

- The aim of the initiative
- The expected financial and qualitative results
- The performance measures which will be used to monitor results and check if they are in line with the overall goals
- The conditions for success and the obstacles to implementation
- The roles and responsibilities of each team member
- A detailed work schedule (the activities)

Each initiative is endorsed by senior management. This formalising process helps to ensure that the design team's work is consistent with the overall objectives of the reengineering project. During the launch phase, the design team receive training in two areas: the reengineering process itself (the operations strategy, the AS-IS operations model, the methods and techniques involved in an improvement programme) and the techniques and methods which will be used to bring about change (group work, brainstorming, conceptual enterprise modelling, problem-solving techniques etc.)

At this point, the resources required for a smooth design and implementation process have been allocated, and the change organisation has been set up (project leader, design teams etc.). The nest step is to carry out the design and the implementation. A procedure for such a change (based on Pendelbury, et.al. 1998) is described below.

9.1.4 Detailed analysis and design

1. Making a detailed analysis of the existing situation in relation to a improvement initiative and identifying all the opportunities it presents

The targeted area for reengineering should be understood in detail. The task is to draw up a precise description of the AS-IS status in relation to the objectives for each improvement initiative. Group work techniques should be used to facilitate this work. The AS-IS operations model should be used as a basis to describe and illustrate operations. If necessary, more detailed illustrations and descriptions should be made collaboratively. The analysis may include the following:

- A more detailed description of some aspects of the AS-IS operations model (a detailed description of the tasks involved in a process, for example)
- A specification of the roles and responsibilities of those involved and the attitude to change of each group of employees, revealing potential obstacles.
- A systematic listing of strengths and weaknesses
- A estimate of the cost and added value for the initiative

This analysis is applied to each improvement initiative. It can, and does, however, take up an excessive amount of time if not properly handled, so it must be borne in mind that the analysis is not an end in itself, but a means which contribute to developing the target and above all to implement change. Involving participants as early as possible in the design and implementation process helps to ensure that

everyone accept and supports the initiative, and users will generally find it motivating to be asked to describe their current situation.

The result of this analysis is that the AS-IS situation is described and modelled in more detail for a particular area. The major weaknesses and opportunities for improvement has been identified, detailed and quantified by those involved. A chart of attitude towards change has been drawn up (supporters, sceptics, waverers, opponents). Each opportunity is rated regarding potential benefit and ease of implementation.

Problems that can be resolved quickly and without the need for any investments (symbolic actions and short-term improvements) should be targeted at this point. Putting immediate improvements into effect as soon as the analysis is completed demonstrates management's commitment. It also helps strengthen the support of the employees, who can see their suggestions being put in place with immediate effect.

2. Devising a detailed plan for each improvement initiative and specifying what must be achieved in each case for the operations strategy to be realised.

For each improvement initiative, a detailed definition must be drawn up of the target, the expected results, performance measures and the implementation plan. All of this must be consistent with the operations strategy. The following sequence shows how a improvement target can be generated:

- Researching best practice relating to the initiative, either internally, among competitors or in other industry sectors.
- Analyse and enhancing the ideas and recommendations produced when the existing situation was described.
- Brainstorming sessions to find an ideal solution.
- Analysing the strengths and weaknesses of each option in terms of their contribution to the operations strategy, their expected results, and the feasibility to implement them.
- Choosing a solution, enhancing and validating it with the help of interested parties throughout the enterprise. This is crucial to lower resistance and increase the support of the majority of the employees.
- Finalising the adopted solution on the basis of the additional ideas and recommendations which have been contributed.

At this point, each improvement initiative has been chosen and specified in detail, its objectives, its contribution to the operations strategy, its expected results, the investment required and the return of investment. Precise descriptions of the new working practices, the new skills to be developed, and the principal milestones in the implementation plan are developed.

A formal process of integrating and harmonising the solutions for all initiatives should be carried out by validating meetings with the senior management. Furthermore, a TO-BE operations model should be developed that provides a holistic picture of future state operations from a resource-, process,-material-, information-, organisation-, and control-view.

9.1.5 Testing and implementation

In some cases, the next step is to implement the new solutions. However, it is useful to carry out testing if the solutions are to be deployed in several parts of the enterprise, or if the changes to be implemented are complex or risky.

3. Carrying out pilot testing

Testing can be carried out to confirm and demonstrate the feasibility of a solution, to test an implementation approach which can be applied generally, or to strengthen the commitment to change by the means of early success.

The chance of success can be enhanced by the following activities:

- Define the aims of the testing carefully (results, performance indicators, scope, tools and other resources to be used, roles and responsibilities for those involved)
- Define a fixed minimum requirement at the beginning of the testing. Over and above this basic solution, participants have the autonomy to identify and implement solutions which are specific to their environment.
- Involve representatives from the area of the enterprise where the solution will be deployed, to encourage their support.
- Communicate frequently with staff, explaining not only the results but also the obstacles encountered and how they were solved.

Testing should proceed as follows:

- Define users' new roles, responsibilities and tasks with precision, and make sure to understand and respond to their questions or concerns. Identify and tackle obstacles, and anticipate and deal with resistance.
- Train users for their new roles, responsibilities, and tasks
- Implement the physical core of the solution.
- Allow users to exercise their new roles, responsibilities, and tasks.
 - Work with users to asses their performance and analyse the causes for good or bad performance.
 - Modify the system of rewards and sanctions if necessary
- Allow the users to apply the results of assessment to change their own way of working.
- Repeat the exercise and assessment process and identify corrective actions as required.

4. Using the results of testing to apply the process of change more generally

This stage should aim to create acceptance for the minimum requirements of each improvement initiative, and to enhance the basic solution by including features that are particular to each application site. General application should also be supported by change management methods (such as communication, training, and coaching) whose effectiveness has been demonstrated in earlier stages.

Proceeding to general application is probably the trickiest stage of implementation. Many improvement programmes fails at this stage, even when fully successful during pilot testing. Major causes of failure are: 1) that general implementation is reduced to simply sending out an instruction, which is very often not sufficient to overcome mental blockages and resistance and to convince the undecided, 2) that general implementation is seen as simply a repeat of the preceding stages of detailed analysis,

design and testing, which often result in a over-burdensome or over-length change process.

Depending on the complexity of the anticipated changes, their depth and their level of acceptance, the process of creating acceptance and implementation require a greater or lesser degree of effort. The straight forward communication of information, backed up by the testimony of those involved in pilot testing, may be enough. In other cases, workshops will be needed to analyse the AS-IS status in order to convince the staff of the need for change and persuade them to identify with the basic solution. In this case, implementation may go through the same stages as testing.

5. Setting up systems to ensure that the change is lasting

The changes should be institutionalised by management systems designed to ensure that employees don't revert to their original ways of working or behaving, so as to guarantee lasting results. Such systems include performance measurements systems and rewards systems, and human resource management and career tracking. Such systems should be structured appropriately to support the operations strategy and the working methods.

9.1.6 Measuring results and close out the project

A project is not finished until all activities are completed, the design and implementation process is reviewed, and lessons learned are determined. As a part of the close-out, the design teams should evaluate both the success of the implemented solutions and the effectiveness of the process that was used to plan and guide it. To measure success, it is necessary to check that the quantitative and qualitative results are consistent with the overall performance objectives, and to monitor the performance by means of operations and financial metrics.

The following sequence can be carried out for measuring results:

- List the expected results for each improvement initiative
- If possible, back up these results with historical data, simulations or estimates.
- Chose metrics for monitoring the expected results
- Monitor the changes in these performance indicators during the implementation process
- Ensure that changes in the indicators and their positive impact are widely publicised
- Continuously assess the results with managers and staff

In addition to the performance measures that were achieved, the perspectives of key stakeholder groups should be considered. How satisfied are they with the results? How satisfied are they with the way the project unfolded? Was they adequately informed? What problems could have been avoided by better planning? What could have been done different to ease the implementation? Questions like these can provide useful information for future initiatives.

A final and very important close-out activity is to acknowledge the work that team members have done. Celebrating their achievements and recognising their work reinforces the new work organisation.

9.2 Flow manufacturing

Flow manufacturing is mainly based on group technology (GT) and socio-technical systems theory, and aims to develop product-oriented and interconnected operations areas in all stages of the enterprise. The objective of flow manufacturing is to change the organisation of tasks, procedures, equipment, and processes from a functional basis to a product-oriented basis. Operations areas are formed which complete all the set (or family) of products or components which they make, through one or a few processing stages, such as metal founding, machining, and assembly, and are equipped with all the machines and other processing equipment they need to do so.

Flow manufacturing aims to create product focused operations areas wherever possible in manufacturing and administration. Such operations areas (i.e. the production line or product family type) are characterised by (Suri, 1998):

- The aim is to complete all operations one or more families of similar raw materials, parts, components, products within the operations area.
- Machines are dissimilar. This is in contrast to the traditional functional organisation where each operations area has similar machines.
- All resources dedicated to a product are located close to each other, again in contrast to a functionally organised enterprise where jobs need to go long distances from one operations area to the next.
- In contrast to the traditional efficiency principle of division of labour, the operations area is staffed with on or more multiskilled workers performing various operations.
- Instead of having a hierarchy of managers and tasks workers, the ownership of the operations area is given to a team of workers
- The operations area is dedicated to one or a set of products, which means that its resources are not diverted to making anything outside that family.

Below, a five steps approach to create flow manufacturing is outlined:

Table 30 How to reengineer for flow

How to create flow manufacturing

Step 1: Organise the manufacturing process into operations areas that are dedicated to a part or product family and cover one or several processing stages.

2. Dimension each operations area in terms of equipment and people. Dedicate, in one area, all resources needed to complete all operations on this family. If necessary, rethink processes, equipment choices, end product design, to enable the family to be self contained and resources to be dedicated.

- 3. Develop enterprise layout and flows
- 4. Create operations area teams
- 5. Modify MPC system and information flows

Each of these steps is described thoroughly below:

9.2.1 Step 1 Create product focused operations areas

Flow manufacturing is initiated by finding the best division between operations areas at every processing stage and to simplify the flow between them. For flow manufacturing, "the law is that any organisational unit at any of these levels must complete all parts it makes through its particular processing stage" (Burbidge, 1989).

The lowest level of product focus is achieved when the flow is streamlined between self-contained but still process focused operations areas. However, a more effective flow can be achieved by organising the enterprise into product focused operations areas that perform all operations on a product family for one or several processing stages. Therefore, within each of the production stages, it is necessary to search for, and evaluate opportunities for operations areas. In the assembly areas, the solution could be lines, assembly cells, or single-operator work stations. Likewise, in the part product on area it is possible to retain a functional organisation or switch to several product focused operations areas.

Identification of product families

The basic principle behind the creation of operations areas is to first create a family of parts or products, and then determine the best manufacturing process for this family. (Note that this task could be considerably simplified if the basis, i.e. the population of parts and equipment, are reduced in beforehand). There are two fundamental ways to form initial families (Burbidge, 1975).

- One way is to rely on product type and product characteristics (such as name, design features, size and raw materials).
- The other way is to use the routing information that specifies the process sequence required for manufacturing.

In addition, one should use other data shown in Table 10, such as competitive basis, type of customer contact, volume, and demand variations. For example, operations areas designed to handle a Make-To-Stock environment will typically be created differently than operations areas in an Assembly-To-Order environment. These two types of operations area will require different levels of flexibility and buffer space, and different planning and control systems. It is therefore crucial to take advantage of several types of data when forming operations areas.

The matrix method for forming operations areas

If the product mix is complicated, the process analysis could be supported by a simplified version of Burbidge's (1975) group analysis. A matrix should be created with production processes on one axis and product on the other axis (see Figure 64).



Figure 64 The matrix approach to form operations areas

Figure 64 shows an example of how the matrix approach can be used to group products and processes in two operations areas. Two potential operations areas and one external operation (5,D) are identified. Operations that fall into the "external operations" category are typically performed on machines that processes many parts, such as heat treat, paint, clean, wash, deburr, and degrease. External operations should be eliminated in order to create effective flow. Burbidge (1975) suggests five ways to simplify the flow:

- 1. Re-routing operations from machines outside a operations area to other machines already in the operations area which are similar in type. (Also check whether the external operations are necessary or it they can be eliminated).
- 2. Reallocation of some machines between operations areas. (Or combine two operations areas so the parts with external operations do not need to leave the enlarged operations area).
- 3. Change of tooling method. (Dublicate the machine capabilities needed for the external operation so that parts do not have to leave the operations area).
- 4. Change of part design. (Redesign so the external operations are eliminated or moved inside the operations area).
- 5. Purchasing instead of making. (If the disadvantages of having parts processed in more than one operations areas is too great, the part should be sourced from a functional area of the enterprise or from the outside).

The matrix approach illustrated in Figure 64 (to find product families and process groups simultaneously) gives a very good illustration of the grouping problem. However, for real industrial problems, this approach can be become very complicated and laboriously. A more effective method for industrial problems is outlined below.

