# Enterprise Modelling supported by Manufacturing Systems Theory

Odd Myklebust

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*And you see that every time I made a further division, up came more boxes based on these divisions until I had a huge pyramid of boxes. Finally you see that while I was splitting the cycle up into finer and finer pieces, I was also building a structure. This structure of concepts is formally called a hierarchy and since ancient times has been a basic structure for all Western knowledge.*

ZEN AND THE ART OF MOTOR CYCLE MAINTENANCE
Robert M Pirsig

# Preface

This work started in 1996 as a part of the Strategic Research programme (1995 -1999) in Production Engineering where one of the main topics was Enterprise Modelling. The programme was a joint action between SINTEF (The Foundation for Scientific and Industrial Research at the Norwegian Institute of Technology) and NTNU (The Norwegian University of Science and Technology) financed by the Research Council of Norway and SINTEF.

The main research areas for the Strategic Research Programme were in addition to Enterprise Modelling:

- Virtual Manufacturing
- Extended Enterprise
- Manufacturing Processes

First I want to thank my supervisor professor Øyvind Bjørke for helping me find the main research topics and for motivating me to start on the enormous challenge to combine architectures of enterprise modelling with logic system theory. I also want to thank him for his help on the programming cases that illustrate how the approach can and will work. I also want to thank both Øyvind and his wife Karin for their great hospitality and for the times I visited them in their home in Germany.

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I want to send a special thank to my friend and former SINTEF colleague Stein Dale who discussed different issues with me and gave critical comments to my writings.

Thanks also to the Research Council of Norway and SINTEF for financing the strategic program where my scholarship was founded.

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# Abstract

There exist today a large number of enterprise models or enterprise modelling approaches. In a study of standards and project developed models there are two approaches: CIMOSA "The Open Systems Architecture for CIM" and GERAM, "Generalised Enterprise Reference Architecture", which show a system orientation that can be further followed as interesting research topics for a system theory oriented approach for enterprise models.

In the selection of system theories, manufacturing system theory is interesting and promising to adapt or extend to further synthesising and usage of enterprise models.

Today the design and creation of an enterprise model are based on a given architecture and available even though this is not always practical. When it comes to execution and operational phases of the model, the possibilities are more limited.

**Manufacturing system theory** [Bjørke 1995] was developed to describe system-oriented approaches to manufacturing systems including product configuration and design processes. This includes a large number of disciplines like mechanics, cybernetics, material science etc. on the physical side and planning activities, economical aspects and optimisation processes on the human side. The theory is based on geometry as the foundation and the methods within the theory are related to concepts of connections. The analysis of the manufacturing systems is the prime area for the usage of this theory and is important in order to bring a science base into manufacturing. But the theory can be used in a more generic way.

**The theory of logic** [Møller 1995] relates also to the concept of connections, being expressed as logic arguments. The theory is generic and has been applied to different model approaches e.g. product configuration, scheduling and planning, railway logic control. This theory of logic is also fully applicable in manufacturing system theory. The theory of logic and the manufacturing systems theory are both based on geometry or more precisely expressed the geometric funded theory of connections.

The main requirement for the enterprise model architecture to be used together with the theory of logic is that it can be divided into a 3D orthogonal space with unique defined axis. In this work a 3D space based upon product, process and organisational axis is preferred, also called the PPO-model.



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In this study combination of the enterprise modelling architecture, GERAM ISO 15704, and the theory of logic are used to show how systems theory can be used in control and management of operational phases of enterprise models. The usage of logic theory within enterprise modelling gives solutions on management and control issues in an operational phase of the product model. If is important to emphasis that this is not an approach for populating or transfer of operative data into a model. The integration of theses theories are illustrated through examples that show modelled entities of an enterprise in operation within areas of:

- Execution of operative manufacturing unit
- Organisational and strategic issues
- Enterprise planning with aspects of uncertainty

An own PPO model for feature based integration within product design and process planning has been developed to show that alternative more simple and detailed architectures also can be used.

## Sammendrag (Norwegian)

Over tid har det vært utviklet et stort antall virksomhetsmodeller eller tilnærminger til virksomhetsmodeller. I en studie av standarder og prosjekter for utvikling av disse er det to modell-arkitekturer som synes mest interessante som videre forskningstema:

- CIMOSA er en åpen systemarkitektur som egentlig er basert på CIM-tankegang.
- GERAM er en generell referansearkitektur for virksomhetsmodellering.

Innen systemteori er det 'Manufacturing Systems Theory', (produksjons-teknisk systemteori) som det er interessant å tilpasse for videre for bruk innen virksomehtsmodellering. Utforming av en spesifikk virksomhets-modell består av selve modellutviklingen ved hjelp av verktøy og metoder som gjerne er utviklet sammen med modellen. Dette er vanligvis tilstrekkelig, selv om det ikke alltid er det mest praktiske. Når det kommer til operasjonelle faser og implementering av modellene er mange metoder svært begrenset.

Produksjonsteknisk systemteori [Bjørke 1995] ble utviklet for å beskrive systemorienterte tilnærminger til produksjonssystemer som inkluderte produktkonfigurasjon og designprosesser. Disse omfatter mange disipliner som mekanikk, kybernetikk og materialvitenskap på den fysiske siden. Når det gjelder menneskelige faktorer er det planleggingsaktiviteter, økonomiske aspekter og optimalisering som blir inkludert. Teorien er basert på geometrisk grunnlag og metodene innenfor teorien ser på forbindelseskonsepter. Selve analysene av produksjonssystemene er hovedområdet for anvendelse av denne teorien og er viktig for å bringe et vitenskapelig fundament inn i produksjon. Men teorien kan også anvendes mer generisk.

Logikkteori [Møller 1995] forholder seg også til forbindelser som begrep, der disse uttrykkes som logiske argumenter. Teorien er generisk og har blitt brukt i ulike modelltilnærminger som produktkonfigurasjon, tidsplan-legging og planlegging og logisk kontroll av jernbanesystemer. Logikk-teorien med sine logiske elementer er også fullt anvendbar innen produksjonsteknisk systemteori. Både logikkteorien og produksjonssystem-teorien baserer seg på geometri, eller mer presist uttrykt, på geometrisk basert forbindelsesteori.

Hovedkravet for den virksomhetsmodelleringsarkitekturen som skal benyttes sammen med logisk systemteori er at den kan bli organisert i et tredimensjonalt koordinatsystem med unike akser. I denne avhandlingen er det tredimensjonale rommet avgrenset med en produktakse, en prosessakse og en organisasjonsakse, også kalt PPO modell.

I dette arbeidet benyttes GERAM, ISO 15704, som valgt arkitektur for en virksomhetsmodell. GERAM benyttes i kombinasjon med logikkteori for å vise hvordan systemteori kan anvendes for kontroll av en driftsfase i en virksomhetsmodell. Det er viktig å gjøre oppmerksom på at løsningene ikke har til hensikt å håndtere implementering av operative transaksjonsdata for virksomheten i modellen. Integrasjonen av teoriene er illustrert gjennom eksempler som viser modellerte entiteter i en virksomhet i drift. De aktuelle områdene for dette er:

- Oppstart av en operativ produksjonsenhet
- Drift og strategiske forhold
- Virksomhetsmodellering med aspekter av operativ usikkerhet

En egen PPO-modell for integrasjon mellom konstruksjon og prosessplanlegging basert på feature er også utviklet for å illustrere alternative og enklere virksomhetsmodeller enn GERAM-arkitekturen.

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# 1. Introduction

Enterprise modelling and use of enterprise models are not a new topic. They have existed since mankind started to do commercial business. Enterprise models (descriptions or recommendation on how to run a business) have been written down or communicated from person to person. The 'new' aspect within Enterprise modelling is to use information and communication technology.

Enterprise modelling has many principles and purposes. Many approaches, architectures, systems and tools to handle enterprise modelling have been developed. Only a few relevant once are however mentioned and focused in this thesis. Some approaches cover similar areas others are more complementary. But any enterprise model aims to make people understand, communicate, develop and execute solutions to business or technical challenges.

Different industry streams have different requirements to applicable models. An Enterprise model made for oil and gas industries differs much in content and form from models made for automotive or food and drink industries. However, many common aspects and structures can be found between sectors and many of the commonly known approaches that exist today are developed, structured and standardised on a generic architectural base.

In the 1990's there was a great effort in order to extend CIM (Computer Aided Manufacturing) models into enterprise models. This can be considered as approaches that started bottom up and later extended their architecture. CIMOSA (CIM-Open System Architecture), whose framework is very much based on the ESPRIT 1 project 688, AMICE is a good example of such a development. The CIMOSA results are extensive and have been of significant value for utilisation of enterprise modelling. There are also Top Down approaches in Enterprise Modelling as a method to understand complex organisations by the models.

But it is quite clear that a model can not comprise totally the real situation. Just like in any other model there has to be defined a "mini-world".

*Logic as a base for Enterprise Modelling*

The first plan for writing the Thesis was to make enhanced integration and information flow or let's say a more knowledge based integration through the discipline interfaces within a enterprise model. More content and more logic should be transferred between lifecycles and disciplines, product, process and organisational matter should be included. CIM solutions so far



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had not managed to cover these three aspects together in a satisfactory way, and there were many industrial examples of challenges and enormous use of resources to fully implement PDM or ERM IT-systems.

During my work over the recent years basically on EU supported and Norwegian research projects I became familiar both with CIMOSA and GERAM, 'Generalised Enterprise Reference Architecture', enterprise models framework and architectures. After I had a course in System Theory with main focus on Logic my interpretation of these enterprise architectures became totally changed. Could there be more than visual similarity between the presentation of multiple logical variables and the CIMOSA and GERAM architectures? I started to work on this, and found that it was possible to use such frameworks as a base for a theory of logic to support enterprise modelling.

The connection with logic system theory and enterprise modelling is in this work focus mainly focussed on the GERAM or GERA (a part of GERAM) architecture, described in chapter 3.5. The demonstrations of connections show logical calculations of cases within an enterprise programmed with APL in the logical interpreter APL 2000.

Another difference of using logical operators on these models is the possibility to support execution and operational cases of the enterprise. The solution so far has been to convert enterprise design models into traditional software platforms supported with relational or object oriented database management systems. Even though a lot of supporting computerised tools for this has been made it has so far been a time-consuming task to convert and transform a conceptual model into an operational phase of a company. A Logic System Theory approach can also be used as a base for realistic simulation of parts of an enterprise during enterprise design or improvements.

The combination of a enterprise modelling architecture and systems theory focus on solving management and controlling problems in the operational phase of enterprise modelling. To fill the model with data and data schemas is not done with system theory. The product model standard ISO-STEP shortly described in chapter 2.5.5 has methodology for that. Such methodologies of implementing schemas for data storage or transfer is a quite different but however related approach. The entities or building blocks in the model structure or data schemas are defined as logical variables and can be used in calculations for logical control of the model.

This thesis is a theoretical thesis. The methodologies and theories that the thesis builds on are however all been used in industry. The examples used can illustrate real situations and builds on experience, but they are all fiction. To have the freedom to work on a purely theoretic basis have been liberation after many years with applied research.

# 2. Enterprise modelling

### *2.1 Definitions and Interpretations for Enterprise Modelling*

In Appendix A, a large number of definitions are included. In this introductory chapter only a few definitions or interpretations for the main subject of this work are presented.

*Enterprise*

The word enterprise has two main meanings:
- an undertaken project, specification
- a business venture or company

In enterprise modelling both definitions are in use. Enterprise can be a synonym for a company or today we often talk about extended enterprises, companies in networks or complex projects. Different enterprise modelling techniques try to cover all these issues.

*Model*

Webster's definitions of model, as applicable:
- A preliminary representation of something, serving as the plan from which the final, usually larger, object is to be constructed
- Pattern person (student)/system/object
- Version (e.g. 2 doors 2001 model of a car)
- A style or design

The word model can be interpreted in different ways depending on the situation. For an architect the model could be a model of a house built of paper, for an artist the model is the person who is posing for a picture, for a business manager the model could be a computerised model of a business process.

As we understand, anything that represents something can be considered a model. A model is also a simplification of the real world or current situation. There has always to be defined a "mini world". To make a road map in scale 1:1 does not make much sense. It will at least be very unpractical in use. That sounds very simple and easy to understand. But the same rule is true for all other kinds of modelling, and limitations are not always the easiest part of the modelling discipline.



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*Modelling*

- to make a model
- to serve as a model

Within Enterprise Modelling the first definition is normally the case when we talk about modelling. In order to do modelling the user makes the model on a computer or a piece of paper. The computer implemented and populated program serves as the model. To display and execute this program is normally not described as modelling but it presents the model of the modelling work.

*Three definitions of enterprise models*

1. *'If a model represents some aspects of an enterprise, it can be considered an enterprise model. The content of an enterprise model can be whatever the modeller finds important for the enterprise operation'* [Vernadat, 1996].
2. *'An enterprise model is a holistic visual representation describing the different enterprise aspects and the interaction between them'*. [Lillehagen, 1995]
3. *'Enterprise models are a class of models that embraces process, product organisation and system structures that industry today use to store and manage target and key process parameters and value sets'*. [Rolstadås, Andersen 2000].

The first one is very generic almost covering everything you find important to model in an enterprise. This can be practical in many cases, but it does not give much content and structure to the modelling.

The second defined interaction between enterprise aspects and that the model should give a holistic and visual presentation. This is more precise than the first one. Here is visualisation is focused, operation is the focus in the to others.

The third one emphasises that an enterprise model consists of classes of models or connected models and the classes should reflect structures within product process and organisation. The enterprise model should handle both management control issues and data storage. The definition has also the constraint that the structures should be based on currently used industry structures. I interpret this to mean that model structures should be applicable to industry.

The three definitions are different, but they are all correct. They serve different purposes and detailing.

### *2.2 Purposes and benefits of Enterprise Modelling*

The complexity of business is increasing. This applies especially for product, process, organisation, technology and market issues. Product lifecycle support and organisational development have got new challenges to operate on, such as extend products and extended enterprises, e-commerce and virtual enterprises. Strategic orientations around these modern disciplines become more important. Extensions of CIM-datamodels to build enterprise models will not satisfy all the requirements in the future.

Modelling the enterprise can be seen as an enterprise engineering process, because it offers a systematic way to improve performance. The idea of creating frameworks for enterprise modelling is built on the philosophy that a enterprise model can be created from the framework independent of business streams or industry.

From a generic point of view this is true, the question is to what detailed level such a framework can be made, both as a generic model, building blocks or as modelling guidelines.

The most important issues to handle within Enterprise Modelling are listed as follows:

- Increased complexity in the markets
- Innovative perspective to handle higher frequency in changes
- Globalisation and customised products
- Sustainability in product design and manufacturing
- More use of information and communication technology

It has become difficult to handle all the information needed to manage the business. The product life cycle shortens which requires shorter lead-time. More work has to be done in shorter time. The information must be made available in an early stage, and the information has to be consistent and valid.

The changed market conditions force the industry to customise products to individual specifications. As a result the manufacturing is moving from stock driven to customer driven manufacturing [Browne, J; et.al, 1995]. Product configuration and handling of customer focused information are key issues.

Due to growing pressure for the protection of the environment and government legislation's, the companies are forced into sustainable manufacturing and less polluting products. Industry is more aware of its responsibility to the environment, also of their task to preserve the environment through cleaner products and processes, by using easily dismounted, even recyclable materials. There is one common characteristic of all these changes in business. They all put more demands on information handling.

An enterprise model may serve many different purposes, but the main aim of an enterprise model is to make people understand, communicate, develop and cultivate solutions to business problems. Three categories of enterprise models are described below [Christensen, 1995]:

- 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.
- Computer assisted analyses where the main purpose of enterprise modelling is to gain knowledge about the enterprise through simulation or deduction.
- Model deployment and activation where the main purpose of enterprise modelling is to integrate the model in an enterprise-wide information system and thereby actively take part in the work performed by the organisation.

Category 3 is the main usage of enterprise model in this thesis.

## *2.3 Background and Development of Enterprise Model concepts*

Enterprise models have followed the state of the art in technology, both concerning modelling techniques and content and usage for the model. The new aspect in enterprise modelling is the usage of computers and modern information and communication technology. The electronic counting machines or the first computers were invented and experimented for use in the 1930s. They were very much improved during the 1950-1960s and became very useful devices to perform advanced calculations, complex text handling and local system or machine control.

They served isolated calculating purposes and input and output formats were paper-based. In the technical and industrial sector the development of computer systems continued to improve and systems like modern CAD/CAM and MRP systems came into the market. Very much can be said about the development and solution for such systems, but the first need and implementation using the computer technology as an information carrier and not only as a calculation device came in the same period. In the 1980s the first drafts of CIM (Computer Integrated Manufacturing) were launched.

The CIM approach with focus on the Integration had the aim to integrate and make communication mechanisms and use of common databases or file systems as repositories for design and manufacturing data. Additionally the CIM concept captured the lower level of manufacturing organisation like resource definitions, tools, machine tools, machine systems and descriptions of related manufacturing processes.

CIM should make bridges among the so-called "Islands of Automation"; isolated computer-based systems along the design and manufacturing process like CAD, CAM and FEM-analyses systems. CIM had its main discipline focus around manufacturing of discrete parts.

In CIM communication should be solved through integration and common application and data interfaces. There were developed different standards solutions e.g. for geometry transfer, like IGES and VDAFS. However, the major standardisation work is carried out by the ISO-STEP, (ISO 10303) (STandard Exchange of Product model data).

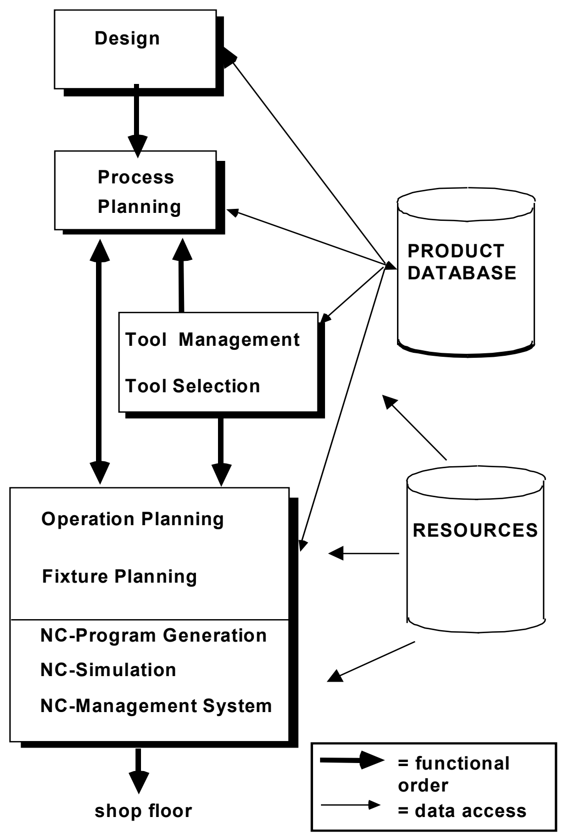


Figure 2.1: Typical CIM Architecture [Myklebust, Crawford 1990]

This standardisation work started in 1984 as an improvement of IGES, but new standard application protocols are still in development, and the scope of this standardisation work has been very much extended since the start. A brief overview of ISO/STEP is given in chapter 2.5.5.

The integration philosophy within CIM started to grow. Industry realised the significance of the processes. Process-orientation and process-focus came to the front in many different areas. As a consequence of the increased attention much effort was made to develop and improve process modelling integrated into the CIM concepts.

When we look into early approaches for Enterprise modelling it is easy to discover a combined product-, manufacturing process- and resource model thinking. The first standardisation attempts where the words “Enterprise Model” are used are in two standard reports for Enterprise modelling framework like the first work of ISO “ISO, Reference Model for shop floor production ISO TC184/SC5/WG1 (1990)”. This work is more closely described in chapter 3.1.

## 2.4 Product-, Process- and Organisational Models main building blocks in Enterprise modelling

A design project can be defined in terms of an **organisation**, (in his case a design project team), carrying out **processes** to produce a **product** satisfying a set of requirements [Christiansen 93]. The project is characterised in terms of product, process and organisation dimensions.

- A product requires configuration management
- A process is a set of tasks leading to a specified goal (defined output)
- An organisation is a group of actors who share the common set of goals (idealistically spoken)

Christiansen deals with project organisation of design processes, but he does not mention the term Enterprise Modelling in his work. He calls this the PIM-space (Project, Information, and Modelling). However the structure with product process and organisational dimensions can easily be extended also to be the main dimensions within enterprise modelling. Such an extension was also done in the Norwegian CAESAR-Offshore project describing product and process models for oil and gas industry. The project uses the same structuring, but the scope has been extended in the direction described above and the model is now introduced as the PPO-Model (Product, Process and Organisation). This PPO model can illustrate a simple framework for Enterprise Modelling [Simonsen, Dale 1993].

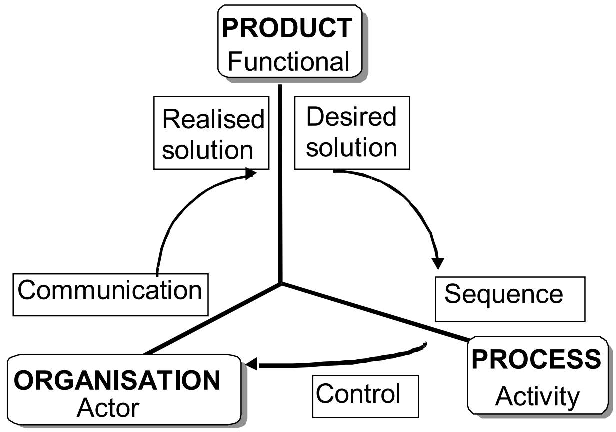


Figure 2.2: Principles of the PPO-Model (Simple generic framework for Enterprise Modelling), [Prytz 1995]

The basic principles of PPO-modelling are illustrated in figure 2.2, which also shows the various dependencies between functions, activities and actors along three dimensions. The PPO approach shows main dimensions of Enterprise Modelling and detailed models capturing product- process- and organisation information and relations can be made. Such detailing can be done though many existing Enterprise Modelling approaches.

The interrelationships between organisational, process and product structures are numerous. For instance members of the organisation are connected to process roles defining their work tasks, competence is connected to process roles, goals are connected to the processes and products, and resources are connected to processes. How to succeed in developing, managing, populating and operating an Enterprise Model is still the main challenge.

In scientific literature we find many other approaches of dimensions. As an example METIS, [METIS 1999], has defined a fourth dimension called “System”. This is of course feasible, but dimensions like “Systems”, “Resources”, “Infrastructure” etc. can normally be reduced into the three main dimensions product, process and organisation.

Also Vernadat defines contents or areas of which an Enterprise Model consists. But he emphasises that the models are not limited by this content only, [Vernadat 1996]:

- **Product Models**, represent geometric and non-geometric features, design details of products and their parts made in the enterprise throughout the product life cycle

- **Resource Models**, layouts, management policies and possible actions of equipment as well as their configurations

- **Activity Models**, operations or actions to execute enterprise activities

- **Information Models**, describe structure and relationship of data information elements of the enterprise information system

- **Organisation Models**, organisation structure of the enterprise in terms of plants, departments, cells, stations and work-centres, authorities and responsibilities assigned to each level

- **Economic Models,** cost oriented analytical view of the enterprise used to evaluate the cost effectiveness of the various parts of the enterprise

- **Optimisation and decision-making models**, operations research and control theory and used by decision support system

In this list of content for an enterprise model both **product, process** (described as activity model) and **organisational** models are defined. In addition we find descriptions of resource, information, economic and optimisation models, and other special models or views to the enterprise model could also have been defined. Such models are either part of the product- process and organisational model or instantiations in execution or operation of the models:

- **Resource models:** cover organisational structures and relations to execute processes.

- **Information models:** cover information systems and content related to the products the processes supporting e.g. manufacturing

- **Economic models:** derive cost related to product and processes and the productivity in the organisation, aggregated economical reports

- Optimisation and decision are making models: improve the operation of an enterprise.

Creation and implementation of enterprise models cannot be fully standardised or generalised, and the different views and models that will be selected for use must fulfil the requirements for the actual model.

In Chapter 3, some selected major approaches are described. Even if they are very complex they do not contain any other description that could have been from an ideal point of view, transformed into a PPO model. However they are approaches that should fulfil the needed detail level in framework of enterprise modelling. In addition descriptions of sources and external factors are always needed.

In the following chapters we will focus on different aspects of Product-Process and Organisational modelling and challenges that influence Enterprise Modelling.

## 2.5 Product modelling

### 2.5.1 Introduction to relevant areas of Product Modelling

The International Concurrent Engineering Forum, 1991 describes an integrated product model in the following way [Anderl 1995]:

- Designed to cover all product definition data and product description data throughout the product life cycle
- Development is based on a methodology that is strongly driven by the application (representing the users interest)
- Based on a formal specification which provides processing by computers directly
- Supports various applications that interpret the integrated product model

From the above definitions the conclusion may be made that product definition data is only released product data. The product model also aims to support the creation of product data, i.e. the design phase.

Support systems contain:

- Product libraries and catalogue data
- Functional solution, various classification systems.

