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Investigating ERP Support for Lean Production

Thesis for the degree of Philosophiae Doctor

Trondheim, August 2012

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“Ambition is critical”

Dylan Thomas, 1914-1953

Executive Summary

This thesis presents work from a three-year PhD project within the research program SFI Norman: Centre for Research-based Innovation – Norwegian Manufacturing Future. SFI Norman is an eight year research program with the vision to develop new and multi-disciplinary research on next-generation manufacturing, and create theories, methods, models, and management tools that enable Norwegian manufacturers to thrive in global competition. SFI Norman has two main research partners – NTNU and SINTEF – and also consists of a number of industrial partners, including Kongsberg Automotive, Benteler Aluminium, and Pipelife Norway.

This research project began in 2009 as part of the SFI Norman research area "Demand Driven Value Chains" (DRIVE). After the mid-term evaluation of Norman, the research areas were reclassified, and in 2011 this project became part of the new research area "Operations Management in Norwegian Manufacturing". A major research topic in this research area is the relationship between lean production and information technology (IT). For example, though the lean principles are nowadays well understood, the relationship between IT and lean production remains a controversial and far less explored topic. Some would even suggest that the two approaches are contradictory in nature, stating that whilst lean is often characterized by decentralized coordination and control, IT is typically best suited to support centralized production planning. This thesis aims to provide illustrative frameworks in order to explore the topic in more detail.

Lean production and enterprise resource planning (ERP) systems have for many years been recognised in the scientific literature and industrial trade journals as enablers of world-class manufacturing operations. Though many companies have undertaken the implementation of either or both of these approaches in order to achieve greater competitive advantage; in the traditional sense, IT such as ERP has often been viewed as a contributor to waste within lean production, for example through the generation of excessive data and unnecessary transactions, and by encouraging overproduction and excessive safety stocks, resulting in high inventory levels. However, as the business world changes and competition from low-cost countries increases, new models must be developed which deliver competitive advantage by combining modern-day technological advances with the lean paradigm.

This PhD project set out to investigate the "contradictory" nature of ERP systems and lean production. Having first carried out an extensive literature review, it was identified that contrary to the traditional view, there appeared to be a potential synergy to be realised in combining both approaches. Therefore, the support functionality of ERP systems for lean production was subsequently evaluated by closely examining the capabilities of a contemporary ERP system in the context of lean production principles. This work was carried out by applying an action research methodology over a twelve month period at a Norwegian SME located in Trondheim, Norway. The company was involved in a concurrent implementation process – applying both a new ERP system and lean production practices. This resulted in two outcomes for the project – a framework for ERP support for lean production; and a model for an ERP-based lean implementation process.

One of the fundamental reasons for the contradictory view of lean and ERP has been the discussion of pull vs. push. Whilst it is common knowledge that lean manufacturing intends to function as a pull system, environments which use ERP- and its associated material requirements planning (MRP) logic have typically been classed as push systems. Therefore, in order to strengthen the validity of this research and to mitigate any bias from the action research, the real-time, participatory research was supplemented by retrospective case study research, and four case studies were carried out in the Netherlands in order to investigate specific ERP support for pull production. This resulted in the development of a capability maturity model (CMM) for ERP support for pull production, which not only identifies the support mechanisms of an ERP system for pull production, but categories them into various levels of maturity.

The outcomes of this project have implications to both theory and practice. The results of the investigation indicate a trend towards the combination of lean and ERP in manufacturing organisations. This has led to a number of contributions to theory and to practice. For example, the framework for ERP support for lean production can be used by researchers and practitioners in applying ERP systems and lean production together in order to increase the competitiveness of manufacturing companies. Secondly, the capability maturity model for ERP support for pull production makes a contribution to knowledge in that it identifies the functionality of ERP systems that can be applied to support pull production, and to practice, allowing manufacturers to benchmark the level of integration between its ERP- and pull systems, providing incentives to continuously improve. These contributions suggest a movement away from the traditional viewpoint of the contradictory nature of lean and ERP, and offer a solution to the recurring debate in the scientific literature as to whether or not lean and ERP are complementary technologies. Thirdly, the framework for an ERP-based lean implementation process also contributes to the field of knowledge within lean and ERP, and can be used by practitioners for the concurrent and synergetic application of lean and ERP.

Acknowledgements

This project would not have been possible without a great deal of help and support from my colleagues, friends, and family.

I would like to first of all thank my supervisor Jan Ola Strandhagen for his help, encouragement, and constructive criticisms over the past three years. Thank you for having faith in me and making me feel welcome at NTNU! I would also like to thank my co-supervisor Heidi Dreyer for all of the helpful advice she has shared with me, and Erlend Alfnes for his input; as a colleague, a friend, a co-author, and as a mentor! Without your guidance and advice this project would have come to a grinding halt.

I will also thank those who joined me as co-authors for their input into this research project. Special thanks go to Jan Riezebos, from the University of Groningen in the Netherlands. You have been a great mentor in helping me to achieve a major International Journal publication. Thanks also go to Thorben Goeldner, for being such a proficient student and generating results that led to a conference paper which set the direction for my research project!

Thanks also to my Danish friends Professor Hans-Henrik Hvolby and Peter Olesen for our fruitful discussions around the topic of lean and ERP, and a BIG thank you to *Docent emeritus* Peter Falster, who is always willing to take the time to read my work and give feedback. His comments have constantly enabled me to understand how to improve my work. I must also thank Peter Falster for his excellent after dinner speeches, hopefully we will hear one soon…

Both in and out of our PhD seminars, my fellow PhD students have been an important source of advice for the development of this thesis. Particular thanks must go to Anita Romsdal and Torbjørn Netland for their valuable input in my development as a young researcher and in the improvement of my scientific writing skills (and basic word processing skills!). Thanks also to Emrah Arica, Bjørn Ragnar Albrigtsen, Mario Mello, Lukas Chabada, Pascal Hofmann, and Maria Kollberg Thomassen. Merci aussi à Dr. Darchicourt!

All of my colleagues and friends at SINTEF Technology and Society also deserve a thank you, particularly Erik Gran, Jorunn Auth, Ottar Bakås, Lars Skjelstad, Marco Semini, and Dag E. Gotteberg Haartveit.

Of course, a research project like this would not have been possible without the input from industry. Therefore I must also show my appreciation to the company representatives that have been involved in this work. Thank you to my contacts in Norway, especially Pål Rune Johansen, Sveinung Ryan, and the entire team at Noca AS in Trondheim; and Terje Sagbakken, Ole Anders Lagmandsveen, and Halvor Sveen from Kongsberg Automotive in Raufoss. Tusen takk! Thanks also to my Dutch friends Rudolf Lunsche from Mark Klimaattechniek; Henderikus Boers and Johan Kooistra from Miedema; Fried Kaanen from Bosch Hinges; Robert Peters of SoftTools; Hendri Kortman, Nico van der Dussen, and Ernst Mik from Variass Electronics; and Gerko Arends, Erwin Koops and Elvert Lusseveld from Altrex. Bedankt!

I would like to extend my gratitude to the projects that have supported both my research and my development as a researcher. Particularly the research program SFI NORMAN; the European research project “European Regions of Innovative Productivity” (ERIP); NCEi Lean; SMARTLOG; CRASH; OPTILOG II; and Ideel Fabrikk, amongst others. These projects have supported me financially and have given me access to a wealth of knowledge to assist me in my development.

I would also like to make a truly unbounded thanks to my family. It was difficult for me to pack my bags in 2009 and leave the UK for Norway, but it is with your help and support that has made me the person I am today. Thanks for always being there when I need you!

Finally, a special thank you is required for my brown-eyed girl. Without my fiancée Karen, I would never have had a reason to take a PhD in Norway. Thank you!

Trondheim, March 2012

Daryl Powell

About the Author

Daryl Powell graduated with an honours degree in Motorsport Engineering and Design from the University of Wales, Swansea Metropolitan University in 2005. The same year, he began studies for an MSc in Lean and Agile Manufacturing, which he graduated from with a distinction in 2008.

In the summer vacations throughout his studies, Daryl worked as a production operator at a number of factories local to his family home in Gloucestershire, England. These included DuPont Textiles and Interiors, Gloucester; Trelleborg Sealing Solutions, Ross-on-Wye; and GlaxoSmithKline's Royal Forest Factory, in Coleford, Gloucestershire. With a keen interest in production management, during the part-time studies for his MSc, Daryl was employed as a graduate trainee at Schaeffler (UK) Ltd in Llanelli, Wales. After his initial training, he began working under the job title of "Continuous Improvement Champion", applying his knowledge acquired from the MSc degree to practice.

During his employment at Schaeffler (UK) Ltd, he was responsible for a number of improvement projects within the fields of production and quality management, and health, safety, and environmental systems. Having gained experience of applying lean manufacturing in the work place and with a desire to continue his education, Daryl began to look for opportunities to study a PhD.

In February 2009, Daryl began studying a PhD in production and quality engineering at the Department of Production and Quality Engineering, Norwegian University of Science and Technology, in Trondheim, Norway. At the same time, he also began working for SINTEF Operations Management, where he was able to apply his prior knowledge of lean manufacturing to current projects within the field of production logistics.

Coming to Norway with a background in UK manufacturing, he soon learned and developed an interest in the "Scandinavian tradition" of action research, where as a researcher working as part of an integral team, he was able to influence change at the companies being studied.

He hopes that he can continue to be part of this tradition as he begins his academic career at NTNU…

Abbreviations

AIDC	Automatic Identification and Data Capture
APMS	Advances in Production Management Systems (International Conference)
APQP	Advanced Product Quality Planning
ATO	Assemble-to-order
BOM	Bill of materials
BOMP	Bill of material processor
CMM	Capability maturity model
CRP	Capacity requirements planning
EOQ	Economic order quantity
ERIP	European Regions of Innovative Productivity (EU Project)
ERP	Enterprise resource planning
ETO	Engineer-to-order
GICS	Global Industry Classification Standard
IJOPM	International Journal of Operations and Production Management
IJPR	International Journal of Production Research
IP	Intellectual property
IT / ICT	Information technology / Information communication technology
JIT	Just-in-time
KA	Kongsberg Automotive
MES	Manufacturing execution system
MITIP	Modern Information Technology in the Innovation Processes of Industrial Enterprises (International Conference)
MPC	Manufacturing planning and control
MPS	Master production schedule
MRP	Material requirements planning
MRP II	Manufacturing resources planning
MTO	Make-to-order
MTS	Make-to-stock
NAICS	North American Industry Classification System
NPS	Noca Production System
OEM	Original Equipment Manufacturer
OM	Operations management
P	Proposition
PAC	Production activity control
PDCA	Plan-Do-Check-Act
POLCA	Paired-cell overlapping loops of cards with authorization
RCCP	Rough-cut capacity planning
RFID	Radio Frequency Identification
RQ	Research question
SFI	Centre for Research-based Innovation
SME	Small- and medium-sized enterprise
SOP	Sales and operations planning
TPS	Toyota Production System
8D	8 Disciplines

List of publications and declaration of authorship

Number	Publication	Declaration of authorship
I	Goeldner, T. & Powell, D.J. (2011) The use of information technology in lean production: Results of a transnational survey. *13th International MITIP Conference, 22-24 June 2011*. Trondheim, Norway: Tapir. (Double blind peer-review process)	Powell constructed the paper using the results of Goeldner's student project. Data collection and analysis was carried out by Goeldner. Goeldner identified the limitations of the study, as well as areas for further work, together with Powell.
II	Powell, D. & Strandhagen, J.O. (2011) Lean production vs. ERP systems: An ICT paradox? *Operations Management* 37 (3)	Powell conceptualized the article along with Strandhagen. Powell carried out the literature review and analysis. Powell wrote the article with input from Strandhagen.
III	Powell, D. (2012) ERP Systems in Lean Production: New insights from a review of Lean and ERP literature. *International Journal of Operations and Production Management* (accepted for publication)	Powell had the idea for the article, carried out the literature review and analysis, developed the research framework for ERP systems in lean production, and wrote the article.
IV	Powell, D., Alfnes, E., Strandhagen, J.O. & Dreyer, H. (2011) ERP support for lean production. *APMS 2011: International Conference on Advances in Production Management Systems*. Stavanger, Norway: Springer. (Double blind peer-review process)	Powell conceptualized the article together with Alfnes. Powell did the data collection and analysis. Powell and Alfnes developed the 15 keys for ERP support for lean. Powell wrote the article with input from Alfnes, Strandhagen and Dreyer.
V	Powell, D., Riezebos, J. & Strandhagen, J.O. (2012) Lean production and ERP systems in SMEs: ERP support for pull production. *International Journal of Production Research* (available online 23 January 2012)	Powell had the idea for the article, and conceptualized the capability maturity model together with Riezebos. Case studies were conducted by Powell and Riezebos. Analysis was carried out by Powell, and Powell wrote the article together with Riezebos, with further input from Strandhagen.
VI	Powell, D., Alfnes, E., Strandhagen, J.O. & Dreyer, H.C. (2012) The concurrent application of lean production and ERP: towards an ERP-based lean implementation process. *Computers in Industry* (in review)	Powell conceptualized the article together with Alfnes. Powell did the data collection and analysis. Powell wrote the article with input from Alfnes, Strandhagen and Dreyer.

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Part I: Main Report

1 Introduction

This chapter gives a general introduction to the PhD thesis, describes the background of the work, and gives rationale and motivation for the research. It also defines the preliminary research questions and sets the objectives of the research project.

1.1 Problem background

Manufacturing is a dominant sector in the European economy. The economic importance of this sector is evident: it provides jobs for approximately 34 million people; and produces an added value in excess of €1 500 billion from 230 000 enterprises with 20 or more employees (Flegel, 2006). However, it is widely perceived to be facing serious challenges. This is particularly true of the manufacturers located in the high-cost regions of Europe, such as the United Kingdom, Norway and Germany. The sector faces intense and growing competitive pressures on several fronts: In the high-tech industry, typically characterised by low volumes and a high variety of products, other developed economies such as Korea are posing the greatest threat. When it concerns production in the more traditional environments, for example the mass production of high volume, low variety products, these industries have seen a pattern of migration to low-cost countries such as China and India. These low-cost countries are in fact also rapidly modernising their production methods and enhancing their technological capabilities.

Therefore, faced with increasing customer expectations and intense global competition, today's manufacturing companies are forced to continuously look for more innovative ways to enhance competitiveness in order to remain profitable. Two popular approaches for enhancing competitiveness are deploying lean production practices, or implementing an Enterprise Resource Planning (ERP) system. For example, Carroll (2007) states that lean and ERP are consistently rated as the most important strategies for achieving competitive advantage in manufacturing operations. Lean production stems from the Toyota Production System (TPS), which was developed by the Japanese auto producer after the Second World War in order to compete with the mass producers of the West who were, at that time, developing and applying computer aided production management methods, namely materials requirement planning (MRP). Advances in information technology (IT) have enabled the development of ERP systems, which are today still very much based on the MRP logic of the 1970s. This means that whilst it is generally accepted that lean production improves manufacturing performance with the application of recognized tools and techniques, and equally assumed that contemporary ERP systems are essential for companies seeking increased efficiency through organizational integration, within the lean paradigm, IT such as ERP systems has often been regarded as a source of non-value adding activity (e.g. Sugimori *et al.*, 1977). For example, the parameters used within the ERP system often include "safety buffers" roughly calculated by the production planner. This can encourage overproduction, leading to the waste of excess inventory (Ohno, 1988). That said, Ward and Zhou (2006) suggest that although proponents of IT integration and lean practices often appear to be at odds, there is no technical reason for such competition. Information systems such as ERP are generally higher level planning systems, whilst lean practices are primarily related to shop floor control and execution activities (Vollmann *et al.*, 2005). Nevertheless, the benefits of lean manufacturing need to be augmented by addressing some of the limitations of lean practices, such as its applicability to environments that do not demonstrate the required characteristics inherent to the Toyota Production System (e.g. standard products, level demand, and short lead times). It is in this area where the application of ERP can be considered to further enhance the integration and optimization of processes, through accurate, timely and dependant information to support manufacturing operations.