A sequential method for forming operations areas

This grouping method is also based on routings, and aims to identify product similarities and process similarities in a sequential order. The following steps to form operations areas should be performed by the use of a spreadsheet:

	A method for forming operations areas					
Step 1	 Obtain a table of sales volume (in NOK, stk, m3 etc.) for the pre- established product families. Broad product families should be used in order to reduce complexity. 					
	• List the main processes needed for each family, and assign them a code (like A0, A1,, B0, B1,). Each product routing is written as a string of letters in alphabetic order.					
Step 2	Identify product families					
	 Sort the product families by descending order of sales volume. Examine high volume product families. Is there a potential family for an operations area among these? 					
	• If no obvious candidate shows up, or the volumes are too small to justify a operations area, then go to the next step.					
Step 3	Combine and identify process groups					
	• Sort the table alphabetically by process groups					
	• Combine product families where the total routing for a product or some shorter part of a routing is identical or similar.					
	• Sort the (new) process groups by descending order of sales volume					
	• Examine high volume process groups. Is there a potential group for an operations area among these?					
Step 4:	Repeat this procedure (combine, sort by volume, examine) until suitable families with sufficient volumes are found.					

 Table 31 A sequential method for forming operations areas

This quantitative method can provide effective results when the number of processes is increasing. The use of letters-digit combinations to code processes gives the ability to represent 260 processes (which should be enough), and the use of a spreadsheet makes it rather easy to sort and combine products and processes. It should be noted that this method follows the basis principle of first creating a family of products, and then determine the best processes. However, in some cases it might be suitable to create a process group first. For example, it might be suitable to create a operations area based on a key machine, which is both rare and capital intensive. Other equipment should then be added to make the operations area self-contained.

This sequential grouping method is illustrated with a example in Figure 65 below.

Step 1 - obtain a table of sale pr. product family - list processes pr. family in alfabetic order			Step 3 - sort processes alphabetically - combine same or similar processes - sort by descending order of sales - examine processes			
Product	Volume	Process		Product	Volume	Process
1	1000	BCE		6 + 3	3100	AD
2	1500	А		4	3000 •	BC
3	1100	AD		5	1800	BDE
4	3000	BC		2	1500	A
5	1800	BDE		1	1000	BCE
Step 2 - sort by de - examine	escending of products	order of sale	es	Step 4 Repeat this examine) u sufficient v	s procedure Intill suitab olumes are	e (combine, so le families with e found
Product	Volume	Process		Product	Volume	Process
4	3000	BC		2 + 3 + 6	4700	AD
6	2000	AD			1000	
5	1800	BDE		1+4	4000	BCE
2	1500	A		5	1800	BE D
~	1100	AD)				
3	1100	7.0				

This example is based on the same products and processes as in Figure 64. Step 1 includes to list six products, their sales volume and major processes (A-E). Step 2 includes examining the high volume product families for operations area candidates. Because none of the product families are suitable or have sufficient volume, step 3 is carried out. Step 3 is initiated by sorting products alphabetically and by combining products with same or similar processes. (Product 1 and 3 are combined in the first iteration). Next, the process groups are sorted according to sale and examined for operations area candidates. If none of the process groups are suitable or have sufficient volume. Step 3 is repeated until candidates are found. The result is the same as for the matrix approach. Two candidate product families with similar processes, and one external operation (5, D) is identified.

Using product characteristics

The alternative approach to form operations areas ignores the processes by which products are currently manufactured. In doing so, this approach overcomes an obvious weakness by the routing-based approaches described above. Namely, that a group of products that should be made in a similar way, follow routings with large differences. This can occur because the existing routings were design for a functional organisation, because the factory planner preferred certain types of operations, or because he planned for certain workloads in the enterprise at the time the routings were created. Ignoring currently used processes in the formation of operations areas allows for a more unbiased way of creating families. The key in this approach is still to focus on a common set of operations needed by the products.

Dedicating assembly areas to broad product families is an obvious design principle for most enterprises. In addition, it might be beneficial to group all parts and subassemblies based on their use in end products. Other manufacturing characteristics, such as product size, weight, shape, special features, and so on, or the process type involved, should also be considered when identifying potential operations areas. One should also consider the function of parts and sub-assemblies when creating operations areas. For example, seats, gas lifts, tilt control, 5 starbase, and casters have different functions on a chair, and could be produced in separate operations areas.

These, more informal approaches, can give sufficient information to create operations areas. However, in many cases it is most effective to use both routing information and product characteristics. The most suitable approach will depend on the complexity of the targeted enterprise.

9.2.2 Step 2. Dimension each operations area in terms of equipment and people.

The first step, formation of families, is the most important and the foundation for all other steps. The nest step is to dedicate, in one or several operations areas, all resources needed to complete all operations on this family, and if necessary, to rethink processes, equipment choices, and end product design, to enable the family to be self contained and resources to be dedicated. Two major issues should be considered when dedicating resources to a operations area:

- What is the proper process completeness in a operations area (should operations be placed in or several operations areas?
- What is the proper resource utilisation in a operations area?

Process completeness and independence

The goal of the overall design process is to achieve performance improvements design with respects to lead time, inventory, delivery precision and other performance objectives. The most effective flow is achieved when an operations area starts with raw materials and ends with finished products, with all operations being completed in the operations area. Such a stand-alone operations area gives maximum ownership and control of the manufacturing process. By closely linking consecutive operations, it is possible to create a rapid flow through all processing stages of a product family. Delays that occur when different operations areas teams are in charge of various parts of the process steps are minimised.

Process completeness can be pushed far, e.g. by integrating sub-assembly, assembly, testing, and packing of a product family in a single operations area. However, a complete standalone operations area often is neither practical nor economical feasible. The reality is that most operations areas supply, or are supplied by, other production units inside or outside the enterprise. Usually, the manufacturing process for an end product is partitioned and allocated to several operations areas due to:

• Differences in required operators skills within a operations area (e.g. skills required for machining versus assembly operations)

- Differences in output rates for various processes (necessitating buffer inventory between production units)
- Environmental or safety reasons (e.g. if some equipment is toxic and should be isolated from the rest of the work place)
- Differences in routings similarity along the process (members of a product family can have a high degree of routing similarity for some portion of the process, but low elsewhere for example, a part family can share one operations area for the first portion of the process but then be split into three operations areas for the remaining operations).
- Some (monumental) equipment that is used by multiple operations areas and cannot practically or economically be placed in all the operations areas. Paint lines and heat treatment facilities are typical examples.
- Delivery time/processing time ratios that requires buffer inventories to deliver in time. Buffer inventories are typically used to separate fabrication and assembly operations and perform them in different operations areas

When completeness is not practical, the manufacturing process should be segmented in several operations areas, each containing only a few consecutive operations for a product family (see Figure 66). An additional reason to split the manufacturing process into several smaller operations areas is process independence. A long line, especially one that relies on mechanised material handling, is vulnerable to breakdowns. Splitting the manufacturing into several operations areas means production can continue even if one of the operations areas stops working.



Figure 66 Two levels of process completeness

Figure 66 shows two alternatives for creating operations areas. Alternative 1 is a stand-alone operations area that contains all operations for product A, B, and C. In alternative 2, manufacturing is organised in three linked operations areas that contains a smaller part of the total process.

Dedication of resources and resource usage

The creation of operations areas implies to dimension each operations areas in terms of equipment and people. This means to determine the minimum number of units of each type of equipment the operations area needs to meet the demand, as well as the minimum numbers of operators needed to run the operations area. The dimensioning should be based on the volume, demand variations, the batch sizes between work stations, the job design, and other operating data.

Most enterprises want to fully utilise these resources because this leads to high outputs and lowers cost per unit. However, high utilisations increase the throughput time through the operations. It is therefore necessary to balance the goal of low throughput time against that of high output. It is also achievable to balance the utilisation of different resources in the operations area in order to increase output. However, because machines have different capacities and because the load balance depends on the product mix, it is difficult to balance the load. One way to reduce this problem is to increase the mobility and skill levels of the operators in each operations area.

9.2.3 Step 3. Develop enterprise layout and flows

The design of a layout is marked by complexity. Chief among the factors which lead to this complexity is the very large number of different ways the operations areas can be combined. It is partly because of this combinatorial complexity that optimal solutions are difficult to achieve in practice. Most layouts are therefore designed by a combination of intuition, common sense, and systematic trial and error.

Before starting the process of layout design there are some essential pieces of information which the designer needs.

- The space required by each operations area
- The constraints on the shape of the operations area
- The degree and direction of flow between each operations area (for example, number of journeys, number of loads or cost of flow per distance travelled).
- The desirability of operations areas being close together or close to some fixed point in the layout.

The last two pieces of information are particularly important because both influence directly the consequences of locating operations areas relative close to each other.

Space requirements

Perhaps the most difficult determination in layout planning is the amount of space required in the facility. Considerably uncertainty generally exists concerning the impact of technology, changing product mix, changing demand levels, and organisational designs for the future. Because of the wicked nature of the problem of determining space requirements, space requirements should be approached systematically and "from the ground up" (Tompkins et. al., 1996). Space requirements should be determined first for individual work stations, and thereafter for each operations area, based on the collection of workstations in the operations area.

A workstation, like all facilities, includes space for equipment, materials, and personnel. The elements to consider when determining work stations space requirements are according (Tompkins et. al., 1996) the following:

	Work station space requirements
Equipment	• The equipment
space	Machine travel
	Machine maintenance
	• Plant service (electric power, compressed air, etc.)
Materials	• Receiving and storing materials
area	• In-process materials
	• Storing and shipping materials
	• Storing and shipping waste and scrap
	• Tools, fixtures, jigs, dies, and maintenance materials
Personnel	• The operator (motions, ergonomics, safety etc.)
area	Material handling
	• Operator ingress and egress (aisles)

Table 32 The elements that require space in a work station

The space requirement should be calculated for all these elements. The resulting sum of equipment space, materials areas, and personnel space, represents the total space requirements for a work station.

Once the space requirements for individual work stations have been determined, the space requirements for each operations area can be established. To do this, the operations area service requirements must be established. Operations area space requirements is not simply the sum of the areas of the individual work stations included in the area. It is quite possible tools, dies, equipment maintenance, plant services, housekeeping items, storage areas, operators, spare parts, kanban boards, and so on, may be shared to save space and resources. However, it is important to ensure that operational inferences are not created by combing such elements. Additional space is required for aisles. Aisles should be located within and between operations areas to promote effective flow. Aisles width should be determined by considering the type and volume of flow to be handled by the aisle. Curves or nonright angle intersections should be avoided.

Flow planning

Flow among operations areas is one of the most important factors in the arrangement of operations areas within a facility. The objective with flow planning is to minimise the cost associated with movement in the facility, sometimes simplified to minimising the total distance travelled. To do so, a simplified version of Burbidges (1989) factory flow analysis is utilised. This flow planning approach is illustrated with a example where a plant layout consisting of six operations areas needs to be improved. The existing layout in this example is illustrated in Figure 68.

The first task is to construct a from-to chart like that in Figure 67, which shows the degree and direction of flow. Such a chart is constructed as follows (Tompkins et. al. 1996):

- List all operations areas down the row and across the columns following the overall flow pattern
- Establish a measure of flow for the facility that accurately indicates equivalent flow volumes. If the items moved are equivalent with respect to ease of movement, the number of trips may be recorded in the from-to chart. If the items moved vary in size, weight, value, risk of damage, shape, and so on. Then items

may be established so that the quantities recorded in from-to chart represent the proper relationships among volumes of movement.

• Based on the flow paths for the items to be moved and the established measures of flow, record the flow volumes in the from-to chart

There are many ways in which this information could be gathered. For example, flow data can be derived from routing information for products and the demand for these products, or by observing the flow over a typical period of time. In the example in Figure 67 the number of trips from operations area (1) to (2) is 10, from operations areas (1) to (3) is 5, and so on.

The second task is to select the dimension that the layout seeks to minimise, for example total distance travelled or total cost of movement. In Figure 67, distance travelled is selected and this data is provided for the existing layout. In this example, the distance travelled between two operations areas one way is the same as the distance travelled going in the opposite direction. In such cases, the procedure could be simplified by combining the number of trips between operations area 1 and 2 and operations areas 2 and 1 and so on, and then using the total trips in the subsequent calculations. However, it would always be best first to complete the analysis given in Figure 67 as subsequent layout options may need to use this data split.

	Trips	/day								Dista	ince t	ravell	ed [m]		
	To		Oper	ations	area					To		Oper	ations	area		
Fro	om	OA1	OA2	OA3	OA4	OA5	OA6		Fro	m	OA1	OA2	OA3	OA4	OA5	OA6
s	OA1	/	10	5	10	40	0		S	OA1	/	40	30	50	60	70
tior	QA2	10	\backslash	0	40	0	0		tior	QA2	40	Ϊ	50	30	70	60
era	OA3	5	0	Ϊ	5	30	10		era	OA3	30	50		40	30	50
å	OA4	10	40	5		0	10		ď	OA4	50	30	40	Ζ	50	30
Ŭ	OA5	40	0	30	0	Ϊ	0		Ŭ	OA5	60	70	30	50	Ϊ	40
	OA6	0	0	10	10	0	/			OA6	70	60	50	30	40	\backslash
				↓												
	Tota	l dista	ance [m]			-									
	To		Oper	ations	area			Total	ľ							
Fro	m	OA1	OA2	OA3	OA4	OA5	OA6	Total								
SL	OA1		400	150	500	2400	0	3450								
tior	ÒA2	400	\searrow	0	1200	0	0	1600								
era	OA3	150	0	\sim	200	900	500	1750								
ð	OA4	500	1200	200		0	300	2200								
	OA5	2400	0	900	0		0	3300								
	OA6	0	0	500	300	0		800								
То	otal	3450	1600	1750	2200	3300	800	13100	I							

Figure 67 Collecting data using a from-to chart

The outcome of this analysis is a chart that shows the total distance for the existing layout. The 230 trips involved a total distance of 13 100 metres per day. This should then be used as a benchmark against which to measure alternative layouts and the gains to be made in terms of reduced travel distances. When considering possible changes, this factor as well as aspects such as the cost of changing an existing layout would help to evaluate alternatives.