Product models support design, which indicates that the product models must contain requirement data and decision data, in addition to definition data and description data. Consequently demand handling is part of the product model.

*Product life cycle*

There are many ways of structuring the product life cycle models. One is to divide the life cycle into appropriate phases, in which we use the various phases as a filing structure.

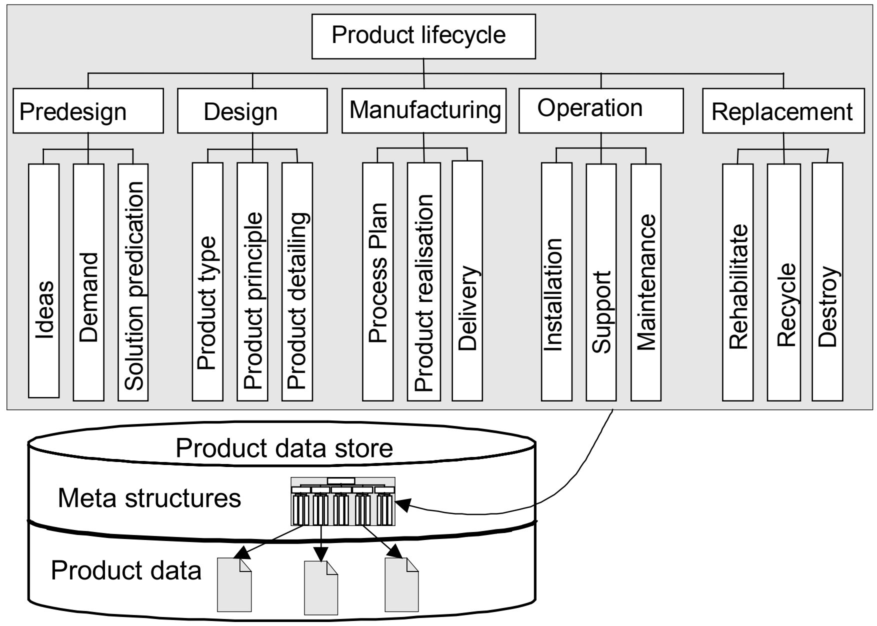


Figure 2.3: The Figure shows an example of structuring of product data according to life cycle phases [Brathaug, Åsebø, Szegheo, 1998]

These structures facilitate retrieval and reuse of product data shows one of many possible classifications of the life cycle [Lamvik, Karlsen 1998].

In the recent work with product models the End of Life Treatment, EOM, of products have been more and more important. The content of the model must then be designed to capture and carry product information that is relevant to processes in all of the product life cycle phases [AEOLOS consortium 2001].

### 2.5.2 Product configuration

The market highly demands customer tailored products at a low volume, while the producers highly wish to produce standard products at low costs. Product configuration is introduced as a compromise to satisfy both parties. Product configuration enables the customers to compose their own products, by selecting from a variety of standardised components.

To enable the customers to select components, a model must be constructed that guides the customer in composition of the products. This would indeed limit the product creation. The model must also manage discrimination, as well as establishing pre-configured variants.

### 2.5.3 CAD, one basis for product modelling

Computer based tools are applied in nearly all activities within product development. Computer aided design is the most central tool and is today used by almost all designers of industrial products. Short product development time, low product development costs and right product qualities are important for an enterprise's productivity. For a company to fully enhance these competitions parameters a variety of tools are implemented. Two of these tools are Computer Aided Design (CAD) and Product Data Management (PDM) systems, see chapter 2.5.4.

Originally CAD was developed to simplify the design work. Next step in the development involves introduction of numerically controlled (NC) tools. Great savings could be achieved by generation of Tool paths directly from geometrical models Computer Aided Manufacturing, CAM. As CAD could make 3D geometric models and development of NC-control from 3D models began. Finite Element Method (FEM) was another great influence on the development of CAD. The CAD systems continue to develop and to support other engineering data.

Many engineers considered feature based CAD as a new stage in the development of CAD systems. Features represent an extension of the present solid models. Features support other designers' software in that they not only contain geometric information but also other forms of engineering data. Research and development on features has been ongoing since the 1970s, and is now about to be implemented in most major CAD systems. Use of features as an integrator is described in chapter 5. Other important drives in the development of CAD are virtual reality, simulation of mechanisms and administration of product data [Aasebø, Myklebust 1998].

### 2.5.4 Product data management, PDM

Product Data Management systems follow the need for electronically administered product information. The primary idea for a Product Data Management system is to structure, control and manage product data in a product development environment. The PDM systems aim at including all information in the whole product life cycle. Functionality for a PDM system may be divided in two categories, the one is connected to data management and the other to the process management [Bratthaug 1996].

The data management modules provide structure to product information, and different administrative tasks are supported. Process management deals with modelling and administration of activities in product development, establishment of design groups, allotment of roles, management of information flow etc.

Product data management systems have been widely spread lately, they introduce a new aspect of product modelling. In addition to ordinary modelling, the PDM systems provide handling of versions and revisions, releasing, data security, data access, and data distribution.

PDM systems have a functionality that can be used for this type of product management. Information created during the creative phase of design is not easy to process, to manipulate, or to integrate by use of computer; therefore informal symbolism is widely used. The models used during this phase are often abstracting, non-detailed, conceptual, and make sense only to people who interpret the models.

A PDM system is the designers' workbench where all information is accessed or stored. A PDM system provides a consistent product information model, in spite of information being created at different places, at different times, on different systems, on many different data formats and by many individuals.

Classification of information is the very fundamental function of a PDM system. For the time being most product information is generated electronically, while it was done on paper before. In most cases it is easy to transform electronic information to paper, but it is practically impossible to transfer paper based information back to an applicable electronic format. A goal one tries to reach through use of electronic information is that one should need to write a piece of information only one time in to the computer system through the product life cycle. For the time being there are greater demands on product data management than before, and more product information is generated due to strict requirements on documentation of products and product development processes [Aasebø, Myklebust 1998].

Typical models and applications covered by PDM :

- Project models
- Product models
- Product life cycle models
- Group technological classification
- Customer based product configuration
- Information and material flow models
- Work flow and change management models
- Organisation structure, functions, roles and work groups
- Customer and vendor process models

*PDM systems' limitations and possibilities*

PDM systems have proven to be superior tools for management of product data. However, many companies meet great challenges in the process of implementation of these systems. These can roughly be divided in technical and cultural challenges. Even though the major challenges in any implementation is cultural, one should not underestimate the technological challenges. The most important factor that creates problems by PDM implementations is integration with other applications related with the approach [Storvik 1998].

In relation to enterprise modelling PDM has the capability to do management and control function of the product data. It is an important requirement to handle product data both within disciplines and actors in an enterprise or network of enterprises and along the product lifecycle.

### 2.5.5 ISO-STEP Standard for the Exchange of Product Model Data

ISO initiated Technical Committee 184 (TC184)/Sub Committee 4 on Industrial Automation Systems, to work in the area of representation and exchange of digital product data. The subcommittee's effort has been named Standard for the Exchange of Product Model Data, STEP [Owen 1993].

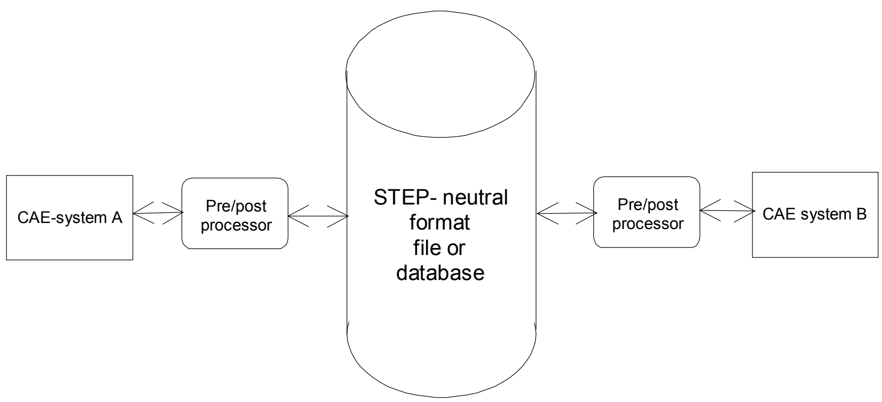


Figure 2.4: Basic concept of ISO-STEP

PDM is about information management of data, ISO-STEP is about the content and format of the data that needs to be transferred and integrated.

The STEP standard has been under development since the mid-1980s and is still active. The Step Organisation together with the American project Product Data Exchange using STEP, (PDES) began their activities as an improvement to the Initial Graphics Exchange Specification (IGES). But ISO-STEP has become the largest internationally co-ordinated knowledge product engineering initiatives.



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A standard like STEP is an important factor to the product data-part of the enterprise modelling approaches. It has well-defined methods how to design the data for transfer between systems in a standardised manner. A short description of this is included in this chapter to show how details modelling can be executed.

The Standard is a neutral mechanism capable of completely representing product data throughout the life cycle of a product. (Neutral in this context indicates independence from any particular computer aided software system.)

Though ISO-STEP is a product model standard it is in many ways a combined product and process model. The first level of each part of the standard is an activity or functional model, (Application Activity Model, AAM) which shows the different activities for the lifecycle of the product description.

The development of ISO-STEP has also created tools and definition languages, e.g. EXPRESS, which brings the standard the whole way from activity diagrams to detailed executable coding and interfaces defined in the application protocols.

The completeness of this representation makes it suitable not only for neutral file exchange, but also as a basis for implementation and sharing of product databases and archiving. There is an undeniable need to transfer product data in computer-readable form from one site to another. These sites may have one of a number of relationships between them (contractor and subcontractor, customer and supplier); the information invariably needs to iterate between the sites, retaining both data completeness and functionality, until the results are ultimately archived. The most cost-effective manner to encapsulate such information seems to be the use of a neutral format description, independent of any computer-aided engineering (CAE) software system.

The methodology underlying the development of STEP includes the use of reference models, a framework for product data modelling, formal definition languages, and an architecture which separates application requirements from physical implementations. To provide a rigorous standard, a number of formal concepts are used to describe both the "logical" content of the information and well-defined syntax at the physical layer.

It should be emphasised that the goal of the STEP effort is to create a complete representation of a product and not merely a graphical or visual representation.

*STEP-for functional modelling*

For the functional analysis IDEF0 is commonly used within STEP. IDEF0 is a method which is used to produce a structured, graphical representation of the processes concerned with a manufacturing system on the one hand or environment and of the information and objects which interrelate those processes on the other hand, Figure 2.5.

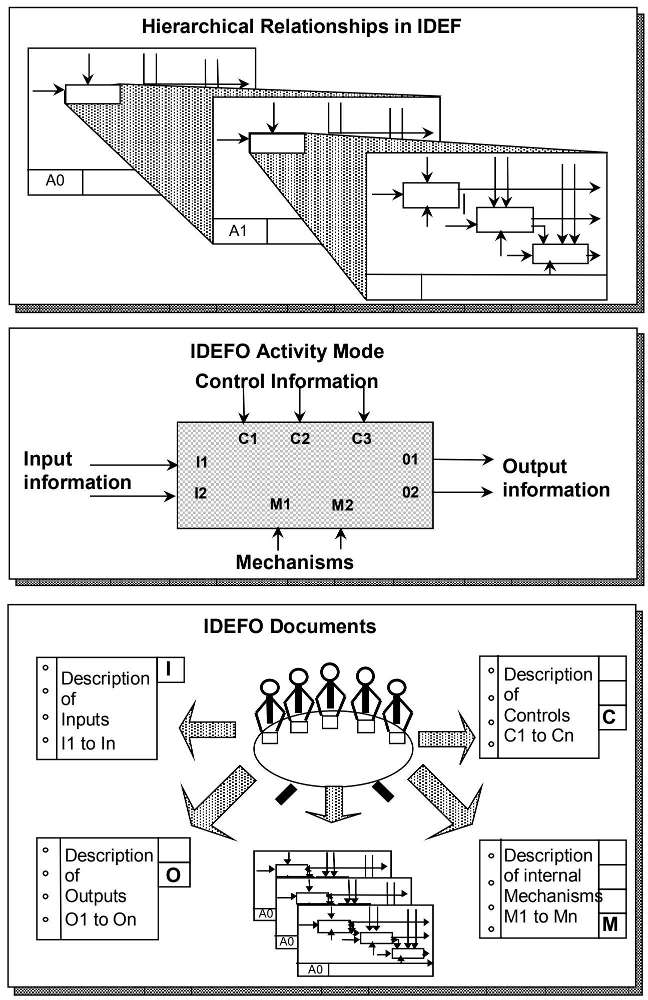


Figure 2.5: Functional Modelling with IDEF0 [Myklebust 1992].

The IDEF0 method is a major subset of SADT (Structured Analysis and Design Technique) which was developed in the early 1970s. The US Air Force program for Integrated Computer Aided Manufacturing (ICAM) published the description of this subset with the purpose of offering structured methods for efficient development of information systems for manufacturing environments. The method allows description of a system as a hierarchy of functions and the relations between them in terms of input and information flows. It also requires controls and uses mechanisms to fulfil the function.

*Data modelling methods*

The information modelling tools can be divided into two kinds: graphical and computer language oriented tools. The graphical oriented tool **EXPRESS-G** provides overview and can easily be used on a conceptual level. They are therefore mainly used for the early stages of modelling. The weakness of these tools is the modelling of cardinalities and constraints because the models get overloaded and thus complicated to understand. After a model becomes more and more stable, computer sensible tools like EXPRESS are the choice.

**EXPRESS** is the alphanumerical declarative modelling procurable language used in STEP for writing of any application protocol. Mapping and converting between EXPRESS-G and EXPRESS can be performed in a smooth way because there is 1:1 representation between them. All STEP models are required to be represented EXPRESS. EXPRESS is the only official modelling language for STEP and it is defined as an own part of the standard.

| | |
|---|---|
| SCHEMA | • provides a context for the definition of the things of interest |
| ENTITY | • thing of interest belonging to a particular context |
| TYPE | • allows user-defined types of attributes |
| RULE | • define constraints on data of instances |
| SUPERTYPE/ SUBTYPE | • allows building several levels of abstraction |
| FUNCTION/ PROCEDURE | • allows the definition of procedural algorithms within the conceptual model |

Figure 2.6: Example of Entity Types in ESPRESS

## 2.6 Process modelling

Process models have been built in numerous ways over the last decades. Some of the areas in which process models have been used are computer science, project management, process management, process design and process re-engineering. Many definitions of process modelling exist.

'*A process model is an abstract representation of a process that excludes much of the real world's infinite detail. The purpose is to reduce the complexity of* *understanding by eliminating the detail that does not influence its relevant behaviour*' [White, 1994].

The term business process is frequently used. The meaning of this is to keep in order or organise the processes in a company that makes the chain from the raw material to the final customer. One definition of business processes is as follows:

'*A chain of logical connected, repetitive activities that utilises the enterprise's resources to refine an object for the purpose of achieving specified and measurable results for internal customers*' (Ericsson, 1993).

The overall purpose of a process model is to gain insight into process flow dependencies. When this insight is established, the process can be analysed, improved, and perhaps implemented in runtime workflow. Process models have different usage and can be suitable models for business process reengineering (BPR), and support implementing of concurrent engineering (CE) and work simplification (WS).

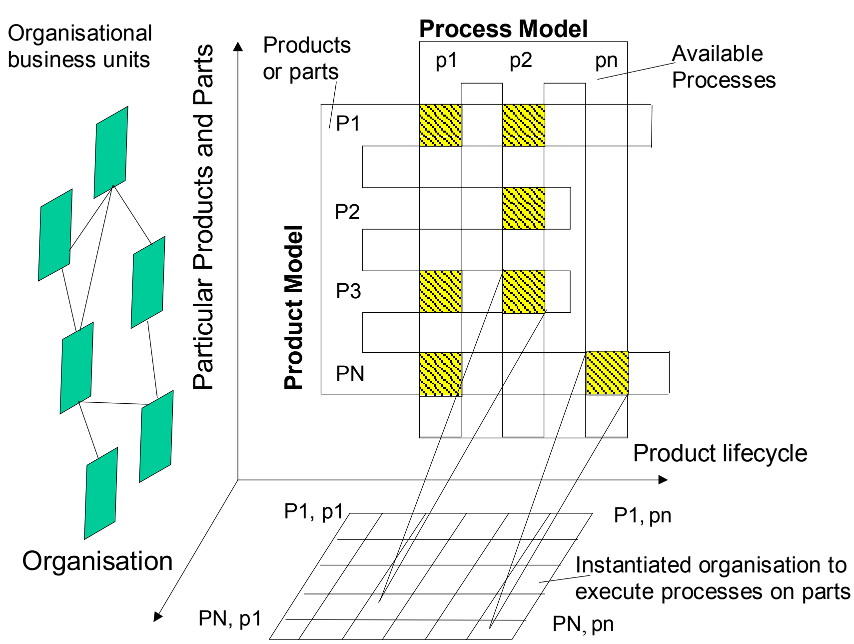


Figure 2.7: Interrelations between Product- and Process models and mapping to instantiated executive organisations

Various types of process models or process aspect structures are built to support different needs. Typical process aspect structures are:

- Business process hierarchy
- Workflow
- Co-ordination maps

The differences between the various process aspect structures are not well defined. The various process models contain overlapping information. In some cases a given model might cover two or more of the types listed above.

- The business process hierarchy shows the business processes and their interdependencies.
- The workflow represents the lowest level of processes in the enterprise. These are the processes that can be automated.
- Ingredient result flows show which information or material is needed and produced by the various processes.
- Co-ordination maps used to visualise the co-ordination of processes with the process routes, events and triggers.
- Process libraries manage generic processes for the purpose of reuse.

A process model can contribute to getting a survey or in-depth knowledge about the enterprise, how it functions, and that way the user can gain a much better understanding of the enterprise. This understanding can be used in the everyday operation, or it can be used in process design or redesign.

The area of process modelling is not new and it is still being development, especially in relation to enterprise modelling. The lack of standards and terminology causes the most problems in process modelling. Though some standards and terminology have been developed, they are often ambiguous and vague.

In relation to enterprise modelling a process model describes the process flow in relation to the product or service refinement the processes perform, and see that in relation to the resources and organisations used to manage and execute the processes. Figure 2.7 shows the interrelations between product and process entities and relation to organisation.

## *2.7 Organisation modelling*

The word organisation in the context of enterprise modelling comprises not only the organisation of humans, but also the organisation of resources (machines and systems), competence, infrastructure, goals, strategies, locations and networks, Table 2-1.

This chapter does not present new development of organisational theories, but an illustration of uncertainty within organisational and strategic planning. It is a challenge to manage such uncertainty, but also to discover the unexpected occurrences and external or internal disturbances that make up the unplanned situations and difficulties. An example to handles this is shown in chapter 4.5.2. The detailed part of the organisation aspect as factory resources etc is described in chapter 3.1.

| **Organisational Aspect** | **Description** | **Level H/L** |
|---|---|---|
| Organisation chart | The organisation charts represent positions, members and vertical communication channels. | H |
| Resource structures | Resources in this case are people, machines and tools. It is important for the enterprises to be aware of the available workforce and technology, and maintain this information in an effective way. Resources modelled to support resource management activities, such as planning, development, acquisition and utilisation of resources. | L |
| Infrastructure (IT) | The model of the IT infrastructure shows the available hardware and software. The IT infrastructure could also show which persons working on, or allowed to work on which software and hardware. The access rights and profiles of the users could be stored in a user architecture model. | H/L |
| Location charts | The physical locations of offices, factories, inventories, departments and resources it is possible to identify the place where a real world object is located and the way to communicate with it. | H/L |
| Strategies | Execute strategic work and organisation development | H |
| Goals, objectives | It must be possible to relate goals and objectives to relevant parts of the enterprise model, such as departments, product solutions and process steps. | H |
| Global organisation structures | A global organisation structure could be used to give an overview of different, network partners, customers and suppliers | H |

Table 2-1: Typical elements in an organisational model [Myklebust 1997]

Organisation modelling helps to get better exploitation of the competence within the enterprise. Organisation models help to identify the need for new competence due to changes in products and processes. An organisation model can help to align the goals of the departments, processes and employees with the goals of the enterprise.

Organisation development and modelling take place on different levels of an enterprise and can be performed in two directions:

- **Top down**, concepts, strategy, markets, networks, corporate management, infrastructure
- **Bottom up**, resources, software integration, workflow, low level processes

Top down and bottom up directions of working can also illustrate who takes part in a strategy process, all in the organisation or only senior management. The Top down way is described in this chapter were we find different way of execute strategic work and organisation development. The bottom up way is more low level and has so far been the most common in many Enterprise Modelling approaches and projects. Table 2-1, shows examples of organisational aspects and where they belong in a high or low level of organisation planing [Myklebust 1997].

### 2.7.1 Different forms of organisations

Henry Mintzberg lists various forms of organisations. A few of them are presented here in brief. The forms of organisations illustrate different postures under different circumstances. The selection below focuses on types of organisations that are closest to the challenges in industry or high-tech enterprises [Mintzberg 1989]:

- **The Machine Organisation.** Classic bureaucracy highly formalised, specialised, and centralised, and dependent largely on the standardisation of work processes for co-ordination; common in stable and mature industries with mostly rationalised, repetitive operating work (as in airlines, automobile companies, and retail banks).
- **The Entrepreneurial Organisation.** None-laborated, flexible structure, closely and personally controlled by the chief executive, who co-ordinates by direct supervision; common in start-up and turnaround situations as well as in small business.
- **The Professional Organisation.** Organised to carry out expert work in relative settings, hence emphasising the standardisation of skills and the pigeonholing of services to be carried out by rather autonomous and influential specialists, with the administrators serving for support more than exercising control; common in hospitals, universities, and other skilled and craft services.
- **The Adhocracy Organisation.** Organised to carry out expert work in highly dynamic settings, where the experts must work co-operatively in

project teams, co-ordinating the activities by mutual adjustment, in flexible, usually matrix forms of structure; found in "high technology" industries such as aerospace and in project work such as filmmaking, as well as in organisations that have to truncate their more machinelike mature operations in order to concentrate on product development.
- **The Diversified Organisation.** Any organisation split into semiautonomous divisions to serve a diversity of markets, with the "headquarters" relying on financial control systems to standardise the outputs of the divisions.

This overview of organisation forms shows a large difference in structure. A challenge with computer supported enterprise modelling is that highly flexible organisations that in a better way fulfil requirements to e.g. market changes and productivity can be more difficult to model than more strictly build organisations.

### 2.7.2 Strategy for organisations

For many companies strategic planning has become a very difficult task to do in a manner where the plans represent true value for the company for the period of time covered by the plan. This is caused by the fact that factors like customers, markets, competitors, vendors, laws, regulations and technology change faster than ever before. This is a situation that will not change in the nearest future, rather on the contrary. Strategic planning and organisational development are viewed as independent disciplines. The strategic work, which results in definitions and objectives, may be input to other activities within organisational development. Strategies may appear on many levels and with different content. Hax and Maljuf define levels for strategies in their presentation of strategic planning [Hax and Maljuf, 1996]:
- Corporate strategy
- Business strategy (strategy within a business unit)
- Functional strategy (strategic planning on a lower level)

This implies for a start that organisational development on the highest level (corporate) will put constraints on strategic thinking on lower business or functional levels. In the article "Crafting strategies" Mintzberg [NTNU-KOMPENDIUM 1996] claims that strategies must be formed on the highest operative level in the company organisation. It is thus natural that this is in focus in the interface between strategy and organisational development.

The main challenge is the rapid changes. Markets come and go. Demand for products changes and company structure is no longer stable. Strategic plans are difficult to make and they are unreliable. At the same time companies must be able to catch new developments, which will play a role in future for good operation or even existence. The strategy should not be so rigid that it is problematic to make changes according to new signals, external sources and requirements. However, a superior and targeted strategy is necessary.

### 2.7.3 Forms of strategy

Mintzberg [Mintzberg 1994] shows that intentions or plans of strategies that one wishes to implement may be called **intended strategy,** Figure 2.8. Some of these intentions or plans will be rejected in the process and not realised. This may be called **unrealised strategy**. An intended strategy minus the unrealised strategy equals the strategy one plans to carry through, also named as **the deliberate strategy**. Furthermore Mintzberg defines a fourth form, which he calls **emergent strategy**. This consists of external and internal incidents that management and planners were unaware of in the preparation of the deliberate strategy, but which the company should consider to in the necessary extent**.** **Realised strategy** will thus be the deliberate strategy plus the amount of emergent strategy one has managed or wished to include.

There are few, if any, strategies that can be exclusively intended, and few can be only emergent. The one direction suggests no learning; prescribing, the other no control; describing. All really realised strategies must mix these in one way or other, in order to try to control without stopping the process of learning. E.g. organisations often have to comply with a so-called umbrella strategy where features are broadly outlined while details can still occur.