1.2 Rationale

Based primarily on the working practices of the Toyota Production System (TPS), lean production is an increasingly applied operations paradigm for enhancing production effectiveness. It can be described as both a philosophy and a set of tools and techniques that aim to systematically identify and eliminate all waste in processes, with an underlying vision of one at a time, no waste flow (Bicheno and Holweg, 2009). Just-in-time (JIT) is a key area of the lean production paradigm, and has been one of the hottest research areas in operations management since the 1980s (Matsui, 2007). Cooney (2002) states that the importance of just-in-time flow is what is distinctive about the lean production concept, and that JIT is seen to be a superior value-adding practice. However, for it to be deployed effectively, there are a number of underlying prerequisites. For example, JIT requires a stable, levelled master production schedule (Cooney, 2002). It assumes minimal setup times, achieved through the application of setup reduction techniques (Shingo, 1981), and it also requires perfect quality (Womack and Jones, 1996). Citing Jina *et al.* (1997), Wan and Chen (2009) point out that lean principles are difficult to apply in high product variety and low volume environments due to turbulences in schedule, product mix, volume, and design.

ERP systems are commercial software packages that promise seamless integration of all information flowing through a company – financial, human resources, supply chain, and customer information (Davenport, 1998). They are designed to provide the information backbone to cope with the complexities of modern business and the global nature of today's markets (Hill, 2005). The origins of ERP can be traced back to the material requirements planning (MRP) systems that were developed in the 1970s with a focus purely on materials planning, inventory accounting, and purchasing. In the 1980s, manufacturing resource planning (MRP II) was born when capacity and financial planning capabilities were added to the MRP system. Finally, the integration of planning, management and the use of all resources within an entire enterprise gave rise to ERP in the 1990s.

Because ERP and lean production have emerged from fundamentally different approaches to production, there is often a dispute as to whether or not both approaches can be used together (e.g. Bartholomew, 1999). For example, one of the most common arguments arising between lean production and ERP systems is that of pull vs. push. Benton and Shin (1998) suggest that there is a common agreement among researchers that a lean production system functions as a pull system, whereas those systems using ERP systems and material requirements planning (MRP) logic are predominantly push. When defined in terms of information flow, in a pull system, the physical flow of materials is triggered by the local demand from the subsequent customer. On the contrary, a push system uses centralized information stored within the ERP system in order to drive all production stages (Olhager and Östland, 1990).

As a result of the pull vs. push debate, ERP systems have often been classed as sources of waste within lean production literature (Bell, 2006; Bruun and Mefford, 2004; Hicks, 2007; Nakashima and Berger, 2000). For example, Halgari *et al.* (2011) suggest that ERP systems have been considered a hindrance to lean manufacturing efforts and have been criticized for encouraging large inventories and slower production. Piszczalski (2000) argues that computer-based planning and control dangerously removes control from the plant and over centralizes it. Thus, he suggests, using ERP systems can lead to a major disconnect between reality on the plant floor and computer-generated schedules. However, many lean practices remain dependent upon high quality data for the processes of problem solving, continuous improvement and effective production control. Therefore, companies have been building hybrid environments in which they take advantage of both approaches as much as possible, facilitated by developments in information technology (Riezebos *et al.*, 2009). Ward and Zhou (2006) identified that even companies that have experienced success through implementing lean practices may benefit from IT integration practices that are available through ERP system implementation. However, there remain gaps in the extant literature in identifying the ways in which ERP systems can be used to support these lean production practices.

The European Commission's 7th Framework Program for Research and Technological Development (FP7) seeks to develop a new European production model which takes the lean manufacturing paradigm further by adding the relevant parts from the European manufacturing culture, standards, and technology (European Commission, 2007). FP7 suggests the realization of synergies through the coordination and collaboration of information and communication technology solutions with the lean paradigm.

Thus, it can be seen that whilst lean production and ERP systems began life on divergent paths, it seems as though recent developments in ERP and changes in the global marketplace have caused both approaches to become convergent in nature. This therefore forms the rationale for this research project. A gap exists in knowledge as to whether or not lean and ERP are genuinely contradictory in nature, and whether modern ERP systems can in fact be used to support lean production principles.

1.3 Research questions

As a result of exploring and defining the rationale for this research project, two preliminary research questions were formulated:

RQ1: Are lean and ERP genuinely contradictory in nature?

This research question aims to shed light on the recurring debate on whether lean and ERP are complimentary or contradictory technologies. Whilst in the traditional sense both approaches have been suggested as competing, modern developments in IT and the functionality of ERP systems may lead us to take an alternative view.

RQ2: How can contemporary ERP systems be used to support lean production?

This research question aims to show how lean and ERP can be considered as complimentary technologies, by giving examples of how modern ERP systems can be used to support the application and use of lean principles and practices.

Offering answers to both of these research questions is of great importance to this research project, as the answers will make a significant contribution to both theory and practice. The questions will therefore set the direction of the research project.

As the project progressed, two additional research questions were formulated:

RQ3: How can contemporary ERP systems be used to support pull production practices in SMEs?

This question aims to explore the very essence of the "contradictory" nature of lean and ERP. In the traditional sense, it is clear that there was a valid argument for claiming that Kanban cards were more effective at controlling pull production (e.g. Sugimori, 1977). However, in a modern day context, with advances in IT, ERP systems now have a greater range of functionality than the MRP systems that came before them. By addressing this research question, I aim to provide explicit examples of how modern ERP systems can be used to support pull production.

RQ4: How can existing methodologies for the implementation of lean production and ERP systems be combined to develop a single "best practice" process for ERP-based lean implementations?

The final research question was formulated during the core action research project, when the company involved in the concurrent implementation of lean and ERP. A synergetic effect was observed during such a dual implementation, and it was suggested that the ERP project itself acted as a catalyst for the application of lean practices. Therefore, it was asked whether a process could be developed for an ERP-based lean implementation.

1.4 Objectives

The aim of this research project is to investigate the "contradictory" nature of lean and ERP. By addressing the four research questions, the objectives of this thesis are to assess the role of ERP systems in lean production, and to provide a framework for ERP support for lean production. The work will evaluate ERP support functionality for lean production, placing emphasis on support for pull practices, and will also investigate the possibility for the development of an ERP-based lean implementation process.

1.5 Research scope

Within the operations management arena, the main scope of this project is to study the interactions between ERP systems and the application of lean production principles in manufacturing organizations. It would be beyond the scope of this investigation to cover the entirety of environments found in the manufacturing industry; therefore the main area for research will be within discrete product manufacturing. It should also be noted that a complete discussion of lean production is well outside the scope of this project, since effective implementation of lean would impact virtually all aspects of an organisation. Therefore, this project will focus upon the areas of lean production and ERP systems that primarily impact the planning and control of manufacturing operations. Finally, the research also places itself nicely within the realm of small- and medium-sized enterprises (SMEs), as these types of organization are very important within Europe's economic structure, even though they are facing significant challenges to remain competitive in light of the demands of their larger counterparts.

1.6 Outline of the thesis

This thesis consists of two parts: Part I, which constitutes the main report; and Part II, which is a collection of six research papers (two of which have been presented as conference papers, two have been published in international journals, one has been accepted to be published in an international journal, and one is a journal article currently in the review process). Part I of this thesis is set out as follows:

Chapter one has been the introduction chapter. I have given a general introduction to the PhD thesis, detailing the background of the research, the rationale for the research, and the research questions to be addressed. I also describe the objectives of the thesis, and limit the scope of the investigation.

In chapter two I describe the theoretical background in relation to the PhD research project. Starting with an overall description of the positioning of the research within the field, I give a brief overview of manufacturing and operations management, and address manufacturing planning and control as the context for investigating lean and ERP. I end the chapter with the development of a conceptual framework which I will use to guide the investigation.

Chapter three covers the research design process. I explain the positioning of the research; describe my own personal considerations in terms of the ontological, epistemological, and methodological viewpoints; and I go into detail regarding the research methodologies which were used to investigate the research questions. Finally, I assess the quality of the selected approach based on recognised quality criteria.

Chapter four reports our empirical findings by firstly describing the results of an exploratory survey that was carried out to investigate the relationships between lean and IT. Then, two exploratory case studies are discussed, which explore the practical considerations in terms of lean and ERP. One of the cases is located in Norway and the other in the Netherlands. I describe the action research project in more detail, where I introduce Noca as the client system, and explain the three phases of the action research project. I make some concluding remarks as to the value of action research for this type of investigation. Finally, I provide an overview of the four case studies that were carried out to further examine ERP support for pull production.

In chapter five I explain the results of the research project, and give a summary of the six research papers that formulate the basis of this thesis in terms of each paper's purpose and overview, and main findings. I describe the contributions of the research, and discuss them in relation to existing theory.

In chapter six I present a general discussion of the overall findings of the research project with reference to the research questions.

Finally, Chapter seven marks the end of the thesis, and I draw relevant conclusions in terms of the research project's implications for theory and implications for practice. I also present the limitations of the research, as well as some directions for further research.

2 Theoretical Background

This chapter describes the theoretical background for the research project. The thesis finds itself positioned within two main bodies of knowledge: manufacturing and operations management. Within these two fields, I focus on two current hot topics: lean production and ERP systems. Finally, in order to investigate these topics on a level playing field, I define manufacturing planning and control as the platform on which the investigation takes place. The positioning of the research is shown in Figure 1.

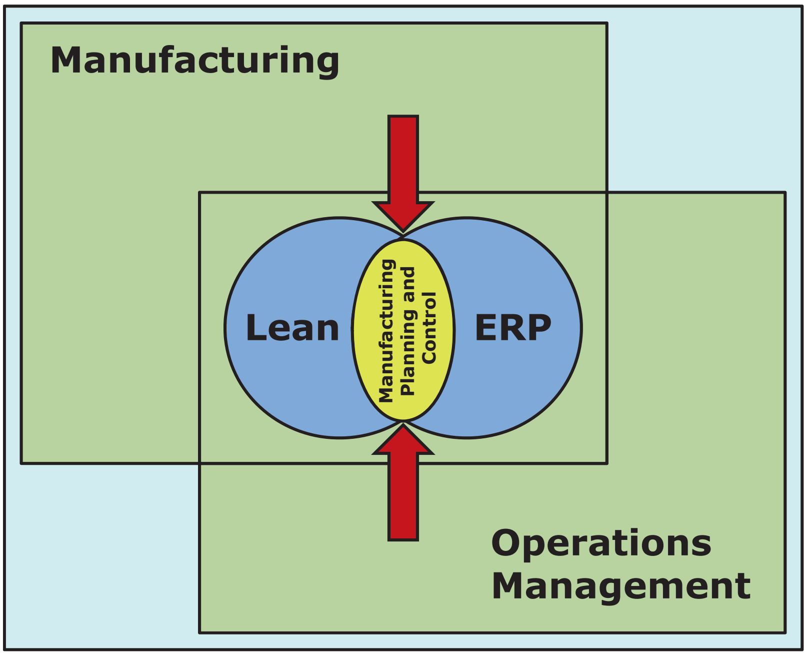

Figure 1: Positioning the Research

2.1 Manufacturing

Manufacturing can be described as a series of interrelated activities and operations involving the design, material selection, planning, production, quality assurance, management and marketing of goods (Blackstone and Cox, 2005). Manufacturing entails the production of physical goods, which encompasses the processing of raw materials, often into intermediate materials, which are then transformed into components, subassemblies and finished products.

(Though some authors attempt to make a distinction between the definitions of "manufacturing" and "production", in this thesis I use the terms synonymously).

The business units that carry out manufacturing activities are called manufacturing companies, or manufacturing organizations. There are a number of means by which manufacturing companies can be classified. Often this is done with reference to the type of product produced. For example, a number of standards have been produced for industry classification based on product type. The Global Industry Classification Standard (GICS) and the North American Industry Classification System (NAICS) are two popular classification schemes that are used today. Some examples of classifications within NAICS include food manufacturing; apparel manufacturing; plastics and rubber products manufacturing; and computer and electronic equipment manufacturing.

Manufacturing companies are also often classified in terms of two dimensions: volume and variety. Usually, if a company produces a high volume of products, it will only produce a limited variety. On the other hand, if a manufacturer offers a high variety of products, it is typical that it only produces these in small volumes. Hayes and Wheelwright (1979) used this classification to develop what they called the product-process matrix, which considers process type as well as the product characteristics described previously.

Process types include job shop; batch; assembly; and continuous flow production (Slack *et al.*, 2007). These can be seen on the left hand side (X-axis) of product-process matrix (Figure 2). The volume and variety classification can be seen in the top of the figure (Y-axis). Notice that Hayes and Wheelwright suggest that low-volume, one-of-a-kind products are best suited to job-shop environments and that high volume, standardised products are better suited to continuous flow production processes. This means that flexibility is often forsaken in favour of automation and process "efficiency" as we move from the project- or job-shop orientated production associated with one-of-a-kind products to the continuous flow production that is associated with food and chemical industries.

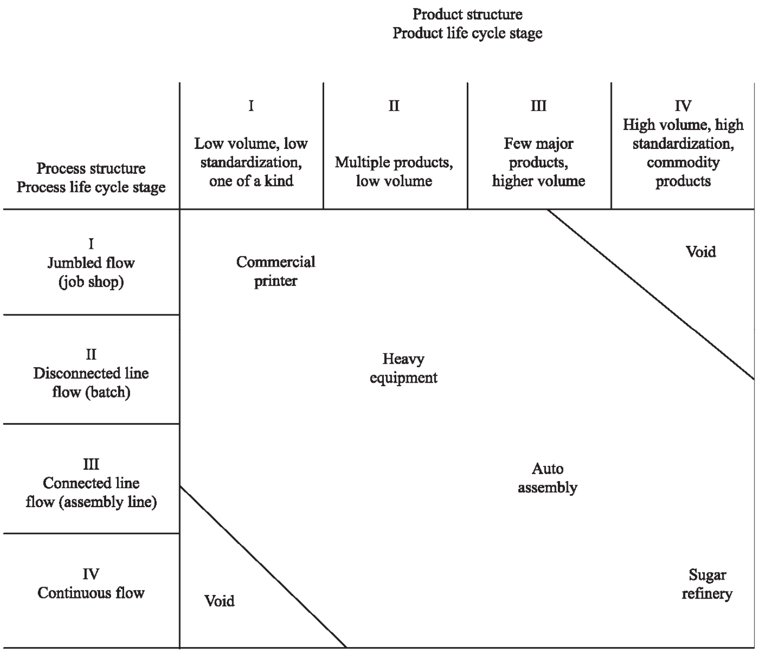

Figure 2: The Product-Process Matrix (Hayes and Wheelwright, 1979)

There are usually many companies involved before a finished product can be delivered to the end customer. For example, in the automotive industry, the identity of the producer of the end-product is common knowledge in the market place. This will be the original equipment manufacturer (OEM), for example Toyota, Ford, or Volvo. However, when we examine the supply chain perspective, the extent of players involved in the production of a motor car is astounding. Counting first-, second-, and third-tier suppliers, and even beyond, we are looking at many hundreds of companies involved in the production of a motor car. The task of managing and coordinating these various types of manufacturing activities across organizational-, national- and cultural boundaries is no minor feat, and this is where the body of knowledge known as operations management can and should be applied.

2.2 Operations management

The field of operations management is large, and much of it originates from manufacturing. Operations management (OM) covers the effective planning, organizing, and control of all the resources and activities necessary to provide the market with tangible goods and services (Waller, 1999), and can be defined as the design, operation, and improvement of the systems that create and deliver the firm's primary products and services (Chase *et al.*, 2004). To put it simply, operations management is about how organizations produce goods and services (Slack *et al.*, 2007).