Given this information, the third task is to illustrate the flow by a flow $chart^{29}$ that shows the basic layout pattern, and then to adjust that flow chart to the area into which the layout must fit. An example of a available plant space and the existing layout pattern is depicted in Figure 68.



Figure 68 A flow chart that illustrates the existing layout pattern

Figure 68 shows the layout and the basic flow pattern which should be improved.

The last and most difficult task is to arrange (on the basis of the flow chart in Figure 68 and the total distance matrix in Figure 67) the operations areas in such a way that the total distance is minimised. In this example, it seems desirable to place operations area 1 and 5 closer together, because the distance travelled between these (80 x 60metres = 4800 metres) are very high. However, this requires that shifting of other operations areas, thereby affecting their inter-area distances and the total distance travelled (see Figure 69).

258

²⁹ Termed material flow system network by Burbidge (1989).



Figure 69 The revised layout pattern

Figure 69 shows the revised layout and flow chart resulting from relocating area 3 and 5. This layout change provided a layout effectiveness of 10900 metres, showing that the new layout has reduced the total distance travelled with 2200 metres. This new layout seems reasonable effective, but it is usually worthwhile to continue the rearrangement of operations areas to see if any further reduction in total flow can be obtained. For example operations area 2 and 4 might be exchanged, and the total distance travelled calculated again to see if any reduction has been achieved.

An alternative qualitative method of indicating the relative importance of the relationships between operations areas is the relationship chart. In certain types of layout problems, numerical flow of items between operations areas either is impractical to obtain or does not reveal the qualitative factors that may be crucial to the placement decision. In such cases, Muther's (1973) systematic layout planning (SLP) can be used. As the example in Figure 70 illustrates, this approach makes use of a priority code to show the preferred proximity of two operations areas.

\geq	To		Oper	ations	area		
Fro	m	OA1	OA2	OA3	OA4	OA5	OA6
ea	OA1	/	E3	U	Е	A1	Х
ar	OA2		/	U	A1	U	Х
suc	OA3			/	0	A1	0
atic	OA4				/	U	A2
per	OA5						U
0	OA6						\backslash

Figure 70 A relationship chart

Figure 70 shows a relationships chart for the layout depicted in Figure 68. The relationships chart make use of priority code to show the preferred proximity of two operations areas (shown as degree of closeness) and a justification code specifying the reason for the desired proximity (see Figure 71).

Value	Closeness	Line code	Code	Reason	
А	Absolutely neccesary		1	Flow of material	
Е	Especially important		2	Speed	
Ι	Important		3	Ease of supervision	
0	Ordinary closeness OK		4	Contact neccessary	
U	Unimportant		5	Share personell	
Х	Undesirable	\sim	*Use	d for example	
	purposes only.				

Figure 71 Codes for systematic layout planning

Figure 71 shows examples of closeness codes and reasons codes that can be used in a relationships chart. From a relationship chart, an flow chart similar to the flow chart in Figure 68 and Figure 69 can be used to illustrate the flow between operations areas. In such flow charts, the closeness value is either illustrated by line codes (as depicted in Figure 71) or translated to numerical values. For example, weights of 16 for "A", 8 for "E", 4 for "I", 2 for "O", 0 for "U", and -80 for "X" could be assigned. The flow chart is then adjusted by trial and error until a satisfactory flow pattern is obtained.

To summarise, the design of a layout should include the following steps (Slack et. al, 2001):

- 1. Collect information relating to the operations areas and the flow between them
- 2. Draw up a schematic layout showing the operations areas and the flow between them, putting the operations areas with the greatest flow closest to each other.
- 3. Adjust the schematic layout to take into account the constraints of the area into which the layout must fit
- 4. Draw the layout showing the actual operations areas and distances which materials must travel. Calculate the effectiveness measure of the layout either as total distance travelled or as the cost of movement.
- 5. Check to se if exchanging any two operations areas will reduce the total distance travelled or the cost of movement. If so, make the exchange and return to step 4. If not, make this the final layout.

9.2.4 Step 4 Design of operations area teams

In flow manufacturing, job design normally involves to create some sort of operations area teams. Teamwork has been one of the most popular slogans and goals in organisational change efforts in the past years. However, team work is often seen as an unambiguous organisational solution, and real support is seldom provided in how to actually design the teams. Many of the lists in literature describing team characteristics seem to have the following four factors in common (Tjosvold, 1991): (1) face-to-face interaction and mutual influence, (2) interdependence between team members, (3) perceived membership, and (4) common goals and tasks. Such characteristics are not very useful for the actual team design, which seeks to specify job structures that meet the requirement of the company and its technology, and that also provide quality of work for employees.

Teams can work together in many different ways and have widely varying responsibilities. This is documented by Tanskanen et. al. (1998), which conclude, after analysing 115 teams in five companies, "that *the* team solution does not exist in practice". This view is also held by Hyer and Wemmerlöv (2002), who suggest that the differences between teams are largely a function of differences in:

- the type of tasks allocated to the operations area team and,
- the degree of cross training (and more specifically task sharing/overlap) among operators.

These two key operations area characteristics determine the amount of autonomy a team has, and how closely operators must work together.

Factors to determine the level of team autonomy

One key design decision is therefore to determine which indirect labour tasks should be performed by the operators in the team. Indirect tasks are all the tasks that not are direct process steps in the manufacturing process (such as planning or quality inspections). The allocation of such tasks therefore determines how much the team can control their own work, and thus, how autonomous the team is. The indirect tasks that should be allocated to operators or to external supervisors are typically (Hyer and Wemmerlöv, 2002):

- material management activities (ordering parts, scheduling work etc.)
- maintenance and housekeeping activities
- manufacturing support (designing tools, NC machine programming etc.)
- quality assurance activities (inspections, analysing quality data etc.)
- training activities
- improvement activities (identifying improvement opportunities, developing and implementing solutions etc.)

The design of teams should begin with strategy. If the strategy is to achieve a competitive advantage by responding rapidly to the customers, a flexible and self-managed workforce may be a prerequisite (Upton, D.M., 1995). The benefits of a high level of autonomy (i.e. empowerment) in a team are generally seen as higher job satisfaction, and better service in terms of faster response to customer needs, faster response to dissatisfied customers, and more enthusiasm in the interaction with customers (Bowen and Lawler, 1992). The empowered team approach also provides benefits in terms of higher quality and delivery precision. However, there are disadvantages with empowered teams such as larger selection and training costs, and higher labour costs. A number of key factors should determine whether the benefits outweigh the disadvantages of empowerment. These factors are contained in Table 33. The closer a team design requirement is to the right of the continuum, the more likely it is than an empowered approach should be adopted.

Factor	Non-empowerment approach	Empowerment approach
Basic business strategy	Low cost, high volume	Differentiation, customised,
		personalised
Links with customer	Transaction, short time period	Relationship, long time period
Technology	Routine, simple	Non-routine, complex
Business environment	Predictable, few surprises	Unpredictable, many surprises
Types of people	Autocratic managers,	Democratic managers,
	employees with low growth	employees with high growth

 Table 33 Factors to determine the level of autonomy (Bowen and Lawler, 1992)

needs, low social needs, and	needs, high social needs and
weak interpersonal skills	strong interpersonal skills

Factors to determine the level of cross training

The second key decision is to determine the level of cross training and task sharing in the team, both for direct and indirect labour tasks. Cross training improves the flexibility of the operations, both for handling volume variations and mix variations, and also for handling irregular events and responding to problems. Cross training especially offers important advantages for jobs that are easy to learn. It enables operators to assist one another when needed and replace each other when absences occur. Cross training also make it possible for operators to actually "share" a task. Task sharing is beneficial in dynamic environments where the level of interaction required to perform a particular task is high, e.g. when there is a great deal of back and forth in terms of work flow and operators must continually react to one another's input in completing work. In more stable manufacturing, a more rigid task allocation between operators might be required to improve productivity.

A number of key factors should determine the level of cross training and task overlap in a team. These factors are contained in Table 34. The closer a team design requirement is to the right of the continuum, the more likely it is that the team should be cross trained in both direct and indirect tasks.

Factor	Low task overlap	Job rotation and task sharing
Volume variation	Stable demand	Unstable demand
Product mix	Few products	Product mix
Skill level	High skill level, specialisation	Low skill level required
Level of interaction	Low interaction required	High interaction and
		collaboration required

Table 34 Factors to determine the level of cross training

A framework to support team design

Based on these criteria, the author proposes a framework to support team design. To make it simple, the framework only shows extreme positions regarding autonomy and cross training. The framework is composed of four types of team solutions: (Type 1) Supervisor led teams with complementary skills, (Type 2) Supervisor led and cross trained teams, (Type 3) Self managed teams with complementary skills, and (Type 4) Self managed and cross trained teams.



Figure 72 Types of operations area teams

Figure 72 shows a decisions-framework for the design of teams. Four types of teams are outlined that provide different levels of performance. The vertical axis illustrates the level of autonomy, and the accompanying level of service (quality, delivery precision and lead time). The horizontal axis illustrates the level of cross training, and the accompanying level of flexibility.

Type 1: Supervisor led teams with complementary skills

This type of team is supervisor led. Operators perform very limited indirect labour tasks (e.g. reporting and recording quality problems, contributing to the solution of problems that arise) but most decisions are in the hands of management. Furthermore, the operators have a low level of multi functionality, i.e. they perform a limited number of direct labour tasks only, and the team members have complementary skills, i.e. they can only exchange each other on a limited set of tasks. The level of cross training is limited, and the interaction and task sharing among operators are also low. Typically, each operator completes some operations on the products, and then hands the product over to another operator. This type of team does not differ much from a traditional work organisation, and is suitable for efficient production of a few standardised products in a relatively stable and certain environment. Management can develop rules and standards that employees can simply execute.

Type 2: Supervisor led and cross trained teams

This type of team is also supervisor lead, and the operators only perform limited indirect tasks. However, every operator is cross trained in all direct labour tasks. This provides a flexibility to handle variations, because operators within the team can be easily allocated to all work stations. Furthermore, operators can assist one another and share tasks if necessary. This type of team is typical in plants that have adopted lean manufacturing (see for example Adler's (1993) or Adler and Cole's (1993) description of the team organisation at the NUMMI plant in California), and provides the flexibility for efficient production of a mix of standardised products.

Type 3: Self -managed teams with complementary skills

This type of team is autonomous, and responsible for the daily management of the work (this includes indirect tasks such as planning and control, and quality improvement). The team consists of operators with complementary skill sets that are responsible for certain tasks. The interaction between operators is limited due to low multi functionality and low overlap. The indirect tasks are performed by selected operators or a team leader that is directly involved in the work, and the high level of empowerment among these operators usually ensures high commitment to team performance and a high level of service (in terms of quality, delivery precisions and lead time). This type of team is suitable in technological advanced enterprises, where operator tasks are mainly to monitor, control, support, and maintain the equipment. It is also suitable in order management, where a team of employees with complementary skills serves a specific market or customer group.

Type 4: Self-managed and cross trained teams

This type of team is also autonomous, and the responsibility for the daily management is distributed among most operators. Management or support personnel make decisions about goals, team structure, and organisational support. Operators are trained in many overlapping tasks and can assist and replace one another. Task sharing and high interaction is possible. Such teams can provide all the benefits of teams that were listed in Table 13, and are well suited in dynamic environments that require high levels of customer service (quality, delivery precision, and responsiveness) and flexibility. Such teams are typical in plants that have adopted socio-technical system design (see for example Sandberg's (1995) description of the team organisation at the Uddevalla plant in Sweden), and provides the flexibility and autonomy for quick response manufacturing of highly customised products (Suri, 1998).

In type 1 and 3, operators hand off work to another (no overlap or task sharing, limited interaction). Note that in some cases, the total manufacturing process for a product in an operations area can be performed by a single caseworker. These caseworkers can still be organised in "teams" that are held accountable for performance and improvement. However, because these operators work in parallel (as opposed to in sequence), they cannot spot one another's error or correct one another's work. This approach can be considered if (1) the process is best suited for a "one and done" approach, i.e. if one operator can master all the skills and tasks required, and handoffs should be avoided. But (2) also to encourage joint accountability and ownership, be able to route incoming work to any member of the team, and foster continual improvement and sharing of best practices among operators engaged in the same work (Hyer and Wemmerlöv, 2002).

To summarise, the staffing of operations areas should include the design of teams that supports the strategy of the company. Teams support several job characteristics that are beneficial in modern manufacturing, such as job enlargement and job enrichment, and are usually beneficial both for management and employees. The key decisions in team design are the amount of autonomy and the degree of cross-training. These characteristics should be determined on the basis of:

- business strategy
- links with the customer
- technology
- business environment

- work force personality types
- volume variations
- product mix
- skill levels required
- level of interaction required.

When it fits with operations strategy and manufacturing environment, a multifunctional, cross trained, and autonomous team capable of participating actively in problem solving, quality improvements, and mastering new products rapidly, can be a source of competitive advantage. When the environment is more stable and certain, efficiency might be improved through more standardisation, specialisation, and supervision. In such cases, teams with limited cross-training and autonomy might be proper to create competitiveness.