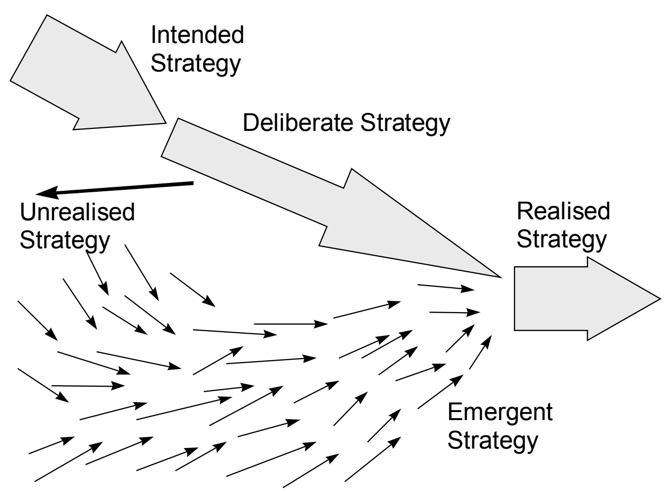


Figure 2.8: Different forms of strategy [Mintzberg 1994]

Thus necessary and planned strategies will not only be good and accidental strategies only bad. A strategy must mix characteristics so that it reflects the present conditions, especially the ability to predict and the need for reaction to unexpected incidents. Below three of Mintzbergs schools of strategy are presented.

### 2.7.4 Organisational development versus strategy formation

Organisation development is looked upon as a part of the internal strategy process or rather strategy is the most important contributor to organisational development. The organisation development can be dived into three levels [Cumming, Worley 1993]:

- Organisational
- Group
- Individual

For the organisational level we find input data from strategy and environment. Figure 2.9 shows a model for a planning phase for organisation development on organisational level. It is the most important relation between strategy and organisation development. There may exist a strategy which interferes with the group or individual level, but as we look upon strategy as the superior navigation process for the enterprise the main links have to be on the organisational level.

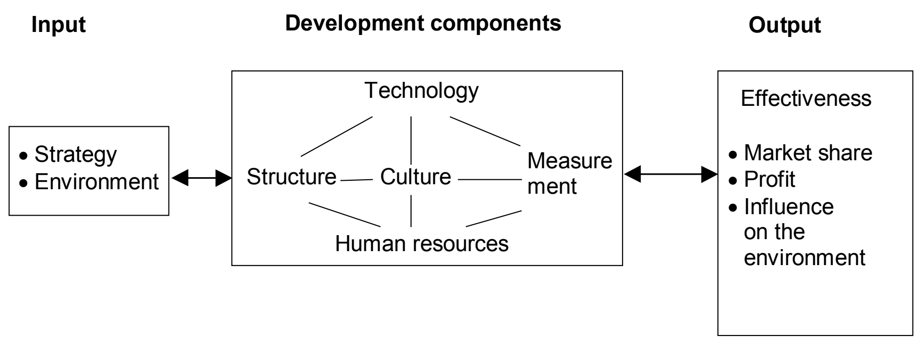


Figure 2.9: Model for the diagnostic phase for organisation development on organisational level, [Cumming, Worley 1993]

Organisation development will thus not be part of the strategy formation itself, but be a close and necessary process in achievement of the strategic goals.

### 2.7.5 Integrated Strategic Management, ISM

Integrated Strategic Management, ISM is a method for organisation development that will attend to the human aspect in organisation development. ISM requires participation from many groups in the organisation, not only from (top) management. The method can be characterised by these factors:

- The total process in developing a strategic plan, achieving accept and support and the implementation of the plan must be done as an integrated process.
- The strategic analysis includes assessment of external and internal (organisational) factors stressing the organisation's ability to implement the changes that the strategy process requires.
- Both individuals and groups in the organisation must participate in the integrated processes, which include analyses, planning and implementation, in order to create the best possible plan that maintains the enterprise's strategic focal point. Furthermore the process is supposed to improve co-ordination within the organisation and create better personal relations and sense of responsibility.

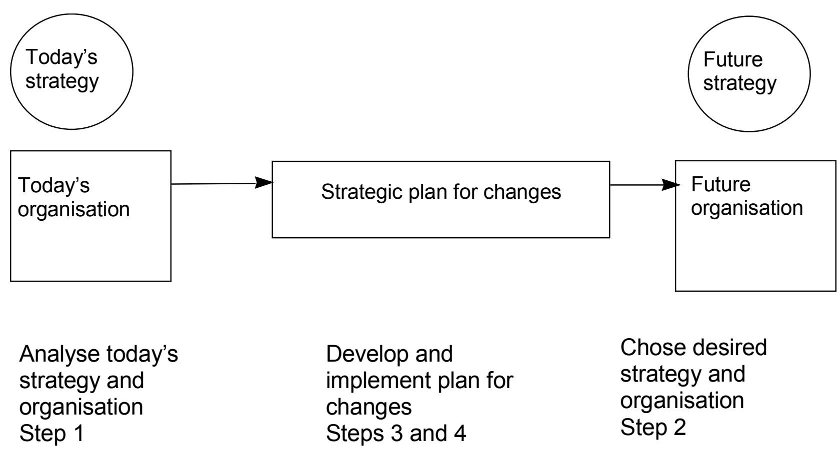


Figure 2.10: Integrated strategic management process, [Cumming, Worley 1993]

The ISM method is illustrated in Figure 2.10, Integrated strategic management process; and as the figure indicates the method leads to four activities:

- Analysis of today's situation
- Choice of future strategy and organisation
- Draft strategic plan for changes
- Implement strategic plan for changes

The model also has clear similarities to other organisational change models, which are used as the starting point for methods for organisation change and development. Such models work with a fixed "as is" situations and planned "to be" situations. The question may be asked whether it is possible to operate with such fixed situations of information for strategies.

*ISM and strategy formation*

In Figure 2.11 Mintzberg's model from Figure 2.8 is transformed into an ISM process of changes. In this way one can achieve a controlled strategy process which takes notice of the organisation and at the same time considers the world around and considers unexpected circumstances (emergent strategy).

This will also correlate with Tom Peters, "Creative Chaos" claims that genuine strategic planning must emerge from below and up and that everyone must be invited to participate in a strategy process [Peters 1990]. Furthermore Peters claims (like Mintzberg) that the process must be managed by an operative manager and not be handed over to separate planners. Jan Carlzon describes a somewhat similar thing in his book "Riv Pyramidene" what concerns participation within the whole organisation: "*An individual who does not receive information can not take responsibility; an individual who is given information can nothing but take responsibility*" [Carlzon 1985].

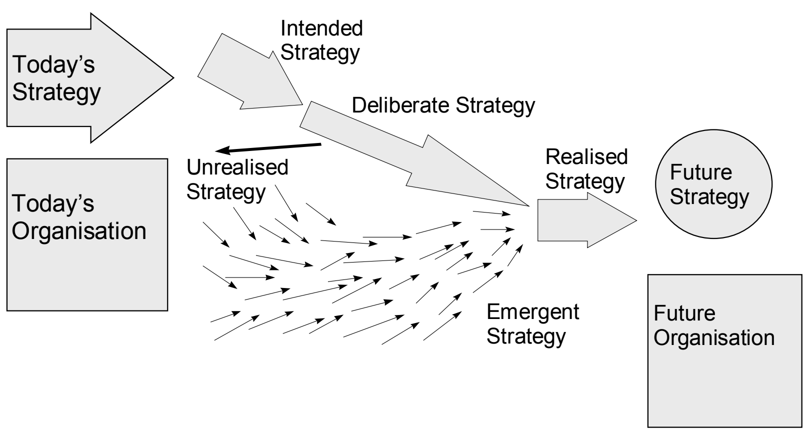


Figure 2.11: Different forms of strategy combined into an ISM process of changes

### 2.8 Summary

A commonly known definition of enterprise model:
"If a model represents some aspects of an enterprise, it can be considered an enterprise model. The content of an enterprise model can be whatever the modeller finds important for the enterprise operation" [Vernadat, 1996].

The chapter gives an overview and background for enterprise modelling. The bottom up approach where CIM models also started to include resource and low level organisation aspects and extended them selves to becoming partly a model of the enterprise.

The main building blocks for an enterprise model are defined to be product, process and organisational aspects. From a generic point of view this can be modelled in a 3D orthogonal space or framework (PPO) model. The advantage with this approach is that redundancy in the model can be avoided more easily. Also the 3D building block will be unique defined elements or entities for further processing of the model.

The general description of product models describes besides lifecycle aspects and PDM (Product Data Management), the ISO/STEP approach which is the largest existing product model standardisation effort in the world. A process model briefly describes a business process hierarchy, workflow and co-ordination maps.

This chapter focuses also on some general organisation descriptions on uncertainty based on emergent in strategy formation. On of the most difficult aspects concerning organisational, market and strategic planning are the many rapid and unexpected changes. This makes high level organisation model much more uncertain to rely on and also difficult to manage. Due to this fact models e.g. for shop floor planning and control are different in nature from models used for market strategy planning and corporate business development. This makes it difficult to use a common architecture for enterprise modelling, and in practical life there exist a number of models that do not communicate.

# 3. Enterprise Modelling Methods and Tools

Friedman and Cornford see the history of the development of computer systems as resulting from attempts to overcome factors which constrain further computerisation at a given time [Checkland 1998]. They have set up three different phases of constraints for computer science:

- Hardware costs and capacity and reliability limitations (until the mid-1960s)
- Software constraints in the shape of productivity limits and difficulties of delivering reliable systems on time and within budget (from the mid-1960s until the early 1980s)
- User-relation constraints arising from inadequate perception of user demands and inadequate servicing of their needs (early 1990s until today)

In this chapter a state of the art description of modelling relevant for Enterprise Modelling is given. The literature and the list of projects within this area are enormous. It has been necessary to be selective, and only major activities that are well known and accepted have been focused on. These activities have been developed through a large number of national and international projects and in many cases they have been accepted as international standards. Beside the product model standard ISO/STEP, described in chapter 2.5.5, this chapter focuses on the two main Enterprise modelling activities that have been developed over the last ten years, CIMOSA and GERAM. In addition some models, tools and languages that are commonly used in such development are briefly described. The standards illustrate a good status of enterprise modelling development work .

### *3.1 ISO, Reference Model for shop floor production ISO TC184/SC5/WG1 (1990)*

In 1990 ISO TC184/SC5/WG1 produced a Reference Model for shop floor production (technical report 10314) for these two purposes:

- to provide a conceptual framework for understanding discrete part manufacturing
- to identify areas of standards necessary to integrate manufacturing systems

In the first part of the document three model areas are described:

- A context for shop floor production
- The shop floor production model (SFPM)
- The generic activity model (GAM)

The shop floor production model (SFPM) builds on a break down structure developed by NIST (National Institute of Standard and Technology), USA. This structure is a hierarchical breakdown of a manufacturing facility into a single workstation, a pure organisational resource model. This NIST structure is shown in Figure 3.1

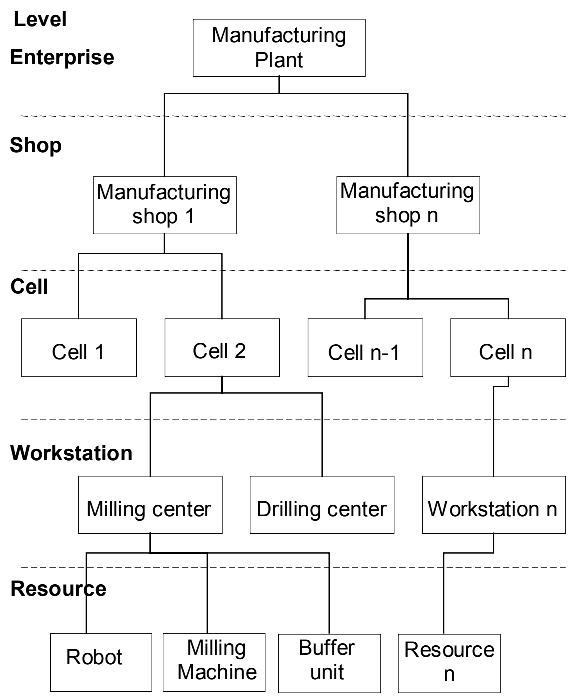


Figure 3.1: The shop floor production NIST structure [ISO 1990]

| **Level** | **Activity** | **Responsibility** |
|---|---|---|
| 1. Shop | Manage shop floor process | Manage the production and service the activities, allocate resources for the activities |
| 2. Cell | Co-ordinate shop floor process | Sequencing the shop floor process |
| 3. Work station | Control shop floor process | Directing the shop floor process |
| 4. Equipment | Execute shop floor process | Executing according to commands |

Table 3-1: The shop floor production model (SFPM)

The Shop Floor Production Model (SFPM) uses four of the five levels in the NIST structure and includes sub-activities to these levels and responsibilities related to the sub-activities. The sub-activities illustrate production processes and relate to the specified manufacturing unit or level.

The last model in this draft standard document is the Generic Activity Model. This is a formal method to describe generic activities or processes that exist on the different levels and the connections and dependencies between them. The generic type of process can be classified into:

- Transport, TP
- Transform, TF
- Verify, VE
- Store, ST

The meaning of the model is that all manufacturing process can be classified and decomposed through these generic process types. The process flow in this model uses product information, resources and materials as input and resource and organisational information as control. This generic activity model has formally much in common with the more known method for activity and functional modelling namely, SADT or IDEF-0.

This early draft of a standardisation document of a framework for enterprise modelling was mainly focusing on manufacturing plants, production resources and production of discrete parts. No lifecycle issues or business process aspects were addressed in this standardisation approach.

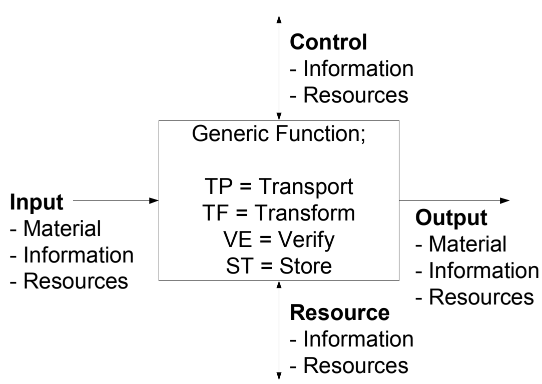


Figure 3.2: General Function of SFPM [ISO 1990]

### 3.2 CIMOSA, Open Systems Architecture for CIM

The Open Systems Architecture for CIM (CIMOSA) has been developed by the AMICE Consortium as a series of ESPRIT Projects (EP 688, 5288, and 7110) from 1986 until 1994. AMICE consisted of 30 major European vendors and users of CIM-systems. The CIMOSA results have been of significant value for enterprise modelling and architecture. CIMOSA has become a part of ENV 40003, "Computer integrated manufacturing (CIM): CIM systems architecture framework for modelling".

CIMOSA focuses of two main areas:
- Enterprise modelling framework
- Integrating Infrastructure

In addition there is also one area with description of the CIMOSA System CIM lifecycle. The framework is structured into three main dimensions;

1. **The dimension of Models**: Modelling and derivation - to organise the requirements in order to realise them by a controlled set of information technology applications (requirements, specification and implementation).
2. **The dimension of Views:** Views and generation - to support the analysis and synthesis of specific aspects of the enterprise (function, information, resource, organisation)
3. **The dimension of Genericity:** Genericity and Instantiation - to support the capture of the enterprise's requirements are using a mapping against a common, neutral framework (generic, partial and particular).

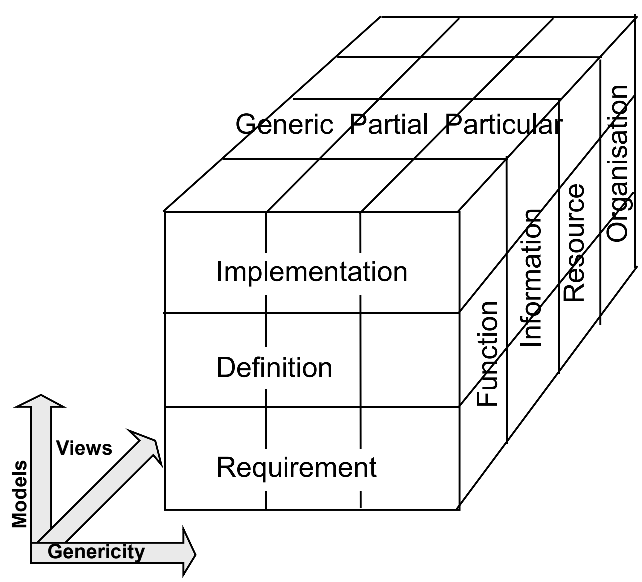


Figure 3.3: CIMOSA Framework.

CIMOSA provides a consistent enterprise modelling methodology. Its process oriented modelling approach describes all enterprise activities in a common way. Such activities include manufacturing process on the shop floor as well as management and administrative processes. It also provides a modular approach (domain process) for enterprise modelling by identifying three levels of genericity, three modelling levels and four views, Figure 3.3 [ENV 40 003 1990].

*CIMOSA, Three levels of genericity:*

**Generic Level**, reference catalogue of basic CIMOSA architectural constructs or building blocks for components, constraints, rules, terms, service function and protocols.
**Partial Level**, library of partial models applicable to a specific category of manufacturing enterprises.
**Particular Level,** model of a particular enterprise built from building blocks and partial models

*CIMOSA, Three modelling levels*

The application of the CIMOSA into an enterprise is divided into three parts:

- **Requirement Definition Level**; decompose the goal of an enterprise for gathering business requirements
- **Design Specification Level**; Alternative technical choices and designs are evaluated in order to select the best available technical solutions and specify optimised system-oriented representation of the business requirements.
- **Implementation Description Level**; implementation a complete CIM system and all its components representations, objects, processes, activities, resources and organisational units of the enterprise.

*CIMOSA Four views*

- **The Function View** describes the work flow of the Enterprise Functions
- **The Information View** describes the Inputs and Outputs of the Enterprise Functions and the integrated information objects of the enterprise
- **The Resource View** describes the resource objects (Humans, machines, Data Processing- programs) required to perform the Enterprise Functions
- **The Organisation View** defines authorities and responsibilities regarding functions, information and resources.

With an acceptable functional view in place, the next step is to create an information view which identifies the individual types of information needed by the business processes, as well as the characteristics associated with each piece of this information. For the implementation the development of data structures is supported to ensure consistent and non-redundant use of data by all applications. The organisational and resource views represent the implementation, organisational and personnel requirements for CIM at all level of an enterprise [ENV 40 003 1990].

*Integrated infrastructure*

The Integrated infrastructure enables IT-technology to have application integration. The Views of the CIMOSA Enterprise Model are reflected in the Services of the CIMOSA Integrating Infrastructure:

- **The Business Services** define an Interpreter for the Function View. This allows the control of workflow as defined in the Function Model.
- **The Information Services** define a set of general functions for the handling of the information defined in the Information View.
- **The Dialogue Services** define an Interpreter for dialogue control programs. These make the link between the Function Model, executing in the Business Services and the heterogeneous set of resources defined in the Resource View.
- **The System Management Services** provide general functions to allow system managers to intervene as defined in the Organisation View, e.g. to change, release, activate, start, stop etc. models, both off-line and on-line.
- **The Common Services** are used for handling of communication providing the location transparency required for the interactions between the IIS Services.

### 3.2.1 Use of CIMOSA in ESPRIT IMPPACT

For the ESPRIT No. 2165 IMPPACT (Integrated Modelling of Products and Processes using Advanced Computer Technologies) project a strategy was developed which is very close to and can be mapped to the generic concepts of the 1990 version of CIMOSA. This strategy contains mainly nine building blocks which are used to deliver a particular CIM solution to a customer by use of generic information stored in reference models and a generic and flexible CIM architecture, see Figure 3.4 and Table 3-2.

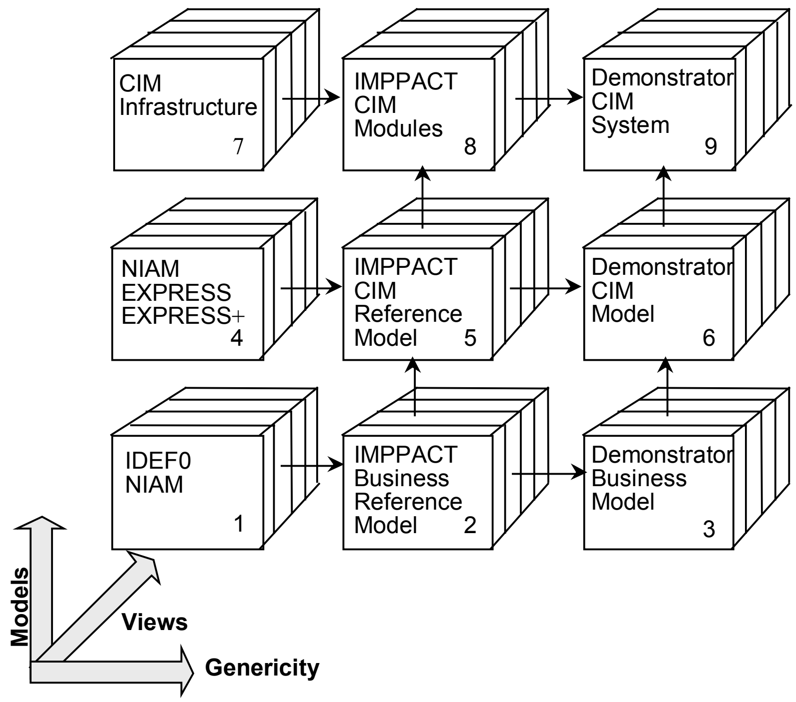


Figure 3.4: IMPPACT CIM Framework project [Bjørke, Myklebust 1992].

Orthogonal to these two axes, every building block can be seen as consisting of four views: the functional, information, resource, and organisational view are understood in terms of business or software functions.

With an acceptable functional view in place, the next step is to create an information view which identifies the individual types of information needed by the business processes, as well as the characteristics associated with each piece of this information.

For the implementation the development of data structures is supported helping to ensure the consistent and non-redundant use of data by all applications. The organisational and resource views represent the implementation, organisational and personnel requirements for CIM at all level of an enterprise.

| | |
|---|---|
| Block 1 IDEF0 and NIAM | The definition of requirements from the end-user community is based on tools which allow to make an information analysis with a strong involvement of the interviewed partner. Functional analysis used IDEF0 and data analysis used NIAM. |
| Block 2 IMPPACT Business Reference Model | This block contains a generalised business reference model which defines an enterprise in terms of the functions and information flows. The enterprise which is modelled is a generalisation of all enterprises of the same industry type, e.g., in mechanical engineering. |
| Block 3 Demonstrator Business Model | These particular models represent finally one company which is named within the IMPPACT project a demonstrator. These demonstrator business models contain the AS-IS and the TO-BE situation of the enterprises which validate and prove the concepts of the concepts of the project. |
| Block 4 NIAM EXPRESS | For data modelling NIAM and EXPRESS are the choice. Function oriented procedural interfaces are models with EXPRESS and evolving standards like ISO-STEP. |
| Block 5 IMPPACT CIM Reference Model | The IMPPACT CIM Reference Model describes the generic specification of conceptual models for information integration between CIM components and their functional behaviour. |
| Block 6 Demonstrator CIM Model | The demonstrator specific model specifies the data and function models for the actual demonstration. This particular model is instantiated from the CIM Reference Model. |
| Block 7 CIM Infrastructure | The IMPPACT CIM Architecture makes use of standardised operation systems, network protocols, presentation systems and database specification languages. |
| Block 8 IMPPACT CIM Modules | Development of a number of software products which are based on the concepts of the IMPPACT CIM Reference Model. These products are finally adopted to suit the needs of one particular demonstrator of the IMPPACT project. |
| Block 9 Demonstrator CIM System | The final demonstrator environment is the collection of IT software components, adopted according to the demonstrator specific models. |

Table 3-2: Description of the individual CIMOSA related building blocks within the ESPRIT IMMPACT project [Bjørke, Myklebust 1992].

### 3.2.2 Standardisation results from CIMOSA

The primary objective of CIMOSA is as earlier mentioned to provide a framework for analysing the evolving requirements of an enterprise and translating these into a system which enables and integrates the functions which match the requirements. The results of CIMOSA's work in this area are covered in the European normative work: **Framework for Enterprise Modelling** CEN/TC 310 ENV 40 003 (1990).

The CIMOSA Reference Architecture contains a limited set of architectural constructs to completely describe the requirement of and the solutions for a particular enterprise.

The results here can be found in the European normative work: **Constructs for Enterprise Modelling** CEN/TC 310 ENV 12 204 (1996). Both are produced by CEN/CENELEC

*Framework for Enterprise Modelling CEN/TC 310 ENV 40 003*

A draft standardisation document (European pre-standard) was issued the same year, 1990, as the ISO document 'Reference model for shop floor production' described in chapter 3.1. The document was the EVN 4003 "Computer Integrated Manufacturing System Architecture Framework for Enterprise Modelling". This work has also the focus on discrete part manufacturing and it aims to be a framework for future standardisation within computer based modelling of enterprises. One goal was that the standard also should be applicable for other industry streams like process industry, food industry or transportation.

The CEN ENV 40 003 was developed very close to the generic concepts of CIMOSA. CIMOSA contains the same building blocks which are used to deliver a particular CIM solution to a customer by using generic information stored in reference models and a generic and flexible CIM architecture.