Meredith *et al.* (1989) state that the field of OM faces multiple new research challenges in the areas of service operations, productivity, quality, technology and many other areas. Prasad and Babbar (2000) also suggest a list of existing topics in OM research (1986-1997), including purchasing and distribution, technology, just-in-time (JIT), and quality management. In fact, as a result of changes in market requirements, the management of operations within both manufacturing and service organizations has evolved tremendously. For example, globalization has resulted in an increase in competition at an international level. The application of information technology (IT) has also significantly altered the landscape in which organizations compete. Furthermore, Collier and Evans (2006) suggest that operations management is continually changing, and that managers should stay abreast of the challenges that will define the future workplace, including technology, globalization, changing customer expectations, a changing workforce, loss of manufacturing jobs in the western nations, and building sustainability as part of corporate social responsibility.

In this thesis, emphasis is placed on manufacturing operations rather than service operations. As such, of particular relevance to this thesis is the topic known within the operations management literature as manufacturing planning and control.

2.3 Manufacturing planning and control

Effective planning and control is a central element of modern production, and as such, manufacturing planning and control (MPC) can be identified as one of the core functions within operations management. The MPC task involves managing the flow of material and the utilization of people and equipment in response of customer requirements, and to provide information that aids decision making in order to meet demand. This section describes the relevance of MPC for this PhD thesis.

It is initially important to clarify definitions of the terms ‘planning’ and ‘control’. According to Slack *et al.* (2007), planning is a formalization of what is intended to happen in the future. However, a plan does not guarantee that an event will actually happen; it is a statement of intention. On the other hand, control is the process of coping with the changes which affect the plan (Slack *et al.*, 2007). Control thus makes the adjustments which are necessary to allow the operation to achieve the objectives that the plan set out for. Slack *et al.* (2007) also state that the balance between planning and control activities changes in the long-, medium- and short-terms, as shown in Figure 3.

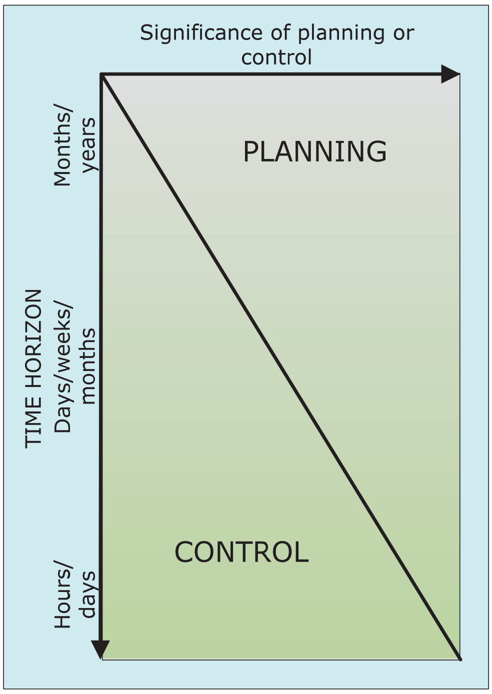

Figure 3: Significance of Planning and Control vs. Time Horizon (Slack *et al.*, 2007)

Having established the definitions of and significant differences between planning and control, a generic framework for the MPC function can now be considered. All stages of the MPC process are illustrated in Figure 4.

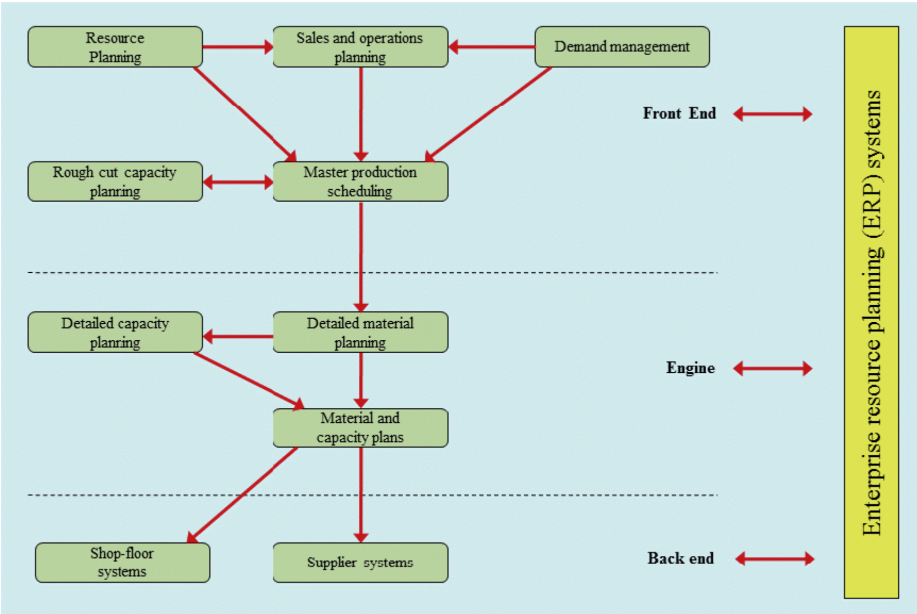

Figure 4: MPC System Framework (adapted from Vollmann *et al.*, 2005)

The centralized, hierarchical MPC system framework suggested by Vollman *et al.* (2005) is a well-recognised and widely used framework. Each of the elements within this framework is briefly described below.

Sales and Operations Planning (SOP) involves the use of aggregate data in order to attempt to balance supply and demand. Olhager and Rudberg (2002) identify three alternative planning strategies within the SOP process – level; chase; and mix (hybrid).

Demand Management is the combined management of customer orders and sales forecasts, and an approach to medium-term capacity management that attempts to change or influence demand to fit available capacity (Slack *et al.*, 2007). Vollmann *et al.* (2005) suggest that demand management not only applies to the medium-term, but it also applies to the sales and operations planning process at a more long-term strategic level. Finally, Higgins *et al.* (1996) show demand management as a link between the sales and operations planning- and the master production scheduling processes.

Resource Planning is the uppermost level of capacity management (APICS, 2009) and involves calculating the amount of resources (labour and facilities) required to support the business plan.

Master Production Scheduling (MPS) is the process of developing the vital schedule which defines the volume and timing requirement of the end items (Slack *et al.*, 2007), and is concerned with the effective use of available capacity, regardless of the manufacturing process (Olhager and Rudberg, 2002).

Rough Cut Capacity Planning (RCCP) is the capacity function that typically corresponds with the master production schedule (MPS). Slack *et al.* (2007) suggest that RCCP is used in the medium to short term to check the MPS against known capacity bottlenecks, thus the feedback loop at this level verifies the MPS against key resources only.

Material Planning, or Material requirements planning (MRP), deals with acquiring the components (either manufactured or purchased) needed to fulfil the master production schedule (Olhager and Rudberg, 2002). Jonsson (2008) refers to this process of the MPC system as order planning, and suggests it is the planning level for materials supply, i.e. raw materials, purchased components, small items and semi-finished products, that are purchased or manufactured at the company in such quantities and at such times that production plans drawn up under the MPS can be fulfilled. MRP is essentially a bill-of-materials explosion of the end items required in the MPS, where individual component requirements are offset based on select parameters, such as due dates and lead times.

Capacity Planning deals with the capacity needed to realise the internal manufacturing of the material requirements plan. It assesses the day-to-day effect of work orders issued from MRP on the loading of individual process stages (Slack *et al.*, 2007).

Shop Floor Systems is the part of the MPC system that lies closest to the production processes and plays an important role in linking the factory floor with the other processes of the MPC system (Browne *et al.*, 1996). It is often synonymously used with the term production activity control (PAC).

Supplier systems contains the purchasing decisions, and is the organizational function that forms contracts with suppliers to buy in materials and services (Slack *et al.*, 2007). As a function, it is often combined with PAC in the MPC system, as they both represent the implementation and control phase of the production system (Arnold *et al.*, 2008). As such, purchasing is responsible for establishing and controlling the flow of materials into the factory.

Though each of these elements together represent a general MPC framework, the specific requirements of the MPC system depend on the nature of the production process, the degree of supply chain integration, customer's expectations, and the needs of management (Vollmann *et al.*, 2005). It is important to note that MPC system requirements are not static, and must be adapted continuously in order to meet changes in products, markets and technology.

This section has given an overview of the general activities found within a typical MPC system that a company would use for planning and controlling its manufacturing operations. Vollman *et al.* (2005) state that changes in information technology have allowed these MPC activities to be encapsulated within ERP systems, which are explained in more detail in the next section.

2.4 Enterprise Resource Planning systems

Vollman *et al.* (2005) suggest that one of the more pervasive and least well forecast changes in manufacturing has been the implementation of enterprise resource planning (ERP) systems, and that the rapid deployment of this type of information technology has been in response to the global need for coordination and communication. They also suggest that it is now most typical to find the MPC system imbedded in an ERP system (see the right hand side of Figure 4). This section evaluates the history and development of contemporary ERP systems, which are now widely used by large corporations around the world (Pollock and Cornford, 2001). ERP systems have evolved from a technique used to plan dependant demand materials, known as Materials Requirement Planning (MRP), via a coherent set of best practices for the planning and control of resources, known as Manufacturing Resources Planning (MRP II). The root of these concepts is the product's bill of material (BOM).

2.4.1 Materials Requirement Planning (MRP)

MRP was developed in the USA in the early 1960s and was widely implemented during the 1970s (Browne *et al.*, 1988). Higgins *et al.* (1996) suggest that MRP thinking has revolutionized manufacturing planning and control. Applications of MRP were built around a bill of material processor (BOMP) which converted the aggregated plan of production for a parent item into a discrete plan of production or purchasing for individual component items contained within the BOM. MRP logic can be summarized as an iteration of three consecutive steps (Higgins *et al.*, 1996):

1. Netting against available inventory.
2. Calculation of planned orders.
3. Bill of materials explosion to calculate gross requirements for dependant items.

The main objective of MRP is to determine what and how much to order (both purchase orders and production orders), and when. The input to this is the master production schedule (MPS). As the MRP calculation process makes no consideration of available capacity, a separate capacity requirements plan (CRP) must also be created. The MRP process can be seen in the centre of Figure 4 (master production scheduling and detailed material and capacity planning).

2.4.2 Manufacturing Resources Planning (MRP II)

In the 1980s, the three separate modules (MRP, MPS and CRP) were combined to make a single system, which was coined as manufacturing resource planning (MRP II). This also included the sales and operations planning (SOP) function and rough cut capacity planning (RCCP), as can be seen in Figure 5. The MRP II systems were also able to close the loop by offering integration with a company's financial management system, and for the first time ever, *"a company could have an integrated business system that provided visibility of the requirements of material and capacity driven from a desired operations plan, allowed input of detailed activities, translated all this activity into a financial statement, and suggested actions to address those items that were not in balance with the desired plan"* (Ptak, 2004). Much of the MPC system in Figure 4 is represented in the MRP II concept.

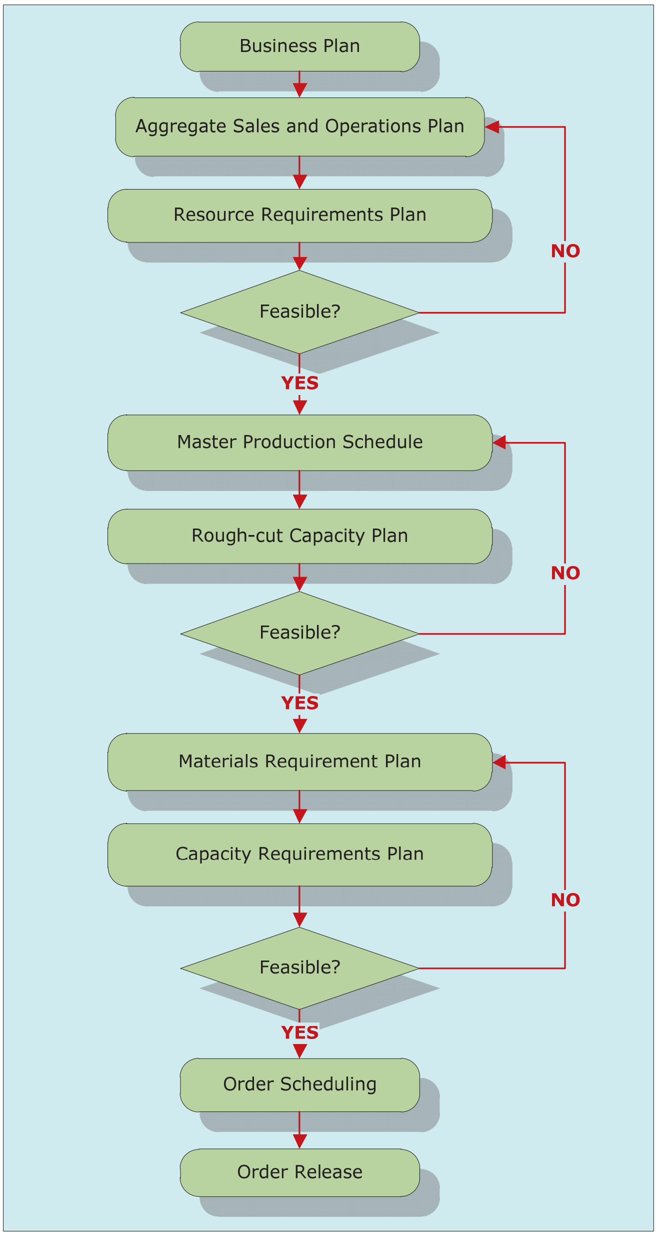

Figure 5: Skeletal Framework for the MRP II Concept (adapted from Zäpfel, 1996)

In the 1990s, as the cost of technology dropped and advances in computing continued to revolutionize business management systems, other functions were added to the MRP II package, including product design, warehousing, human resources, and accounting, and enterprise resource planning (ERP) was born.

2.4.3 Enterprise Resource Planning (ERP)

Today, companies are increasingly using off-the-shelf ERP solutions (Al-Mashari, 2002). In fact, ERP is one of the most widely accepted choices to obtain competitive advantage for manufacturing companies (Zhang *et al.*, 2005). ERP systems are business systems that are designed to provide seamless integration of processes across functional areas with improved workflow, standardization of various business practices, and access to real-time data (Mabert *et al.*, 2003).

Figure 6 is an illustration of what I consider to be a representative, simplified overview of an ERP system. Notice how the context of the term "ERP system" consists of much more than simply materials requirement planning (MRP) or manufacturing resource planning (MRP II), which are only part of the "Inventory and Manufacturing" module within the ERP system architecture shown in the figure. ERP has evolved to encompass much more than the material management associated with MRP and the manufacturing resource management enabled by MRP II. Contemporary ERP systems take a much more process-oriented view (rather than the traditional "resource" view), and provide integration of processes beyond the borderlines of individual companies, spanning also suppliers and customers.

With particular relevance to this thesis, I also include "Bolt-on" solutions within the context of ERP systems for the consideration of ERP support for lean production, especially when the support functionality for pull production is considered.