9.2.5 Step 5 Modify MPC system and information flows

Each operations entity is governed by the enterprise MPC system. The essential task for the MPC system is to manage efficiently the flow of material, the utilisation of people and equipment, and to respond to customer requirements by utilizing the capacity of suppliers, of internal resources facilities, and (in some cases) of customers to meet customer demand (Vollman et. al. 2005). An important distinction here is that the MPC system provides the information upon which managers make effective decisions. The MPC system does not make decisions nor control the operation – managers perform these activities. The MPC system provides the support to do so wisely.

The manufacturing planning and control system provides information to efficiently manage the flow of materials, effectively utilize people and equipment, coordinate internal activities with those of suppliers, and communicate with customers about market requirements. A wide range of alternatives are available in designing MPC systems. These include basic approaches such as MRP. MRPII, JIT, OPT, periodic control systems, and finite scheduling systems. To develop methods that are both well suited for to their specific application and mutually consistent across applications, Hopp and Spearman, (2001), recommends the following steps in developing a MPC system:

- 1. *Divide the overall system appropriately*. Different control methods for different portions of the process, different product categories, different planning horizons, different shifts, etc. can be used. The key is to find a set of divisions that make each piece manageable, but still allow integration.
- 2. *Identify links between the divisions*. For instance, if production plans for two products with a shared work station are made separately, they should be linked via the capacity of the shared process. If different tools are used to plan manufacturing requirements over different time horizons, one should make sure that the plans are consistent with regard to their assumptions about capacity, product mix, staffing, etc.
- 3. *Use feedback to enforce consistency*. All analysis, planning, and control tools make use of estimated parameters (e.g. capacity, machine speeds, yields, failure and repair rates, demand rates, and many others). The system should be configured in such a way that various tools are updated with timely and consistent information.

This thesis will focus on the two first steps in this procedure, while the third is merely an information and database technology type of issue, and outside the scope. The author will argue that a logical and customary way to break the manufacturing planning and control problem in to manageable pieces (i.e. step 1), and to design a system that is consistent across divisions (step 2), is to develop a control model that shows the main processes and their control methods, and which also encompasses a hierarchical planning framework such as the framework shown in Figure 36. Based on the current state operations model, and the planned changes in areas such as layout, processes, organisation and material flows, the control model and the MPC system should be configured to support the overall strategy of the enterprise.

The enterprise and each manufacturing unit should be supported by an efficient infrastructure. A matrix is therefore presented that links manufacturing control and organisation to strategy. The matrix will enable companies to make structured and consistent decisions in the development of manufacturing enterprises.

There is temptation to view some MPC design options as a continuum where movement toward lean (rate based material planning and pull shop floor control) is "good". This is not the right conclusion. The MPC must be matched with the ongoing needs of the company's market, the operations strategy, and the manufacturing process. Choosing the right approach to manufacturing planning and control is a strategic issue critical to the short- and long-term prosperity of a business (Berry and Hill, 1992). MPC system design is affected by strategy, market and process design. This is depicted in figure 73. In addition, the desired MPC system is affected by the existing MPC system. In some cases, improvements can be made by investing in the evolution of the existing systems design, in other cases, it is necessary to start afresh (Vollman et. al. 2005).



Figure 73 Areas affecting MPC design

Berry and Hill (1992) present a by now well-established framework for MPC design options. It contains a number of alternative approaches for each of the three levels of manufacturing planning and control activities described earlier. These three decision areas are called *customer order decoupling point, material planning approach*, and *shop floor control approach*. Options for customer order decoupling point are make-

to-order (MTO), assemble-to-order (ATO) and make-to-stock (MTS). Material planning can be carried out using either a time-phased or a rate-based approach. Finally, the shop floor is controlled using either push- or pull-principles. The framework used does not recommend concrete tools and techniques for planning and control.

Choosing market interaction strategy

The choice of market interaction strategy depends greatly on the market requirements, and the operations strategy (inclusive process choice) for a line of products. Some key strategic variables for choosing market interaction strategy are listed in Table 35.

Strategic variables	MTO (or ETO)	ΑΤΟ	MTS
Product design	Customised	Modularised	Standard
Product variety	High: unpredictable	Medium: unstable	Low to medium: stable
Volume pr. Unit	Low	Medium	High
Demand pattern	One-off/irregular	Irregular	Repeated
Delivery speed	High	Medium	Short
Delivery reliability	Low	Medium	High
Process choice	Job/low volume batch	Batch	High volume batch/line
Finished goods invent.	None	Low or none	High

Table 35 Linking market requirements and strategy to the choice of market interaction strategy (adapted from Vollman et. al. 2005)

A *make-to-order* (or *engineer-to-order*) interaction strategy supports products of wide variety and custom design, which are produced in low unit volumes and frequently involves the development of engineering specifications. The delivery time is often long, and delivery precision is somewhat difficult to guarantee, since products are customised to meet individual customer needs. Since the operations mission often involves providing a broad range of production capabilities, the process choice supports low volume batch production. Fluctuations in sales volumes are typically managed through adjustments of the customer order backlog.

An *assemble-to-order* interaction strategy represents an intermediate position of the customer order decoupling point. Products of both standard and special design are produced, and variety is accommodated by customer selecting from a wide series of standard options. The unit production volumes are relatively high at the module level, and delivery speed enhanced by buffering modules that are ready for final assembly. Delivery precision is well accommodated, even for large changes in product mix, as long as the overall volumes are kept within planning parameters.

The *make-to-stock* interaction strategy supports products of standard design produced in high unit volumes in narrow product variety for which short delivery time is critical. The process choice is usually line manufacturing or high volume batch manufacturing. The finished goods inventory can provide short delivery time and high delivery precision, and can buffer for fluctuations in sales volumes. This also enables stabilisation of production levels, reliable production schedules, and cost efficiency. (Vollman et. al., 2005)

Choosing MPC systems

The choice of MPC system, and especially the material planning and shop floor approach depend greatly on the manufacturing process characteristics. A range of market/process factors are listed in Table 36 that can affect the choice of MPC system. A MPC option is proposed when the factors are at their worst setting (in the left column), at their best setting (in the right column), and when the factors are mixed (the column in the middle). Note that when all factors are at their worst setting, the enterprise is most likely to operate in a MTO mode. On the other hand, when all factors are at their best, the enterprise is probably operating in a MTS mode.

Strategic variables	Time Phased/ Push	Time phased/Push-pull	Rate based/ Pull
Demand variability	High	High or low	Low
Set up time	High	High or low	Low
Lot sizes	Large	Large or small	Small
Transfer batches	Large	Large or small	Small
Flow pattern	Complex	Complex or simple	Simple
Bottle necks	Severe	Severe or balanced	Balanced
Process uptime	Low	Low or high	High
Labour flexibility	Low	Low or high	High
Delivery reliability	Low	Low or high	High
Manufacturing quality	Low	Low or high	High
Supplier performance	Low	Low or high	High

Table 36 Choosing MPC systems (adapted from Hyer and Wemmerlöv, 2002)

MPC based on time phased material planning and push

The most difficult planning situation is when all the factors are at their worst setting, i.e. when set up time are high, the flow pattern is complex, bottlenecks are severe, manufacturing quality is poor, demand variability is high, etc. Nothing is simple here. The most obvious conclusion is to design a system capable of scheduling production. Reactive pull systems, based on automatic replenishment (use one, make one), would be highly inappropriate, and the implementation of flow manufacturing would be very difficult. In such cases, the material planning for internal operations and suppliers should be performed by MRP. The shop floor control should be centralised and based on MRP & priority lists, or a finite scheduling system (see Table 15)

MPC based on rate based material planning and pull

When all factors are at their best setting, i.e. when set up times are low, flow pattern are simple, bottlenecks are balanced, manufacturing quality is high, demand variability is low etc., planning and control can be relatively easy. Such environments are ideal for flow manufacturing and the use of pure pull systems. In such cases, the material planning for internal operations and suppliers should be rate based. The shop floor control should be decentralised, and based on product specific pull systems such as Kanban. (see Table 15)

MPC based on time phased material planning and push-pull

If the factors are mixed, for example, when the volume and mix variability is too high for pure pull systems, a push-pull approach should be considered. Such a hybrid system is based on MRP for material planning for internal operations and suppliers. The shop floor control is based on schedules (developed from MRP work orders) and a generic (non-product specific) pull system that controls the material flow (see chapter 4.7.6).

To summarise, it is shown how a company can design the manufacturing control according to market and process characteristics. Companies that deliver standard products, with high volume and narrow product range, should choose line-production or high-volume batch-production and a MTS design. This configuration enables the company to deliver high volume products at low costs, with high delivery speed and precision. Companies that deliver highly customised products in low volumes should choose job-shop or low volume batch production, and a MTO design. The product range and degree of customisation simply makes it uneconomically to supply all possible variants from a final stock. The MTO design enables the company to produce exactly what the customer wants, and not all other possible variants.

It should also be clear that some enterprises are easier to control than others. It is easier to manage enterprises in environments characterised by the best rather than the worst settings in Table 36. Pure push systems are most suited for highly dynamic and unstable environments where control is difficult, while pure pull systems will always outperform push systems in stable and repetitive environments. Therefore, whatever starting conditions, one should always try to reengineer the enterprise to make manufacturing conditions simpler and with less variability. One way to do this is to reengineer for flow. Flow manufacturing is best suited for conditions where the factors in Table 36 are at their best setting. Organising the enterprise in clearly defined operations areas are very difficult in conditions characterised by random demand, low process reliability, varying and complex flow patterns, and so forth. However, if flow manufacturing is possible, manufacturing conditions and especially the planning and control task can be greatly simplified. This "simplicity" is, to a large part, a result of more decentralised control. With operations areas, the order release point can be changed from the machine to the operations area level, and the scheduling can be executed by the operations area team. By delegating planning and control to the operations area, the centralised MPC effort can be radically reduced.

9.2.6 Summary of benefits of flow manufacturing

An enterprise reengineering for flow manufacturing and product focused operations areas has several benefits:

- Simple and clear product flows, leading to high visibility of jobs and ease of control.
- Reduction in material handling, which not only cuts down on time and cost, but can also reduce the defects caused by frequent handling and movement.
- Job enrichment, leading to increased worker satisfaction
- Ownership combined with cross-training and frequent communication, leading to continuous improvement efforts, which reduce non-value-added activities such as setups and downs times, and also improve productivity through continuous improvements
- Better quality and reduction of rework

- Decentralisation of detailed scheduling and control, leading to simpler central systems that have a greater chance of success in their tasks
- Ability to run small batches, which, combined with proximity of operatos and transfer batching, result in short lead times and low WIP

As a result of all these benefits companies have seen dramatic productivity increases and floor space reductions. Although the benefits of flow manufacturing can be substantial, reengineering the enterprise into product focused areas is not a trivial process. To much focus on the technical issues can lead to resistance, delays or even close-outs. A flow manufacturing initiative that aims to succeed and achieve lasting changes should therefore follow the change procedure outlined in this chapter in order to deal with the human aspects.

9.3 Summary

The design and implementation phase of an enterprise reengineering project can encompass several improvement initiatives that aim to realise the revised operations strategy. These initiatives should be organised and managed in order to synchronise activities in time and use resources effectively. At the launch of a new change initiative, resources are allocated and the change organisation is set up. Furthermore, a detailed plan has been developed to specify aim, results, performance measures, success factors and obstacles, the roles and ground rules for team members, and a detailed project plan.

A design and implementation procedure are outlined to ensure effectively and efficiently realisation of the strategic objectives. The procedure includes the following steps:

- 1. A detailed analysis and identification of opportunities
- 2. The choice and specification of solutions
- 3. Pilot testing
- 4. General implementation
- 5. Ensuring that the change will last

Participatory design is an overall principle for this procedure. Often it is organisational or social obstacles that hinder a best practice programme (such as the flow manufacturing programme that are proposed in this chapter) to reach its full potential. Widespread participation in design and implementation can create a range of good ideas, reduce potential resistance, and increase the likelihood that changes will be lasting.

An operations strategy can encompass a range of targets that can be achieved by implementing best practices. If the decisions in the revised operations strategy are to perform improvements in manufacturing planning and control, order management, layout and flow, or inventory, the flow manufacturing programme should provide practical guidance and a set of principles to support reengineering.

Based on the flow manufacturing principles developed in chapter 4, a five-step procedure to flow manufacturing reengineering is proposed:

- 1. Creating product focused operations areas
- 2. Dimensioning each operations area in terms of equipment and people

- 3. Developing enterprise layout and flows
- 4. Creating operations area teams
- 5. Modifying MPC system and information flows

A reengineering for flow manufacturing has several benefits. The experience from the case study and several field studies is that flow manufacturing has resulted in performance improvements such as shorter throughput time, shorter response time to customer orders, lower inventory levels, improved product quality, and lower unit costs.

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The enterprise reengineering methodology – design and implementation

10. Case study: HÅG - an office chair manufacturer

This chapter describes how an operations strategy can be realised through the development of operations models. Early in the 90s, HÅG carried out a comprehensive reengineering process in a project named HÅG FAST. The project was based on a new time-based operations strategy. The company wanted to compete on delivery time based on direct distribution from Røros to the markets in Europe. All operations (administration, manufacturing and warehousing) were centralised at the main factory in Røros, and a new operations model with solutions for assembly-to-order production and direct distribution to dealers was implemented. Such a reengineering of the value chain made it possible to efficiently deliver customised chairs for European markets – a strategy known as mass customisation. The project resulted in shorter delivery times, lower prices, and improved delivery precision, and has enforced HÅG's competitive position in the European furniture market.