*Constructs for Enterprise Modelling CEN/TC 310 ENV 12 204*

The normative paper Constructs for Enterprise Modelling CEN/TC 310 ENV 12 204 from 1996 define a set of generic building blocks of the CIMOSA Framework. The document builds on the content of CEN ENV 40 003. The constructs, as the building blocks are called, are all defined and described, but also declared as data objects in CIMOSA's declarative language. Also aggregations of constructs and relationships are defined.

CIMOSA is also an important part of other and newer standardisation approaches for Enterprise Modelling e.g. GERAM, ISO 15704, 2000 'Industrial automation systems – Requirements for enterprise-reference



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architectures and methodologies' and ARIS respectively described in chapters 3.4 and 3.5.

### 3.3 ISO 14258, "Industrial automation systems – Concepts and rules for enterprise models"

A new standardisation activity within ISO TC184/SC5/WG1, led to the new ISO standard, ISO 14258, "Industrial automation systems – Concepts and rules for enterprise models".

| | "What activities" | "How activities" | "Do activities" |
|---|---|---|---|
| **Plan and Build Phase** (e.g. before sell/buy title transfer) | • Develop goals<br>• Define strategy<br>• Define product needs | • Develop requirements<br>• Define concept<br>• Design product<br>• Plan to manufacture product<br>• Plan to support product | • Manufacture part<br>• Manufacture product<br>• Test product<br>• Ship product |
| **Use and operate phase** (e.g. after sell/buy title transfer) | • Define support needs<br>• Define use | • Define use requirements<br>• Define support requirements | • Use product<br>• Support product |
| **Dispose and recycle phase** (e.g. after product is no longer useful) | • Define recycle/ dispose needs | • Define recycle/ dispose requirements | • Recycle product<br>• Dispose product |

Table 3-3: Overview illustrating enterprise model concept of the ISO 14258, "Industrial automation systems – Concepts and rules for enterprise models"; the mapping between system life-cycle phases and system activities What, How and Do [ISO 1998].

The standard was completed in 1998 with a new version in 2000. It is interesting to see that this newer standard and the major differences between this standard and the 10 years older ISO document from 1990 (described in chapter 3.1). The ISO 14258 standard does not define enterprises, processes organisations or modelling concepts, but is an overall definitions of how enterprise model standards should be developed. In many ways this standard is a meta-model for enterprise modelling. It is also a complete and accepted ISO-standard (IS) and not only a normative document.

The standard specifies concepts and rules for computer understandable models of a manufacturing enterprise to better enable processes to incorporate. The standard define itself to cover manufacturing industry, but is much wider than being a high level definition of integrated CIM systems. The document focuses both on human and mechanical resources as well as organisational, information and capital aspects. Table 3-3 describes the main phases and activities. It tries to map system-lifecycle phases with main system activities.

In the standard there is focus on system theory as a basis for enterprise models: "Enterprise models confirming to this International Standard shall be constructed to confirm to the relevant elements of system theory". System theory can of course be widely defined since in literature there are many various system theory approaches derived from general system theory. Concepts entities described in this standard are also shown in Table 3-3.

## *3.4 ARIS-SCHERER*

Professor W.A. Scheer, University of Saarbrücken, Germany developed ARIS, 'Architecture for integrated Information Systems'. ARIS is generic and constitutes a framework where integrated application systems can be developed. It has much in common with CIMOSA, and ARIS builds on the same modelling levels as CIMOSA: Requirement definition, Design specification and Implementation descriptions.

While CIMOSA has it focus Computer Integrated Manufacturing (CIM) deals ARIS more with Business process within Enterprises. The ARIS structure is illustrated by the typical triangles figure or 'ARIS House', shown in Figure 3.5.

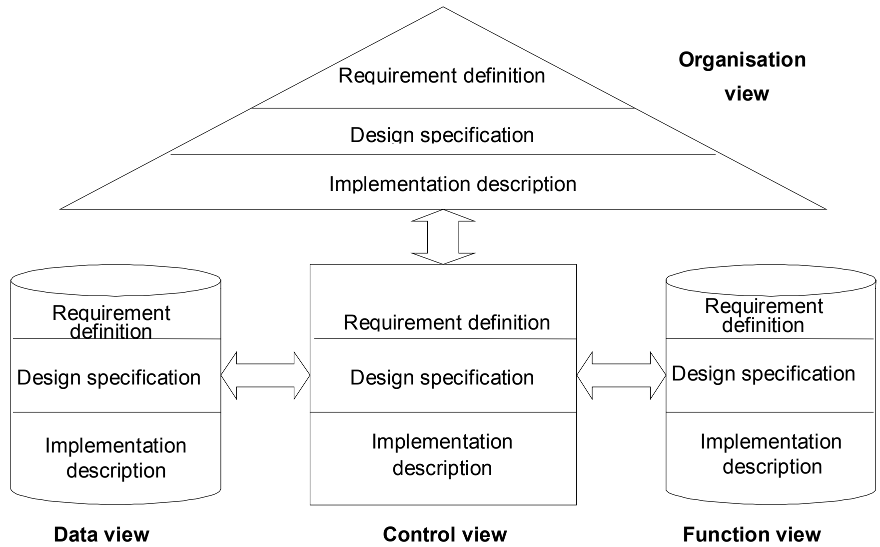


Figure 3.5: ARIS, Architecture for integrated Information Systems, [Scheer 1992]

The implementation strategies and methods of ARIS build on traditional Entity-Relationship (E-R) Models, both for the data-schemas definitions and for meta-modelling purposes.

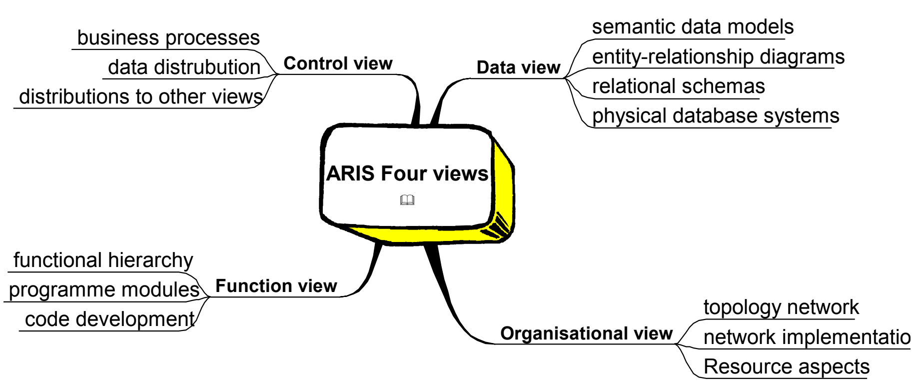


Figure 3.6: ARIS' four views defined views have dedicated functions. These views are also much the same as the views we find in the CIMOSA architecture.

ARIS is today supported by a software tool, ARIS-toolset and are much in practical use for Enterprise Modelling and Business Process Re-engineering. The Entity Relation representation makes in very much applicable with common used databases. The ARIS-toolset is also related with modelling purposes for implementation of the most common ERP-system, SAP.

### *3.5 ISO 15704, 2000 'Industrial automation systems – Requirements for enterprise-reference architectures and methodologies'*

GERAM, a 'Framework for Enterprise Engineering and Enterprise Integration' is developed by "Generalised Enterprise Reference Architecture" group and the IFAC/IFIP Task. This work started in 1990 and became an ISO standard, ISO 15704 in 2000. GERAM is built on the methods for enterprise modelling developed in CIMOSA, GRAI (GRAI Laboratory) and PERA (Purdue University) methodologies. But there have also been many other contributors to the standard.

GERAM is not a method, it defines a tool-kit of concepts for designing and maintaining enterprises during their entire life. GERAM is meant to organise existing enterprise integration knowledge. GERAM provides a description of all the elements recommended in enterprise engineering and enterprise integration. It does not impose any particular set of tools or methods but defines the criteria to be met.

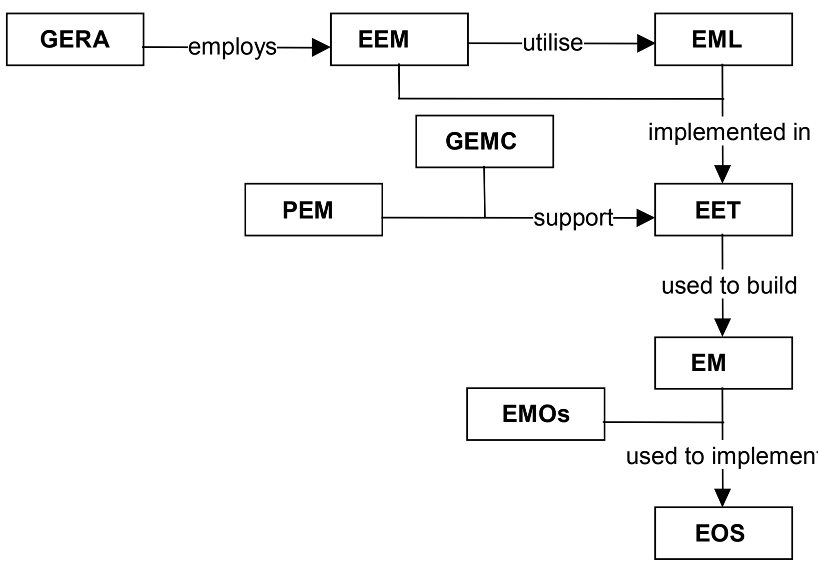


Figure 3.7: GERAM framework components [Globeman 1999]

The **GERAM** components shown in Figure 3.7, can briefly be described as follows [Bernus 1999]:

**GERA: Generic Enterprise Reference Architecture:** defines the enterprise related generic concepts recommended for use in Enterprise Engineering

and integration projects. GERA is the most important component of GERAM. A more detailed description of GERA is given in chapter 5.3.1.
These concepts can be categorised as:

- Human oriented concepts
- Process oriented concepts
- Technology oriented concepts

**EEM: Enterprise Engineering Methodologies:** describe the process of enterprise engineering and integration. These methodologies may be expressed in the form of process models or other structured procedures with detailed instructions for each enterprise engineering and integration activity.

**EML: Enterprise Modelling Languages:** define the generic enterprise modelling constructs for enterprise modelling adapted to the needs of the people creating and using enterprise models. In particular enterprise modelling languages will provide constructs to describe and model human roles, operational processes and their functional contents.

**GEMC: Generic Enterprise Modelling Concepts:** (Theory and Definitions) define and formalise the meaning of enterprise modelling constructs

**PEM: Partial Enterprise Models (reusable, paradigmatic and typical models):** capture characteristics common to many enterprises within or across one or more industrial sectors. Thereby these models capitalise on previous knowledge by allowing model libraries to be developed and reused in a "plug-and-play" manner rather than developing the models from scratch. Partial models make the modelling process more efficient.

Partial Enterprise Models are also referred to in the literature as reference models, or reference architectures.

**EET: Enterprise Engineering Tools:** support the processes of enterprise engineering and integrating by implementing enterprise engineering methodologies and modelling languages. Engineering tools should provide for analysis, design and use of enterprise models.

**EM: Enterprise Models:** represent the particular enterprise. Enterprise models can be expressed using enterprise modelling languages. EMs include various designs, models prepared for analysis, executable models to support the operation of the enterprise, etc. They may consist of several models describing various aspects (or views) of the enterprise.

**EMO: Enterprise Modules:** provide reusable products to be employed in the design, implementation and operation of the integrated enterprise. Examples of enterprise modules are human resources with given skill profiles (specific professions), types of manufacturing resources, common business equipment or IT infrastructure (software and hardware) intended to support the operational use of enterprise models.

**EOS: (Partial) Enterprise Operational Systems:** support the operation of a particular enterprise. Their implementation is guided by the enterprise engineering designs, which provides the system specifications and identifies the enterprise modules used in the system implementation.

### 3.5.1 GERA - Generalised Enterprise Reference Architecture

GERA defines the enterprise related generic concepts recommended for use in Enterprise Engineering and integration projects. GERA is the most important and developed part of GERAM and a more detailed description of the module is given below. These concepts can be categorised as:

- **Human oriented concepts;** human roles, the way in which human roles are organised, the capabilities and quality of humans
- **Process oriented concepts;** deal with enterprise operations (functionality and behaviour) and cover enterprise entity life cycle and life cycle activities
- **Technology oriented concepts;** deal with various infrastructures used to support processes and include models

*Human oriented concepts*

Information about human has to address several aspects:

- Role of humans in the enterprise and the task they perform
- The knowledge and skills possessed by each individual human
- Understand the decision-making process
- Social needs of employees (wages, salaries, training, vacation, etc.)

GERA requires the role of humans to be developed and expressed. It is consequently necessary to define:

- Human tasks and roles in the enterprise
- The organisational structure of the enterprise

*Process oriented concepts*

Business process oriented modelling aims at describing the processes in the enterprise capturing both their functionality (WHAT has to be done) and their behaviour (WHEN things are done).

In order to achieve a complete description of the processes a number of concepts have to be recognised in the guiding methodologies: life-cycle and life-cycle activities, life history, enterprise entity type, etc.



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*Life-cycle and Life-cycle activities*

GERA life cycle is applicable to any enterprise or any part of its entities. Life-cycle activities encompass all activities from inception to end of live of the enterprise or entity. Seven life cycle activity types have been defined (Figure 3.8).

- **Identification:** identifies the contents of the particular entity in terms of its boundaries, its relation to its internal and external environment.
- **Concept:** defines the entity's mission, vision, values, strategies, objectives, operational concepts, policies, business plans
- **Requirement:** describes the operational requirements of the enterprise entity, its relevant processes and the collection of all the functional, behavioural, informational and capability needs.

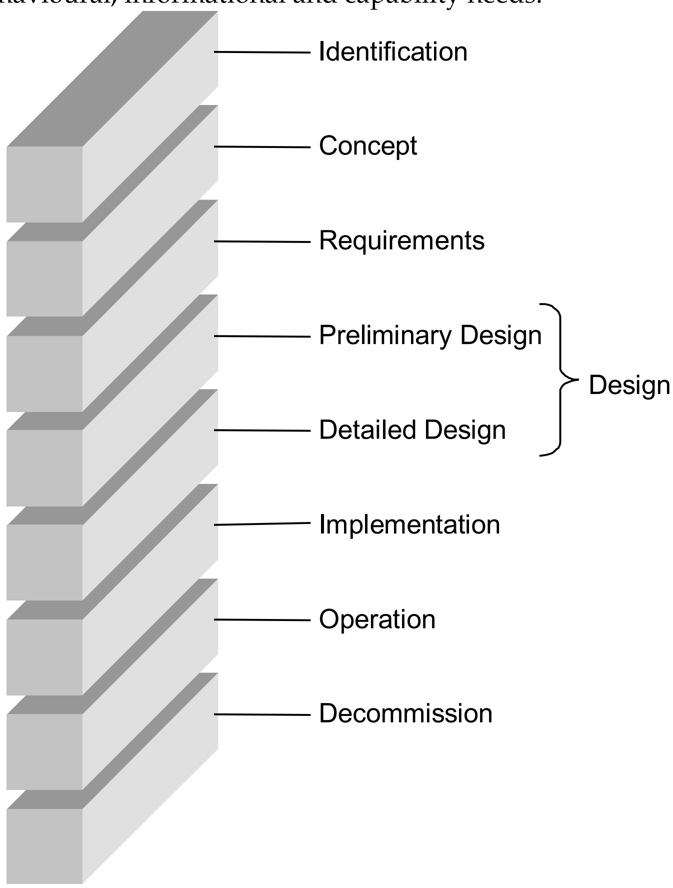



Figure 3.8: GERA life cycle activity types

- **Design:** specifies the entity with all of its components that satisfy the entity requirement. Dividing design into functional design and detailed design permits the separation of overall enterprise specifications (sufficient to obtain approximate costs) from the major design work necessary for the complete system design suitable for fabrication of the final physical system.

- **Implementation:** covers three main parts:
    - commissioning, purchasing, (re)configuring, manufacturing and control resources
    - hiring and training personnel, developing or changing the human organisation
    - component testing and validation, system integration, releasing into operation
- **Operation:** produces the customer's product or service. Deviations from goals and objectives or any feedback from the environment beyond the ability of the current control to account for may lead to request for change, which includes enterprise re-engineering or continuous improvement.
- **Decommissioning:** decommissions, retrains, redesigns, recycles, preserves, transfers, disbands, disassembles, or disposes of all or part of the entity, at the end of its useful life in operation.

*Life history*

The life history of a business entity is the representation of all the different tasks, which have been carried out on the particular entity during its entire life span.

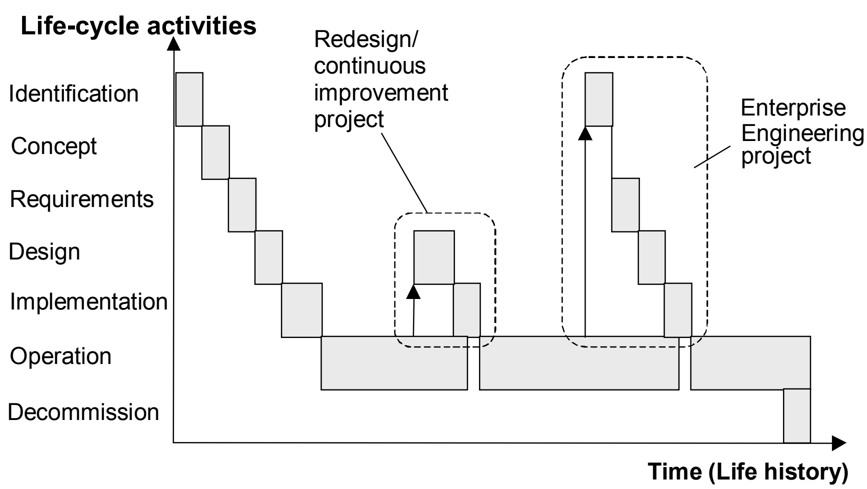



Figure 3.9: Parallel processes in the entity's life history [Bernus 1999]

Life histories of entities are all unique, but all histories are made up of processes, which in turn rely on the same type of life-cycle activities as defined in the GERA life cycles.

*Entity types in Enterprise Integration*

Life cycle activities of two entities may be related to each other. In Figure 3.10, the operation of entity A supports the life cycle activities for design and implementation of entity B. For example, entity A may be an engineering entity producing part of entity B, such as a factory. Examples of other relations between the life cycle activities of enterprise entities may be defined. However, it is always the case that only the operational one of any entities will influence the life cycle activities of other activities.

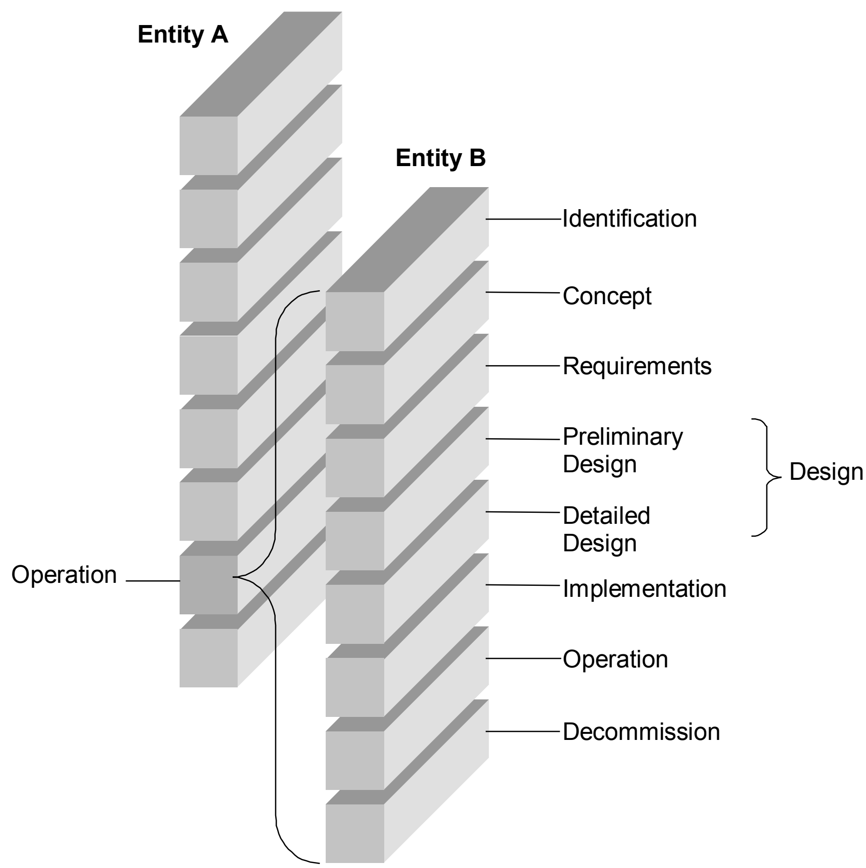



Figure 3.10: Example of the relationship between life cycles of two entities [Bernus 1999]

*Technology oriented concepts*

Technology oriented concepts have to provide descriptions of the technology involved in both the enterprise operation and the enterprise engineering efforts.

It is often proposed that the ultimate solution would be the development of a set of computer executable models, which would be the basis for a computer-based operational control system for the enterprise. For such an operation-based technology to succeed, all of the technology-oriented concepts noted above have to be related to resource models and resource organisation models [ISO 2000].

### 3.5.2 The Overall Architecture of GERA

GERA describes an architecture, Figure 3.11, which is based on the life-cycle concept and which identifies three dimensions for structuring the components of enterprise modelling.

- Life-Cycle Dimension
- Generic Dimension
- View Dimension

The development of the life-cycle dimension is described in chapter 3.5.1.

**Generic Dimension** (also called "instantiation"); contains three levels, where the first two levels are reference models:

- The first level brings generic Building Blocks. They are the first concepts of modelling.
- The second one contains a library of generic models, describing typical enterprises of a same domain: like car producers, banks, etc.
- The third level is the particular model of the enterprise.

**View Dimension**; GERA defines a set of the kinds of models, which are deemed desirable, allowing for the fact that an even finer subdivision may be prescribed by GERAM-compliant candidate architecture. The following sub-entities of model views have been identified in GERA:

- **Entity Model Content Views**: function, information, resource, and organisation.
  Four different model content views have been defined:
  - Function View
  - Information View
  - Resource View
  - Organisation View
- **Entity Purpose Views**: product, customer service, management and control.

- **Entity Implementation Views**: human activities and automated activities.
- **Entity Physical Manifestation Views**: software, hardware.

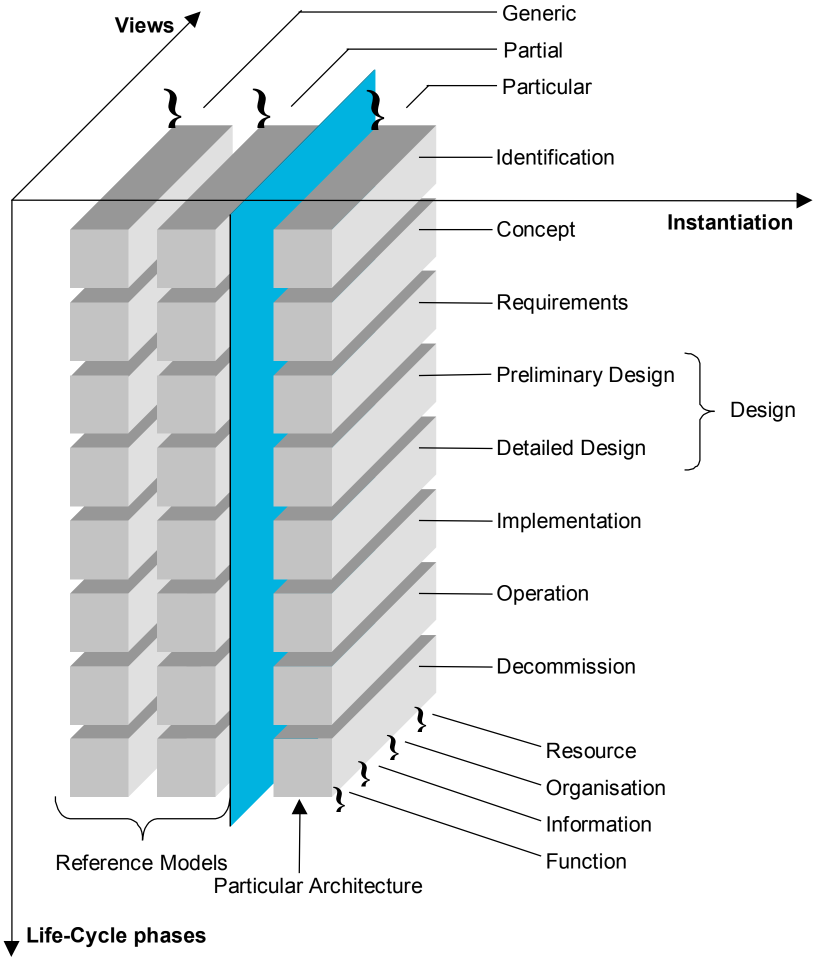



Figure 3.11: Generalised Enterprise Integration Architecture [Bernus 1999]

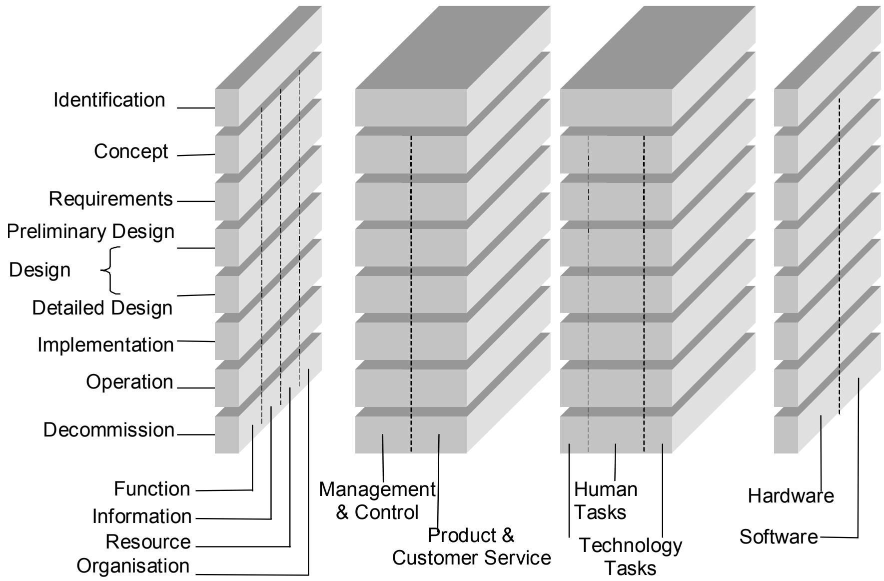



Figure 3.12: The Four View Divisions [Globeman 99]

## 3.6 Summary

As described above the number of enterprise modelling approaches are unlimited. For an overview of existing methods and tools only the most commons once are presented. Many of the models and architectures described here are based on standards.