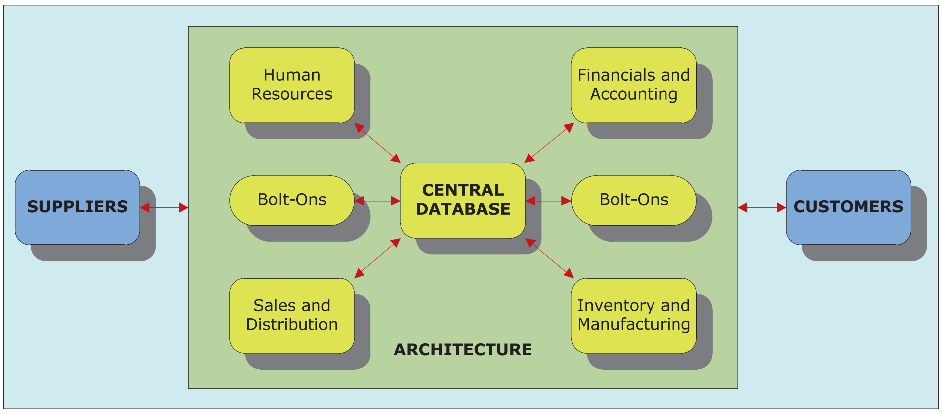

Figure 6: An Overview of an ERP System (adapted from Mabert *et al.*, 2001)

Mabert *et al.* (2001) define "bolt-on" modules as "*extension software*", or "*specialized systems that normally provide a customized capability, often taking the form of a decision support system*". Either way, bolt-ons are identified as an integral part of the ERP system architecture in this research project. Some examples of bolt-ons can be seen in Table 1:

Table 1: **A Sample of Bolt-on Modules** (adapted from Mabert *et al.*, 2001)

Demand Planning *e.g. Demand Planner (Baan)*	**Order Tracking** *e.g. Intelliprise (American Software, Inc.)*
Inventory Management *e.g. EXceed (EXE Technologies)*	**Factory Planning and Scheduling** *e.g. Capacity Planning (JD Edwards)*
E-Procurement *e.g. Oracle Order Management (Oracle)*	**Online Collaboration** *e.g. ActivEra E-Business (JD Edwards)*
Business to Business *e.g. Verano Supply Chain Portal (Verano)*	**Warehouse Management** *e.g. eOperate (Aspect Development, Inc.)*
Integrated Suite Systems *e.g. RHYTHM (i2 Technologies, Inc.)*	**Data Mining Systems** *e.g. Darwin (Oracle)*

Borell and Hedman (2000) present a summary of ERP capabilities, which includes:

- Human resources
- Financial accounting
- Sales and distribution
- Materials management
- Procurement
- Production planning and control
- Quality management
- Plant maintenance
- Project management
- Master data management
- Workflow
- Data warehouse
- Supply chain management
- Customer relationship management
- Advanced planner
- E-commerce (B2B & B2C)

2.4.4 Benefits of ERP Systems

The fundamental benefits of ERP systems do not in fact come from their inherent "planning" capabilities but rather from their ability to process transactions efficiently and to provide organized record keeping structures for such transactions (Jacobs and Bendoly, 2003). ERP systems provide distinct advantages to the companies adopting them as they can integrate business applications using real-time information (Spathis and Constantinides, 2003). ERP has been shown to deliver a number of business benefits by automating basic, repetitive operations. Some examples of which are:

- Cost reduction
- Lead time reduction
- Inventory reduction
- Productivity improvement
- Quality improvement
- Customer service improvement
- Performance improvement
- Improved decision making
- Improved delivery times
- Build external linkages (with suppliers and customers)
- Support organizational changes
- Empowerment
- Facilitate business learning
- Build common visions

(Shang and Seddon, 2000; Spathis and Constantinides, 2003)

2.4.5 Modern trends in ERP

By considering recent developments in the field of ERP systems, I have been able to identify a number of key trends. I have summarised these into ten major areas:

1. Reduction in cost and implementation time
2. Consolidation
3. Vertical solutions
4. A move towards SMEs
5. Customizable ERP
6. Collaborative ERP
7. Software as a service (SaaS) and Cloud Computing
8. Web-enabled ERP
9. User-centric, Mobile ERP
10. Real-time ERP

Reduction in cost and implementation time

With today's economic challenges, organizations are looking for ways to reduce the deployment cost and long-term total cost of ownership of ERP systems. Ease of deployment has become a key requirement from the users of ERP systems. No longer are lengthy, time-consuming implementations acceptable. This means that vendors have begun to develop ERP systems that are less complex to install and use. This reduces the amount of time spent on implementation, and also reduces the cost.

Consolidation

Vendor consolidation is an on-going trend in the ERP marketplace. The major players in the ERP world are SAP, Oracle, and Microsoft, closely followed by Sage, Infor and Lawson. Mergers and acquisitions amongst these have been commonplace in recent times. For example, the acquisition of JD Edwards by Peoplesoft in 2003, and the subsequent acquisition of Peoplesoft by Oracle in 2005, as well as the merging of Intentia and Lawson in 2006. In 2009, Microsoft boosted Dynamics AX with intellectual property (IP) purchases from three of its partners. The acquisitions included a process-manufacturing solution from Fullscope Inc.; a professional service solution from Computer Generated Solutions Inc.; and two retail solutions from LS Retail EHF and To-Increase Denmark A/S. This illustrates a trend towards developments in vertical solutions, the next key trend in ERP.

Vertical solutions

The more traditional, expensive, off-the-shelf ERP systems are very “static” and difficult to customize. These systems face stiff competition from players in the vertical market. There has been a trend toward offering vertical solutions for different industries, for example construction, production, and retail. SAP builds fairly deep levels in vertical markets, whereas Microsoft relies on partners for vertical customization. Vertical solutions may be more appealing to small- and medium-sized enterprises (SMEs), which have been increasingly targeted by niche ERP vendors of late. A move towards SMEs is also a recent trend in the ERP world.

A move towards SMEs
New customer growth in the large firm market is becoming minimal for ERP vendors. Instead, a reduction in the cost of computing, a growing importance of information utilization within firms, and an ever growing technically competent workforce means that ERP providers are focussing sales growth on the SME market. SMEs are gaining efficiency and competitive advantage through the implementation of ERP systems. This is one of the reasons why I have chosen to focus this research on SMEs, as I consider the concurrent application of lean and ERP to be of significant value to SMEs.

Customizable ERP
Today's volatile markets require customizable and adaptable ERP systems. Unlike traditional ERP solutions, vendors are beginning to develop flexible systems on metadata architecture that allows simple adaptations without impacting future upgrades of the system. Such architecture also allows for the easy integration of additional "bolt-on" modules, such as customer relationship management (CRM) and business intelligence (BI) applications. CRM will help to make an organizations sales and customer service functions more effective and efficient, whilst companies will continue to look to BI in order to provide operational data to support informed decision making.

Collaborative ERP
Collaborative ERP can provide measurable benefits to users within the enterprise and across the supply chain. An example of collaborative ERP is the combination and integration of familiar tools such as Outlook, Excel, and SharePoint with the ERP system for structured access and presentation of transactional and BI centric information.

Software as a service (SaaS) and Cloud Computing
On-demand and SaaS offerings have increased the choices for users in the ERP marketplace. Applications of SaaS and Cloud computing continue to grow, and SMEs are increasingly moving to Cloud solutions as the preferred method of running their businesses. These trends are also linked to customizable ERP, as SaaS and Cloud computing enables companies to source further apps and bolt-on modules such as CRM, BI, Workflow, and Data Warehousing.

Web-enabled ERP
Web-enabled ERP allows stakeholders and / or third parties to access information at any time and from anywhere through the use of Internet connectivity. This has enabled problematic events to be addressed immediately and in near real-time. Connecting objects that move along the supply chain to the Internet will also be enabled by mobile computing, and the introduction of mobile ERP.

User-centric, Mobile ERP
Developments in information technology have enabled ERP systems to become more user-centric. Traditionally, an ERP system would only be used by "enterprise process-driven users". These systems would typically be back-office based, and used by managers for manipulation of enterprise-level business processes. However, contemporary ERP systems can be made more responsive by addressing aspects of "user experience" (Woods, 2008). Modern business challenges require that ERP is made relevant for dif-

ferent types of business user, for example, information-driven users who need to use the ERP system in their everyday activities to drive business change and improvement. I consider current development in customizable ERP as a key enabler of user-centric ERP. The advent of mobile ERP applications also supports this movement. For example, advances in the mobile device market have allowed individuals greater access to the information contained within ERP systems via iPads, iPhones, smartphones, etc. These devices are becoming everyday business tools, and mobile applications will drive functionality out towards all employees.

Real-time ERP
Future ERP enhancements will require real-time data processing – handling hundreds of thousands of events-per-second. Systems that enable massive real-time service execution are currently in use by companies such as Amazon and Google (Hofmann, 2008). Therefore, developments in real-time ERP solutions are becoming more prevalent.

To summarize this section, many of the operational and organizational benefits of ERP systems as well as the modern trends in ERP development are in fact aligned with lean thinking. I would even suggest that ERP systems are moving towards becoming lean. In order to extend this idea, the next section gives an overview of lean production, which aids in the development of a conceptual framework that will be used to guide the investigation.

2.5 Lean production

In addition to ERP systems, lean production has also become one of the hot topics within the manufacturing and operations management literature in the past two decades. The term "lean production" was first coined by Krafcik (1988), and was later popularized by Womack *et al.* (1990) in their seminal book *The Machine That Changed The World*, when they compared the mass production principles of the Western world to the very simple production principles of Toyota. It is for this reason that lean production is said to have its roots in the Toyota Production System (TPS).

TPS is based upon two concepts: the reduction of costs through the elimination of waste (anything that adds costs without adding value, known in Japanese as *muda*); and the full utilization of workers' capabilities through the 'respect-for-human' system (Sugimori *et al.*, 1977). Lean philosophy aims to create value for internal and external customers (Womack and Jones, 1996), and is based upon continuous improvement that seeks to minimize waste that improves manufacturing performance and competitiveness (Katayama and Bennett, 1996). In lean, production is streamlined and synchronized with demand through the application of just-in-time scheduling (Shah and Ward, 2003). The coordination of materials acquisition and different production teams to meet common schedules and goals reduces inventory and lead-times and also increases productivity.

Just-in-time (JIT) production is a key element in the materialization of the elimination of waste concept, and is achieved through the use of 'pull' systems, which explicitly control the amount of work in progress that can be in the system (Hopp and Spearman, 2004; Nicholas, 1998). This helps minimize cumulative lead-times and prevents overproduction and excessive inventory, two of the most prominent types of waste identified by Ohno (1988).

With reference to the MPC activities discussed in section 2.3 (Figure 4), Arnold *et al.* (2008) describe the modifications that must be made to the MPC system when applying lean and JIT production. They suggest that JIT in no way makes the MPC system obsolete, but rather changes the focus of each of the elements. Specifically, they state that JIT should simplify the MPC problems. Thus we can reasonably assume that the application of lean and JIT production will not automatically remove the need for an ERP system.

In my own experience, many companies have deployed the foundational elements of lean production, such as 5S and value stream mapping, but have not ventured further into the development of flow production and the application of pull systems (e.g. Powell *et al.*, 2009; Powell, 2012b). Though lean production is perceived as a very attractive way to achieve competitive advantage in manufacturing, it is of course important to realise that lean is not a "one-size-fits-all" product, it must be adapted to each individual setting. Not all manufacturers are Toyota; neither do they necessarily share the same characteristics as Toyota. Of particular relevance is the product and process types that identify a manufacturer, as shown in Hayes and Wheelwright's (1979) Product-Process Matrix (Figure 2). As lean was pioneered in the automotive industry, one would suggest that manufacturers with assembly line processes with high volumes of a few major products would be best suited to pull production. Thus, it would take additional capabilities to achieve pull production in job shop environments and the continuous flow structure of the process industry.

Needless-to-say, in order to aid companies on their lean journey, Womack and Jones (1996) identify five core lean principles. I consider these to be important for this investigation, as the lean principles are well known in practice and theory, and serve as a logical foundation when investigating lean in the context of other areas of operations management.

2.5.1 Five Lean Principles

It is not solely the automobile industry that has been experiencing changes in operational practices. In fact, nowadays all industries exposed to global competition and changing technological possibilities are facing similar pressures to transform their practices in ways that are better attuned to the changing environment (Kochan *et al.*, 1997). Globalization has put serious competitive pressure on the old mass production model in the West. In their book *Lean Thinking* (1996), Womack and Jones renewed their lean message, extending it beyond the automotive industry. In doing so, they proposed five lean principles:

1. Specify *value* from the point of view of the customer;
2. Identify the *value-stream* and eliminate waste;
3. Make value *flow;*
4. *Pull* at the customer's rate of demand;
5. Seek *perfection* through continuous improvement.

Value

"The critical starting point for lean thinking is value. Value can only be defined by the ultimate customer. And it's only meaningful when expressed in terms of a specific product (a good or a service, and often both at once), which meets the customer's needs at a specific price at a specific time" (Womack and Jones, 1996 p.16)

Defining value from the point of view of the customer is of great importance when it comes to lean production. Williams (2010) suggests that most lean practitioners have failed to properly understand and apply the first and most important lean tenet – to truly and deeply understand what customers value, and will value. By selecting a forward looking long-term strategic view of customer value rather than a backward looking short-term tactical view on customer satisfaction, manufacturers can better understand the requirements for customer value creation. In a mass production, product-focused approach, an organisation attempts to find customers for its products by using mass marketing efforts, whilst with lean production, a customer centric approach requires products and services to be developed to fit customer requirements (Powell, 2011). We suggest that the definition of value is a critical step towards the identification and elimination of waste within the manufacturing enterprise.

Value stream

"The value stream is the set of all the specific actions required to bring a specific product through the problem solving task from concept through detailed design and engineering to production launch, the information management task running from order-taking through detailed scheduling to delivery, and the physical transformation task proceeding from raw materials to a finished product to the hands of the customer" (Womack and Jones, 1996 p.19)

Having defined value from the point of view of the customer, the next task is to identify the value stream. Though it is called the value stream, it is actually made up of all of the activities that are involved in making a product, both value-adding and non-value adding. And while many take an internal "door-to-door" plant view of the value stream, we suggest that the term "value stream" can also include external suppliers and customers. That's to say material flow to and from customers and suppliers, and likewise information flow.

Flow

"Once value has been precisely defined, the value stream for a specific product family fully mapped by the lean enterprise*, and obviously wasteful steps eliminated, it's time for the next step in lean thinking…make the remaining, value-creating steps flow"* (Womack and Jones, 1996 p.21)

It is clear that flow is an essential element of lean production. If we can imagine lean representing "the continuous flow of product to the customer" on one end of a scale, traditional "batch-and-queue" production would be placed at the opposing end, with frequent and excessive waiting as batches move slowly through the value stream. With an emphasis on waste elimination, the objective with lean production is to continuously reduce throughput time by cutting batch sizes and balancing production operations.

Pull
"Pull in simplest terms means that no one upstream should produce a good or service until the customer downstream asks for it" (Womack and Jones, 1996 p.67)

Following on from the concept of flow, the next step is to synchronize the already balanced production operations to the rate of demand of the customer. This is pull in a nutshell, and Kanban is a mechanism that is typically used to control the pull system. Kanban is a Japanese term for card or signal, and represents a simple authorisation mechanism to enforce pull production. When an operator receives a Kanban card, it gives him authorisation to produce or move products or materials (production Kanban or transport Kanban). Kanban cards can also be sent to suppliers to replenish component parts (supplier Kanban). I consider pull production to be the absolute ideal of lean production.

Perfection
"As organizations begin to accurately specify value, identify the entire value stream, make the value-creating steps for specific products flow continuously, and let customers pull value from the enterprise, something very odd begins to happen…suddenly perfection doesn't seem like a crazy idea" (Womack and Jones, 1996 p.25).

The final of the five lean principles is perfection, which represents the culture of continuous improvement that is required for lean production to succeed. Continuous improvement, or Kaizen (Imai, 1986) is a central part of lean production. We suggest that a focus on improvements raises the importance of visual management and performance measurement.

The five lean principles give a good conceptual overview of lean production. When put into the perspective of ERP systems, we can immediately see how important it is to have accurate and timely data if ERP is to operate alongside, or even integrate with, a flow-orientated pull system. For example, excessive lot sizing and the addition of "just-in-case" buffers in lead time and safety stock parameters will lead to disrupted flow and overproduction, as well as excessive inventory.