10.1 Introduction

Mass customisation is an important strategy for manufacturing enterprises that wants to improve their competitiveness in a market. Such a strategy implies a mass production of products that can be customised to individual customers. This makes it possible to provide customers with a freedom of choice, and simultaneously be competitive on price and delivery. However, the implementation of such a strategy is challenging. In the well-known article "The limits of mass customisation", Professor Zipkin at Yale University in USA warns companies against implementing this strategy for all types of operations. Zipkin argues that mass customisation requires a high level of flexibility and responsiveness in all stages of the value chain. Therefore, it is very few companies that have been able to realise the mass customisation strategy.

HÅG is one of the few companies that have succeeded with mass customisation. The reengineering process was carried out with SINTEF as a competence partner. SINTEF contributed with the state-of-the-art solutions that were required to realise the new strategy. SINTEF also contributed with a reengineering approach based on operations models, which enabled the project to be accomplished efficiently. The project was a great success for the company, and also a very good example of how improved operations can enforce the company's competitiveness in the marketplace.

The purpose of this case study is firstly, to show how the realisation of an operations strategy can provide a competitive advantage for a company, and secondly, to demonstrate how the enterprise reengineering methodology can structure and support the operations improvement. All phases of the operations strategy realisation are described, except change management aspects, which were poorly documented.

10.2 A new operations strategy for HÅG in 1991

HÅG was founded in 1943 by Håkon Granlund, and has been located at Røros, Norway since 1957. For the first 25 years the firm manufactured office chairs and steel tube furniture for kitchens. In 1970 the latter market declined, and so HÅG opted to focus on office chairs. Collaboration was also begun at this time with a group of designers, and they have been instrumental in helping develop the principles that HÅG bases its business on today.

Today HÅG is a leading supplier of office chairs in Scandinavia and among the 10 largest in the region. In Norway, HÅG has been the market leader from the end of the 70s with approximately 40 percentage market share. Most of the customers are located in northern and central Europe, and in US, and the export share constitutes 80 percentages of the total sales. Sales companies are established in several countries, and an increasing share of the sale is abroad.

10.2.1 Business objectives

HÅG focuses its business on seating solutions. The basic idea behind HÅG's products is that people are not designed to sit still, but naturally tend towards movement and variation. They call this the HÅG movement, and the business is based on the following mission:

HÅG's shall achieve profitability and growth by providing different and better seating solutions for active working people.

HÅG's products shall encourage to movement and variation by enabling each individual to adjust their chair in a simple manner. HÅG aims to be a international design-driven company with seating solutions for work, visits, and conferences, and to stand out for the customer as different and better than the competitors. The strategy is to offer highly functional and ergonomical products, with a distinctive and attractive visual appearance. Furthermore, the choice of materials should give associations to environmental friendliness and quality.

HÅG's design is attractive in the international market place. The popularity is reflected in the large number of copies that has been made in other countries. The company also has won several design prices for their chairs. For example, HÅG has twice been elected as the Norwegian design-company of the year. HÅG is also a four-time gold medal winner at Neocon, the largest furniture exhibition in USA. HÅG's international offensive has been very successful, and was the reason why the company was awarded with the Norwegian export price in 1991.

10.2.2 A shift in market requirements in the 90s

The market for office chairs changed in the beginning of the 90s. The demand for standard chairs with a repeat nature was declining. HÅG's innovative design increasingly attracted customers that wanted to specify the fabric, colour, casters, and other features on their chairs. The products demanded by the customer were increasingly more special and unique. Another challenge was that short delivery time and high delivery precision became order qualifiers for many customers. HÅG, who

exported 70 percentage of their volume, therefore had to compete on delivery performance with manufacturers that were centrally located in Europe. The shift in market requirements for HÅG's office chairs are shown in Table 37.

External performance dimensions	Before 1990	After 1990	
Product	Standard office chairs	Innovative and customised office chairs	
Order winners	Price	Product design Product specification	
Qualifiers	Quality conformance Delivery precision Delivery lead time	Delivery lead time Delivery precision Quality conformance Price	
Main performance objectives	Cost Quality	Range flexibility Delivery time Delivery precision	

Table 37 Market requirements for HÅG's office chairs

In 1991, HÅG sold 143.400 office chairs and offered 2 million combinations. In principle, this means that every chair might have been unique.

10.2.3 The existing operations strategy

HÅG's operations strategy, based on make-to-stock interaction with customers, became disadvantageous in the new market situation. During the 80s, HÅG had built a distributed value chain structure in order to be located closer to their international markets. The main manufacturing enterprise was still located at Røros, but two assembly plants were built in other countries. One assembly plant was built in North-Carolina to supply the US market, and another was built in Mönsteräs, Sweden to supply the markets in Sweden and Denmark. Final goods stocks were established in North Carolina, Mönsteräs, Oslo, Bergen, Trondheim and Røros. The next logical step according to this strategy was to establish a new factory in Central-Europe to supply Germany and Netherlands.

However, this strategy had not improved HÅG's competitiveness. In spite of large stock levels, HÅG experienced many stock outs, which caused extra costs and low delivery precision. Compared to their competitors, HÅG had weak profitability and low delivery performance. It was obvious for everybody in the company that changes were required in order to survive. For manufacturing operations, the necessary strategy shift can be illustrated by the product profile scheme in Figure 74.

		Typical chara	cteristics of	process choice
Aspects		jobshop	batch	line
	1			
Products and markets	Product type	Special	0	Standard
	Product range	Wide	0	Narrow
	Customer order size	Small	0	Large
	Level of product change required	High	0	Low
	Rate of new product introductions	High	0	Low
	Order winner	Delivery speed/ unique capability	0	Price
Operations	Process nature	Generalpurpose	•	Dedicated
	Process flexibility	High		Low
	Operations volumes	Low		High
	Operations key strategic task	Meet specification delivery speed		Low cost operations
Investments	Level of investement	Low		High
Product position				

Figure 74 The product profile for HÅG in 1990

The product profile illustrates that HÅG's existing operations strategy not was aligned to market requirements. New operations for more flexibility, lower volumes, more customisation and faster delivery were required.

10.2.4 Gap analysis

The gap analysis scheme in Figure 75 illustrates the need for a strategic shift in 1990.



Figure 75 The gap between market requirements and actual performance

Figure 75 shows a major gap between actual and desired performance on delivery time and delivery precisions. HÅG's customers wanted customised and innovative chairs that could be delivered within a few days. However, performance

measurements showed that average delivery time was 21 days, and average delivery precision was 87 percentages. The scheme also illustrates the potential for higher prices. Customised and innovative chairs, delivered fast, on time, and with sufficient quality, are less price-sensitive than standard office chairs.

10.2.5 A new operations strategy

HÅG did not make much money, and some stakeholders wanted to move the entire enterprise closer to the markets. However, HÅG was the largest work place and an industrial locomotive in Røros. HÅG was also the major customer for a range of subsuppliers that were located in the region. The top management therefore wanted operations to continue at Røros.

HÅG had already distinguished themselves as a creative, different, and better company in areas such as design, human resource management, and environmental friendliness. However, it was also a potential for creative and different solutions in operations. In the autumn of 1991, ideas about the use of just-in-time principles were introduced at HÅG – ideas that should lead to radical changes for operations. The insight in just-in-time resulted in a new ambitious strategy for the company:

We will move HÅG from Røros to Europe!

The strategy-shift was based on the assumption that closeness to a market means closeness in time, and not necessarily geographical closeness. HÅG decided to abandon the "distributed" strategy where competitiveness should be achieved by establishing operations/warehouses close to the major markets. Instead, all production and administration should be centralised as a single enterprise at Røros. HÅG-Røros should manage the total value chain from suppliers to customers. More efficient operations in production, distribution and administration should make it possible for HÅG to deliver customised chairs faster and more precise than other European competitors. In the long term, the new "centralised" strategy implied the winding-up of the assembly plants in North-Carolina and Mönsteräs, and the warehouses in Bergen, Trondheim and Oslo. Further, that the administration of operations should be moved from Oslo to Røros.

The new strategy emphasised time as the most critical performance objective. The objective was to deliver customised chairs from Røros to Europe in 5 days. This should be supported by a time based guarantee scheme, that allowed customers to cancel their orders if chairs not were delivered on-time. The guarantee scheme required that the delivery time were reduced to a quarter and that the delivery precision was radically improved. By offering such short delivery times, HÅG would gain a competitive advantage compared to European competitors. The major strategic events in the period 1991 - 1993 are listed in Table 38.
Year	Strategic event						
1991	Strategic planning – a new operations strategy						
1992	Implementation of flow oriented layout						
1993	Assemble-to-order interaction strategy						
	Organisation in operations areas						
	New control model						
	- rate based material management						
	- customer order control in seam, assembly, packaging and shipment						
	- kanban control of part production, sub-assembly, and procurement						
	Implementation of the ERP system Movex						
	Available-to-promise planning system						
	Team organisation of order handling, planning, and procurement						
	Just-in-time partnerships with suppliers						
	Integration with the core supplier Protex						
	New direct distribution system based on time guarantee scheme						
	Assembly plant in Mönsteräs closed down						
	Warehouses in Oslo, Bergen, and Trondheim closed down						

Table 38 Strategic events 1991 - 1993

It should be mentioned that the operations strategy for 1991 - 1993 did not imply heavy investments. Performance should mainly be improved through infrastructural changes. However, since 1993, HÅG has invested heavily in automated production technology in order to improve efficiency and reduce costs.

The major strategic activities and their performance objectives are illustrated in Table 39.

Decision areas			irea	IS	Tasks/events		Perf. Objectives					
	Х				Flow orientation of layout				Х	Х		
					х	ATO interaction strategy			х			
					х	Rate based material planning			Х			
					х	Order control in assembly			Х			
	х				х	Kanban in part production	х		Х	Х		
		Х				Implementation of MOVEX	х					
		Х				Available to promise system					Х	
				х		Team organisation					х	
	х			х		JIT supplier partnerships	Х			Х		
	х	х	х			Integration with Protex			х			
	х					Direct distribution			Х			
x						Assembly plant in Mönsteräs closed						
	х					Warehouses close down	х					
Resources	Materials	Information	Processes	Organsation	Control		Costs	Quality	Del. time	Del. precision	Flexibility	Innovation

The operations strategy matrix shows the major strategic tasks that were carried out in 1991 - 1993, and their major performance objectives. The performance objectives for the new operations strategy was to achieve:

- Improved delivery precision
- Shorter throughput time in production
- Reduced inventory and work-in-progress
- Improved production flexibility
- Improved collaboration with suppliers
- Shorter delivery times to customers
- Improved control of inbound and outbound transport at HÅG-Røros

Many of these tasks were initiated to improve HÅG's delivery performance (delivery time, flexibility, precision). However, all tasks also had a positive effect on costs and quality. The result was radical improvements, both in terms of costs, quality, <u>and</u> delivery performance. The mapping, analysis and design (based on an AS-IS and TO-BE operations model-set) that resulted in these strategic events are described below.

The company initiated the project HÅG FAST to realise the strategy. The project involved a mapping and analysis of manufacturing and office operations, and the development and implementation of a new operations model for the enterprise. The details in this work are described below.

10.3 Mapping

A mapping of the operations was carried out to identify the actions that were necessary to realise the new strategy. The mapping covered the enterprise at Røros, and the value chain it was situated in. But the mapping was performed in several sub-projects and the available information is scattered and incomplete. Based on information and illustrations available, and informal interviews with central persons at SINTEF and HÅG, an holistic operations model-set is developed by the author. The AS-IS operations model-set is incomplete, and contains some graphical representations of resources and materials view, and the control view. For the other views, only textual descriptions are provided. Furthermore, no initial data-analysis (product-volume analysis, ABC analysis etc.) were carried out in 1991.

10.3.1 The mapping data set

The mapping carried out in 1991 did not document much quantitative data about products, equipment, and personnel in existing operations. Some information was documented about customers, suppliers, inventory levels and performance. The available information is described below.

Products

HÅG's office chairs are composed of ca. 150 components. The main components are seat, back, gas lift, tilt control, 5 star base, and casters. HÅG produces 70 chair-models that are grouped in nine families. All models can be delivered in many variants. The customer has several options on all main components and can choose among a great number of fabrics. No data is available on the status in 1991 per product line on volumes and demand pattern.

Equipment and personnel

The major production processes involved in the making of a chair is pressing, cutting, welding, varnishing, and sub-assembly. Furthermore, seam of covers, upholstery of seats and backs, final-assembly, and packing. Most operations were performed manually in job-shop type of processes, and the level of automation was low. No detailed data is available on the status in 1991 of the manufacturing equipment (number, capacity, capability etc.) and manufacturing personnel (number of shifts, skill levels etc.)

Customer requirements and delivery performance

The chairs were delivered from stock, and HÅG had final-goods warehouses at Røros, Oslo, Bergen, and Trondheim. Deliveries to southern Norway and Europe (86 percentage of the volume) were supplied from the warehouse in Oslo. As the sale of customised chairs (especially the customisation of upholstery fabric and colour) was growing, the make-to-stock interaction strategy became unsuitable.