Standards have the advantage that they normally are carried out by a large number of people representing different environments, backgrounds and interests. International standards also give good snapshots of status.

ISO TC184/SC5/WG1, Reference Model for shop;

- provides a conceptual framework for understanding of discrete part manufacturing
- identify areas of standards necessary to integrate manufacturing systems

CIMOSA, The Open Systems Architecture for CIM, developed by the AMICE Consortium, focuses of two main areas:

- Enterprise modelling framework
- Integrating Infrastructure

ISO 14258, "Industrial automation systems – Concepts and rules for enterprise models" does not define enterprises, processes, organisations or modelling concepts, but is an overall definitions, of how enterprise model standards should be developed. The standard specifies concepts and rules for computer understandable models of a manufacturing enterprise to better enable processes to incorporate.

ARIS, Architecture for integrated Information Systems, is generic and constitutes a framework where integrated application systems can be developed. ARIS has much in common with CIMOSA, builds on the same modelling levels. ARIS is today supported by a software tool, ARIS-toolset and are much in practical use for Enterprise Modelling and Business Process Re-engineering. The ARIS-toolset is also related with modelling purposes for implementation of the most common ERP-system, SAP.

GERAM, Generalised Enterprise Reference Architecture, is not one more method, it defines a tool-kit of concepts for designing and maintenance of enterprises during their entire life. GERAM is meant to organise existing enterprise integration knowledge. GERAM provides a description of all the elements recommended in enterprise engineering and enterprise integration. It does not impose any particular set of tools or methods but defines the criteria to be satisfied.

GERA defines the enterprise related generic concepts recommended for use in Enterprise Engineering and integration projects. GERA is the most important and developed part of GERAM. GERA provides architecture based on a life-cycle concept and identifies three dimensions for structuring the components of enterprise modelling.

- Life-Cycle Dimension
- Generic Dimension
- View Dimension

# 4. Modelling, control and operation of enterprise models

### *4.1 Systems Theory*

The are many different approaches within Systems Theory. A term like General Systems Theory covers nearly all kinds of scientific disciplines. Even if we go back to the old Greeks we find persons like Plato, the founder of Geometry and Aristotle who introduced the terms of logic. Euclid formulated Greek Geometry 300 years BC where he also made the first model of the physical world. Geometry at that time was not to make visualisation, but was used to represent models of the physical world, as motivation of moving objects. It was a physical language where the objects' behaviour could be described. Newton built on Euclid's work in his work Principia, in 1687 where he formulated classical mechanics [Bjørke 1995].

Over the years there has been many contributors within System Theory, each with its own specific feature. The different systems theory approaches have significant differences but they have common fundamental motivations and aims. K-E Boulding describes it this way:

*'General Systems Theory is a name which has come into use to describe a level of theoretical model-building which lies somewhere between the highly generalised constructions of pure mathematics and the specific theories of the specialised disciplines…..*

*Because in a sense mathematics contains all theories, it also contains none, it is the language of theory, but it does not give us the content. At the other extreme we have the separate disciplines and sciences with their separate bodies of theory. Each discipline corresponds to a certain segment of the empirical world, and each develops theories which have particular applicability to its own empirical segment, Physics, Chemistry, Biology, Psychology, Economics and so on all carve out form themselves certain elements of the experience of men (and women[1]) and develop theories and patterns of activity (research) which yield satisfaction in understanding, and which are appropriate to special segments.*

*In recent years increasing need has been felt for a body of systematic theoretical construction which will discuss the general relationships of the empirical world. This is the quest of General Systems Theory. It does not seek, of course, to establish a single, self-contained "general theory of everything" which will replace all special theories of particular disciplines. Such a theory would be almost without content, for we always pay for generality by sacrificing content, and all we can say about*

[1]writer's remark

*practically everything is almost nothing. Somewhere, however, between the specific that has no meaning and that the general that has no content there must be, for each purpose and at each level of abstraction, an optimum degree of generality.'*[Boulding 1956]

Epistemology is defined as the branch of philosophy that investigates the origin, structure, methods and validity of knowledge. George J. Klir states that one important result of epistemology is the discovery that there are necessarily some limits of knowledge. The general systems theory as outlined is based essentially on this epistemological result [Klir 1969].

The first known scientist that developed a General System Theory was an Austrian scientist Ludwig Von Bertalanffy who later moved to the USA. He first introduced System Theory thinking in the area of Biology, but later the theories were made general. He gave some presentations of his works in the 30ies, but the first written papers came after World War II. Later he made approaches like "An outline of General System Theory" from 1950 and "General System Theory" in 1968. His latest work was published in 1975 "Perspectives on General Systems Theory" three years after his death in 1972 [Bertalanffy 1975].

Von Bertalanffy also populated his work into other scientific areas like social science, physiology, economics and technical specialisation's. He was convinced that General System Theory was multidisciplinary and could reduce the chasm between social and technical science. He felt it important that this was a fundament that could bring technical science away from a positivistic classical way of thinking and more into a theoretical fundament.

One interesting aspect of Von Bertalanffy's thinking is his view on organisation and enterprises [Bertalanffy 1968]. From a system point of view an organisation can have very many different forms; an organisation can be everything from atoms and molecules through living organisms to complex companies, human society and nations. Organisations deal with issues like wholeness, growth, differentiation, order, dominance, control, competition etc. This does not appear in physics. But system theory is capable of dealing with these matters. A modern complex enterprise deals with most of these typical organisational relations. There are also strong relations between human and mechanical interaction and both internal and external behaviour influence the operation of the enterprise.

George J. Klir states that the approaches of systems theories are more or less general in nature. And that we can find levels of details or applications within different theories. We can divide this into two main categories of theories [Klir 1969]:

- Low level of generalisation – application or discipline oriented theories like theory of mechanical systems, theory of design, theory of manufacturing, theory of electronic circuit's etc.

- High level of generalisation – application independent, theories like theory of algebraic systems, theory of logic (binary), structure or grouping theories.

We can also find approaches with elements of both, serving a larger area but still have some scientific or engineering boundaries defined.

### 4.2 Theory of Connection

Professor Ole Franksen and Professor Øyvind Bjørke basically developed different areas of the Manufacturing System Theory. Their origin of the work is the Theory of Connection, which is based on continuos systems.

*Manufacturing System Theory* [Bjørke 1995] was developed to describe system-oriented approaches to manufacturing processes included product configuration and design processes. This includes a large number of disciplines like mechanics, cybernetics, material science etc. on the physical side and planning activities economical aspects and optimisation processes on the human side. The theory is based on *geometry as the foundation* and the methods within the theory are related to concepts of connections. The analysis of the manufacturing systems is the prime area for the usage of this theory and is important in order to bring a science base into manufacturing. But the theory can be used in generic ways.

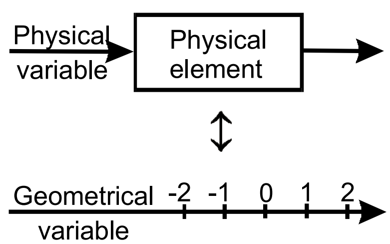



Figure 4.1: Physical Variable mapped with Geometrical Variables

For a long time there has been ongoing research to develop theories within manufacturing. We can find some approaches from the 60's when Eugene Merchant introduced a concept of "Manufacturing Systems". His theory was lifecycle oriented and a quite early approach in that direction especially when we consider that he covered Product development (design), manufacturing in an integrated manner. He also covered lifecycle aspects like maintenance, and recycling of discrete products [Bjørke 1995]. Merchant put much focus on machine resources and tooling with human interactions. He is close to mentioning Computer Integrated Manufacturing directly when he describes very early architectures of CIM like systems that in other literature leads further to the earliest Enterprise Model approaches.

Eugene Merchant had six overall areas in his integrated manufacturing approaches or fields for optimisation [Merchant 1968]:

- Design for production
- Part family manufacturing
- Other applications of computers to manufacturing
- Numerical control
- Adaptive control
- Manufacturing systems

Merchant has the vision of a fully automated design and manufacturing environment and the usage of the computer will be the key device to support these solutions. Even though important research within these fields over the last 30 years has contributed to enormous improvements in productivity within manufacturing, his vision of a fully self-optimising and automated system has not become the reality. The vision is still far into the future and it is probably not the ultimate goal any longer either. However, to organise the design, manufacturing and also other product lifecycle phases into more specified system thinking are still very valid.

The Theory of connections is based on the general abstract viewpoint of connection of physical entities into a system. The Theory has geometry as its foundation and is based on the use of continuos spaces. Its workplace can be a geometrical 3-space or more typically an n-space volume (A Euclidean space $R^N$). A vector represents a point in the Euclidean space, or primary space, from the origin to the point. The vector is called the contravariant vector:

$\mathbf{x} = x^1\varepsilon_1 + x^2\varepsilon_2 + x^3\varepsilon_3$ where $\varepsilon_1$, $\varepsilon_2$, $\varepsilon_3$ are the basis vector along the three axis.

A point in the corresponding dual space defines another vector; a covariant vector, we get the following representation:

$\mathbf{a} = a_1\boldsymbol{\varepsilon}^1 + a_2\boldsymbol{\varepsilon}^2 + a_3\boldsymbol{\varepsilon}^3$ where $\boldsymbol{\varepsilon}^1$, $\boldsymbol{\varepsilon}^2$, $\boldsymbol{\varepsilon}^3$ are the basis co-vector along the three axis.

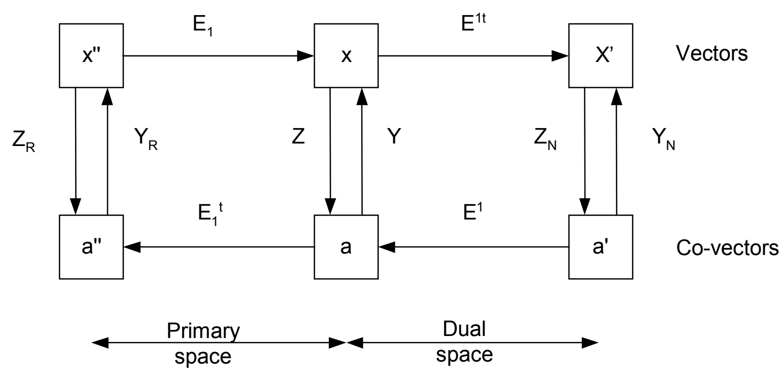



Figure 4.2: Transformation of vectors and co-vectors (Simplified version of Roth's diagram)

As far as physical system modelling is concerned the aim is to formalise the different equations that describe the dynamic behaviour of the system in array theoretical terms [Bassam 1999]. Figure 4.2 shows how the transformations in the spaces are performed, and how they are related. The foundation of the vectors used is shown in Figure 4.3.

### 4.3 The Theory of Logic

*The theory of logic* [Møller 1995] relates also to the concept of connections, but now of logical variables. The theory of logic is a parallel to the theory of connection. It is just using logical variables in stead of physical variables and should be able to replace the geometry-founded theory for any manufacturing system approach.

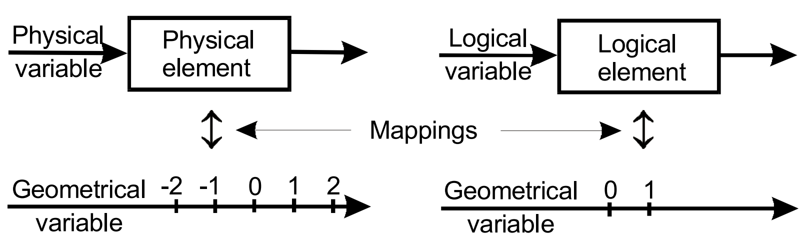



Figure 4.3: Mapping Physical and Logical Variables on Geometrical Variables

The theory of logic has been used in different ways to solve and control configuration challenges like configuration of complex products in the design phase, configuration of different networks, like power networks or railroad interlocking systems.

The system theory can be divided into to streams:
- The Physical System Modelling
- The Logical System Modelling

*Major Advantages*

The theory of connection and the theory of logic may be used in all industrial areas requiring physical and logical decisions, such as design, production systems, project management, control systems e.g. PLC, and CNC. Usage of System Theory Approaches has many advantages within information technology. Complex information technology challenges can be solved by the theory:

- Object oriented design of database
- Complete and consistent applications
- No distinction between input and output
- Deduction with incomplete data
- High speed decisions by table lookup
- Parallel processing

## 4.4 Enterprise Modelling and Manufacturing System Theory

### 4.4.1 GERAM architecture combined with the Theory of Logic

In chapter 1 we went through some main approaches within enterprise modelling. The two most structured once, GERAM and CIMOSA can fit well into a 3 dimensional orthogonal space similar as the Product, Process and Organisation (PPO) model. The main advantage of similar 3D structure is that the models should have unique identified axis and in this avoids double descriptions and redundancy of information and entities in the model.

A system can be defined as an organised group of entities such as people, equipment, methods, principles and parts that come together and function as a unit. In this term a manufacturing company can be seen as a system. [Haavardtun, 1995]. Enterprise can in this term be seen as a synonym for manufacturing company.

In other words the modelling must be done in such a way that the axis defines unique representations of entities. The uniquely defined entities or building blocks as it also can be expressed can then be converted to logic 3-space objects.

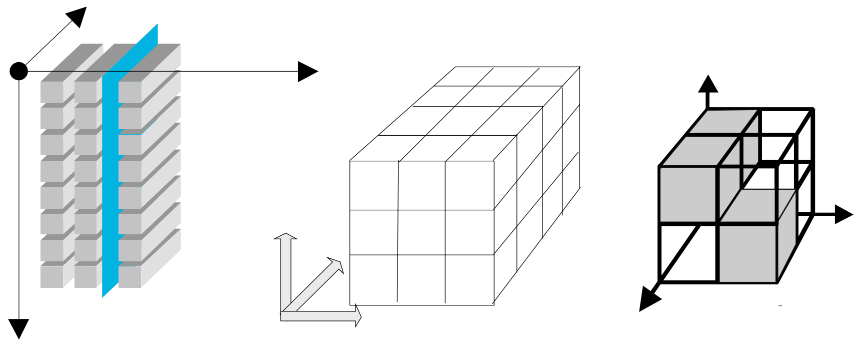



Figure 4.4: Visual similarities of Enterprise Modelling Architectures and logical system variables

The achievement we then get is a model that can be used in operational phases of the enterprise. The model can be a steering or management-supporting tool indicating logical expression for status of operational phases. Dependencies between the entities can be set up and external sources with logical values (FALSE or TRUE) will make influence to the execution of the system. The logical operation of the enterprise model can be used on any level, from shop floor control to organisational and marketing situations. The logical approach will not be a model solution for enterprise operational data storage.

In the further work GERAM is the enterprise modelling architecture used for further development and usage in this thesis. CIMOSA is to generic to be used directly. GERAM fits also more into the PPO architecture. But n many cases e.g. within engineering of an enterprise this new enterprise are the product axis and not a consumer product that will be manufactured when the plant is completed.

To make an own and specific definition for enterprise modelling based on the constraints and requirements from this work the sentence could be the following:

*'Enterprise models are classes of models that embraces process, product organisation structures in a 3D space, to manage target and key parameters'.*

This is a reworked version or specific variant of the third definition of enterprise models in chapter 2.1.

An example of relationship between life cycles of two entities is shown Figure 4.6 which builds on Figure 3.10, 'Example of the relationship between life cycles of two entities'.

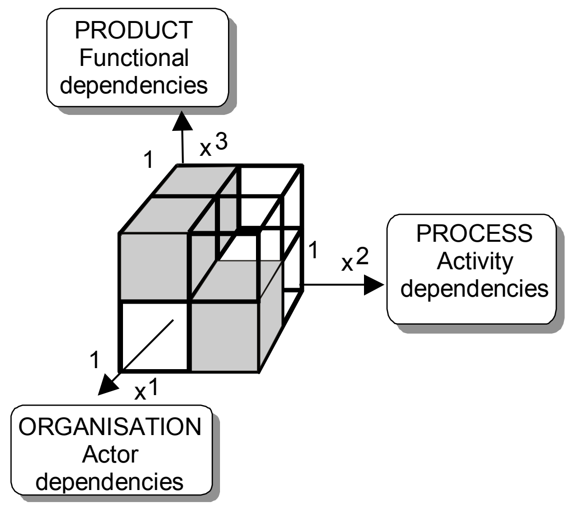



Figure 4.5: The generic PPO-Model mapped into a generic logical 3-space for Enterprise Modelling

### 4.4.2 First Logic Calculation example, two premises, Example 1

If we take the GERA Lifecycle Model in Figure 4.6 from the GERAM concept and try to make a simple case where an overall operational situation can be described by Theory of Logic. The situation can be the following:

- Entity A is an engineering company or constancy that support the life cycle activities from design to implementation of entity B.
- Entity B can be a manufacturing unit or a factory that shall be put to operation (start up the production) with the required Functions, Information, Organisation and Resources.
- The operations phase of entity A makes or improve activities in entity B.
- A decision to make a new product (P) can start the processes, at entity A, to make a new or improve an existing manufacturing plant, entity B. (A decision to make a new model of a car will bring changes both in main assembly lines and mostly at all sub-suppliers in the manufacturing network.)

- The organisation of plant (B) has to be implemented.
- Entity A: Engineering/consulting company
- Entity B: Manufacturing company/factory
- Product P: Product to be produced in Entity B

If product P is being produced the factory B is in active production (operating) and the engineering task at entity A to design the factory is completed (not active). And if the factory, entity B is operating the organisation of entity B has been implemented.

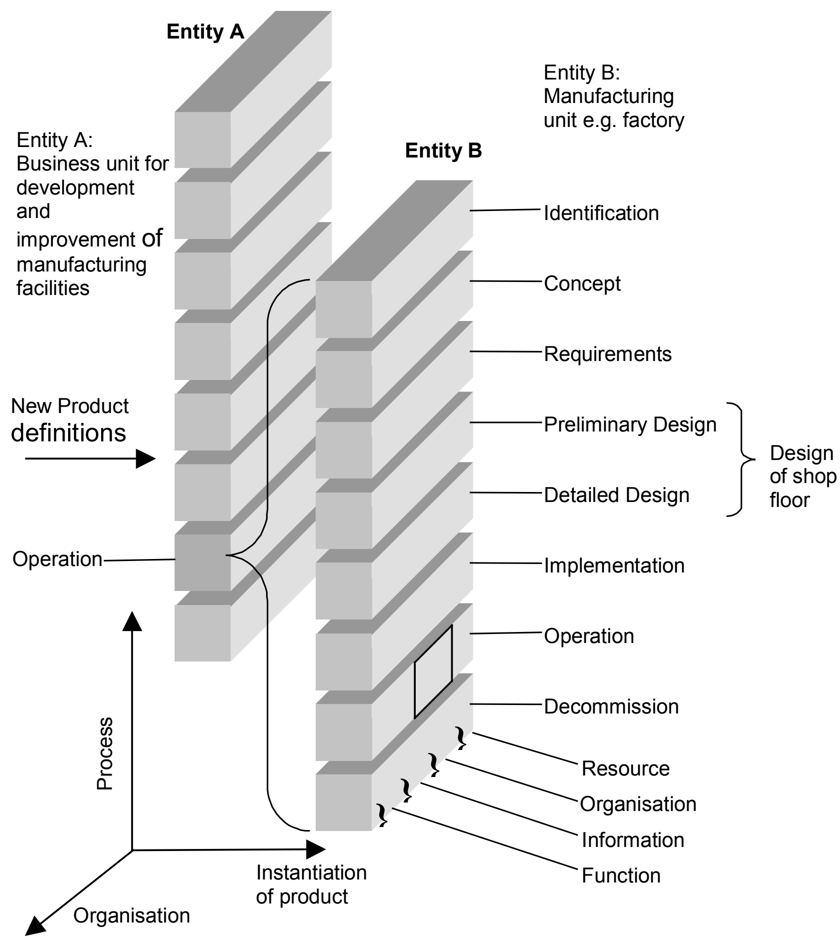



Figure 4.6: GERA-Model as a basis for a Theory of Logic approach

- If product P is in production then factory B is operating and engineering unit A is not operating.
- If plant B is operation then the organisation is implemented

- The organisation is not implemented
- Product P is not produced

This will give us the following variables:

E: Plant B is operating
F: The engineering unit A is operating
G: The organisation of plant B is implemented
H: Product P is produced

There are four independent elements each described with one variable E, F, G, H. The logical function *f*(E,F,G,H) can be set up as a binary 4 space.

The relations between the elements, expressed by the logical variables, can be as follows:

Premise 1: $H \Rightarrow (E \wedge (\neg F))$, Premise 2: $E \Rightarrow G$

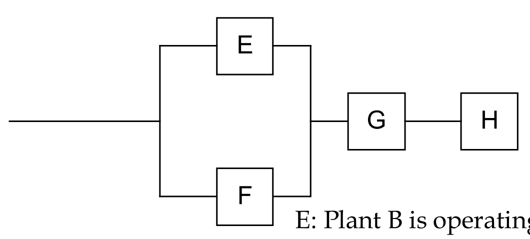
We can define a source given by an External influence as:

External influence: $\neg G$ (The organisation of factory B is not implemented)

The result will then be $\neg$ H (The product P is not being produced)

We can then go further with the example and try to do more general calculations.

In the logical function *f*(E,F,G,H) all the four variables can be true or false.




E: Plant B is operating
F: The engineering unit A is operating
G: The organisation of plant B is implemented
H: Product P is produced

Figure 4.7: Flow chart of the particular production problem

| Logical Variable | False | True |
|---|---|---|
| Variable E | 0 | 1 |
| Variable F | 0 | 1 |
| Variable G | 0 | 1 |
| Variable H | 0 | 1 |

Table 4-1: Logical variables

Premise 1 (P1): H ⇒ (E∧(¬F))
H, E and F are set to the logical values 0 1 before the calculation

P1 ← H imp (E and (not F))
11 00
11 10

Premise 1 is shown in Figure 4.8

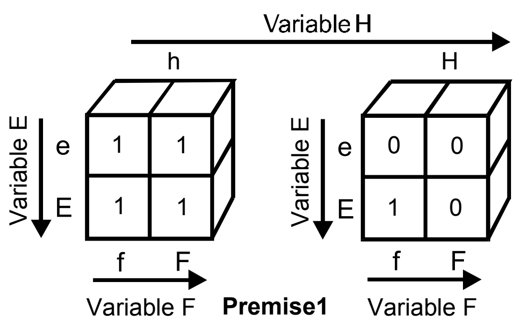



Figure 4.8: Premise 1 of the calculation

Premise 2 (P2): E ⇒ G
E and G are set to the logical values 0 1 before the calculation
P2 ← E imp G
11
01

Premise 2 is shown in Figure 4.9

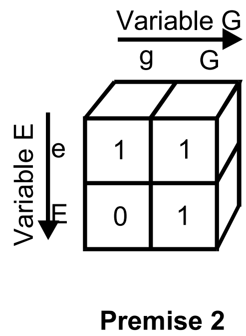



Figure 4.9: Premise 2 of the calculation

The total system can be found by taking the AND operation between the two premises:

System = Premise 1 $\wedge$ Premise 2

The 5-dimensional object with two E axes can be reduced to a 4 dimensional system. This is shown in Figure 4.10.