2.5.2 Just-in-Time Production

The five lean principles (pull in particular), all point towards achieving just-in-time (JIT) production, a term that is often used synonymously with both lean and pull production. In fact, Schonberger (2012) describes the global propagation of lean production as a transition from JIT to lean. Describing JIT as a central element of TPS, Sugimori *et al.* (1977) suggest that JIT production is a method whereby production lead times are greatly shortened in order to allow "all processes to produce the necessary parts at the necessary time and have on hand only the minimum stock necessary to hold the processes together". In their discussion of JIT production, Sugimori *et al.* (1977) consider three defining characteristics:

1. Levelling of production
2. One piece production and conveyance
3. Withdrawal by subsequent processes

Levelling of production

Sugimori *et al.* (1977) state that if the quantity to be withdrawn by subsequent processes varies consistently, then effort should be made to level the production at the final assembly line. This is because it is the final assembly line that gives authorization for production to the upstream processes in the JIT environment at Toyota. In lean production, the term used for levelling is Heijunka. Heijunka is a method for production levelling and scheduling that aims for a harmonized production flow. Its purpose is a quantitative production balance, without passing the difficulties on to suppliers or customers (Dickmann, 2006). It levels both the volume (rate) and mix (type) of production over a predefined length of time (Marchwinski and Shook, 2006). This means that a balanced rate of production is established (rate-based production). Smoothing the production process eliminates queues in front of the workstations. Heijunka is normally used at the pacemaker process, for example the final assembly line, in order to control and pace the whole plant (Bicheno and Holweg, 2009).

One piece production and conveyance

One piece flow is the second requirement for JIT production, and each process should approach the condition where it can produce only one piece, convey it one at a time, and have only one piece of work-in-process (WIP) between processes (Sugimori *et al.*, 1977). For example, no two identical products should follow each other. This ensures mixed model production. This type of single-piece flow assumes that setup times are negligible. Therefore, in order to achieve this, emphasis is required on reducing setup times. Toyota succeeded in reducing setup times and lot sizes by applying a method known as single minute exchange of dies (Shingo, 1985).

Withdrawal by subsequent processes

The final characteristic of JIT production is "withdrawal by subsequent process", or what is commonly known as pull production. Instead of the preceding process supplying parts to the following process, TPS adopted a method of the subsequent process withdrawing parts from the previous process. This is because with JIT production, "the necessary parts are produced by the various processes in the necessary amounts at the necessary timing for assembling a vehicle as a final product of the company". Sugimori *et* *al.* suggest that the first requirement of JIT is to enable all processes to quickly gain accurate knowledge of 'timing and quantity required'. Then, as all processes become synchronized, "the entire company can engage in JIT production without the necessity of issuing lengthy production orders to each process".

Buxey (1989) states that in a JIT environment, only the final assembly line receives a generated schedule, which dispenses with expensive production control software and systems. Where traditional MPC methods rely on heavy use of computers, JIT systems attempt to simplify procedures by applying such tools as Kanban (Zäpfel and Missbauer, 1993). However, this relies on smooth flow of materials achieved through the continuous improvement of the physical production processes (e.g. setup reduction). Stating that the workshops of Toyota "have no longer relied upon an electronic computer", Sugimori *et al.* (1977) list three reasons for having employed Kanban instead of computerized systems:

1. Reduction of cost of processing information
2. Rapid and precise acquisition of facts
3. Limiting surplus capacity of preceding shops

Reduction of cost processing information
They suggest that there is a significant cost associated with the implementation of a system that provides a production schedule to all production processes and suppliers, as well as its alterations and adjustments by real-time control.

Rapid and precise acquisition of facts
They also state that Kanban can be used to allow managers to perceive such information ('continuously changing facts') as production capacity, operating rate, and man power, without the help of a computer. This also promotes continuous improvement activity.

Limiting surplus capacity of preceding shops
Finally, they suggest that since the automotive industry consists of multistage processes, the demand for items generally becomes more erratic the further the process point is removed from the point of original demand for finished goods. Because preceding processes become required to have surplus capacity, they become more exposed to the waste of overproduction. This final reason is directly related to the Bullwhip effect (Lee *et al.*, 1997) in that the slightest distortion of information at the customer end of the supply chain can cause tremendous inefficiencies upstream.

I consider JIT to be a fundamental aspect of lean production. However, it is very difficult to apply in manufacturing environments which do not demonstrate the prerequisites identified in the scientific literature, e.g. those environments that have a high variety of low-volume products and high variation in customer demand. It is in these types of manufacturing companies where I would suggest that models and methods should be developed to enable ERP systems to support the systematic application of pull production.

2.6 Pull Vs. Push: The Lean-ERP Paradox

Japanese production management (e.g. Schonberger, 1982; Schonberger, 2007) and lean production (e.g. Holweg, 2007; Krafcik, 1988; Womack *et al.*, 1990); as well as material requirements planning (MRP) and enterprise resource planning (ERP) systems (e.g. Browne *et al.*, 1988; Orlicky, 1973; Ptak, 2004); are recurrent themes within the field of operations management, particularly when we consider the options for achieving competitive advantage in modern manufacturing. There is no doubt that lean production has been shown to lead to performance improvements (e.g. Womack and Jones, 1996; Krafcik, 1988; Shah and Ward, 2003; Sugimori *et al.*, 1977; Womack *et al.*, 1990). More recently, the application of ERP systems has also been shown to effectively improve the performance of manufacturing companies (e.g. Hitt *et al.*, 2002; Laukkanen *et al.*, 2007; Murphy and Simon, 2002; Shang and Seddon, 2000; Tsai *et al.*, 2007). Although the application of lean and ERP are consistently rated as the main contributors to competitive advantage in manufacturing operations, there has been a recurring debate as to whether lean and ERP are compatible, or whether they are contradictory in nature.

Whereas in the past, information technology such as ERP has been regarded as a source of waste by lean purists, in the current climate, the majority of manufacturers are using ERP systems to plan manufacturing operations whilst also developing a desire to realise the benefits associated with lean production. ERP systems have become a requirement for modern manufacturers, whose customers demand an ever-increasing portfolio of products, resulting in 100s if not 1000s of stock keeping units (SKUs). Managing such a wide range of parts is not a simple task, hence the growing number of ERP systems available today. In order to manage such an array of products also makes the elimination of non-value added activity even more appealing to producers, hence the big question, ERP, lean, or both?

A common argument arising between lean production and ERP systems is that of pull vs. push. Benton and Shin (1998) suggest that there is a common agreement among researchers that a lean, Kanban controlled production system functions as a pull system, whereas those systems using MRP-logic in an ERP system are predominantly push. We can suggest that it is in fact the MRP-logic that is the source of such a paradox. For example, Rother and Shook (2003) suggest that to qualify as pull, parts must not be produced or conveyed when there is no Kanban, and the quantity produced must be the same as specified on the Kanban. They suggest that the MRP system should be turned off to realise a future-state value stream based on Kanban and pull production (Rother and Shook, 2003 p.78).

When defined in terms of information flow, in a pull system, the physical flow of materials is triggered by the local demand from the subsequent customer, often via Kanban cards. On the contrary, a push system uses global and centralized information stored within the central ERP system in order to drive all production stages (Olhager and Östland, 1990). This leads to the next contrast between lean and ERP.

Where lean strives for decentralized control of production through empowered workers, ERP remains a centralized planning and control database. Stadtler (2005) suggests that ERP systems are incapable of performing real time control of production operations at the shopfloor. Rother and Shook (2003) also suggest that for lean production, a producer should get rid of those elements of an MRP system that try to schedule the different areas of a plant. A further contrast between the two approaches is that of the time-phased vs. rate-based decision (Alfnes, 2005). With lean, the aim is to achieve a level schedule of mixed-model production, synchronized with the rate of customer demand (takt-time). With ERP, the system often calculates an 'economic batch quantity' which is often based on machine utilization. Thus, it becomes apparent that the main disconnect between lean production and ERP systems is that lean flow methods are used to control production activity over the short-term time horizon, and ERP in the form of the master production schedule (MPS) and materials requirement plan (MRP) work over the medium- to long-term. The lean-ERP paradox is summarized in Table 2.

Table 2: **The Lean-ERP Paradox** (Powell and Strandhagen, 2011)

Lean	ERP
Production based on consumption (Pull)	Production based on forecasts and machine utilization (Push)
Decentralized control & empowerment (Bottom-up approach)	Centralized planning and control (Top-down approach)
Rate-based, mixed model production	Time-phased, batch production
Focus on maintaining flow	Focus on tracking material movements

The lean-ERP paradox gives an overview of the classical differences between lean and ERP, which have arisen from the distinction between JIT and MRP. It is clear that the two have emerged from fundamentally different approaches to production management: Just-in-time, pull production from Japan (Sugimori *et al.*, 1977); and MRP push from America and the West (Wight, 1984). However, due to extensive developments in the capabilities of ERP systems, it now appears that there is a potential synergy to be realized in combining the two. For example, Riezebos *et al.* (2009) suggest that ERP systems can dramatically reduce the amount of time required to obtain information relating to products and processes, as well as helping to increase the speed and quality of management decisions, whilst simultaneously reducing costs. Al-Mashari (2002) also states that the use of ERP can stimulate the adoption of standardised business processes throughout an organisation. These motivations and benefits are clearly well aligned with the principles of lean production. Furthermore, many lean companies are using ERP based approaches for communicating demand through the supply chain in order to facilitate just-in-time delivery, to the point where lean control principles (such as Kanban) take over.

Martin (2010) argues that IT applications and lean can be synergistically integrated in two ways. Firstly, IT applications should be deployed effectively and efficiently to increase an organizations flexibility in responding to external demand within the constraints of available resources, helping achieve the goals of lean production. Secondly, he suggests that IT systems can be modified to accelerate the deployment of lean production in order to improve operational performance. He suggests that MRP II systems are designed to push materials through a supply chain, but they can be modified to pull materials through portions of the same supply chain to increase its flexibility and responsiveness, reducing inventory and operational costs and increasing schedule attainment.

Benhabib (2003) suggests that MRP and JIT strategies are not competitive but can actually be seen as complimentary inventory management strategies. He states that whilst JIT emphasizes the initiation of production only when a firm order is placed, MRP complements this by back-scheduling the start of production in order to avoid delays for lengthy production activities. According to Benhabib, one can easily see the natural place of JIT in manufacturing companies today, where orders are received via the Internet and passed on to the shopfloor as they arrive.

Cunningham and Jones (2007) suggest that having a centralized ERP system is enormously important for a lean company. A standardized ERP system provides a common toolset that simplifies decision making processes, as all employees can view, discuss, and make decisions from the same standardized information. They also suggest that two of the most complex and important areas for the ERP system within a lean environment are order entry and order management. This is because lean manufacturing does not require products to be produced to forecast stocking levels nor to maximize the operating capacity of the facility. Therefore, a key discussion point is the integration of Kanban with the ERP system.

In lean production, the operator takes a Kanban item off the shelf and uses it; turns in the Kanban card and more items are ordered. Cunningham and Jones state that it doesn't matter to the operator if the ERP system thinks there are 1 or 1000 items in stock, as he has the one he needs and he knows more are on order because Kanban is a manual and visual process. However, it is the fact that Kanban is a manual process that poses the greatest risk where there is a lack of disciplined operators. For example, when the operator forgets to place the Kanban card in the correct place for the replenishment process to begin, the whole system fails. This is again where the application of automatic identification and data capture technologies (AIDCs), such as RFID, can help to reduce risk. When a Kanban item is removed from stock, a replenishment signal can be automatically logged or sent to the supplier.

To summarize, Gibbons-Paul (2008) suggests that though many lean purists believe that information technologies such as ERP are incompatible with the discipline, nothing could be further from the truth. Because ERP systems can help increase the speed and quality of management decisions, Riezebos *et al.* (2009) suggest that they offer a satisfactory level of support for lean production, making computer-aided production management and lean manufacturing complementary technologies. This helps to confirm the previously defined research questions that will guide this research project.

2.7 Conceptual framework

By examining the relevant theory, and exploring the fundamentals of lean and ERP, a conceptual framework can be constructed to guide the research process. A conceptual framework is used in research to outline a researcher's approach to an idea or proposition. It is the lens through which the problem is viewed. Put simply, it is a research tool intended to assist a researcher in developing awareness and understanding of the situation under scrutiny, and to communicate this (Smyth, 2004).

Reichel and Ramey (1987) describe a conceptual framework as a set of broad ideas and principles taken from relevant fields of enquiry. Therefore, in order to successfully investigate ERP support for lean production, I identify the five lean principles of Womack and Jones (1996) as the *a priori* constructs for analysis in my conceptual framework. In simple terms, the conceptual framework indicates my assumption that a contemporary ERP system will provide support functionality for each of the five lean principles: value; value stream; flow; pull; and perfection. The framework is used throughout the research project in order to:

- Provide clear insight from theory in developing the research questions;
- Inform the research design;
- Provide points of reference for discussing literature, methodology and analysis of data.

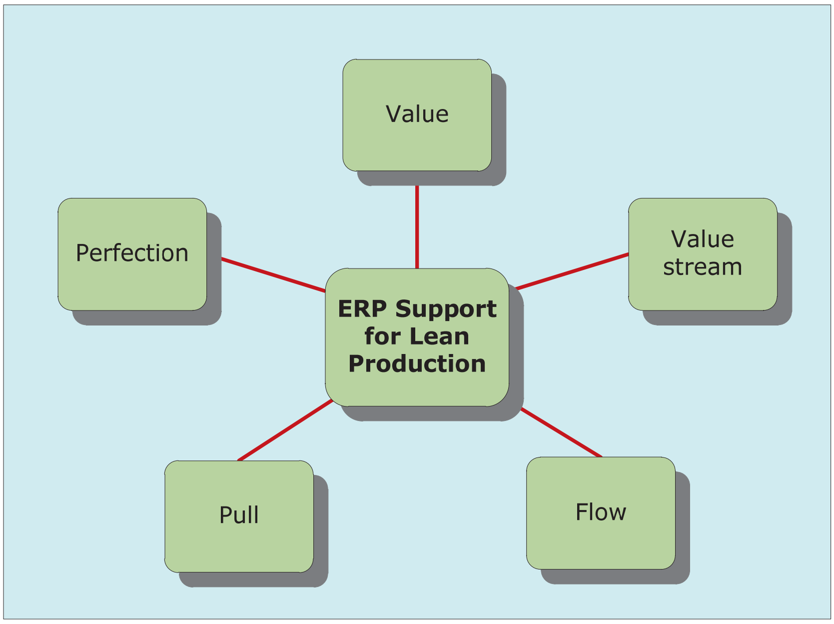

Figure 7: Conceptual Framework

The framework gives clear insight from theory in formulating and confirming the appropriateness of my research questions. The five lean principles are a well-known representation of lean production in both theory and practice, and through systematically operationalizing the lean principles as the constructs for investigation, we can identify the specific support functionality that exists in contemporary ERP systems for lean production. Also, by using the conceptual framework in this manner, we can begin to address the lean-ERP paradox. For example, by investigating ERP support functionality for pull production, we will be able to suggest new ways of thinking, other than the traditional mind-set which associates ERP systems with MRP-logic and push production.

Having identified the preliminary research questions, defined the *a priori* constructs, and developed the conceptual framework that will guide the investigation, the research design process will now be described.

3 Research Design

This chapter considers all aspects of the research design process that were applied during this research project, including the positioning of the research, my personal view of the philosophical approach, and the selected research methods. Based on the the chosen research methods, this chapter also discusses the quality of the research findings. Each individual article (in Part II of this thesis) contains methodological descriptions that supplement those given in this chapter.

Many of the choices that were made regarding the research design have been directly influenced by my previous experiences, (see the "About the Author" section at the front of the thesis). For example, following the exploratory survey that was used early on in the project (see Chapter 3.3.1), I could have chosen to apply more comprehensive, descriptive survey research. However, stemming from my experience and involvement in continuous improvement activities in UK manufacturing, as well as my close contact with Norwegian and European industry through various SINTEF projects, the research design of this thesis is predominantly based on a qualitative approach. I have primarily applied action research, which I have also supplemented by multiple case studies.

The action research methodology was selected as I am enthusiastic to engage in partnerships with practitioners in order to make contributions to both practice and theory. Unlike conventional social science, action research is not largely aimed at understanding social arrangements, but should also effect desired change as a path to generating knowledge and empowering stakeholders (Bradbury-Huang, 2010).