- In 1991, average stock level was 600 chairs in Oslo and 6000 chairs at Røros. The stock levels at Røros were growing steadily, and could be as high as 10 000 chairs at some occasions in 1991.
- The delivery performance was also low, and delivery time could be as long as 25 days in the worst cases
- The delivery performance was 87 percentages. The management pointed out that such a performance was far to low, and that to much resources (e.g. in the form of overtime) was used to achieve this level

Suppliers and their performance

HÅG's production (600 chairs per day) consumed 100 ton steel, 300 ton wood, 140 ton rubber foam, 200 000 square meters of textile, and some plastic parts. HÅG bought materials and parts from a great number of suppliers that operated under very favourable conditions. The supplier situation can be described as follows:

- purchased parts and materials (c.a. 1200 different items) constituted 59 percentage of the capital turnover for HÅG-Røros.
- it was 200 suppliers
- average delivery time was 22 working-days
- average time between deliveries was 10 working-days

This situation required that HÅG had to make orders minimum four weeks before an item should be available for production.

The performance data summarised for HÅG-Røros

- Turnover: 118 million NOK
- Production volume: 143 400 chairs
- Inventory turnover: 7 times per year
- Average throughput time: 55 days
- Delivery precision to customers: 87 percentages
- Delivery time to customers: 3 weeks
- Delivery time from suppliers: 3 weeks

10.3.2 The existing control model

The mapping carried out in 1991 provided information in all dimensions that should be examined in an enterprise reengineering process. However, the available information and illustrations from 1991 was not sufficient to make a complete modelset of the enterprise. The illustrations in the following operations model-set (except the layout drawing in Figure 78) and the textual descriptions are therefore developed by the author. The overall control model from 1991 is illustrated in Figure 76.



Figure 76 The principal control model in 1991

Figure 76 shows the existing operations model at HÅG. No details are shown regarding the planning system, except that the detailed material planning was MRP. The control model shows that the enterprise was built as a set of functionally focused operations areas, each receiving and delivering parts or products to a storeroom. An ERP-system provided MRP work-orders and procurement-orders that were distributed to the operations area on a weekly basis. Each operations area functioned independently and was free to optimise their work as long as the MRP-schedule was followed.

10.3.3 Processes

The major process steps in manufacturing and administration are illustrated and described below. (No graphical models were developed of the existing manufacturing processes).

Manufacturing operations

The mechanical department produced all tubular steel parts for the chair. Steel in several dimensions was cut and pressed into different parts. Some of the parts were welded together to larger items. The varnishing department painted all metal parts in black or grey. The sub-assembly put together larger components such as tilt control, gas lift, arm rests, and base. In the upholstery department, foamed rubber was glued to wooden seats and backs. The seats and backs were then upholstered with a cover made at Protex, a textile supplier that was localised a few kilometres from Røros. In the final assembly, the different components was put together to a complete chair, packed in boxes, and transported to final-goods storage.

Office operations

The order management was time and resource consuming, and it took 2-8 days from order-reception to start of production. The order management process is illustrated in Figure 77.



Figure 77 The existing order process

Figure 77 shows the cumbersome order process, which was the major reason for the time delay:

- The order-handler received an order and should determine delivery date. An inquiry was sent to the planning office which calculated the requirement of components and materials in a MRP-system.
- A material- and component list was printed and sent to the foremen in part production and assembly, who checked the stock-levels physically.
- Complete orders with delivery date were sent to the planning office which checked the order for a second time. The net requirement was calculated in the MRP system, and work-orders were sent to production.
- Frequent stock outs, and thus changes of production plan, required rush-orders and frequent communication with suppliers. However, it often occurred that parts or materials not were delivered fast enough.

10.3.4 Resources and materials

Resources and materials flow was represented in a layout diagram. The existing layout was characterised by:

- The stock for materials and parts was placed at the centum in order to supply all areas of the factory.
- The placement of machines and equipment was unstructured and created unnecessary internal transport and intersecting material flows.

Figure 78 shows the principal layout and an example of the material flow for the component "5 star base".



Figure 78 Principal layout and material flow for the component "base" in 1991

The example illustrates that the flow not was optimal, and measurement showed that the average throughput time for the component was 55 days.

10.3.5 Information

No model is available that shows the existing information system and flows in 1991. An ERP-system was in use, but the functionality of the system was not good enough in a range of areas. Especially, it did not enable the integration of all business units of an international company such as HÅG. Moreover, the system was only supported in Norway, and no local support was available in other countries.

10.3.6 Organisation

No organisational maps are available that shows the organisational structure in 1991. The organisational structure is described in the text below.

Administration

Sales-offices, and the sales and order management operations was distributed throughout the company. Personnel with dedicated responsibility for customerservice, order management, manufacturing planning and control, procurement, and distribution, were located at several locations and the communication between them was poor. For example, order-handlers had poor knowledge of the status in transport and manufacturing, and it was problematic for them to determine reasonable delivery dates.

Manufacturing

The manufacturing organisation at HÅG was functionally organised as a set of departments led by foremen. Each operator was dedicated to a limited set of tasks, and the skill-versatility within each department was low. Furthermore, there was no cross-training between departments.

10.3.7 Planning and control

The production was based on a make-to-stock strategy and was controlled by MRP. The planning of production and procurements was carried out in a materials requirement planning system that calculated net requirements from the registered stock levels, order backlog, and forecasts. Such an control system caused the following problems:

- Sales forecasts, and thus, production plans, seldom reflected the real sale. The high level of variants made it very difficult to determine the sales volume of each product type.
- Rush orders was often required to fulfil customers orders on time. These orders came on top of the planned production and caused extra work and overtime.
- It was difficult for the purchaser to estimate the required volumes for different parts. Corrections and follow-up orders was therefore common and caused extra work for purchasers. Another consequence was that orders had to wait until a particular part arrived.
- When the already delayed materials and parts arrived at the factory, much resources were used to push the waiting orders through the production process.
- The fixed lead times in the MRP system was set to be too long in order to allow for potential delays. This caused unnecessary safety buffers at several stages in the manufacturing process.
- A lack of shop-floor control (only based on weekly MRP work-orders) made operators free to prioritise their own work. The result was overproduction and piles of inventory.

10.4 Analysis

The mapping had shown that the time-based guarantee scheme required performance levels that not could be achieved with the current operations model. The existing order process was too time consuming and too little customer-oriented. The customer often had to wait several days before HÅG could confirm the delivery date. The increasing number of variants made it almost impossible to forecast the demand for different configurations, fabrics and colours. The MRP calculations for such a wide product-range became time consuming, imprecise, and cumbersome. Frequent delays and rush-orders, and therefore overtime was common. A complex layout, organised around a central store room, contributed to worsen an already unsatisfying operations situation.

10.5 Design

It was decided to implement a new operations model that would allow materials to flow rapidly from suppliers to the final customer. The new operations model was based on the following motto:

Make only what someone is willing to pay for – NOW!

This motto implied that the production had to become very fast and flexible in order to handle the large demand variations in product mix and volume.

The new operations model was based on an assembly-to-order interaction strategy. Rather than making chairs to a final-goods stock, final assembly should pick components from a buffer and assemble the chair directly on customer order. This solution should make it possible to produce a customised chair (as long as the product configuration was standard, and the production load was less than 600 chairs per day) in one to two days. The implementation of the new operations model brought a long new planning and control methods, a new layout, a more efficient order process, new routines for inbound and outbound transport based on bar codes, and a closer collaboration with suppliers and distributors

10.5.1 The new control model

Figure 79 shows the new principal control model for HÅG.



Figure 79 New principal control model

Figure 79 shows the processes, buffers, material flows, information flows, and control methods in the new flow-oriented control model.

10.5.2 Processes

Manufacturing operations

Customer-specific manufacturing (seam, upholstery, final assembly, packing) was controlled by customer-specific work-orders. Work orders (one order for each chair) were sent to Protex. The work order was attached to the cover and specified all down streams operations on the chair. The principle was that orders were pushed through the manufacturing process from seam at Protex to packaging and distribution. First, Protex should make the covers, secondly, upholstery should complete the seat and back, thirdly, final assembly should finalise and pack all components for a particular chair, and finally, the chair should be distributed to the customer.

Part production and sub-assembly was controlled by the stock-levels of buffers that were placed between processes. Parts and components were pulled through the manufacturing process from mechanical operations to the component buffer that supported final-assembly. The material flow between processes was based on a customer – supplier relationship. Sub-assembly should supply final-assembly, varnishing should supply sub-assembly, and mechanical should supply varnishing.

Office operations

The order management process was radically simplified. The new process was based on a available-to-promise system that enabled order handlers to immediately promise delivery dates. See the process scheme in Figure 80.



Figure 80 The new order handling process

Figure 80 shows the major steps in the order handling process. Three order handlers used the system to place customers-orders on days with free capacity, and produce confirmed customer orders. Based on this information, a final assembly schedule, work orders, and procurement orders for special items, were created in Movex. Work orders were sent to production (to Protex and attached to the cover). Procurement orders for special items were sent to suppliers. All parts production and the procurement of standard items were controlled by kanban.

10.5.3 Resources and materials

A new flow-oriented layout was established, and the central inventory was removed. Instead, small buffers were established at each operations area in order to improve the flow of parts. The final-goods stock was also altered. This stock normally contained several thousand chairs. In the new solution, it became a distribution area that was emptied at a daily basis by the distributor. Based on a layout analysis, machines and inventory was placed more adequately to improve the spatial utilisation of the factory. The major principle was to physically group production processes that were dedicated to the same product families, and to ensure a one-way flow between these groups. The new layout is illustrated in Figure 81.



Figure 81 The new layout

Figure 81 shows the new layout and segmentation in operations areas. Each stage is defined as an operations area for the mechanical operations, welding, and varnishing. The sub-assembly operations were segmented in two areas, one for high volume products and another for low-volume products. In the final-assembly, dedicated assembly lines were established for each product line. The simplified material flow and the new operations model resulted in shorter throughput times and reduced inventory. The new layout also made the operations system more adaptable for the introduction of new products. The latter was of great importance, because HÅGs policy was to introduce at least one new product per year.

10.5.4 Information

A new ERP-system was implemented with functionality for economy, accounts, order handling, production, inventory and procurement. The reason for a replacement of ERP-system was primarily that the old system did not support HÅG's international growth, and that the support was insufficient. The use of information technology, on the other hand, was severely increased in HÅG Fast. The project included major investments in an ERP-system and the development of a Available-To-Promise information system that was integrated with the ERP-system.

The new system, Movex, had modules that made it easy to extend functionality, and had local support in many countries. However, the decisive factor was that Movex had product configuration functionality. This functionality should make it easy to handle products with many variants, such as a chair with many different types of fabrics, without defining a new product structure for each variant. Movex was used to integrate HÅG and Protex in the same order handling system, but was not used for manufacturing planning and control. The planning and control functionality in Movex was based on MRP, and not very suitable for the small series and high number of variants that characterised HÅG. Within operations, Movex was used for the registration and processing of customer orders, work orders, distribution orders, procurement orders, and for invoice and inventory control. The production was controlled manually, and inventory levels were only updated when purchased materials and parts were registered (reception), and when final goods where registered (distribution).

In addition, a new IT-application for order handling was developed and integrated with the new ERP-system. When orders were received per. post, fax, and phone, they were registered in this order system. The maximum capacity (under normal conditions) was set to 600 chairs per day. The new system also functioned as a capacity planning system, and made it possible to determine the delivery date immediately for standard variants. The system was updated every 5 second and showed the capacity and load in final assembly. Figure 82 illustrates the order handling system.



Figure 82 IT-application for order-handling

Based on customer orders, the ERP-system generated a final-assembly schedule that was updated every day. The schedule specified the details of each chair and the time schedule for order completion. Based on schedule, work orders were generated that specified each chair, i.e. customer name and address, type of chair, fabric, colour, arm rests, and so on. The work order was printed on paper at Protex, and initiated the production of a cover. The cover was transported from Protex two times per day. The order was attached to the cover, and followed the chair through the entire process from seam, to upholstery, final assembly and packaging.

10.5.5 Organisation

Manufacturing organisation

A more decentralised control was required to achieve flow oriented manufacturing. Variations in the material flow that not could be eliminated, e.g. because of unreliable process technology, should be controlled of the people closest to the source of variation. The operator therefore was provided with the necessary information and authority to take some decisions locally. Decentralised responsibility for the prioritising of jobs should provide improved flexibility and responsiveness.

The manufacturing organisation was segmented in product-focused and coupled operations areas. Each operations area was a physically defined area with dedicated processes and operators. Each area served one or several product families. For example, sub-assembly was organised as two operations areas, one area for high volume products and a second area for low volume products. Each operations area was a semi-autonomous organizational unit, and had the responsibility to supply down-stream areas with parts, and each area was either controlled by customer order, kanban or forecast. All processes dedicated to a control area were grouped together, and the boundaries between each area were marked with colours.

Another important building block was the new working-time arrangement. In several years, HÅG had encouraged a company-culture where people took initiative and responsibility, and dared to create a different and better company. The employees gave away several traditional goods so HÅG should be able to handle volume variations in demand. For example, working hours were 1-2 hours longer in the high season, and shift work was used in periods. Such a market-adjusted working time arrangement was introduced to secure the jobs at Røros.

Administrative organisation

An important goal for HÅG was to take control of the total value chain. Customer service was moved from Oslo to Røros, and the responsibilities of the unit were enhanced. Personnel with different responsibilities were located together and cross trained in a new unit with the responsibility for order-handling/sales, manufacturing planning and control, procurement, and distribution. The new administrative operations area made it possible for customers to get information about the total value chain at one place (single-point-of-contact).