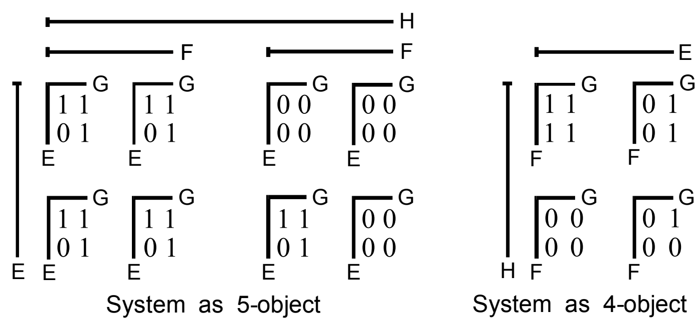



Figure 4.10: The system 5-object left, reduced 4-object right

If we continue and include the external source to be a part of the total system with the sources applied, Sa.
Sa = Sy and (not G)

Sa = Sy $\wedge$ $\neg$G, and more detailed: Ts $\leftarrow$ 1 2 3 4 4 tra Sy and
(not G).

The 5-dimensional object has two G axis which again can be reduced to a 4-dimensional system. This is shown in Figure 4.11 where the 4-object in the right part of the figure represent Sa, which we can do a deductive reduction on of the variables E, F and G.

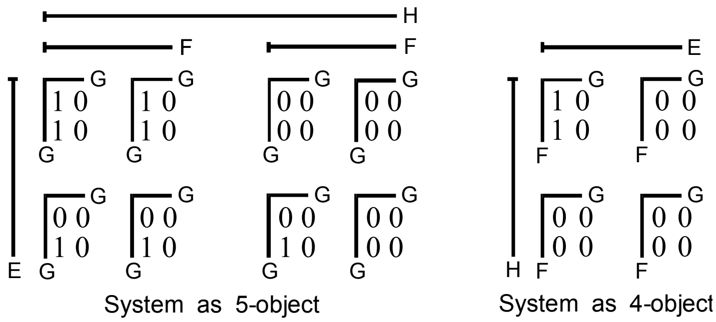



Figure 4.11: The total system with sources reduced from a 5 to a 4-object

When we do a deduction of Sa we see that the computed logical result is ¬ H, the product P is not produced, Figure 4.12.

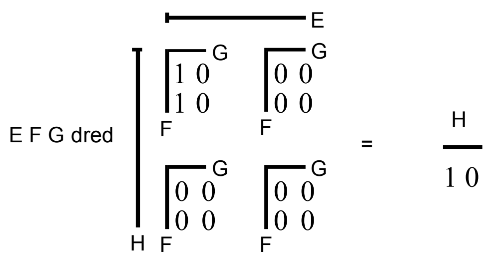



Figure 4.12: Deduction reduction of the variables E, F and G

### 4.4.3 Second Logic Calculation, three premises, Example 2

The first example is quite simple and should in a practical operational or management situation be extended with a lot more variables. The number of variables included in a general case has not really any upper limit, but this will of courses need structured modelling tools, good calculation algorithms implemented and enough calculation capacities.

Every defined n-dimensional logic cube we want to include into the system will be a new variable. In this example we just add one more logical variable.

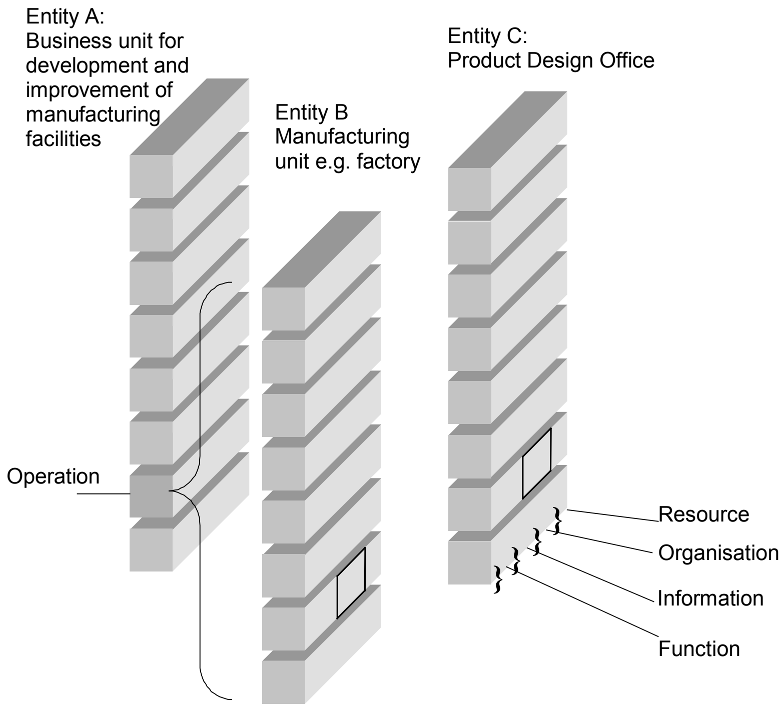



Figure 4.13: Logic Theory Example with use of a GARA-lifecycle model with three entities

We still follow the GEARM structure and the following setting can then be defined:

- Entity A is an engineering company or constancy that support the life cycle activities from design to implementation of entity B.
- Entity B can be a manufacturing unit or a factory that shall be put into operation (start up the production) with the required Functions, Information, Organisation and Resources.
- Entity C is a product design Office
- The operations phase of entity A makes or improve activities in entity B.
- A decision to make a new product P can start the processes, at entity A, to make a new or improve an existing manufacturing plant, entity B. (A decision to make a new model of a car will bring changes both in main assembly lines and mostly at all sub-suppliers in the manufacturing network.)
- The organisation of plant B has to be implemented.
- The product design has to be delivered to the factory, i.e. design office has completed its work

- Entity A: Engineering/consulting company
- Entity B: Manufacturing company/factory
- Entity C: Product design office
- Product P: Product to be produced in entity B

1. If product P is being produced the factory B is in active production (operating) and the engineering task at entity A to design the factory is completed (not active).
2. If the factory B is operating, the organisation of entity B has been implemented.
3. If product P is being produced the factory B is in active production (operating) and the product design office has delivered their design/drawings (not active).

- If product P is in production then factory B is operating and engineering unit A is not operating.
- If product P is in production then factory B is operating and design office C is not operating.
- If plant B is operation then the organisation is implemented
- Design office C is operation (external source)
- Product P is not produced (result)

This will give us the following variables:

D: Design Office C is operating
E: Plant B is operating
F: The engineering unit A is operating
G: The organisation of plant B is implemented
H: Product P is produced

There are five independent elements each described with one variable D, E, F, G, H. The logical function $f$(D,E,F,G,H) can be set up as a binary 5-space.

The following premises can express the relations between the elements:

Premise 1: $H \Rightarrow (E \wedge (\neg F))$ Premise 2: $E \Rightarrow G$
Premise 3: $H \Rightarrow (E \wedge (\neg D))$

We can define a source given by an external influence as:

External influence: $\neg D$ (The design office is not working)

The result will then be $\neg$ H (The product P is not being produced)

We can then go further with the example and try to do more general calculations.

In the logical function *f*(D,E,F,G,H) all the five variables can be true or false.

| Logical Variable | False | True |
|---|---|---|
| Variable D | 0 | 1 |
| Variable E | 0 | 1 |
| Variable F | 0 | 1 |
| Variable G | 0 | 1 |
| Variable H | 0 | 1 |

Table 4-2: Logical variables

Premise 1 (P1): $H \Rightarrow (E \wedge (\neg F))$
H, E and F are set to the logical values 0 1 before the calculation

P1 ← H imp (E and (not F))
11 00
11 10
Premise 1 is shown in Figure 4.14:

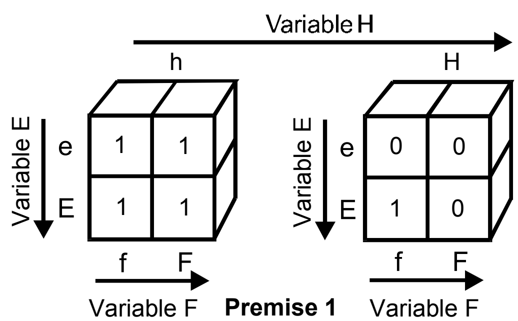



Figure 4.14: Premise 1 of the calculation

Premise 2 (P2): $E \Rightarrow G$
E and G are set to the logical values 0 1 before the calculation
P2 ← E imp G
11
01
Premise 2 is shown in Figure 4.15

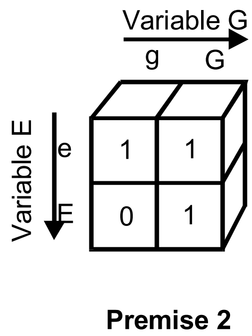



Figure 4.15: Premise 2 of the calculation

Premise 3 (P3): H ⇒ (E∧(¬D))
H, E and D are set to the logical values 0 1 before the calculation

P3 ← H imp (E and (D))
11 00
11 10

Premise 3 is shown in Figure 4.16.

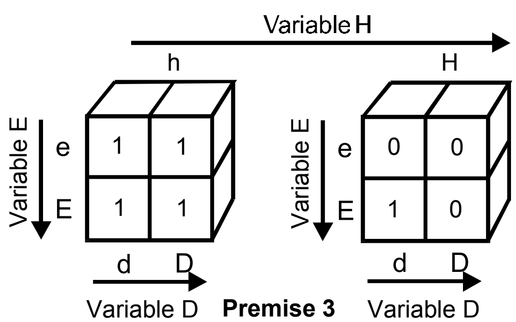



Figure 4.16: Premise 3 of the calculation

The total system can be found by taking the AND operation between the three premises:

System = Premise 1 ∧ Premise 2 ∧ Premise 3



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```
print P1„premise 'H imp (E and (not F))'
 |-------E
   __H  __H
 |11  |11
 |01  |00
 F    F

   print P2„premise 'E imp G'
   __G
 |11
 |01
 E

   print P3„premise 'H imp (E and (not D))'
 |-------D
   __H  __H
 |10  |10
 |11  |10
 E    E

 print Ei„premise 'D',    External influence
 __D
 10

   print total„join P1 P2 P3 Ei
     |---------------------D
     |-------F     |-------F
       __H  __H      __H  __H
  ┬  |00  |00   ┬  |10  |00
  |  |00  |00   |  |10  |00
  |  G    G     |  G    G
  |    __H  __H |    __H  __H
  |  |00  |00   |  |00  |00
  |  |00  |00   |  |10  |00
  E  G    G     E  G    G

      dismat  varH„7  deduct  total,     Deduction
along axis H (axes 7)
.---.
|1 0|
'---'
The  results  are  not  true,  Product  P  is  not
produced.
```

Figure 4.17: APL calculation of Example 2

### *4.5 The organisational dimension*

#### 4.5.1 Example from the organisational areas within GERAM, Example 3

Organisational and strategic issues is an important but difficult part of Enterprise Modelling, and another challenge is how these issues can be modelled and through Enterprise Modelling e.g. with use of Theory of Logic.

The first challenge is to set up n organisational oriented cases where a logic approach and its solutions tell something useful.

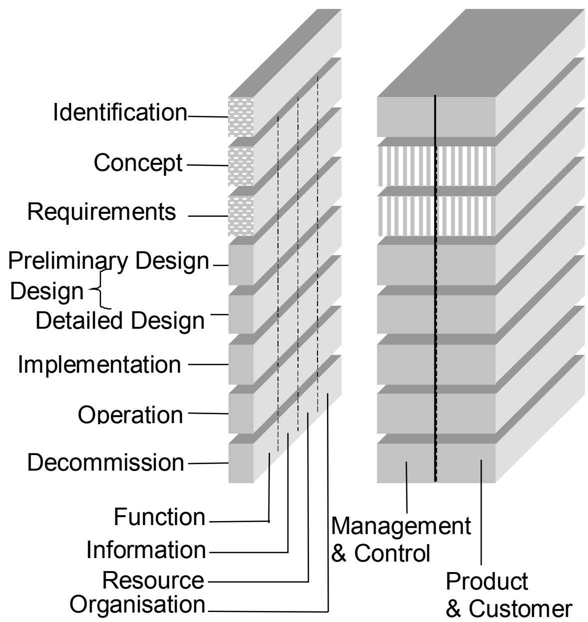


Figure 4.18: Theory of Logic example with focus on organisational dimension

We will again start with a view from GERAM illustrated in Figure 4.18, where we define the following situation:

- Identification of new enterprise and new product to handle new possible market
- Development of concept to utilise this product or service in this market
- Evaluate dedicated market segments
- Planned strategy and organisation for new an enterprise unit

This setting could have been an earlier phase of the previous examples, and the planned outcome of a new unit could be the factory or Entity B in the two previous examples. We set up the conditions for the case and do the logical calculation.

- Sketch of new product developed
- New possible market discovered, identified by customer service
- Management engineering group to make new enterprise concept established and active
- Evaluation of market 1
- Evaluation of market 2
- Engineering of new enterprise unit is active.

This will give us the following variables:

A: New product sketch developed
B: New possible market discovered
C: Management Engineering Group established
D: Marketplan 1
E: Marketplan 2
F: Engineering of new enterprise unit

There are seven independent elements each described with one variable A; B; C; D; E, and F. The logical function *f*(A,B,C,D,E,F) can be set up as a binary 6 space. The relations between the element can expressed by the logical variables are the following:

Premise 1: $C \Leftrightarrow (A \wedge B)$
Premise 2: $F \Leftrightarrow (C \wedge (D \vee E))$

External influence E (market segment 1) FALSE

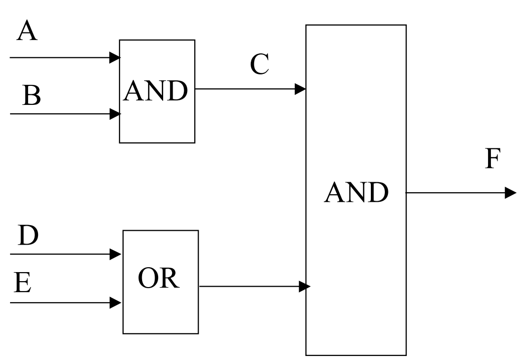


Figure 4.19: Logical diagram of example 3

```
Formulation of the problem

     print P1„premise 'C bimp (A and B)'

 |-------A
  __C  __C
 |11  |10
 |00  |01
 B    B

      print P2„premise 'F bimp (C and (D or E))'