As the project ensued, it was realised that the action research should also be supplemented by case study research in order to explore and analyse the relationships between ERP systems and pull production. After all, "social science" may be strengthened by the execution of a greater number of good case studies (Flyvbjerg, 2006). By examining the ways in which ERP systems hypothetically support pull production practices, and exploring these in four practical cases, I have combined an empirically deduced model with the findings of the action research project in order to strengthen the scientific contribution of the work.

Gill and Johnson (1991) state that the research process "is not a clear cut sequence of procedures following a neat pattern but a messy interaction between the conceptual and empirical world, with deduction and induction occurring at the same time". Despite such a "messy"' approach, there is a need to adopt a structured and disciplined methodology in order to guide the research project and deliver valuable results. Table 3 shows a simplified overview of the research process for this PhD project.

Table 3: A Simplified overview of the research process (adapted from Bryman, 1988).

Positioning the Research	1. ***Identify a broad area of study***	Lean production & ERP.
	2. ***Select the research topic***	ERP support for lean production.
Research Philosophy	3. ***Decide the approach***	Insights from constructivism – interpretivist.
Research Strategy	4. ***Formulate the plan – select appropriate research method/s***	Action research supplemented by case research.
	5. ***Collect the data***	Sources of evidence: *Interview; documentation; direct observation.*
	6. ***Analyse and interpret the data***	Within-case and cross-case analysis; generalization.
	7. ***Present the findings***	Framework for ERP support for lean production; CMM for ERP support for pull production; ERP-based lean implementation process.

3.1 Positioning the research

It is imperative that the subject of the research is defined and understood, and that the current theoretical and empirical state of knowledge in the subject is identified (Croom, 2009). In order to position the research, a general mapping of the operations management literature on lean production and information technology (IT) helped to identify lean and ERP as the general area of study for the research project. A subsequent review of the literature helped to identify six areas within the field of ERP systems in lean production that would make interesting topics for further research (see Chapter 5.3). The gaps identified in the operations management literature directed the research project to investigate the support functionality offered by ERP systems for lean production. My contribution to the field of knowledge concentrates in this precise area, which I term "ERP support for lean production".

3.2 Research philosophy

Research philosophy is concerned with the fundamental challenge for any form of research, namely to adopt an approach to a study that will provide insight into the phenomenon or process of interest (Croom, 2009). When describing the scientific approach for any type of research, a researcher is faced with three questions – the ontological question; the epistemological question; and the methodological question (e.g. Arbnor and Bjerke, 2009; Bryman, 1988; Guba and Lincoln, 1994). These three questions are interconnected in such a way that the answer given to any one question, taken in any order, constrains how the others may be answered (Guba and Lincoln, 1994). For example, each of the various research paradigms: positivism; post-positivism; critical theory; and constructivism will have a varying opinion as to the answer to each of the questions.

3.2.1 The ontological question

Guba and Lincoln (1994) suggest that this is a question of the form and nature of reality and what can be known about it. Ontology is the science of being, and concerns the question of how the world is built. On one side of the ontological scale, the world is real (without quotation marks) and is independent from our knowledge. On the other side, there is no real world. The world is socially constructed with outcomes dependant on a specific time or culture.

As an action researcher, my philosophical position is slanted toward the constructivism paradigm. Though I consider it possible to discover general rules and cause-and-effect-like relationships about how manufacturing systems tend to behave, I still suggest that the transfer and application of knowledge can result in subjectively constructed outcomes.

3.2.2 The epistemological question

Guba and Lincoln (1994) state that the epistemological question is about the nature of the relationship between the knower and what can be known. Epistemology is therefore the theory of knowledge. A researcher's epistemological position reflects his view of what we can know about the world, and how we can know it. The two major distinctions here are either it is possible to acquire knowledge about the world unmediated and with no interference (implying objectivity – everyone sees the same thing); or, on the other hand, our observations are never objective but dependent upon our social constructions of "reality".

Again taking insight from the constructivist paradigm, I would tend to take the epistemological position of an interpretivist, as I attempt to make sense of, and to provide interpretation of, the research phenomenon – ERP support functionality for lean production. Although as an engineer I would like to think that my findings are true, I realise that it is through collaboration with the action research team that our findings have been constructed, implying a certain amount of subjectivity.

The two completely opposite positions in ontology and epistemology have led to the different research paradigms identified previously – positivism through to constructivism. Depending on the ontological and epistemological position, there is usually a specific choice as to the researcher's methodological position.

3.2.3 The methodological question

The final question is of methodology, and considers how the researcher can go about finding out whatever he believes can be known. Basically, there are two main methodological positions: quantitative and qualitative methods. Quantitative methods are usually employed by positivists who look to verify hypotheses, whilst qualitative methods are usually employed by constructivists, who will interpret the results, often by applying dialectical reasoning. The general aim of a positivist is to produce causal explanations or scientific laws with no interpretation – the results are irrefutable. On the other hand, a constructivist considers the world to be socially constructed, with phenomena requiring interpretation, thus constructivists are often also known as interpretivists.

Thus, for the methodological question, Croom (2009) suggests that constructivism is very much suited by a qualitative approach, as opposed to the quantitative methods which characterise positivist research. Therefore, based on the recommendations from the research methodology literature, and considering my previous experiences, I have chosen to select mainly qualitative research methods for this research project.

The three philosophical questions and the various research paradigms are summarised in Table 4.

Table 4: Three Questions and The Various Research Paradigms (adapted from Guba and Lincoln, 1994)

	Positivism	**Post-positivism**	**Critical theory**	**Constructivism**
Ontology	Naïve realism – "real" reality but apprehendable	Critical realism – "real" reality but only imperfectly and probabilistically apprehendable	Historical realism – virtual reality shaped by social, political, cultural, economic, ethnic, and gender values	Relativism – local and specific constructed realities
Epistemology	Dualist / Objectivist – findings true	Modified Dualist / Objectivist - findings probably true	Transactional / Subjectivist – value-mediated findings	Transactional / Subjectivist – created findings
Methodology	Experimental / Manipulative – verification of hypotheses; quantitative methods	Modified Experimental / Manipulative – falsification of hypotheses; may include qualitative methods	Dialogic / Dialectical	Interpretive / Dialectical

These considerations are important to the outcomes of the project, as my own personal beliefs and experiences will undoubtedly have some effect on the results. I do however suggest that taking a qualitative, hands-on approach to solving this particular research gap will generate useful understanding that reflects the practical nature of the problem. Using theoretically grounded insights, knowledge can be created by developing solutions with real-life cases, in real-time.

3.3 Research strategy

As well as the ontological and epistemological considerations referred to previously, the nature of the outcomes from using quantitative and qualitative research strategies differ greatly depending upon the researchers perceived connection between theory and research. For example, where qualitative research takes an inductive approach in which theory is generated from research, quantitative methods take a deductive approach in which research is used to test theory. As no tangible theory currently exists as to the role of ERP systems in supporting lean production, it would be very difficult to apply a theory-testing approach by using quantitative methods, for example. Therefore, this thesis has primarily been developed by applying a qualitative, inductive approach in order to build theory.

A combination of different research methods has been applied throughout the duration of the project. Table 5 gives a summary of the research articles that form Part II of this thesis, and the respective research methods that have been used.

Table 5: Summary of research articles and associated methods

Article Number and Title:	Article Type:	Research Method:	Article Outline:
1) The use of information technology in lean production: A transnational survey	Conference paper (presented) – MITIP 2011	Survey	Presents results of a transnational survey that was conducted amongst manufacturing companies in Norway and Germany to investigate the applications of IT and lean production.
2) Lean production vs. ERP systems: An ICT paradox?	Journal article (published 2011) – Operations Management	Literature review	Reviews literature in order to compare lean and ERP as two different approaches to production management.
3) ERP Systems in Lean Production: New insights from a review of Lean and ERP literature	Journal article (accepted 2012) – IJOPM	Literature review	Literature review of ERP systems in lean; develops a framework & identifies relevant research areas for ERP in lean production.
4) ERP support for lean production	Conference paper (presented) – APMS 2011	Action research	Documents the first phase of an ERP implementation process, and examines the potential support functionality of the ERP system for lean principles.
5) Lean Production and ERP systems in small- and medium-sized enterprises: ERP support for pull production	Journal article (published 2012) – IJPR	Multiple case study (4 cases)	Develops a capability maturity model for analysing the level of support functionality offered by an organization's current ERP system for pull production.
6) The concurrent application of lean production and ERP: towards an ERP-based lean implementation process	Journal article (in review) – Computers in Industry	Action research	Follows a concurrent implementation of ERP and lean practices in order to propose a process for ERP-based lean implementations.

3.3.1 Survey

Though my background and choice of philosophical position favours a qualitative approach, early on in the research project I was given the opportunity to define and supervise a student project. As the student had previous experience with statistical analysis, a project was identified whereby a survey instrument was created in order to explore the relationships between the application of lean production practices and the use of information technology (IT) in manufacturing companies. Forza (2002) suggests that exploratory survey research takes place during the early stages of research on a phenomenon, when the objective is to gain preliminary insight into a topic, and provides the basis for more in-depth research, survey or otherwise. The results of the exploratory survey (see Goeldner and Powell, 2011) were combined with two exploratory case studies in order to identify the research topic.

3.3.2 Structured literature review

A fundamental part of any academic research is to review the existing academic literature in the field of interest (Croom, 2009). This enables the researcher to know the lierature, and also allows the researcher to understand where the research fits within the subject field. Therefore, an early task in the research process was to conduct both a general mapping of the literature, as well as a thorough and critical literature review to identify any research gaps. Existing theories regarding lean production and ERP systems were examined, which helped to identify the specific areas where the research should focus, and also established the legitimacy of the research. It also ensured the researchability of the topic before any empirical analyses began (for a thorough literature review, see Paper 3).

3.3.3 Action research

Philips (2004) suggests that there is a broad Scandinavian tradition for action research. Drejer *et al.* (2000) suggest that this is because Scandinavian researchers feel very strongly that they must justify their existence by "solving" problems for firms/managers. As such, action research can be defined as a participatory, democratic process concerned with developing practical knowing in the pursuit of worthwhile human purposes, grounded in a participatory worldview (Reason and Bradbury, 2006). Essentially, it focuses on bringing about change (action) and contributing to knowledge (research). Reason and Bradbury go on to say that action without reflection and understanding is blind, just as theory without action is meaningless. McNiff and Whitehead (2009) suggest that doing action research involves the following:

1. Taking action (changing something);
2. Doing research (analysing and evaluating both the change and change process);
3. Telling the story and sharing your findings (disseminating the results).

Traditionally, science has privileged "knowing through thinking" over "knowing through doing". More recent accounts of reality however, particularly in the field of action research, have seen the privilege of experience and action over insight per se (Reason and Bradbury, 2006). Reason and Bradbury suggest that action research can in fact lead to 'better' research because the practical and theoretical outcomes of the research process are grounded in the perspective and interests of those immediately concerned, and not filtered through an outside researcher's preconceptions and interests. After all, the aim of action research is to provide a detailed and accurate picture of the "phenomenon".

As the main goal of this research project is to investigate ERP support for lean production, I selected action research as the primary research method, and was welcomed to join the team at a local company in Trondheim (Noca AS) that was implementing lean practices together with a new ERP system (Jeeves Universal). Action research is considered as an appropriate methodology for this study as both lean production and ERP systems are very much applied in industry, thus a "learning by doing" approach is very suitable. Having primarily been addressed by the structured literature review, the first research question was also dealt with by the action research project:

RQ1: Are lean and ERP genuinely contradictory in nature?

Our findings form the action research also suggested that lean and ERP are not contradictory in nature, and the results of the project were also used to address the second research question:

RQ2: How can contemporary ERP systems be used to support lean production?

The action research project was also used to tackle research question four:

RQ4: How can existing methodologies for the implementation of lean production and ERP systems be combined to develop a single "best practice" process for ERP-based lean implementations?

Research question three was dealt with by case study research, which is covered in the next section.

3.3.4 Case study research

As the research project progressively developed, a more apparent area of investigation was that of ERP support for pull production, the fourth lean principle of Womack and Jones (1996). Therefore, it was decided that the action research described previously should be supplemented by multiple case study research, in order to focus and explore the relationships between ERP systems and pull production.

Case research has consistently been one of the most powerful research methods in operations management, particularly in the development of new theory (Voss *et al.*, 2002). Benbasat *et al.* (1987) put forward a number of key characteristics of case studies, including:

- The phenomenon can be studied in its natural setting and meaningful, relevant theory can be generated from the understanding gained through observing practice;
- Case research is useful in the study of *why* and *how* questions, which can be answered with relatively full understanding of the nature and complexity of the complete phenomenon;
- The case method lends itself to early, exploratory investigations where the variables are still unknown and the phenomenon not at all understood.

With this in mind, and in order to strengthen the validity and contribution of the action research project, I chose to apply multiple case study research to address the third research question:

RQ3: How can contemporary ERP systems be used to support pull production practices in SMEs?

The investigation was restricted to SMEs as the client system in the action research project can be categorized as an SME under the European Commission's (2010) definition:

"less than 250 employees and less than €50m annual turnover"

The four Dutch case studies (Bosch Hinges, Variass Electronics, Altrex, and one that shall remain anonymous) were therefore selected on the basis of these criteria.

In accordance with Benbasat *et al.* (1987), Yin (2009) also suggests that case study research is the most appropriate overall research methodology if "how" or "why" questions are being posed. Yin suggests that case studies should be applied where the researcher has little control over events; and the focus is on contemporary phenomenon within a real life context. As the research question is a "how" type question, and as the focus is on contemporary phenomenon within a real life context (ERP support for pull production), case study research is considered to be a suitable approach for this investigation. The goal in case study research is analytic generalization and not statistical generalization (Yin, 2009). This also supports the choice of case study research, due to the qualitative nature of this project.

Silverman (2001) argues that qualitative data has the ability to provide a deeper understanding of certain phenomena than quantitative. A multiple case study approach was therefore chosen to provide insight into the use of ERP systems to support pull production in SMEs. One drawback of this methodology is however its time-consuming nature, which makes it necessary to limit the number of studies. We therefore restricted the investigation to four actual case studies. Any detrimental effect of small sample size was however mitigated by applying explicit criteria in the selection of the cases. For example, Pettigrew (1990, p. 275) makes a number of recommendations for the choice of research settings (Snider *et al.*, 2009):

- The phenomenon must be "transparently observable";
- The cases must represent "…polar types… which illustrate high and low performance";
- The cases must be clearly familiar with the research phenomenon.

On this basis, it was decided that the case studies used in this investigation should satisfy the following criteria: the company should be using an ERP system; the company should be using a card-based pull system; and the company should of course fit the European Commission (2010) definition of an SME. In order to be current in the research field, cases were also selected on the basis that both the ERP system and the pull system had been implemented at the company within the past ten years. For practical reasons, we limited the set of cases to locations in one geographical region (the Northern part of the Netherlands). Within the group of cases, we also aimed for polar types with respect to the level of integration of the companies' ERP- and pull systems.

In terms of data collection, each case study involved an interview with a primary on site contact, which was usually the CEO or production manager. Consultants and/or project managers involved in the ERP or pull system implementation were also present. In order to enable the interview activity to be consistent across all cases, I took the role of the primary interviewer, and was present at all interviews. Triangulation was carried out by direct observation and through use of documentation, in order to strengthen construct validity. Notes made during the interviews were used to compile a case study description as soon as possible after the interviews, the accuracy of which were also confirmed and verified by the interviewees.

Furthermore, and with respect to data analysis, analytical inferences were made from the qualitative data through the development of a coding scheme. In line with Miles and Huberman (1994), the data was systematically reduced into categories. This type of categorization is useful for both within-case and cross-case analysis, as the researcher first becomes intimately familiar with each case as a stand-alone entity in order to allow any unique patterns to emerge, before seeking to generalize across cases. The results were then examined in order to identify cross-case patterns, which is a key step in case research (Voss *et al.*, 2002), as it is essential for enhancing the generalizability of any conclusions drawn from the cases.