10.5.6 Planning and control

Production and procurement were controlled by three different control methods: by customer-orders, kanban, and forecasts. The processes closest to the customer were controlled customer orders. In seam, upholstery, final-assembly, and packing, operations should only be carried out when requested by a customer order. The final assembly was the bottleneck in the manufacturing process, and should be decoupled from part production by a component buffer. The component buffer was prerequisite for the available-to-promise planning, which promised due dates based on free capacity in the final assembly, and thus, assumed that components always were available. The component buffer was also the customer order decoupling point (CODP) that decoupled part production from customer specific processes. The task of mechanical operations, painting and subassembly was to refill the component buffer, and these operations were performed independently of customer orders.

Ordering and procurement should be controlled by kanban. Such a system provided a simple and visual overview of the material flow. The kanban system determines the maximum number of parts that could be stored in each buffer, and guides operators in their prioritising of jobs. The challenge was to dimension the kanban system (i.e. production capacities, buffer-levels, card numbers, and order quantity at each card), so that materials flows smoothly and cost-efficient. The exception in the part production was the procurement and initial machining and stamping of steel, which should be based on forecasts. The reason for this type of control was long set-up times on machines, and that the preferred supplier was unwilling to supply so small amounts of steel. The steel was the main material in all metal parts, and characterised by a relatively stable and predictable demand.

10.6 Suppliers

Suppliers that wanted to collaborate with HÅG had to agree on just-in-time contracts. The new type of collaboration required small volumes and frequent deliveries, and the implementation of a procurement process based on kanban. In order to ensure high delivery performance, a supplier development programme was carried out. The reasons for this initiative were:

- To develop a partnership with suppliers that wanted to be a just-in-time supplier
- To concentrate on a limited number of large suppliers that could support HÅG in their strive for competitiveness
- Long term contracts
- Mutual competence development

An objective with the development of "co-suppliers" was to reduce the number of suppliers from 200 to ca. 80. The purpose was to achieve higher volumes per. supplier, lower total procurement costs, more reliable quality, improved delivery precisions, and fewer and closer supplier relationships. The new solutions resulted in less planning and reduced the number of rush-orders.

10.7 Distribution system

The HÅG FAST strategy implied radical changes of the distribution system. The time guarantee scheme required a short transport times and predetermined freight costs for whole Europe. The scheme should enable dealers to give a exact price and delivery

date at early point of time. The delivery terms that were offered are illustrated in Figure 83.



Figure 83 Time guarantee scheme

Figure 83 shows the delivery terms for different markets in Europe. The scheme implied that deliveries from Røros to for example Germany, should arrive maximum 5 days after order confirmation (1-2 days production, 3 days transport). Final goods were transported to nearly the same destinations in Europe as the raw materials were collected from. It was therefore possible to coordinate the transport of raw materials and final goods in Europe. The new distribution system can be characterised by:

- coordination of inbound and outbound material flow
- delivery guarantee scheme from HÅG to the markets
- simplified routines for information handling and use of new information technology
- electronic tracking of goods

An important condition for the implementation of the new solution was that the distribution task and management could be sourced out to a single distributor. HÅG did not have resources or competence to run such a complex logistic themselves. They therefore choose to outsource this responsibility to a professional actor with a high competence and a well-functioning distribution system. Every day at 1400 and 2200, the production was picked up at Røros and distributed to HÅG's customers. In order to utilise the transport capacity, the distributor transported raw materials to HÅG on the trip back.

10.8 Results

HÅG FAST resulted in a radical improvement of the competitiveness in almost all competitive dimensions (better flexibility, shorter delivery time, better delivery precision, and reduced costs in production and distribution). The effects of the changes were summarised by manager Ole Holden in 1994: "The implementation of flow oriented manufacturing a couple of years ago has been very successful for HÅG. We have become more competitive, both regarding product quality, delivery time and price".

The project resulted in the following improvements from 1991 to 1994:

- The sales were increased from 118 NOK to 230 NOK
- The final goods inventory was eliminated and chairs were distributed daily
- The inventory turnover was increased from 7 to 14 times per year
- The throughput time was reduced from 55 to 26-27 days
- The order-handling time was reduced from 3 to 1 day
- The production volume increased from 143 400 to 167 800 chairs. This increase happened without significant investments in machines and equipment.
- The delivery precision to customers was improved from 87 percentage to 98 percentage
- The delivery time to customers was reduced from 21 to 5 days
- Number of suppliers was reduced from 200 to 120
- The delivery precision from suppliers was improved to 95%
- Delivery times from suppliers to HÅG was reduced from 22 to 2,5 days

These are improvements that support the mass customisation strategy, and that have provided a competitive advantage for the company.

10.9 Conclusion

HÅG FAST set an example for other companies that want to improve their competitiveness through an improvement of operations. Much of the success was based on innovative solutions that were developed and realised in close collaboration between SINTEF and HÅG. The control model was used actively in the development process, and was an important tool to create a common understanding among managers and researchers. The result was state-of-art solutions that were well adapted to the company needs.

For HÅG, mass customisation was the strategy that was most suitable. Assembly-toorder and direct distribution made it possible to compete on delivery time from Røros to Europe. Modularisation and standardised components ensured efficient production, and provided the customer with a range of optional configurations. HÅG therefore could satisfy the customer's need for freedom of choice, and simultaneously compete on price and delivery performance.

For this research, the case study has been useful to demonstrate the performance improvements that can be achieved by flow manufacturing. The case study has also served as the means to demonstrate how the enterprise reengineering methodology can be used to structure and support an improvement effort. The tools developed in this thesis have to some extent been used to explain the reengineering. The strategy checklist was used to structure the strategy process at HÅG, and illustrate the critical decision areas that were targeted to improve lead times and precision. The operations model-set was used to represent some of the six perspectives that should be included in enterprise mapping, analysis and design.

Even though this case study is based on historic events that were carried out without the participation of the author, the conclusion is that the case study has demonstrated the usefulness of the methodology for understanding and structuring improvements projects.

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Case study

11. Conclusion

11.1 Research story line

Point of departure

The major concern of this research has been manufacturing enterprises, and how these can improve their competitiveness through a systematic reengineering that merges best practice methods into a unique solution for manufacturing and office operations. To support such efforts, enterprises have been viewed not only from a process perspective but also from a resource, materials, information, organisations, and control perspective. Such a reengineering is seen as a way to realise operations strategy.

According to Voss (1995), operations strategy consists of four distinct research fields: 1) competing through operations, 2) strategic choices in operations strategy, 3) best practices, and 4) the process of operations strategy development. This research has mainly been conducted within the research field termed best practices, which focuses on the choice and implementation of best practices in order to improve performance.

Operations strategy is a continuous effort of aligning and extending operations capabilities and market requirements. However, most enterprises have not managed to adopt best practices in a way that fully exploit their operations resources and support business strategy. Thus, the research problem addressed in this thesis has been:

• The lack of success experienced by many manufacturing enterprises in their efforts to close the gap between market requirements and operations capabilities by implementing best practice methods.

A brief review of the research area concluded that there was a need for new theories, methods, models and techniques to guide and support enterprises in their efforts to close this gap. The difficulties experienced in projects aiming to improve competitiveness by implementing best practice methods (and thus, close the gap) are caused by several sub-problems that were addressed in this thesis:

- The disconnection from business strategy
- The lack of enterprise models that provide the big picture
- The lack of understanding of human and organisational factors in improvement projects
- The lack of concrete and practical guidance in some best practice concepts

Many issues could be studied in order to address these problems; however, the scope of this thesis was restricted to;

• Manufacturing and office operations in an enterprise (group of departments, plant, or group of closely located plants), and how these operations could be modelled and improved.

Objectives

The overall objective for this research was:

• To establish enterprise reengineering as an approach that enables manufacturing enterprises to achieve fit between market requirements and operations capabilities.

Enterprise reengineering is a sub-discipline of enterprise engineering that coins "extended" process reengineering. However, the discipline has previously not been very well defined. This research therefore aimed to establish enterprise reengineering as a strategy-driven and model-based approach that takes a systems approach to process reengineering. The overall objective was divided into more specific objectives:

- To develop a strategic framework for enterprise reengineering
- To develop a consistent and practical enterprise reengineering methodology to support the formulation and realisation of operations strategies
- To develop architecture for conceptual enterprise modelling that ensures a coherent, decomposed, and holistic picture of enterprise operations
- To establish "flow manufacturing" as a (optional) best practice programme for enterprise reengineering

Together, the strategic framework, the methodology, and the modelling architecture should enable enterprises to achieve their performance objectives through an enterprise reengineering effort. In cases where an enterprise mapping and analysis concludes that improvements in manufacturing planning and control, order management, layout and flow, or inventory, should be performed, the flow manufacturing programme should provide practical guidance and a set of principles to support reengineering.

Limitations

The research was limited to the following research areas:

- Strategic decisions that shape operations processes (such as the choice of a best practice method) and how such strategies can be formulated and realised
- Enterprise reengineering, a sub-category of enterprise engineering, which focuses on the improvement of operations processes
- Architectures for conceptual enterprise models that can be used for human sense making and communication in enterprise reengineering efforts
- Change management aspects that should be addressed in order to enable participatory design and knowledge-creation in enterprise engineering projects
- A few best practice programmes are believed to support process orientation of enterprises. One such approach, flow manufacturing, was studied in detail.

Research approach

The scientific approach adopted in this thesis was the systems approach. The objective of this approach is to define a system, its components and the relationships between them. Most of the work in this thesis was focused on developing new "system" theory, which included, among others, an enterprise reengineering methodology useful for changing a particular type of system (i.e. manufacturing enterprises) from the existing strategic position to a future strategic position.

The utility of the methodology for analysing and understanding enterprises was demonstrated through a historical "case" study of a reengineering process that took

place at HÅG AS in the period 1991-1993. The main reason for the choice of study was the remarkable effects that were achieved in this particular reengineering effort. The case study was based on qualitative data collection methods: direct observation, interviews and documentation review.

The research of the thesis is also based on several field studies. The same methodology has been applied with success at Raufoss Chassis Technology, Hydro Automotive Structures, Protex AS, and Hagen Treindustrier AS.

The outcome of this research

The work carried out in this thesis has resulted in a strategic framework for enterprise reengineering (Chapter 3), and a methodology (Chapter 7 - 9) that include:

- A operations strategy checklist (Chapter 2)
- Four flow manufacturing design principles (Chapter 4)
- An architecture for conceptual enterprise modelling (Chapter 5)
- Seven change management principles (Chapter 6)
- A procedural guide for enterprise reengineering (Chapter 7, 8 and 9)
- An operations performance audit sheet (Chapter 8)
- A five-step approach to flow manufacturing reengineering (Chapter 9)

11.2 Evaluation of quality of research

Without rigor, research is worthless, becomes fiction, and loses its utility (Morse et. al., 2002). This research is therefore evaluated on its contribution to knowledge, contribution to practice, theoretical and practical foundation, and methodological coherence.

11.2.1 Contribution to knowledge

Research should contribute to existing knowledge with theories and constructs not yet explored in existing knowledge. The contributions of this research correspond to the research objectives defined in chapter 1:

• Enterprise reengineering is established as an approach that enables manufacturing enterprises to achieve fit between market requirements and operations capabilities.

This overall contribution is based on several more specific contributions:

- A strategic framework for enterprise reengineering
- A strategy-driven and model-based methodology for enterprise reengineering
- An architecture for conceptual enterprise modelling
- A best practice programme for flow manufacturing

Enterprise reengineering approach

Even though studies on operations strategy development and enterprise engineering have been around for quite some time, the issue of enterprise modelling in operations strategy development is a relatively new one.

Best practice programmes constitute a central research field within operations strategy, and several studies can be found that highlight the need for strategic

approaches to merge best practice methods "so that they become complementary rather than competitive" (Euske and Player, 1996), or to provide "a unique strategy customised to the demand needs" (Lowson, 2002). These studies mainly focus on the classification of best practice methods (in terms of focus area and performance objectives) and do not provide much guidance into how to actually combine and implement them. To quote Lowson (2002) "Further research is of course necessary. The process by which these strategies are developed and deployed is a prime area for investigation". Several studies can also be found that highlight the need for coarse conceptual enterprise models to support enterprise engineering projects at the "macro level" (Ortiz et. al., 1999) "because of their informal, easy to grasp, syntax or formalism" (Vernadat, 1996). However, few studies can be found that aim to use conceptual enterprise modelling architectures as the means to drive operations strategy development in general, and to implement best practices in particular. One exception is Maull et. al. (2003) who identified "taking a strategic approach" and "creating business process architectures", as two central themes for effective implementation of BPR.

In this thesis, enterprise reengineering is introduced as an approach that combines research within operations strategy, and particularly research regarding best practices, - with research within enterprise engineering, and particularly research regarding enterprise modelling architectures. Enterprise reengineering is established as a systematic and model-based approach for enterprises to effectively and efficiently create fit between market requirements and operations capabilities. Enterprise reengineering mainly targets the infrastructural aspects of operations strategy, and does not support all types of strategy developments equally well. The focus is on long term decisions regarding operations processes, and how they are organised and controlled. The process focus is adopted from BPR, but compared to BPR, enterprise reengineering represents a systematic and holistic approach to enterprise improvement. The total transformation process can be decomposed into a large collection of concurrent processes executed by a set of operations entities that contribute to business objectives. Enterprise reengineering is essentially a matter of modelling and improving these processes.