   |-------D
    __F  __F
┬  |11  |00
|  |10  |01
|  E    E
|   __F  __F
|  |11  |00
|  |00  |11
C  E    E

      print Ei„premise 'not E',    External influence

  __E
  10

      print totei„join P1 P2 Ei

      |---------------------B
      |-------D     |-------D
       __F  __F      __F  __F
 ┬ ┬  |11  |00   ┬  |00  |00
 | |  |00  |00   |  |00  |00
 | |  E    E     |  E    E
 | |   __F  __F  |   __F  __F
 | |  |11  |00   |  |00  |00
 | |  |00  |00   |  |00  |00
 | C  E    E     C  E    E
 |
 |    |-------D     |-------D
 |     __F  __F      __F  __F
 | ┬  |11  |00   ┬  |00  |00
 | |  |00  |00   |  |00  |00
 | |  E    E     |  E    E
 | |   __F  __F  |   __F  __F
 | |  |00  |00   |  |11  |00
 | |  |00  |00   |  |00  |00
 A C  E    E     C  E    E
```

Figure 4.20 APL calculation of Example based on: Premise 1: C⇔ (A∧B) Premise 2: F⇔ (C∧(D∨E)) and External influence E (market segment 1) FALSE, Example 3.

This example shows us that we can make any logical set-up of the GERAM approach. These three examples could be combined and all phases of the enterprise modelling and even operational issues of any stage of enterprise covered within the modelling could have been executed through this logic.

### 4.5.2 Controlling uncertainties within enterprise modelling

Strategic plans are often the basis for development of the enterprise or creation of new enterprises. Also on a lower level, strategic planning can be part of a total enterprise renewal. Emergent strategies will occur in both cases. If enterprise modelling is used as a tool for formation of the enterprise, strategy in general should be an important element. The problem we then get is that scenarios will be influenced by unplanned external sources. Such sources can have random effect on the original planned work and in practical life it needs manual reactions and rapid changes of models and plans.

As stated in chapter 2.7.5 Integrated Strategic Management, ISM, the main problem with strategic planning is the uncertainty of the occurrences of emergent strategies.

However over the years the computer has managed to solve more and more complex problems even for human based processes. The problems and challenges we face if an enterprise strategy really fails, like large unexpected hindrance from competitors, new difficult legislation's or even changes in trends occur the situation for an enterprise can be very difficult. But there is nothing that indicates that human experience, intelligence and also intuition will be less important to handle such situations also in future. The computer solutions are only a support. Use of logic theory within enterprise modelling can make it possible in a more smooth way to make use of the conceptual models in an operational phase for management and control.

The three examples above show relatively simple modelling situations. There are, however, many situations where the internal enterprise model itself can be straightforward to model, but the external influences can be very difficult to handle. For a manger to retrieve assistance in the handling of complex operational problems the various external influences need to be dealt with within the model. The executed models need to be changed and updated based on unexpected external changes.

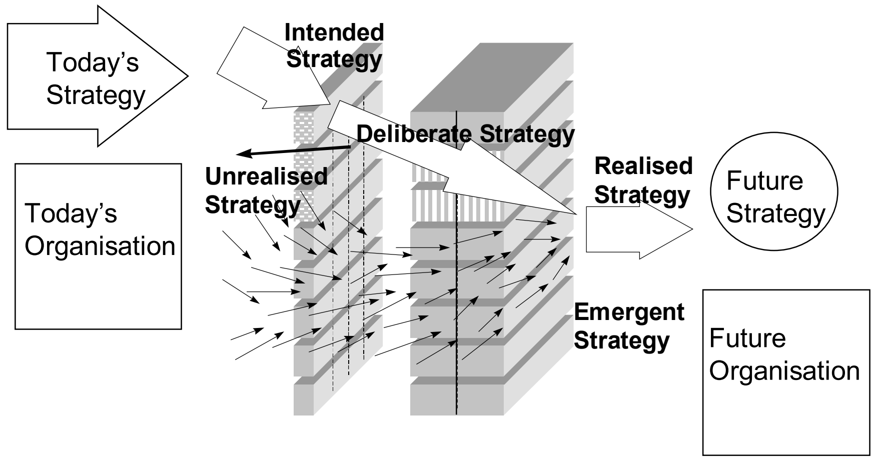


Figure 4.21: Enterprise Modelling as a part of organisation development and strategy formation

*Example with uncertainty included, example 4*

This new example where different external sources or occurrences are included is a variant or extension of example 3:

Planned enterprise engineering processes

A: New product prototype developed
B: New possible market discovered
C: Management Engineering Group established
D: Market plan for market 1
E: Market plan for market 2
F: Engineering of new enterprise unit
K: Total market

There are six independent elements each described with one variable A; B; C; D; E, F and K. The logical function *f*(A,B,C,D,E,F,K) can be set up as a binary seven space.

The relations between the element can expressed by the logical variables are the following:

Premise 1: $C \Leftrightarrow (A \wedge B)$
Premise 2: $K \Leftrightarrow (D \vee E)$
Premise 3: $F \Leftrightarrow (K \wedge C)$

In this example we will do the calculations with two different external influences options:

We presume that Premise 1 is TRUE; C: Management engineering group is established.

The 'or' logic between variables D and E means if at least one of the marketplans exists K is TRUE. Premise 3; 'Variable F Engineering of a new enterprise unit' is TRUE if C and K is true. We can simulate such situation and set Premise 3 'TRUE'.

To make the situation more complex two more external occurrences and one variable exist:
G: Competitor threats
H: Unknown external constraints (e.g. new legislation)
I: Final output

| G: Competitor threats | | | | |
|---|---|---|---|---|
| Threat description | (G1), Cheaper competitive product | (G2), Competitive new technology | (G3), Competitor alliances | Total G (G1, G2, G3) |
| Possible State | TRUE or FALSE | TRUE or FALSE | TRUE or FALSE | TRUE or FALSE |

| H: Unknown external constraints | | | | |
|---|---|---|---|---|
| Uncertain threat description | (H1), New environ-mental requirements | (H2), New tax system | (H3), Local regional regulations | Total H (H1, H2, H3) |
| Possible State | TRUE or FALSE | TRUE or FALSE | TRUE or FALSE | TRUE or FALSE |

Table 4-3: Example of an evaluated set of logical indicators for external sources or disturbances

A logical pre-setting or evaluation of the different externally connected variables where a FALSE or TRUE value can be given based e.g. on a market or environmental assessment or alternatively manual or computer supported assessments. An example with such logical indicators is given in Table 4-3.

The significance of total external logical the values of G (G1, G2, G3) and H (H1, H2, H3) should be manually determined. In the final evaluation or risk assessment of the external influences, both AND and OR logic can be used. But the decided logic cannot be changed within the same calculation. An OR logic will be more restrictive and have a larger number of G and H combinations (threats) to be TRUE. Which logic that will be used in a case will also depend on the total risk assessment of the particular project. The G and H values for the example are shown in Table 4-4.

| G1 | G2 | G3 | G | H1 | H2 | H3 | H | G∧H | G∨H |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 |
| 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 |
| 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 |
| 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 |
| 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

Table 4-4: External indicators value (G1, G2, G3, H1, H2, H3) all combinations and total evaluated G and H values.

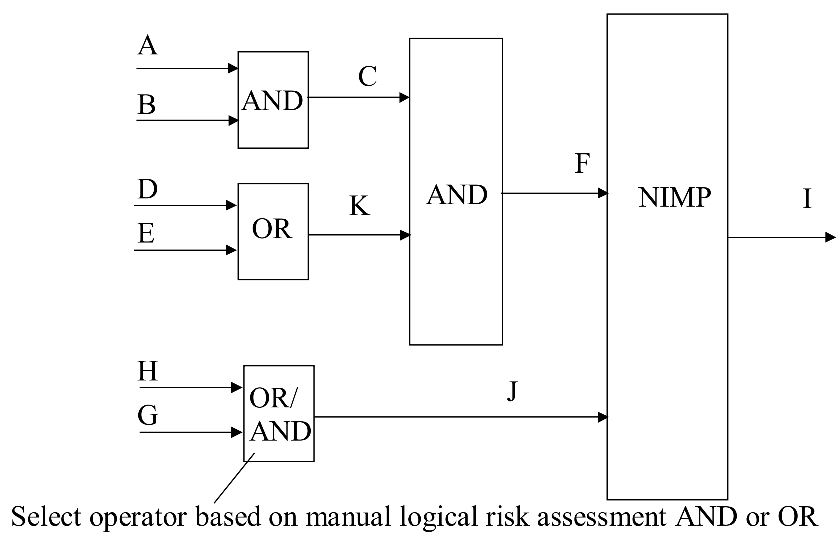


Figure 4.22: Logical flowchart of the total situation with the external disturbances or threats included, (NIMP: Direct Non-implication)

Based on the approved markets plan(s) the engineering of a new enterprise unit goes on. Competitor threats and eventually other unknown external constraints are monitored. The settings in the remaining system will then be:

F: Engineering of new enterprise unit
G: Competitor threats
H: Unknown external constraints (e.g. new legislation)
J: Total external constraints
I: Final output

| Variable | True state | False state | Array values |
|---|---|---|---|
| F (output, premise 1) | Engineering | No engineering | 0 1 |
| G (external input) | Competitors | No competitors | 0 1 |
| H (external input) | Constraints | No constraints | 0 1 |
| J (total ext. constr.) | Constraints | No constraints | 0 1 |
| I Final output | Project continue | Project stops | 0 1 |

Table 4-5: Variables in the reminding primitive system

The system can then be connected in to alternative ways:

Premise 3: $\neg(I \Rightarrow F \wedge (G \wedge H))$, (AND logic on variables G; H)

Premise 3': $\neg(I \Rightarrow F \wedge (G \vee H))$, (OR logic on variables G; H)

If the selected G and H logic gives J is TRUE, the external sources or threats should indicate that the engineering development work should stop, I is FALSE. The work should terminate and new plans should be made based on the new input.

If J is FALSE the external values are assessed not to be of such significance that the plans should be stopped or reworked, work can continue. But to get I to be TRUE the first premises F also must be TRUE. This requires the NIMP, Direct Non-Implication connective as the last logical operation in Figure 4.22.

## 4.6 Summary

This chapter shows the mapping between a structured enterprise modelling architecture and manufacturing systems theory. The main point in the mapping is to have three orthogonal non redundant axes in the enterprise model. This work uses the product, processes and organisations as the three axes. The GEARM enterprise modelling standard fits well into this requirement and is used as the selected architecture for the definitions and integration into the manufacturing systems theory.

Manufacturing systems theory can be used in almost any kind of applications, both the physical and the logical parts. In the resent years the logical theory has been used both in the area of product configuration and control of complex systems e.g. traffic control in railway stations. Due to this fact it is very challenging also to try to use this theory within enterprise modelling.

The main purpose for this integration is to show that enterprise modelling architecture more directly can be used in the operation phases of the enterprise.

The defined entities or building blocks in the architecture are defined as logical variables in the systems theory, and logical calculations can be performed on the model directly.

There are examples that cover both operational phases of manufacturing and organisational aspects of an enterprise. The aspects of uncertainty in an organisation are always critical. By use of systems theory external influences like threats or other constrains can be defined into the system. By this way warnings can be given so that the project or operation can be modified or in the most serious situation stopped at an earliest possible stage.

It is also important to emphasise that the logical usage different building blocks or entities of an enterprise model (product-process or organisational model) has not as goal to make data schemas that shall be filled with operational data. This logical approach deals with logical connections and context between the entities and how this can be managed within operation. This is the main different with this approach and other system-oriented approaches compared with data modelling activities as ISO-STEP. But conceptual models or structured architectures can be a common base for both modelling approaches but the operationalisation will be different.

# 5. Extended Integrated Solutions Basis for Development of Original Enterprise Models

## *5.1 Original Enterprise Model Development*

In this chapter we will show that design of an original or self-developed enterprise model can be done by integration of related models. The first standardisation approach, introduced in chapter 3.1 'ISO, Reference Model for shop floor production ISO TC184/SC5/WG1 (1990)' describes an integrated description of a shop floor manufacturing environment. In approaches and examples in chapter 1, where an enterprise modelling architecture was combined with logic theory, GERAM was chosen as the enterprise model architecture.

Any other structured architecture could have been selected for this purpose as long as the requirements of orthogonal independent axes like the PPO model are fulfilled. In this chapter this is shown through integration between models for Design Theory and Design, Features and manufacturing resource selection within a design and manufacturing environment. The model is self-developed and much more detailed than GERAM. The background for the development is own research work over the last years both from early work on the thesis and other research projects. The chapter concludes with a PPO oriented model based on an extension into manufacturing of the design theory. The completed model shown in Figure 5.8 in the last part of this chapter is on a more detailed level than GERAM. But the principles are similar to the GERAM based instantiation.

## *5.2 Extended view from design to manufacturing processes.*

### 5.2.1 The Theory of Domains

The design theory, "The Theory of Domains", presents central elements of a theoretic foundation for mechanical design. The theory is based on four views of a system which leads to a generic model for the results of the design task, the so-called 'Chromosome' model. This theory comes from the Workshop 'Design-Konstruktion', (WDK) school [Hubka 1992].

The objective of the theory is to support more systemised and overall design theory, focusing on these four different systems views or Domains [Andreasen 1996]:

- **The process system (Process Domain)**, which describes the appropriate transformation that takes place in the product
- **The function system (Function Domain)** which describes the effects which the machine create
- **The organ system (Organ Domain)**, which describes the entities which create the effects
- **The constructional system (Part Domain)**, which describes the way in which the organs are realised, i.e. the machine considered as mechanical parts.

The WDK School means that these four domains represent the necessary and sufficient way of looking into the design process on a high level. The design work should at any stage be related to one of the four domains. Each of the domains has definitions of entity relations and model constructs.

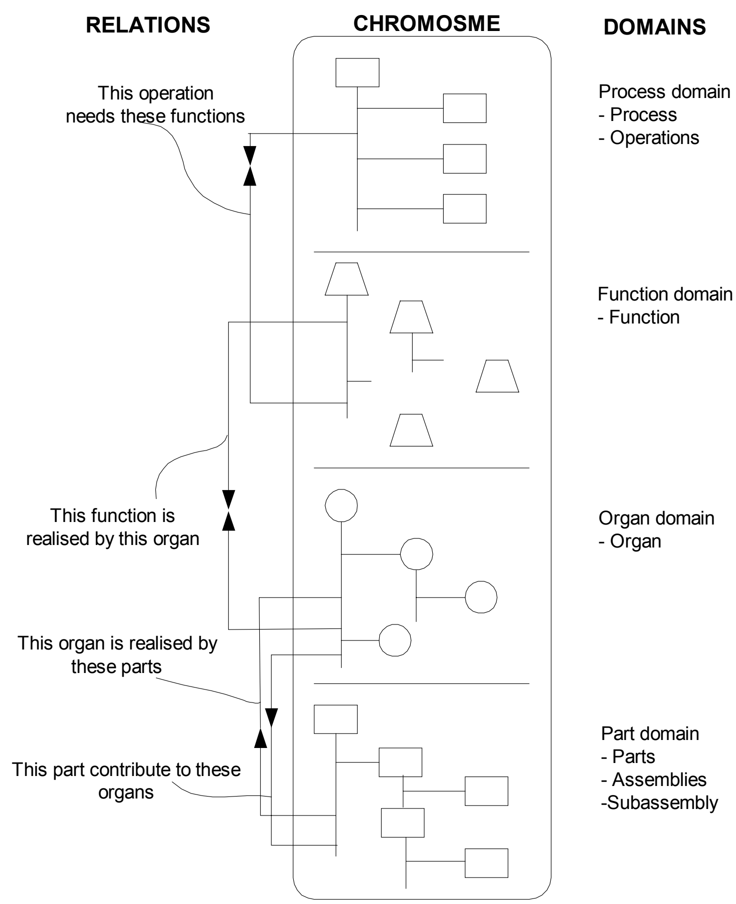


Figure 5.1: Structured data derived from the four domains [Andreasen 1996]

Figure 5.1 shows the structure of the four domains. The data structure will be instantiated through execution of the design task. The model will contain geometry specifications of the product in the part domain and generic and semantic design data in the other domains. The chromosome metaphor has been introduced as we use a product model (the product chromosome) for storage of the data created by practical use of the theory.

### 5.2.2 Connection from design to manufacturing, a link through process planning

Process planning includes the determination of which operation tasks are necessary in order to transform raw material into the finished part, and the sequence in those tasks should be performed. In some cases the selection of blank part parameters like size and shape is also included. Process planning is the first activity within the manufacturing area. The purpose of the process planning is to determine the main manufacturing processes.

A process plan tells managers which resources are necessary to make a part, and how long they will be in use. It describes the work to be done by operators, and allows supervisors to monitor their progress. Without an accurate process plan it is impossible to set realistic process times and manufacturing costs. A process planner needs detailed knowledge of manufacturing techniques in general, and the facilities available within the particular company [Myklebust, Crawford 1990].

The detailed description of each operation task is operation planning. At this stage, specialisation becomes necessary. This depends on operation types, product complexity or whether the information is being produced for a human or a computer. Process planning has the job of coordinating the different specialised operation planning systems. It contributes to co-ordination of all tasks in the pre production phase and offers access to the downstream sub systems.

An examination of the information flow in a design and manufacturing environment shows a central, controlling role of process planning activities. There are upstream interfaces to design systems, downstream interfaces to manufacturing, scheduling and control systems and sideways interfaces operation planning, NC programming and tool selection.

The process planning system needs a unique part identifier. This part oriented identification has to be the key item for all the different systems that are treating the work piece. In a modern integrated CAE environment a product model can handle this.

Information about tolerances, blank part geometry, surface roughness, surface treatment such as painting, anti-corrosion covering etc. has to be given to the process planning system. All kinds of technical information (non-geometry) for the actual part must be stored in a structured way.

Concepts of Design for Manufacturing, DFM have their main challenges and possible extensions by combining or establishing improved communication between design and process planning, both on a practical and theoretical level. In a classic approach the part design, the material and functionality are all 100% determined when the process planner starts the work. It is easy to understand that solutions both related to cost and quality are not necessarily optimal if the production knowledge has not been revealed for the designers.

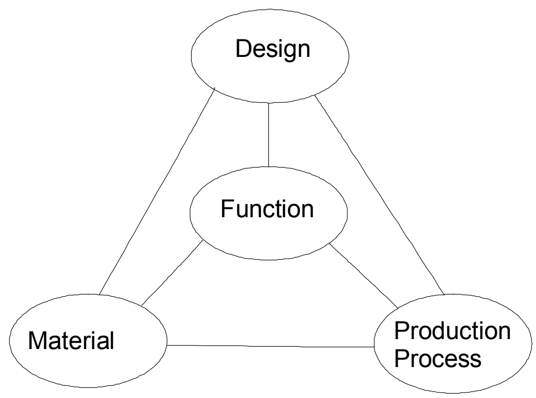


Figure 5.2: Relations between Design, Material, Production Processes and Function; Integrated Product Development [Jakobsen 1988]

### 5.2.3 Principles of Features Modelling

In a perspective of product design and definitions there are many types of product information requirements. First there is the customer or market expressed needs and requirements, which are often expressed informally. These needs and requirements are treated and transformed into product specifications and product functions. Then they are transformed in the conceptual phase to physical principles and superior layout. In the detail design phase the product is broken down in modules and components, and production plans and production methods are selected. Furthermore plans are laid out for assembly, installation, use and maintenance.

Features, as carriers of information and communication medium, are believed to give better support to the design processes. Features may be grouped within form, tolerance, function, material and assembly.

A large variety of models for process- and product models within design can be used. They are on different levels of abstraction and contain different types of information. It is unrealistic to believe that the nearest future can bring a uniformed and relatively spoken simple model that covers all needs for product information. Features still seem to be a promising technology since product information on many levels of abstraction can be connected to the same object.

Some of the ideas behind development of features originate from cognitive psychology, where it is claimed that the human brain stores and associates knowledge in contextual structured bunches of related facts, information and procedures. Comparing present situations with similar cases and conclusions can be based on association. By using features we try to use association connecting information to geometrical elements. A feature can be seen as a set of related data and procedures, where geometry is a part of the information source. The designer can not work in a purely geometrical environment, the workbench for designers needs to integrate geometry, technology, systems and functions. One approach to implement an integrated interface between the design and manufacturing phase is features [Aasebø, Myklebust 1998].

Features can then be seen as the integration between the design and production planning. Features can be used in several disciplines where they can help solve an integration problem and provide improved information flow between different phases e.g. design and manufacturing. In the design and manufacturing world we can define two main groups of features:

- Design features
- Manufacturing features

### 5.2.4 Design features

Design features are defined as form features associated with the semantic of their engineering meaning. Features are treated as objects in the world of engineering design. All information that belongs to the real design element can be connected to a design feature. This includes information such as technological attributes, values depicted from standard tables and a self explaining sketch of the feature which is presented as an icon during feature selection. By adding rules and constraints which are caused by technical conditions, the features can be seen as intelligent design objects.

Feature based CAD is by many considered as a step forward within development of CAD systems. Features represent an expansion of Present solid models. Features support other design software in that they contain not only geometrical information but also other forms of engineering data. Research and development on features have taken place since the 1970s and are about to be implemented in most major CAD systems. Also feature based platforms for integration between CAD/CAM have been interesting topics over the resent year [Aasebø, Myklebust 1998]

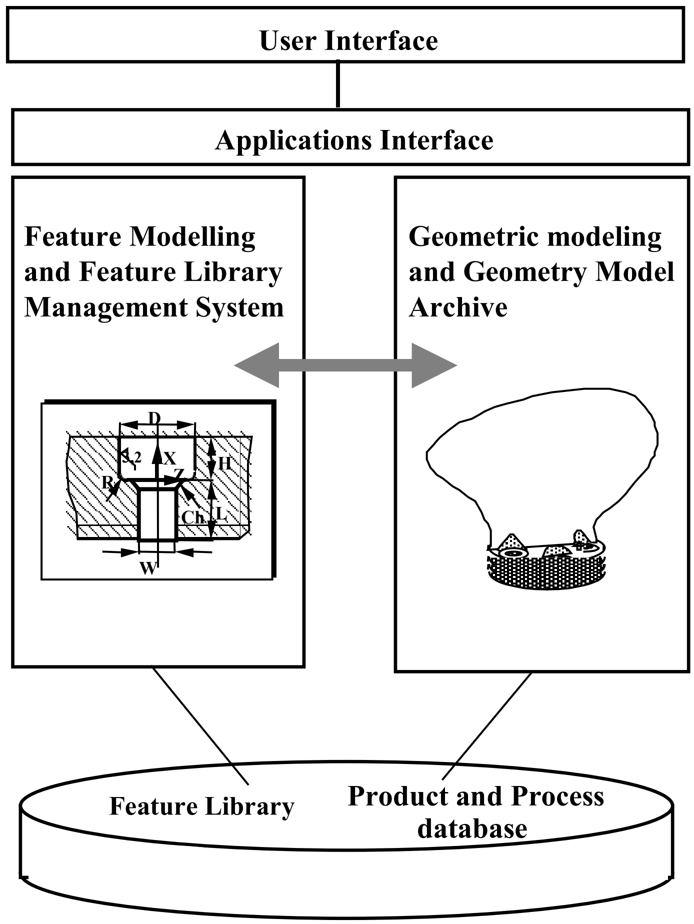


Figure 5.3: Main principles of the Feature Modelling System

The product modelling part of a feature system must also contain a feature library management system. All types of product related information e.g. shapes and tolerance descriptions should be included. The feature based technology information is included in the design can be picked up and used within process planning. Feature descriptions may also contain procedural description. The feature data structure carries also non-geometrical information belonging to the features of the designed part and the reference to the related geometry. Figure 5.3 shows the main principles of the feature-based system.

### 5.2.5 Manufacturing features

The manufacturing features can be used to reduce or eliminate interactive user input within process planning. When the part description has been approved and released for production, the computer aided process planning system can access the feature modelling system model and search for applicable features. The design features are structured according to feature classification and prepared as input to the manufacturing logic.

Computer aided process planning is normally understood as an interactive session guided by a process planning program. The process planning can only be improved through direct access to product descriptions. Evaluating the product design with reference to a feature library that stores descriptions about manufacturing activities can generate certain manufacturing processes.

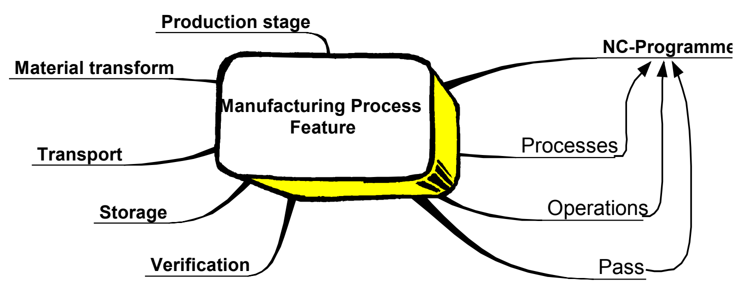


Figure 5.4: Production Process Feature Model

Manufacturing logic involves design features and manufacturing process features. Manufacturing process features is a record of which processes it is possible to carry out using defined manufacturing equipment. Machine description and feedback from the shop floor influence the knowledge. Use of feature within process planning includes adding of recommended elements to the process plan being generated. It also includes preparation of input to other manufacturing systems e.g. NC-systems. The contents of manufacturing process features are in accordance with the diagram shown in Figure 5.4. The overall aim of resource selection logic is to collect this knowledge and to turn it into a logic that can run on computers. Figure 5.5 shows how a resource selection in the process planning can work.



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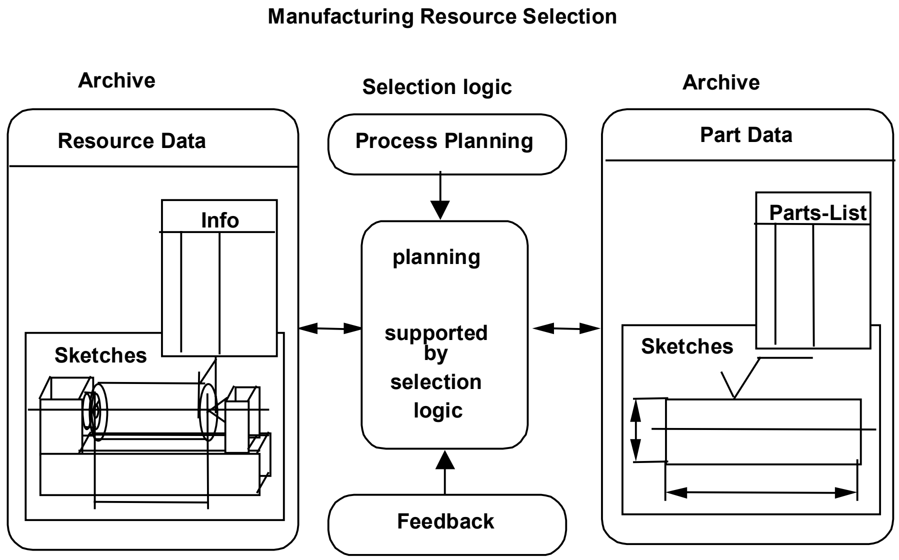


Figure 5.5: Selection of Manufacturing Resources in an Integrated Planning Environment.

### *5.3 Production process model divided into domains to extend the design theory.*

Though there is a lot of interrelation between design and production on many levels the interface between design and process planning is the most important. Process planning makes use of design information as direct input, and it is the last virtual or engineering phase of the product development before the physical production. After the process planning the part will be materialised in a physical blank part, and be transformed into the finished part during the described manufacturing processes.

Design and process planning are due to this fact logically close related. The process planner requires the design information, and the designer will benefit greatly from having background information of process planning available during the design activities.

Years of research work to combine these activities have never become really successful in a general way. Complex products require much detailed knowledge to be manufactured with the most optimal manufacturing processes. An information platform that gives the designers a correct view into the manufacturing world can give significant improvements in the manufacturing knowledge within the design process.

An extension of the "Theory of Domains", Figure 5.1, will include aspects of manufacturing. This is a theoretical approach that will cover "Integrated Product Development" where design and planning aspects of manufacturing are combined.

This extension will be on the most detailed level, the part domain. Design decisions on the functional and organ level will often give totally different manufacturing processes and production in different industries. Mechanical, electrical, chemical and software oriented functions or organs require totally different manufacturing.

The integration focuses on Process Planning as the manufacturing view for the designer. The approach is mechanical engineering oriented, but the concepts should be possible to use also in other industries. Design for assembly (DFA) is not specifically covered as a separate own topic, but the content should in general also have relevance to assembly processes.

Comparable situations have been discussed in the paper of "Linking Product and Product Life Modelling to Design Theory", [Mortensen 1995], where the domain theory is used to relate more homogeneous product knowledge into a product model.

Design for Manufacturing, DFM may be discussed on several levels within an organisation "Design for Production - Overview and Methods", [Andreasen 1996]:

- Company level, where strategic choices of process and materials technology and strategic product technology are made; fitted to each other.
- Product assortment level, where the product family relations and reuse, modularity in the product portfolio and the utilisation of processes and equipment are decided.
- Product structure level, where especially where assembly structure highly influences the production and assembly content and sequence.
- Component level where the detailed choice of approaches chain for each part is made and where the detailed design of the part shall ensure an unproblematic efficient production.

### 5.3.1 Process oriented Domains

As mentioned the design theory organises the design process into four domains.

- Process domain

- Function domain
- Organ domain
- Part domain

Based on the solutions for features and resource selection the content of a conceptual model for process planning to be integrated with the design theory can be organised in this way:

- **Production Part Domain** which characterises the part geometry, raw material or blank part descriptions and technical characteristics of the part which will be addressed by the process planning activities. The process domain connects product data with the part domain.
- **Production Task Domain**, which characterises the task (processes and operations) that is required to manufacture the part. This is a logical domain organisation of the process planning area. But with relations from this production oriented domains to the design domains. Decisions of production issues can more easily be visualised to a designer. The designer will get production knowledge structured to view manufacturing processes. This is also the domain that capture the manufacturing features and perform the integration to the part domain.
- **Production Process Domain**, which characterises the set of processes, considered by the process planning activities. Based on this the process planning can be multi technology oriented. Within a particular manufacturing technology, a system can consider only a subset of manufacturing processes that are feasible; e.g. turning processes for rotational parts. This domain contains also mechanisms for resource selection and the connections to the production resource domain.
- **Production Resource Domain**, which characterises the available resources e.g., machine tools, fixtures, tools etc. in given potential shop floor(s). The resource domain must support the feasible processes in the process domain. This domain is enterprise dependent.

In addition to this to get a model complete the part domain must be extended to handled design features.

The four production oriented domains are shown in Figure 5.6. They focus on the relation between the part, planning and physical resource. The logic representation of a manufacturing resource should support the designer in searching for the most suitable one e.g. a machine tool or a set of possible manufacturing devices. The information of machine tool data and a potential selection of machine tools done by the designer have their relation to the part domain of the design theory.

The manufacturing logic must associate properties of the part that relates to the machine tool. The assignment of part related to machine related data is a comprehensive and difficult task. Even without detailed selection logic, it seems to be impossible to give an overall management solution for this problem by using traditional database implementation and integration between CIM modules (e.g. CAD/CAM).

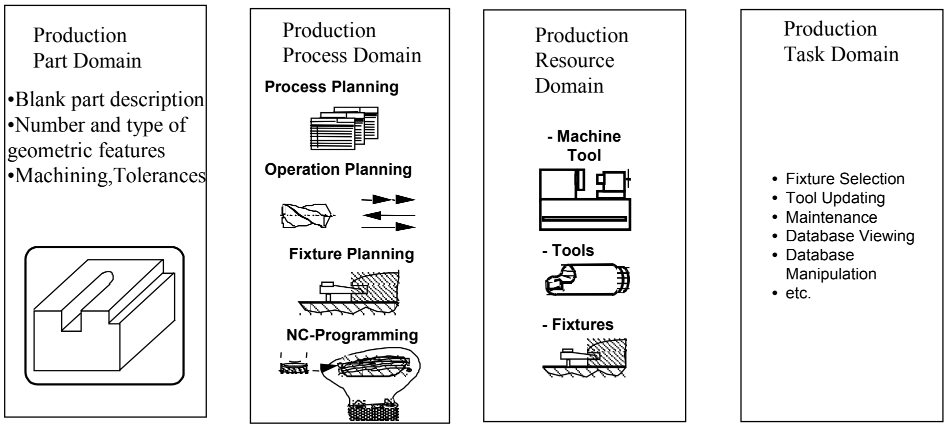