To summarise, each of the research methods used in this thesis are shown in Figure 8, along with the major outcomes of each approach. For example, it shows that the literature review resulted in a clear picture of the theoretical background which was used to formalize the lean-ERP paradox and helped to develop a research framework for ERP systems in lean production. An exploratory survey and two exploratory case studies were used to give insight into the practical relevance of the research. Then, action research was used to arrive at two of the three major contributions of this work, a framework for ERP support for lean production, and a model for an ERP-based lean implementation process. Finally, case study research was used to investigate specific ERP support functionality for pull production, which resulted in a capability maturity model for ERP support for pull production.

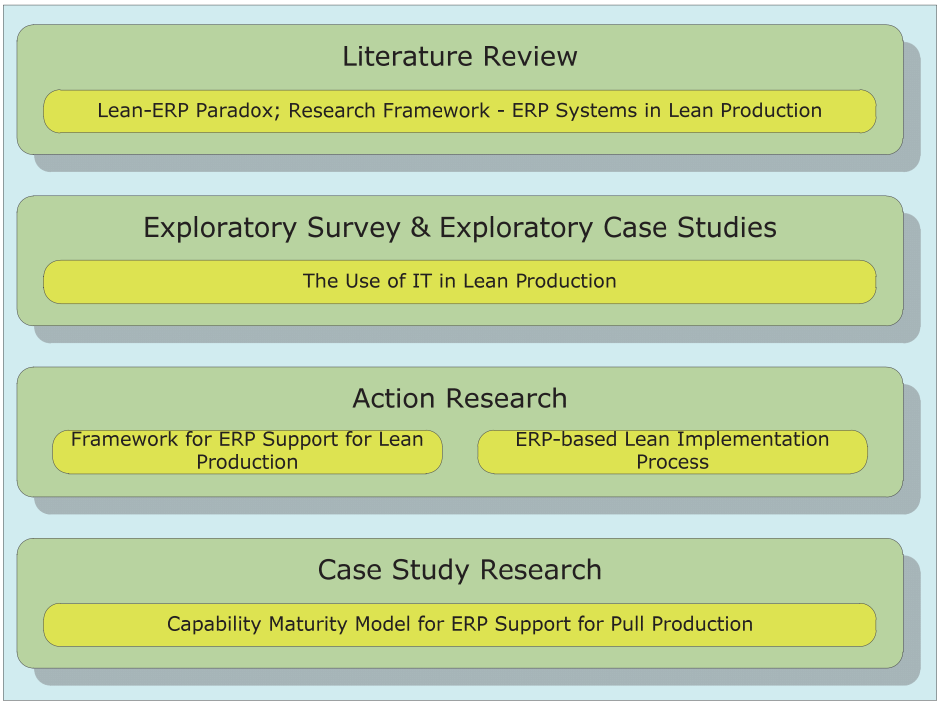

Figure 8: A Summary of the Research Methods and Outcomes of This Work

3.4 *Quality of the research design*

Though Karlsson (2009) discusses the concept of research quality in operations management as four particular requirements: construct validity, internal validity, external validity, and reliability, Halldórsson and Aastrup (2003) state that these quality standards are too much inspired from quantitative / positivistic ideals. As such, they suggest alternative, parallel criteria for the increasingly qualitative nature of logistics research: credibility (internal validity), transferability (external validity), dependability (reliability), and confirmability (construct validity) (see also Guba and Lincoln, 1989). Guba and Lincoln (1994) suggest that the ultimate objective for quality research in operations management is "trustworthiness".

Kidder and Judd (1986) and Yin (2009) also discuss the quality of research design in terms of the same four tests, specifically for case studies. Thus, this section discusses the quality of the overall research design in more detail, and uses the original four validity tests to evaluate the "trustworthiness" of the results. Therefore, the four quality requirements will now be considered in more detail. Table 6 presents a number of tactics that were considered in order to strengthen the quality of the research design.

(Though the tactics in Table 6 are primarily aimed at case study research, they are also considered applicable to an action research approach, which can often be compared to a longitudinal case study).

Table 6: Tactics for Four Design Tests (Yin, 2009)

TEST	Case Study Tactic	Phase of Research
Construct validity	• Use multiple sources of evidence • Establish chain of evidence • Have key informants review draft case study report	• Data collection • Data collection • Composition
Internal validity	• Do pattern matching • Do explanation building • Address rival explanations • Use logic models	• Data analysis • Data analysis • Data analysis • Data analysis
External validity	• Use theory in single-case studies • Use replication logic in multiple-case studies	• Research design • Research design
Reliability	• Use case study protocol • Develop case study database	• Data collection • Data collection

Construct validity

Yin (2009) suggests that the construct validity test is especially challenging in case study research. Table 6 shows three tactics for increasing construct validity when using the case study method. In this research project, multiple sources of evidence were used in order to encourage convergent lines of inquiry. For example, the use of direct observation (e.g. during plant tours) has been applied in order to confirm the results of the interviews. Documentation has also been used to confirm the results where necessary. This type of triangulation ensures that any would-be anecdotal evidence suggested at the interview stage is confirmed and witnessed, thus strengthening the quality of the research results. The strengths and weaknesses of the different sources of evidence used in this investigation are detailed in Table 7. Triangulation allows the realization of the strengths and reduces the impact of the weaknesses associated with each type.

Also supporting construct validity was the chain of evidence that was established through the use of a case study protocol, which also encouraged a standard format for case study descriptions. This allows an external observer (i.e. the reader) to follow the derivation of any evidence from the original research questions through to the final case study conclusions. The draft case study reports were also written up as soon as possible after the case study was carried out, and reviewed by key informants, which also helped to strengthen the construct validity of the case studies conducted as part of this research project.

Table 7: Sources of Evidence, Strengths and Weaknesses (Yin, 2009)

Source of Evidence	Strengths	Weaknesses
Documentation	• Stable – can be reviewed repeatedly • Unobtrusive – not created as a result of the study • Exact – contains exact data • Broad coverage – long span of time, many events, many settings	• Retrievability – can be difficult to find • Biased selectivity – if collection is incomplete • Reporting bias – reflects (unknown) bias of researcher • Access – may be deliberately withheld
Interviews	• Targeted – focuses directly on case study topics • Insightful – provides perceived causal inferences and explanations	• Bias – due to poorly articulated questions • Inaccuracies – due to poor recall • Reflexivity – interviewee gives what the interviewer wants to hear
Direct observations	• Reality – covers events in real time • Contextual – covers context of the case	• Time-consuming • Selectivity – broad coverage difficult without a team of observers • Reflexivity – event may proceed differently because it is being observed • Cost – hours needed by human observers

Internal validity

The test for internal validity is mainly a concern for explanatory case studies (e.g. trying to explain why event x led to event y). If the researcher incorrectly concludes that there is a causal relationship between events x and y without realizing that a third factor z caused event y, then the research design has failed to deal with the threat of internal validity. However, this logic is not so applicable to the case studies conducted as part of this research project where a causal situation is of no concern. Therefore internal validity has not been identified as a priority when making considerations of the quality of this research design.

External validity

External validity tests the problem of generalizability. Are the results generalizable beyond the immediate case study? Yin (2009) suggests that the external validity problem has been a major barrier in doing case studies, yet defends the generalizability of case studies by stating that where survey research relies on statistical generalization, case studies rely on analytical generalization, in which the researcher is attempting to generalize a particular set of results to a broader theory. This theory must then be tested on further case studies, and if the same results occur, they may be accepted as providing strong support for the theory. External validity was strengthened in this research project by using replication logic. By constructing a capability maturity model (CMM) for ERP support for pull production (Chapter 5.5), a common platform was created by which all four case studies could be benchmarked, thus strengthening external validity. The use of multiple cases also strengthens the results by replicating the pattern-matching, thus increasing confidence in the robustness of the theory.

Reliability

The objective of the final test, reliability, is to ensure that the same findings and conclusions would be reached if a later investigator followed the same procedures and conducted the same case study all over again. Thus, the goal of reliability is to minimize errors and bias in a study. A case study protocol and database was developed to strengthen the reliability of the cases studies that were carried out in this investigation. However, bias can be inherent to action research, as the researcher takes the role of active participant rather than a passive observer. For example, Herr and Anderson (2005) state that while bias and subjectivity are natural and acceptable in action research as long as they are critically examined rather than ignored, other mechanisms may need to be put in place to ensure that they do not have a distorting effect on the outcomes. Therefore self-reflexivity was applied during the action research in order to reduce the effects of bias, and to allow me as the researcher to examine my own subjectivity. Involving a group of people in the action research project also reduced the bias in the study, by having the group challenge my opinions and suggestions.

It has already been identified that where positivists prefer validity, constructivists prefer trustworthiness. However, neither of these terms reflects the action-oriented outcomes of action research. Therefore a number of additional quality criteria have been identified for this research method (e.g. Herr and Anderson, 2005). The five validity criteria in Table 8 are directly linked to the five goals of action research.

Table 8: Quality Criteria of Action Research (Herr and Anderson, 2005)

Validity Criteria	Goal of Action Research
Dialogic validity	The generation of new knowledge
Outcome validity	The achievement of action-oriented outcomes
Catalytic validity	The education of both researcher and participants
Democratic validity	Results that are relevant to the local setting
Process validity	A sound and appropriate research methodology

Dialogic validity

In the action research project, dialogic validity was achieved as the research reflected a dialogic nature, involving collaborative dialogue with stakeholders within the client system and other action researchers, which enabled alternative explanations of outcomes from the research.

Outcome validity
Outcome validity was supported through the use of the plan-do-check-act (PDCA) cycle (Deming, 1986) and continuous involvement within the implementation team, which increased the extent to which action occurred, and lead to a resolution of the "problem" that was investigated in the study – an action-oriented outcome.

Catalytic validity
Catalytic validity highlights the transformative potential of action research. During the project, any changes of my understanding and / or the understanding of the participants were duly noted. The stakeholders of the project and I all agree that we learned a lot from the action research process.

Democratic validity
In order to support democratic validity, the research was carried out in collaboration with the majority of stakeholders within the client system (those that have a stake in the investigated problem). Also known as "local" validity, collaboration within the client system ensured relevant and applicable results to the local setting.

Process validity
Finally, process validity was realised by applying triangulation, which was used to guard against viewing events in an over-simplistic way. This was carried out through the use of multiple informants in interviews, and multiple sources of evidence (e.g. interviews; direct observation; documentation).

3.5 Concluding remarks

To summarize, some reflections can be made regarding the appropriateness of the choice of action research as the primary methodology for such a research project, in terms of fulfilling the objectives and answering the research questions to a satisfactory extent. A significant part of this investigation involved active participation in an action research project with a Norwegian SME that was involved with the concurrent implementation of lean practices and a contemporary ERP system. This was a rewarding experience, both in terms of my personal development and for the research project in general. Furthermore, by supplementing the results of the action research project with those of a multiple case study approach, useful insight can be given to future research projects within the field, particularly for PhD projects. Particular emphasis should be made on the similarities between action research and longitudinal case study research, which could yield very similar results dependent upon the role and influences of the researcher.

4 Investigating Lean and ERP in Practice

This chapter describes the empirical part of the research project in more detail. Firstly, a brief overview of the exploratory research is given. Then the action research project is discussed in more detail. Finally, the case study research is described.

4.1 Exploratory survey: Lean and IT

To investigate the relationship between lean and IT, a questionnaire was developed and distributed amongst German and Norwegian manufacturing companies, including the SFI Norman companies. Of the 138 online questionnaires administered, 24 were correctly completed and returned, including 8 from the SFI Norman industrial partners. Though the response rate was relatively low, the results were certainly interesting. For example, contrary to popular belief, the findings suggested that those companies that employ more advanced IT (e.g. ERP systems instead of Excel), demonstrated a greater level of application of lean practices. Also interesting was that of the ten lean practices investigated (workplace organization; continuous improvement; total productive maintenance; total quality management; standardization; quick changeovers; levelled production; pull; supplier relationship management; and customer relationship management), the least applied lean practices were shown to be levelled production and pull. As a result of the survey, it was suggested that research should investigate the role of ERP systems in lean production, particularly in terms of its support functionality. Therefore, lean and ERP were selected as the broad area of study for this PhD project. For a more in depth account of the survey, see Goeldner and Powell (2011).

4.2 Exploratory case studies: Lean and ERP

Having identified the broad area of study, the next step was to identify a plausible research topic. Many doctoral theses begin with one or more exploratory case studies in order to generate a list of research questions that are worth pursuing further (Voss *et al.*, 2002). Therefore, it was decided to carry out two exploratory case studies: the first at the Kongsberg Automotive plant at Raufoss Industrial Park, Norway; and the second at Mark Klimaattekniek in Veendam, Netherlands. A case study protocol was developed, and the case studies were carried out in November 2010 to investigate each of the company's respective applications of lean and ERP. Data collection was carried out primarily through semi-structured interviews that were based around the case study protocol, and documentation and direct observation were also used for triangulation in order to verify facts. Case study descriptions were written-up in November 2010 so as to increase their accuracy, and they were systematically reviewed by the respective contact persons at the companies, strengthening the trustworthiness of the reports. This section gives a short overview of the two exploratory cases.

4.2.1 Kongsberg Automotive

Kongsberg Automotive (KA) is headquartered in Kongsberg, Norway and has 49 facilities in 20 countries. With close to 9000 employees, KA provides system solutions to vehicle makers around the world. Kongsberg Automotive is a global provider of engineering, design, and manufacture for seat comfort, driver and motion control systems, fluid assemblies, and industrial driver interface products. Targeting the automotive, commercial vehicle and industrial markets; its product line includes systems for seat comfort, clutch actuation, cable actuation, gear shifters, transmission control systems, stabilizing rods, couplings, electronic engine controls, speciality hoses, tubes, and fittings. The production facility in Kongsberg has 220 employees and an annual turnover of €67M. KA has been applying lean principles at the Kongsberg plant since 1999 through the deployment of "The KA Way – 14 steps to lean". The company has also been using an ERP system from SAP since 2006, and it was identified that they would like to discover how the ERP system can be used to effectively support lean production control principles (e.g. pull and Kanban).

4.2.2 Mark Klimaattekniek

Mark is Europe's biggest producer of climate control products for the industrial and utility market, and has approximately 100 employees and a turnover of €24M. The Mark product range consists of air heaters, radiant heating, ventilation products, air handling units and pipe bending machines. These product groups can also be separated into gas fired, oil fired, or steam heating products. Mark's lean journey began in 2010 when the company became one of the first small- or medium-sized enterprises (SMEs) in the Netherlands to be part of the Dutch Innovative Productivity Centre (IPC) under the European Regions for Innovative Productivity (ERIP) project. (The main aim of the ERIP project was to develop a lean change methodology specifically for SMEs). The company's lean implementation began with value stream mapping and process mapping. This was followed by 5S, SMED, and the design and implementation of a pull system (currently ongoing). Mark's ERP system, Exact Globe, was installed in 2006. During the interview, it was suggested that the company wanted to know how to use the ERP system to the greatest potential in order to support lean production.

As a result of the two exploratory case studies, it was concluded that many companies, particularly SMEs, would benefit in knowing how ERP systems can be used to effectively support lean production principles. This confirmed the practical relevance, as well as the theoretical relevance, of research into ERP support for lean production.

4.3 The action research project: ERP-enabled Lean Production

Having confirmed the relevance of the research project, and having posed suitable research questions, the next step in the process was to carry out an action research project to investigate ERP support for lean production. This section describes the action research project in detail, which gives useful insight into the role of ERP systems in supporting lean production.