Strategic framework for enterprise reengineering

A second theoretical contribution is a strategic framework that represents the main issues in enterprise reengineering and how they are connected. The framework depicts enterprise reengineering as an approach that aims to transform the enterprise from an existing operations model (and the strategic position induced by it), to a new operations model that contributes to an improved future strategic position. This transition should be guided by operations strategy, and supported by:

- Design elements from best practice programmes such as flow manufacturing and lean manufacturing
- An architecture for conceptual enterprise modelling
- Change management principles

Strategy-driven and model-based methodology for enterprise reengineering

A third theoretical contribution is a methodology for enterprise reengineering that supports improvement efforts through a procedural guide and a toolkit. Enterprise reengineering has been regarded as a sub-discipline of enterprise engineering that coins an "extended" process reengineering. However, the discipline has not been very well defined regarding terms, scope, models, methods etc. In this thesis, a strategydriven and model-based methodology has been developed that enables a systems approach to enterprise reengineering.

The methodology guides the decision-maker through the phases of an enterprise reengineering process defined as strategic planning, and operations mapping, analysis, design, and implementation.

- *Strategic planning* is supported by a stepwise procedure to understand and revise business objectives, translate market requirements into performance objectives, evaluate the current operations strategy, and finally, based on the knowledge gained from operations mapping and analysis, to revise the operations strategy. The strategy planning is also supported by a strategy checklist that enables the decision-maker to evaluate major decisions regarding their contribution to overall performance objectives, and their effects on various operations areas.
- *Mapping* is supported by a modelling architecture that enables the decision-maker to create an AS-IS operations model, which represents the enterprise through six different views. The AS-IS operations model-set is a tool to support understanding and communication, and to enable the decision-maker to get a holistic picture of the enterprise.
- *Analysis* is supported by an operations audit that analyses broad areas of strengths and weaknesses, and thus helps the decision-maker identify improvement areas for the reengineering effort.
- *Design* of new solutions is visualised in a TO-BE operations model. In addition, a five-step procedure for flow manufacturing is provided for improvements in manufacturing planning and control, order management, layout and flow, or inventory.
- *Implementation* is supported by a set of change management principles that enable participatory design and knowledge creation.

This methodology represents a powerful approach for enterprises that wants to achieve fit between operations capabilities and market requirements through extended process reengineering.

Architecture for conceptual enterprise modelling

A core element of the methodology is an architecture for enterprise modelling which can be used to represent the AS-IS and TO-BE status for operations. In such an operations model, the processes are viewed in the context of the enterprise's resources, material flows, information flows, organisation, and control methods. This enables decision-makers to understand their strategy formulation and realisation efforts from different perspectives. Conceptual enterprise models can be developed in a range of different ways and with more or less formality. The proposed architecture provides a systematic approach for modelling the most relevant views of the enterprise.

Despite some practical limitations, such as the use of redundant models and lack of detailed computer processing abilities, this architecture for operations modelling is a very useful tool for enterprise analysis and design. The architecture consists of resource-, materials-, information-, process-, and organisation modelling views. In addition, the crucial aspects of these models can be synthesised in an overall control model, which provides a holistic picture of the enterprise.

Best practice programme for flow manufacturing

An enterprise reengineering effort can use a range of best practices (such as a lean manufacturing, BPR, or quick response manufacturing) to improve performance. One such approach, flow manufacturing, is introduced in this thesis. Flow manufacturing is a form of manufacturing where materials flow is balanced and runs rapidly through a set of operations areas in an enterprise. Flow manufacturing was initiated at NTNU/SINTEF in the 1980s (Quistgaard et. al 1984) and has been implemented in more than 20 Norwegian companies. The contribution of this research is to:

- Broaden the scope of flow manufacturing from process design and layout design to also encompass job design and MPC design.
- Propose a set of design principles to create effective flow and short throughput times. These are:
 - Creating product-focused operations areas
 - Creating a flow-oriented layout
 - Creating multi-skilled and cross-trained operations area teams
 - Decentralising planning and control to operations areas
- Propose a five-step approach to flow manufacturing reengineering. These are:
 - 1. Creating product focused operations areas
 - 2. Dimensioning each operations area in terms of equipment and people
 - 3. Developing enterprise layout and flows
 - 4. Creating operations area teams
 - 5. Modifying MPC system and information flows

A flow manufacturing reengineering based on these principles should be viewed as one (optional) approach to improve competitiveness. However, the experience from the case study and several field studies is that flow manufacturing has resulted in performance improvements such as shorter throughput time, shorter response time to customer orders, lower inventory levels, improved product quality, and lower unit costs.

In conclusion, the research objectives described in this thesis have been fulfilled, and the research has provided some important theoretical contributions to the understanding and improvement of manufacturing enterprises.

11.2.2 Contribution to practice

The research outcome should prove to be useful and relevant to practitioners. Several field studies have been carried out to apply the methodology developed in this thesis. A list of companies and an overview of the application areas are given in Table 40.

	Мар	ping	Analysis	Des	sign	Implementation		
	Op. Strategy	Op. Model	Audit scheme	Op. Strategy	Op. Model			
HÅG	Х	Х	Х	Х	X	X		
HAST	Х	Х	Х	Х				
RCT				Х	Х	X		
Protex	Х	X	Х	Х				
Hagen	Х	X			X	X		

Table 40 Application of enterprise reengineering methodology in Norwegian companies

Table 40 shows that the enterprise reengineering method has been applied to structure the historical study of HÅG. In addition, the methodology has been applied in several Norwegian manufacturing companies.

Raufoss Chassis Technology (RCT) was in 1999 nominated as the sole supplier of aluminium control arms to the new General Motor Epsilon Platform. A new manufacturing enterprise was therefore established at Raufoss, Norway, to serve Opel Astra and Saab. An early version of the reengineering methodology was used in 2001 to design and implement an operations strategy and operations model-set for the new enterprise (Alfnes et. al. 2002).

Hydro Automotive Structures (HAST) is a manufacturer of aluminium components to the European automotive industry. The reengineering method was used in 2005 to map and analyse the M-24 production line at Raufoss, Norway. The current status of the project (01.06.05) is that a revised operations strategy has been proposed by SINTEF. Further research is necessary to develop a new and improved operations model-set for the enterprise (Hagen et.al., 2005).

Protex AS is the sole supplier of seat-covers to HÅG. The reengineering method was used in 2005 to map and analyse their major plant located in Ålen, Norway. The current status of the project (01.06.05) is that a revised operations strategy has been proposed, and some changes are under implementation. Over the next few months, a new and improved operations model-set will be developed for the enterprise (Andresen et. al., 2005).

Hagen Treindustrier AS is one of the ten largest stair-manufacturers in Europe. The reengineering method was used in 2003 to map, analyse, and reengineer their major plant located in Stryn, Norway. A new operations model was designed and is partly implemented today (01.06.05). The implementation is still ongoing under the supervision of the author and other researchers from SINTEF (Alfnes and Skjelstad, 2004).

The following points summarise what this author believes to be the major contribution to practice of this research:

• The operations modelling architecture has improved the modelling effort in all field studies.

- The enterprise reengineering methodology has been used successfully to structure mapping and analysis at HAST.
- The operations audit has been successfully used by SINTEF to evaluate and bring insight about operations performance in two Norwegian companies (HAST and Protex).
- The operations strategy checklist has been used to identify and evaluate the operations strategy in RCT, HAST, and Protex.

The major finding from these field studies is that the enterprise reengineering methodology provides a very useful way to structure a reengineering effort, and also a very useful "toolbox" to support the activities in strategic planning, and operations mapping, analysis, design and implementation.

11.2.3 Theoretical, practical and methodological foundation

The research should be based on sound knowledge of existing theories in the area of investigation. Although focused on enterprise reengineering, the theoretical foundation of this thesis is comprehensive. The reengineering of enterprises is viewed from the perspectives of operations strategy, enterprise engineering, enterprise modelling, and change management. In addition, the field of flow manufacturing is reviewed in order to propose a set of (optional) reengineering principles within the area of process design, layout design, job design, and MPC design. Together, these fields of theory cover many of the issues related to a strategy-directed and effective improvement of enterprises.

The practical foundation is also comprehensive. Development of new theories should develop from synthesis of data which is obtained from the use of existing theory in practice. This research is founded in a practise developed at SINTEF during two decades of flow reengineering projects in Norwegian Industry. The most successful and best documented of these projects is the reengineering of HÅG, which is the case-company in this thesis.

11.2.4 Methodological coherence

The research question must match the research method, which should match the data and analytic procedure. The approach taken in this research follows Arbnor and Bjerke's (1997) system approach. Following their view of the system approach, this study has:

- Determined the type of system (i.e. the enterprise from an operations point of view)
- Described the system (i.e. determined the decisions categories or modelling views)
- Guided how the system should be approached (i.e. how to map, analyse, design, and implement changes in a system)

Further, the research has followed the main heading of Arbnor and Bjerkes's (1997) description of a system study to determine relations, describe, and guide. That is, a system analysis should be conducted using traditional data collection techniques adapted to the specific study situation and made into methods via methodical

procedures; i.e. by using secondary material, direct observation [e.g. case studies], and interviews. The scientific approach to this research was based on theoretical studies and open sources of information, and interviews with representatives from HÅG and SINTEF. Furthermore, a case study was used to demonstrate the applicability of the methodology developed in the research.

The researcher has not endeavoured to create a hypothesis to test in the study, but instead tried to determine the type of system, and to describe, determine a relation, forecast, or guide the system. The results of a systems approach theory does therefore not result in an absolute theory (as understood in the analytical approach). The results and experiences can only be used as mental inspirations (analogies) in the study of systems with similar orientation and content.

Based on the examination in this section and the research approach taken, this research is considered valid and reliable.

11.3 Future work

Based on the results in this thesis, several suggestions for further research are proposed.

To establish enterprise reengineering as an distinct discipline

Enterprise reengineering is a relatively new approach to enterprise improvement. Even though some work has been carried out in this thesis to carve out the fundamentals of enterprise reengineering, further work is necessary to establish enterprise reengineering as a distinct discipline. This research should define assumptions and terms, and develop concepts, models, methods, and architectures. Some suggestions to support this research are proposed below.

To establish a set of design elements for operations strategy development

Enterprise reengineering is based on the use of design elements from flow manufacturing, lean manufacturing, quick response manufacturing etc. Further work is necessary to describe and classify a set of best practice methods as design elements in operations strategy. The content of each best practice method should be described (design principles, procedures, and tools) and each method should be classified in terms of the affected strategic decisions areas and major performance objectives. This should enable decision-makers to evaluate a set of predefined practice methods and merge them into a unique strategy.

To develop a computerised methodology for enterprise reengineering

Further work is necessary to integrate models, tools, and methods of the enterprise reengineering methodology into a common ICT-platform.

- Strategic planning should be supported by a set of predefined best practice methods and functionality to evaluate major decisions regarding performance objectives and decisions areas.
- Mapping should be supported by a dataset structure and a predefined set of information categories to structure and speed up data collection processes.

- Analysis should be supported by additional tools for analysis of operations. Examples of such tools are systems for computer-based analysis of materials flows, and a tool for performance measurement before and after enterprise reengineering. In addition, the operations audit scheme should be refined through the definition of a set of standard questions to rate performance.
- Design should be supported by predefined design elements from flow manufacturing and other best practice programmes.
- Implementation should be supported by a learning module, which provides stakeholders with knowledge in operations strategy development, enterprise modelling, and best practice methods.

To develop a computerised modelling architecture for the extended enterprise

The modelling scope should be broadened to encompass several enterprises in a value chain. This implies that the model should also represent value chain structure and flows, integration of processes across enterprise boarders, value chain information systems and flows, and best practice methods for value chains (such as Vendor Managed Inventory). The architecture should be computerised and improved in order to support rapid development of operations models. This implies to extend and refine the set of templates for each view, and to improve the dependability and relationships across models.

Further case studies

Further case studies should be carried out in order to explore and document how enterprises can improve their operations capabilities through enterprise reengineering. Some key issues in these case studies (in addition to improved performance for the case companies) should be to refine the mapping dataset and modelling architecture, and to further test and document the effects of flow manufacturing and other best practice programmes.

11.4 Closure: The key points of the enterprise reengineering methodology

Enterprise Reengineering

The enterprise reengineering methodology supports manufacturing enterprises in efforts to improve operations performance.

The objective is to achieve fit between operations capabilities and market requirements through a reengineering of operations processes.

The methodology is model-based and applies an enterprise modelling architecture to represent different views of enterprise operations.

Reengineering efforts are typically carried out when some problem makes it difficult for operations to achieve their performance objective.

The enterprise reengineering process includes:

- Mapping and evaluating the *current operations strategy*, i.e. the strategic decisions regarding operations (such as the implementation of a best practice method) and the affected decisions areas and performance objectives.
- Mapping the *AS-IS operations model*, and representing the enterprise graphically from a resource-, material-, information-, process-, organisation-, and control view. The control view (termed control model) should represents a synthesis of the other views and provide a holistic picture of how operation processes are organised and controlled.
- Analysing the current operations model on operation capabilities (operations processes, control methods, layout etc,) and their ability to meet the demand situation.
- Analysing operations capabilities in an *audit sheet* in order to rate the performance in broad areas of strengths and weaknesses. Based on this analysis, improvement areas are identified and problems to be solved are formulated.
- Designing a *revised operations strategy* that targets the improvement areas identified in the mapping and analysis.
- Designing a *TO-BE operations model* that represents the new solution for operations. The design efforts can be supported by best practice methods such as flow manufacturing.
- Implementing the operations model.



Figure 84 The enterprise reengineering methodology

11.5 References

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