Figure 5.6: The four Process- oriented Domains

A process planner's work can not in a general case be substituted with computers and designers. There are to many manufacturing details and variants that have to be taken care of. But a designer's view into the manufacturing area will give great efforts of steering the product into optimal manufacturing processing.

### *5.4 A New PPO based Enterprise Model Approach*

This merge of design theory and production-process models can be seen as a more detailed view or entity description of a Part, Process and Organisational model (Enterprise Model). In this case the features will be the practical integrators, but logical examples can also be made here just like with the GEARM Enterprise Model.

This model is an own designed version of a PPO based Enterprise Model. This model could have been used for the logical examples in chapter 4 instead of GERAM. But since GERAM is a well-known approach and also an ISO-standard it was better to try to use GERAM the bases for the logical integration.

**Process Domain**
- Appropriate transformation that takes place in the product

**Function Domain**
- The effects which the machine create

**The organ Domain**
- The entities which create the effects

**Part Domain**
- The realisation of organs
- The parts design
- Design features

**Production Part Domain**
- Specific Raw material shapes description
- Material processing dependency
- Part descriptions

**Production Task Domain**
- Knowledge experience of manufacturing data from existing plans
- The detailed Process Plan to downstream processing
- Cost and time calculations
- Time calculation
- Manufacturing feature

**Production Process Domain**
- Main standard processes, structures and templates
- Libraries with structured generic Manufacturing logic
- Manufacturing processes focused on specific lifecycle requirements e.g. environmental impact or logistics
- Overall cost estimate

**Production Resource Domain**
- Machine tool capabilities and properties
- Labour
- Tool and fixture capabilities and properties
- In house versus subsupplier manufacturing capabilities
- Cost structures for resources

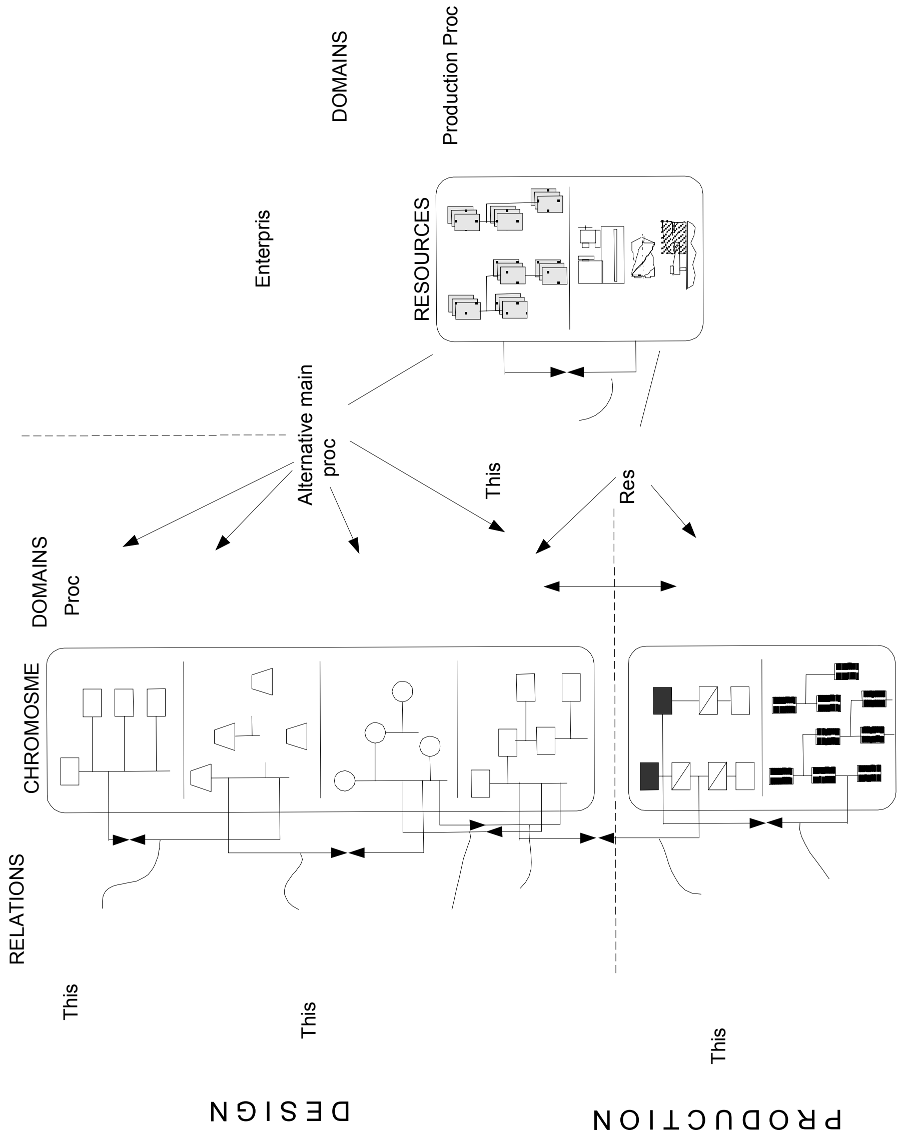


Figure 5.7: Relations between the design and manufacturing domains

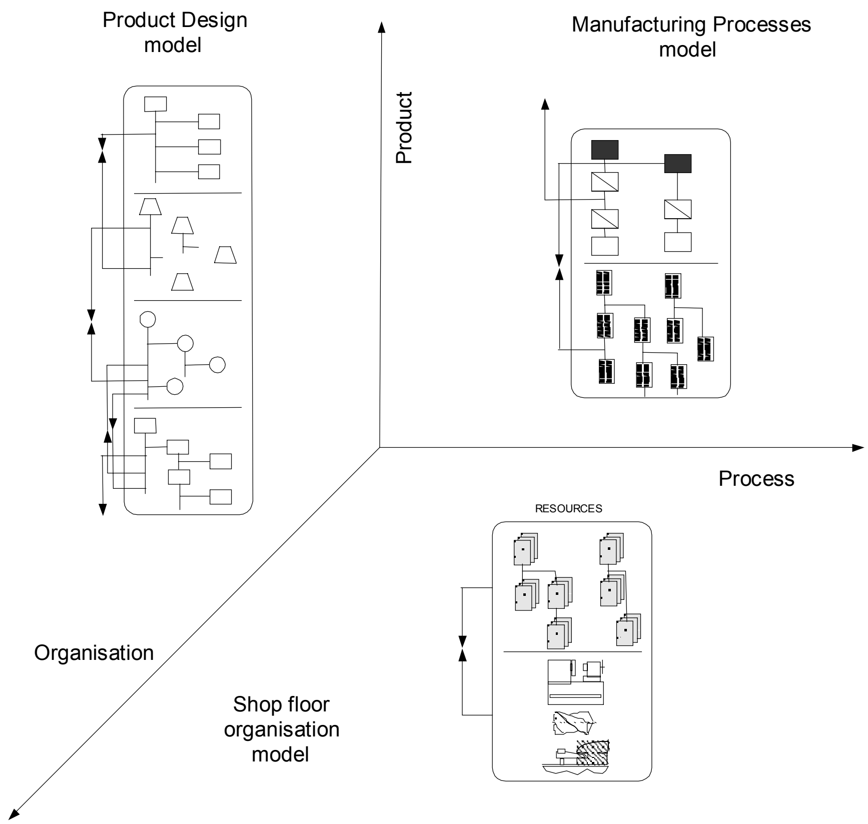


Figure 5.8: The design manufacturing model in context of the PPO-model

In Figure 5.8 the extended domain theory is transformed into the PPO model. Logical cases to control or monitor the integrated design and manufacturing process can be modelled. The calculations from this model will be similar to the examples in chapter 4. Any structured Enterprise Model approach can in practice been use for logical calculation platform and move the Enterprise Model designs a step forward into an operational phase.

### 5.5 Summary

The meaning of this chapter is to illustrate that there is no need to use large standardised enterprise modelling solutions like GERAM or eventually CIMOSA and similar approaches to make a structured design of an enterprise model. The model in this chapter covers the design, manufacturing and manufacturing resources. The model is a combined feature and resource model extended into the framework of design theory. This extension gives the designer a view into manufacturing processes.

On the manufacturing side the model could have been extended to cover more details like tools and fixtures. Production logistics (material flow between production resources) and scheduling could have been other extensions.

# 6. Future Use of Enterprise Modelling

In the childhood of philosophy, people believed that God had created the world in the language of mathematics. Later it has been realised that mathematics, in the way it appears today, is not fully able to describe the world satisfactorily. Mathematics assumes that everything is measurable.

Besides, mathematics describes the ideal world, while we live in the materialised world. Even with modern science it is impossible to perform precise measurements, so models will not be satisfactory. So far the programming languages do not bring in any conceptual news, but it is rather an implemented system of mathematical operators, and thus it can handle complex problems, [Brathaug, Åsebø, Szegheo, 1998]

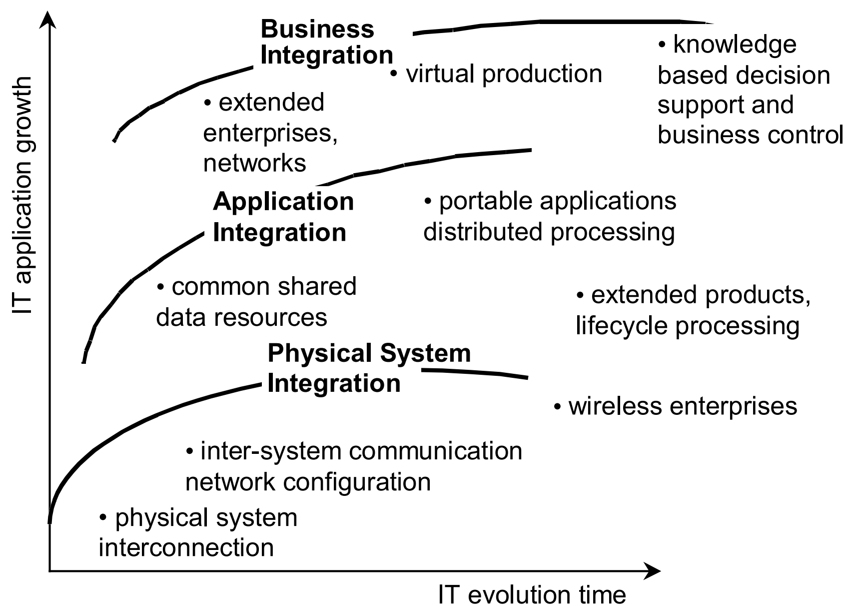


Figure 6.1: Levels of Enterprise Integration.

This is true from both an ideal and practical viewpoint. But as a general comment, the time to reach these limits is still far to go. Computer science and advanced computer applications will bring us further and more advanced operations e.g. business and management processes can be automated or computer supported in the future.

Enterprise models approaches have so far basically been modelling architectures, standards and tools. The way from the conceptual models to operational phase as detailed data modelling is along and complicated discipline to manage. For many enterprise modelling architectures it has been never tried.

There exist today impressing commercial systems like SAP and Baan those make control function and data implementations with many possible user aspects of enterprise models. The systems are, however, time-consuming and expensive to implement and have so far been oriented towards large enterprises. The software platforms used are normally based on standard and common IT-technology. Also array-based solutions within product configuration and scheduling have also been applied.

In the It- and Communication world the future is coming fast to us. Only a very few years ago we booked the air tickets at the travel agency and they sent paper tickets by post. Today we can book the tickets via a mobile telephone with a colour screen and Internet connection. When entering the plane only a plastic card must be drawn. This is a big change in technology, but the business model and the process chain for making a flight are also completely changed.

In Figure 6.1 a scheme showing the IT-evolution in time compared with the application growth are shown. In the years to come we will se the wireless enterprise to be implemented more and more compared with virtual production and knowledge based decision support and business control. From a situation where we have managed to improve the modelling and to full implementation there is still a way to go. There is definitively a need for models that not only capture data, but also are able to handle the control, management and logic between elements, both for modelling of virtual production and the steering and management of the implementation for operation of a wireless enterprise.

*Extended use of enterprise modelling*

The main goal must be that the models for virtual production will be converted into operational system that can handled both the data and the management aspects. Combinations of product or PDM-technology, logistics models and simulation of manufacturing partly manage this today, but the model aspects of the connections are too weakly described. Merging different models and systems that do not build on a structured architecture makes the connectivity and logic challenges difficult. The main goal must be that models used e.g. for virtual manufacturing can be converted and implemented into operative control systems.

Another important challenge of enterprise modelling is to take into account the product lifecycle issues and the requirements for reuse and recycling of products. Different directives from the European Union for treatment products over its lifecycle e.g. electronic and automotive products will not only lead to extended product models. Enterprise models can also structure the information related to process and organisational issues needed along the product lifecycle. There will be new actors executing the needed processes for recycling, re-manufacturing, energy recovery or landfill.

The recycling aspects require models and definitions of methodology for the different potential new actors. New actors or new roles for existing actors can be like this:

Original Equipment Manufacturers, OEM, will consider the EOL options for their newly designed products in order to determine environmental load and the economic costs. Such information might be used to build the cost of EOL treatment into the product cost. OEMs will enable the determination of EOL product strategies that ensure compliance with legislation and that best meet their primary and secondary market requirements. OEMs will also be facilitated in identifying secondary market marketing requirements. The OEM's will be the responsible part for the products in the EOL treatment.

Remanufacturers will determine EOL product strategy as regards treatment and to demonstrate compliance with legislation and in some cases with OEM strategy. Such companies may also need methodology as a means of supplying feedback to the manufacturer regarding product design to facilitate remanufacture.

Recyclers or material recycling companies need models and methodology to highlight market and technological deficits which may be used to lobby for investment. Recyclers will also have awareness of the greater context of their activity which could strengthen their commercial bids for business and arguments to policy makers for investment in marketing and infrastructure. [AEOLOS, 2001]

Further development of Enterprise Models that will cover the aspect mention above logical configuration need to be an important part of the model. The relations and constraints in the models and the external influences will be more complex and the demand to navigate in the logic will increase. Large companies today already have digital 3D visual virtual models that shows the development form the first product characteristics the product via e.g. simulation of manufacturing to views of the future sales store. The main challenge is to do the modelling and capture the logic in such a way that the models can be used in manufacturing and other operative disciplines along the product lifecycle.

# 7. Conclusion

Enterprise models have until now to much illustrated concepts of drawings. There are however many examples of business- or CIM systems implemented on basis of enterprise modelling, but the modelling results is normally only a part of the software specifications. If we take as an example the description for an operational phase for enterprise modelling architecture as GERAM it is limited to be:

*Enterprise Operational Systems support the operation of a particular enterprise. They consist of all the hardware and software needed to fulfil the enterprise objective and goals. Their contents are derived from enterprise requirements and their implementation is guided by the design models that provide the system specifications and identify the enterprise modules used in the system implementation,* [ISO 2000].

Further on the same standard document states the following:

*It is often proposed that the ultimate solution would be the development of a set of computer executable models, which would be the basis for a computer-based operational control system for the enterprise. For such an operation-based technology to succeed, all the technology-oriented concepts have to be related to resource models and resource organisation models* [ISO 2000].

The commercial systems today that offer solutions for implementation are often not build on any enterprise modelling architecture. A common and natural focus on these systems is that they are focusing on data modelling and perform input and output data handling for given processes. This is necessary for any system to operate. Examples of such systems are Material and resource planning systems, CIM components like CAD and CAM systems. The systems are also to some extent connected to data interfaces for data communication with other systems or storage to databases. An example here can be ISO-STEP. We also have PDM systems for management of product data.

This thesis focuses on the connection between the entities in an enterprise model and is using logic system theory to solve this connections. An enterprise model can also serve as a managing or control system for execution of an operation. This can be done on any working level of the enterprise or on engineering of an enterprise.

The requirements for doing this is that the enterprise model we are using is structured defined. In this work Product, Processes and Organisation are defined as the orthogonal axes in the enterprise model (PPO-model). Many model approaches can be defined into this. Chapter 1 shows a self developed that serves this purpose. In the main work the theory of logic is used together with the standardised enterprise modelling architecture GERAM.

When logical system theory is used in the enterprise model the entities in the model, on any defined level, will be defined as logical variables. The connection between these variables can be set up as logical premises and the values can be set TRUE or FALSE. This logical value can be set by the system itself, based on rules for evaluation of the data or by a manual input.

The main issues are the structuring of the enterprise model and the definition of the logical premises. This way to modelling the connections or connectivity of a model is quite different from most other approaches. It is quit common to use logical variables as checkpoints. But definitions of premises and logical calculations based on the theory of logic form a new and different approach within enterprise modelling.

The theory has previously been used within product configuration, controlling systems of power networks and railway interlocking systems. The step into enterprise modelling is a large one since normally both the structure and the logical relationships are more unstructed.

A logical navigator or configurator of the different aspects and areas of enterprise models will make the operational phase for real use of the model more close to practice.

*Extension and continuation of this work*

The software used for the examples is as mention the introduction is the APL 2000 interpreter. It logical statements are the direct input to the work-set in the software and the programmer works directly with the editor. This software illustrates the possible and proves the examples in a very well way, but for larger and real situation the software platform should be changes. An alternative her could be the Array Database™.

Array Technology AS is a Danish company founded in 1996 to develop and commercialise new software tools and services on the technology of array-based logic. Array Database™ is a software product family for automatic modelling and run-time execution of large configuration problems. The founder of the company is Gert L. Møller. He has long experience in the software industry and made an important thesis in development of array technology, ”On the Technology of Array-Based Logic”, at the Technical University of Denmark in 1995. How the Array Database™ will work with problems within enterprise modelling is not tested. The alternative is to develop new software that can fulfil the requirements for logical control of enterprise models.

For integration with operation the model must also match the entities or data schemas that are used in the software in the enterprise. If the structures in the enterprise model are different from the operative data structures the logic cannot work right.

Connection to visualisation is also an important factor. User interfaces both for development of and use of the models must be developed. In addition views defined for different user groups.

Even the main goal is to simplify and make control systems with higher quality and more reliable than we have in systems like PDM and MRP to day it is still a way to go.

I have in this work showed that enterprise model architectures directly can be connected to the theory of logic so the models can be used for control and management purposes in an operational phase of the enterprise.

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# Appendix A, Glossary

### *IMS-Globeman21 Glossary*

**Enterprise integration in manufacturing - Key terms in IMS-Globeman21 project [Globeman 1999]**

| **GERAM definitions** | **GM21 conceptual definitions** | **Other GM21 definitions** |
|---|---|---|
| Life cycle<br>Life history<br>Recursive life cycles<br>Genericity<br>Dimensions<br>Architecture<br>Framework<br>Methodology<br>Masterplan<br>Model<br>Enterprise<br>Enterprise engineering<br>Business process | Extended enterprise<br>Network<br>EE/VE network<br>Virtual enterprise<br>Product life cycle<br>Product Life Cycle Management | Core competence<br>Work preparation<br>Taxonomy<br>Typology<br>Product Life Cycle Characteristics<br>Product Life Cycle Typology<br>Generic Product<br>Product Configuration<br>Realised Product |

*GERAM definitions*

The following definitions are quoted from GERAM (ISO/DIS 15704), which has been used as the reference architecture for much of the work in Globeman21. Australian Globeman21 partners from Griffith University and CSIRO have played a very active role in the development of GERAM.

**Life cycle**
The finite set of generic phases and steps an entity/system may go through over its entire life history. The generic life cycle phases in GERAM are: Identification, Concept, Requirements, Design, Implementation, Operation and Decommission

**Life history**
The actual sequence of steps a entity/system goes through during its lifetime

**Recursive life cycles**
Recursiveness is the relation between different dependent life cycles, which means that in its operational phase one system life cycle creates or supports the life cycle of another system or entity.

**Genericity**
The extent to which a concept is generic

**Dimensions for defining the scope and content of enterprise modelling**
Life cycle dimension – providing for the controlled modelling process of enterprise entities according to the life cycle activities (see also: life cycle).

Genericity dimension – providing for the controlled particularisation (instantiation) process from generic and partial to particular.

View dimension – providing for the controlled visualisation of specific views of the enterprise entity

Model content view (function, information, resource and organisation)

Purpose view (customer service & product)

Implementation view (human task, mission support technology and management and control technology)

Manifestation view (hardware and software)

**Architecture**
A description (model) of the basic arrangement and connectivity of parts of a system (either a physical or conceptual object or entity)*NOTE: There are two, and only two, types of architectures that deal with enterprise integration. These are:*

- Enterprise reference architectures (type 1 architectures) that deal with the structural arrangement (design) of a system, e.g. the computer control system part of an overall enterprise integration system; and
- System architectures (type 2 architectures) that deal with the structural arrangement (organisation) of the development and implementation of a project or programme such as enterprise integration or other enterprise development programme

**Framework**
A structural diagram that relates the component parts of a conceptual entity to each other. *NOTE: Neither the structure involved nor the relationship of the parts to each other has a life cycle or time relationship in contrast to the enterprise-reference architecture (type 2 architecture) * Like in GERAM we consider 'framework' to be the superior concept, and hence there can be an architecture as a*

*part of a framework, not the reverse. There can therefore be a framework for architecture to help classify the components of that architecture. In other words the framework can be used to structure the elements of an architecture.*

**Methodology**
A set of instructions (provided through text, computer programs, tools, etc.) that is a step by step aid to the user. *NOTE: In carrying out needed aspects of the life cycle of the entity integration project, the methodology prescribes or describes the processes of enterprise engineering and integration. A methodology takes account of any involved social, political and economic aspects.*

**Masterplan**
The documentation of the major engineering and operations planning effort carried out prior to any large enterprise integration or other systems engineering project. *NOTE: The masterplan is based on management goals for the project and uses functional and economic analysis techniques for the preliminary engineering of the project to achieve an initial design specification and prove economic feasibility.*

**Model**
An abstract representation of reality in any form (including mathematical, physical, symbolic, graphical, or descriptive form) to present a certain aspect of that reality for answering the questions studied. *NOTE: A model can be used to describe the enterprise activities or the different phases of the life cycle of the enterprise.*

**Enterprise**
One or more organisations sharing a definite mission, goals and objectives to offer an output such as a product or service. *NOTE: This term includes related concepts such as extended enterprise or virtual enterprise*

**Enterprise engineering**
The discipline applied in carrying out any efforts to establish, modify, or reorganise any enterprise

**Business process**
Business process is a partial ordered set of enterprise activities that can be executed to realise a given objective of an enterprise or part of an enterprise to achieve some desired end-result

*Globeman21 Conceptual definitions*

**Extended enterprise**
Globeman21 sees the extended enterprise as a concept covering the totality of different concepts dealing with the expansion or extension of enterprise activities.

Extended Enterprise is the concept of (manufacturing) business operations that looks at all the participants in the creation or manufacture of a product. The significance of the Extended Enterprise as distinct from the conventional sub-supplier relationship is in the extent of information flows that facilitate the tightening of manufacturing design and production.

**Network**
A network is a system of interrelated entities. *NOTE: a network can be more or less formalised ranging from loose relationships to formal networks of enterprises like a supply chain*

**EE/VE network**
The EE/VE network is a network based on the extended enterprise concept with the purpose of creating and supporting virtual enterprises, which in turn is created to fulfil a specific customer demand. *NOTE: the EE/VE network can be more or less formalised or more or less prepared) for creating and supporting virtual enterprises. This is also true for the virtual enterprise and the product, meaning that the both the virtual enterprise and the product can be more or less prepared before it is actually instantiated.*

**Virtual enterprise**
A Virtual Enterprise is a customer solutions delivery system created by a temporary and reconfigurable aggregation of core competencies enabled by ICT. In Globeman the VE is seen as the outcome of a more or less formalised network of enterprises or business entities

**Product life cycle**
The finite set of generic phases and steps a product goes through over its entire life history

**Product Life Cycle Management (PLCM)**
The management of the Product Life Cycle comprises the management of different organisational and operational issues like e.g. product related processes and the necessary flows in the organisations like information flow, material flow and work flow.

*Other Globeman21 definitions*

**Core competence**
Core competence refers to an organisational embedded knowledge asset that can deliver differential value through a functionality that a customer is willing to pay for and that competitors find hard or impossible to imitate [Prahalad & Hamel]. *NOTE: In the virtual enterprise the core competencies are organised as customer focused value chains forming the product delivery system*

**Work preparation**
The degree of work preparation or work preparedness is defined as a method-engineering concept expressing how much effort (and money) is used to prepare a certain work before the work is carried out or executed (be it physical or knowledge production). *NOTE 1: In traditional Industrial Engineering the degree of work preparation among other things express itself in the level of automation/mechanisation of work. But work preparation efforts can express itself in many ways: formalised rules of doing work, investments in hardware and software, explicit determination and definition of company specific features, standardisation, time and effort used in choosing a team leader, time and effort used in defining targets, etc. International standardisation work in this way is company-common work preparation.*
*NOTE 2: In GERAM terminology the degree of work preparation manifest itself as an extent of automation.*

**Taxonomy**
In Globeman21 taxonomy is defined as a set of descriptive parameters related to the different elements in the extended enterprise concept (the network, the virtual enterprise and the product life cycle). The taxonomy consists of design parameters and situational factors:

Design parameters (internal) – describes different configurations of extended enterprises. To be decided by the EE decision makers.
Situational factors (external) – affects the configuration of the elements of the extended enterprise. Cannot be changed by the EE decision makers (the system environment)

**Typology**
In Globeman21 typology is a collection of different feasible configurations (types) of extended enterprise configurations (it is a reference architecture – type 1 – confer GERAM). The typology is defined based on a taxonomy for the extended enterprise concept.

**Product Life Cycle Characteristics**
Product Life Cycle Characteristics are used to describe different life cycles and for the categorisation of different types of life cycles (see: typology). Product Life cycle Characteristics can be differentiated in Situational Factors and Design Parameters.

**Product Life Cycle Typology**
A Product Life Cycle Typology comprises different types of life cycles (LC) which are significant for different levels of market orientation and levels of standardisation.

**Generic Product**
A generic product is a solution for the standardisation of parts and modules by using the same modules in different products and product lines. A

generic product can be understood as a unit construction system. *NOTE: The intention of creating a generic product is to cover a whole market with different product lines. The generic product consists of highly predefined modules and parts, which can be used in different product lines, and a set of product structures, which are more or less the skeletons for different product lines.*

**Product Configuration**
Product Configuration is the aggregation of a product structure and different modules for one product line. The products in a product line may differ in certain respects, so that e.g. different sizes are achievable by using parameters in defining the product components. *NOTE: A product configuration is either derived from a generic product as a solution for a market segment or a created from a market demand driven project. In the second case the design of the product line has to be created while in the first case, the design is mainly taken from the generic product (structures/modules).*

**Realised Product**
The Realised Product is the solution to the customers needs and the means to create customer satisfaction. Every Realised Product has an individual product life.

### *Glossary from other sources*

**Framework**,
Frameworks supported by methods, methodologies and tools make the modelling endeavour more effective and reproducible. The term framework refers to a collection of elements put together for some purpose. The term architecture refers to an organised set of elements with clear relationships to one another, which together form a whole defined by its finality. [Sze '99].

**Methodology**
A methodology is a set of methods, models, and tools to be used in a structured way to solve a problem. The approach is organised into methodological phases, and the phases into tasks [Ver '96].

# Appendix B, Tools in use for Enterprise Modelling

Tools in use for different purposes of enterprise modelling can basically be divided into two categories:

- Methodology dependent modelling tools
- Methodology independent/generic modelling tools

The following is a list of commercial tools that can be used for enterprise modelling. The functionality of the tools and their intended purpose have a wide range of variety:

1. ARIS from IDS Prof. Scheer GmbH
2. Architect from James Martin & Co.
3. Baan
4. BIF (Business Improvement Facility) from Virtual Software Factory Ltd.
5. BPwin and ERwin from Logic Works, Inc.
6. CA-BPT (SAP R/3 ABAP/4 Development Workbench) from SAP AG
7. Design/IDEF from Meta Software Corp.
8. Enterprise Developer from Symantec Corp.
9. Enterprise/Integrator from Apertus Technologies, Inc.
10. Enterprise Modeller from Business Integration Technologies Ltd.
11. Extend from Imagine That, Inc.
12. FirstSTEP from Interfacing Technologies Corp.
13. FlowMark from IBM
14. GEM from Phoenix Systems Synectics
15. IEF from Texas Instruments
16. METIS from NCR
17. Workflow Factory from Delphi Consulting Group.
18. Ithink from High Performance Systems, Inc.
19. Paradigm Plus from Protosoft, Inc.
20. PowerTool from ICONIX Software Engineering, Inc.
21. Process Modeller from Oracle
22. ProcessWise Workbench from ICL
23. ProSIM Workbench from Knowledge Based Systems, Inc.
24. Ptech from Ptech, Inc.
25. ServiceModel from ProModel Corp.
26. SES/objectbench from SES, Inc.
27. SIMSCRIPTS/SIMPROCESS/SIMFACTORY from CACI Products Company.
28. WITNESS from AT&T ISTEL