In the research methodology literature, action research projects are often defined as two separate projects. For example, Zuber-Skerritt and Perry (2002) distinguish between the core action research project (carried out at the client system) and the thesis action research project. Whereby the core project is a collaborative venture consisting of cycles of action and reflection in first and second person practice, the thesis project involves the independent work of the researcher both before and after the collaborative core action research project (see Figure 9). Thus, this section seeks to provide an independent evaluation of the action research, making reflections on the action that has been taken and the experiences that I have gained as an action-researcher.

Through direct involvement in the action research project, I have been able to work with the company in order to highlight the potential support functionality of contemporary ERP systems for lean production; we have developed a concept for the company's own "company-specific Production System" (xPS); and I have used my experiences and observations to suggest a process for ERP-based lean implementations. These contributions will be explained over the next few pages.

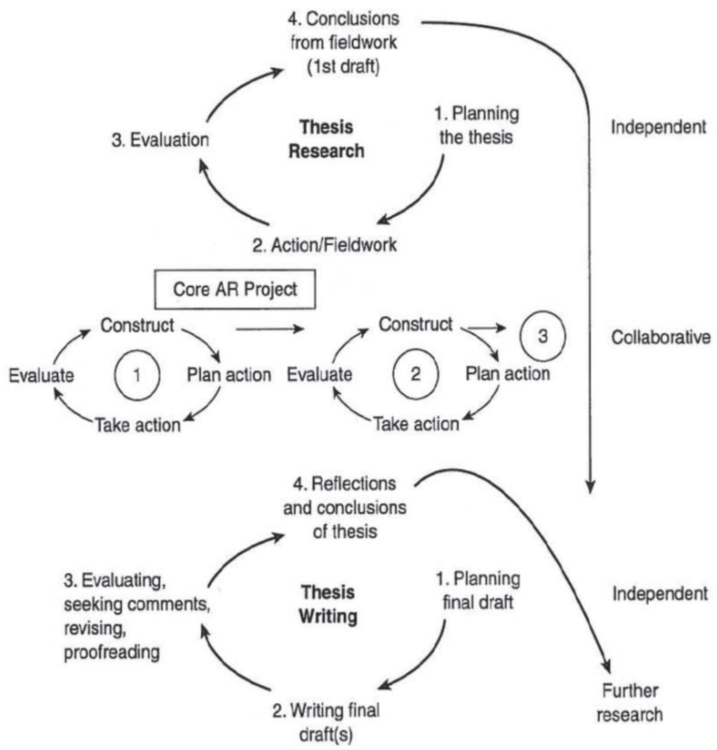

Figure 9: Two Separate Projects: The Core- and Thesis Action Research Projects (adapted from Zuber-Skerritt and Fletcher (2007) in Coghlan and Brannick (2010))

Coughlan and Coghlan (2009) describe the action research methodology as a number of steps, primarily consisting of a design phase and an implementation phase, as shown in Table 9. The phase descriptions given in the table were used to guide the action research process at the client system in this research project, Noca AS.

4.3.1 The client system: Noca AS

Based in Trondheim, Norway, Noca is a manufacturing and service supplier within electronics and electronics development. Established in 1986, Noca delivers development, prototypes, batch production, and assembly for customers within innovation and entrepreneurs in high-tech industries. Noca has 50 employees and an annual turnover of €11.5m (2010). The company recently began applying lean practices to their operations, having started with value stream mapping (VSM) in late-2009, followed by 5S in 2010. Also in 2010, Noca management decided that the existing information system could no longer support efficient facility operation and proposed that it be replaced with a contemporary ERP system. After critically reviewing several available options, which included Microsoft Dynamics Navision amongst others, Noca selected the Jeeves Universal ERP system.

Table 9: The main phases of action research *(adapted from Coughlan and Coghlan, 2009)*

Design Phase	
Framing the Issue	Coghlan and Brannick (2005) suggest that framing and selecting an issue is a complex process.
Determining the Scope	The question of who selects the scope is critical, as in any research project. In a growing number of settings, action research is constructed as collaborative research between an organization and the researcher (Adler *et al.*, 2004)
Gaining Access	Two types of access are relevant : primary and secondary (Coughlan and Coghlan, 2009). Primary access refers to the ability to get into the organization. Secondary access refers to access to specific areas of the organization or specific levels of information and activity.
Negotiating an Appropriate Role	Most commonly, action researchers are outside agents who act as facilitators of the action. In this role, the action researcher is acting as an external helper to the client system, working in a facilitative manner to help the clients inquire into their own issues and create and implement solutions (Schein, 1995).
Implementation Phase	
Pre-step: Context and Purpose	This pre-step ensures understanding of the context of the project, and is characterised by two questions: what is the rationale for action? And what is the rationale for research?
Diagnosing/Constructing	Diagnosing involves naming what the issues are, and should be done carefully and thoroughly through engaging relevant others within the client system. Coghlan and Brannick (2010) opt to rename this phase "constructing" rather than "diagnosing", and reframe the step as a dialogic activity in which the stakeholders of the project engage in constructing what the issues are as a working theme, on the basis of which action will be planned and taken.
Planning Action	Key questions to be addressed here are: What needs to change? In what parts of the organisation? What types of change are needed? Whose support is needed? How can commitment be built? How can resistance be managed? (Beckhard and Harris, 1987).
Taking Action	The client implements the planned action, of which may extend over one or more design iterations, taking some weeks or months.
Evaluating Action	Evaluation involves reflecting on the outcomes of the action, both intended and unintended, and a review of the process in order that the next cycle may benefit from the experiences gained.

Figure 10 illustrates Noca's business strategy, and can be used to explain how the operationalization of lean production principles and the new ERP system will deliver benefits that align and integrate with the business goals, as well as the company's vision, mission and values.

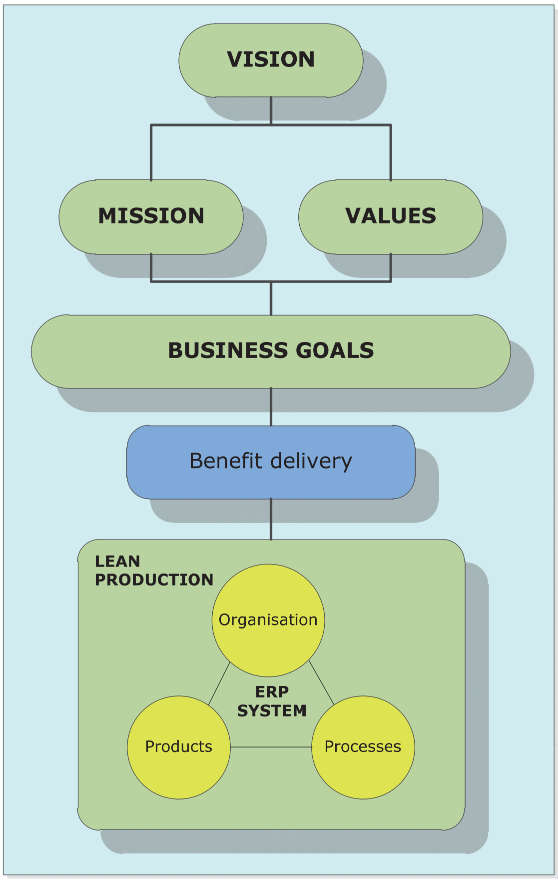

Figure 10: Noca's Business Strategy

Noca have defined a number of business goals which are aligned with its vision, mission and values. The lower part of Figure 10 adopts a systems view of lean production (Loureiro *et al.*, 2004), and illustrates how effective adoption of lean production will influence the entire system, i.e. the organisation, its products, and its processes. It also shows where ERP fits within the entire system, and how the ERP system will offer support to each of the three elements in order to deliver business benefits that will help to realise the business goals. Thus, by adopting a systems perspective, it is clear to see the roles of both lean and ERP in achieving the aims and objectives of the business strategy. For example, even if the new ERP system is implemented, without a product that creates value for the customer; the lean value-adding processes that deliver this product; and the lean organisation to support it; the new system will potentially fail to deliver the expected benefits. Likewise, even if Noca succeed in deploying a selection of lean practices, the maximum potential of the benefits cannot be realised without the integrated support of the ERP system.

Therefore, in October 2010, I was personally contacted by Noca management and informed that the company would like to combine the ERP implementation project with the application of lean production practices. I was subsequently invited to join the implementation process, with an active role in the implementation project team – responsible for lean production. The ERP implementation process at Noca was to consist of three phases: a design and analyse phase; an implementation phase; and an improvement phase. I have followed the entire process thus far, and have examined the first two phases in order to develop an answer to the second research question:

RQ2: How can contemporary ERP systems be used to support lean production?

Corresponding to the two main phases of action research (design phase and implementation phase) as identified by Coughlan and Coghlan (2009), the action research project was first designed as follows:

- The main issue was framed (ERP support for lean production)
- The scope of the study was determined (manufacturing and support operations at the client system)
- The researcher gained access to the client system (both to the organization and to specific levels of such)
- The researcher negotiated an appropriate role (the researcher was responsible for lean-related issues within the action research project).

As for the implementation phases of the action research, the action research project was subsequently defined and executed as three parts: ERP system design and analysis; development of Noca Production System; and Deployment of ERP-enabled lean production. The three implementation phases will now be described in more detail.

4.3.2 ERP system design and analysis

In January 2011, I joined the ERP project team on-site at Noca for the design and analysis phase of the ERP implementation project. This phase included three weeks of intensive meetings where the out-of-the-box Jeeves Universal product was considered against the Noca requirements specification. The main operational areas considered during this time were:

- Finance
- Purchasing
- Customer relationship management
- Orders
- Inventories
- Production planning
- Quality assurance
- Product data management
- Product calculations
- Project management and industrialisation

Throughout the meetings, I was present in order to give advice and guidance regarding possible interactions with the lean implementation. Any discussions around the subject of lean were recorded in a journal, and were later compared to any findings in the scientific literature in order develop a framework for ERP support for lean production, with both theoretical and practical insights (see Powell *et al.*, 2011).

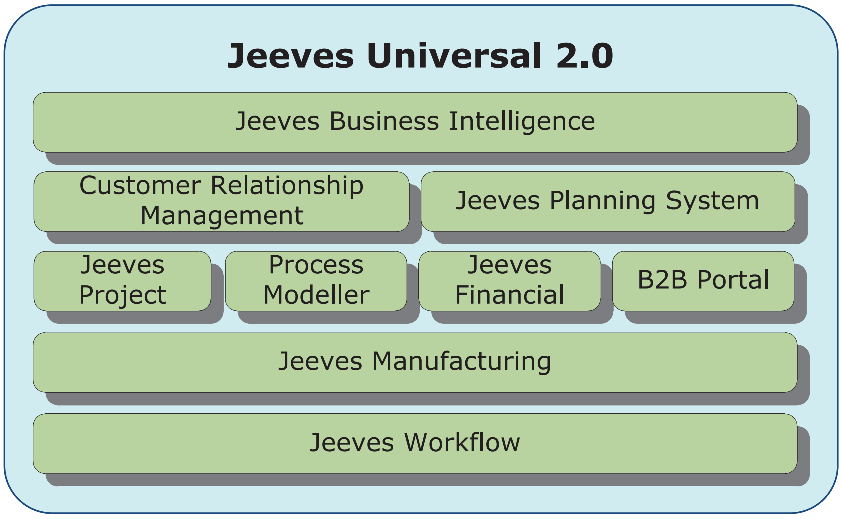

Figure 11: Noca's Jeeves Universal 2.0 System

The selected ERP system and modules are shown in Figure 11, and a comparison with the ERP capabilities identified by Borell and Hedman (2000) is made in Table 10.

Table 10: Capabilities of the Noca / Jeeves ERP System

ERP Capabilities	Noca / Jeeves	ERP Capabilities	Noca / Jeeves
Human resources	X	Master data management	X
Financial accounting	X	Project management	X
Sales and distribution	X	Workflow	X
Materials management	X	Data warehouse	X
Procurement	X	Supply chain management	
Production planning and control	X	Customer relationship management	X
Quality management		Advanced planner	X
Plant maintenance		E-commerce (B2B & B2C)	X

By comparing the Noca configuration of the Jeeves Universal ERP system with the ERP capabilities identified by Borell and Hedman (2000), it can be seen that the selected ERP system is quite a comprehensive system, providing a great deal of support functionality relevant for the lean practitioner.

4.3.3 Development of the Noca Production System (NPS)

Lean is often described by reference to the Toyota Production System (TPS). As such, many companies have developed and deployed their own "company specific" production systems, triggered by the success of TPS (Omar *et al.*, 2011). As most of these "company specific" production systems were constructed based on the TPS / lean practices, ERP systems seem to have been neglected when it comes to having a central supporting role to the success of the business strategy. Therefore, the second phase of the action research project was carried out with the aim of developing a concept for the

Noca Production System (NPS), which would also base itself around the fundamental lean practices. It was also suggested that the NPS concept should incorporate ERP as a central element.

In May 2011, a presentation of "company specific" production systems was given to the Noca team, including the fundamentals of the Toyota Production System. As part of this presentation, a draft concept for NPS was suggested to the Noca team (Figure 12). Emphasis was placed on the new ERP system, which as an integral part of the systems "triad" identified in Figure 10 was considered as a key enabler of Noca's business goals.

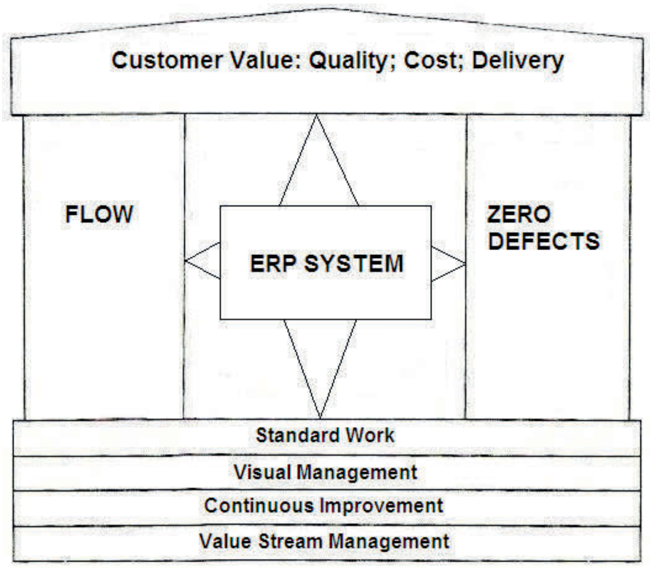

Figure 12: Draft NPS Concept

Soon after the introduction to "company specific" production systems, Noca too had developed its own version of a Noca Production System concept, shown in Figure 13, the "second evolution of the NPS concept". However, at this stage, no reference was made to the ERP system.

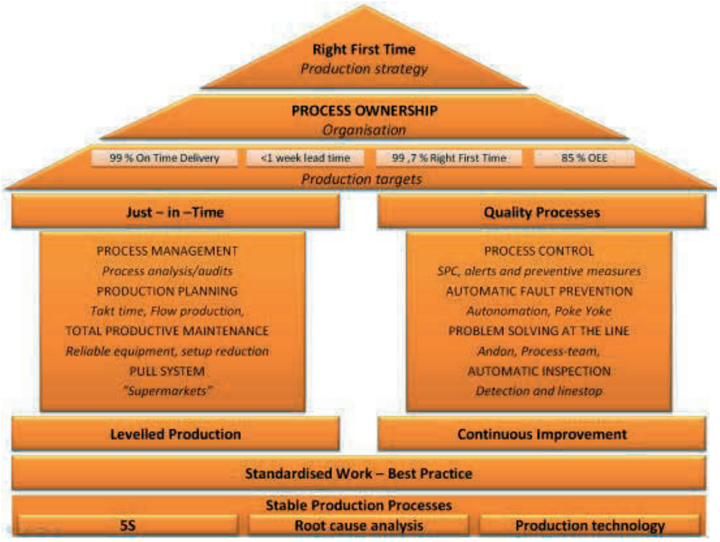

Figure 13: NPS Concept – Second Evolution

At this point, the true value of action research came into play, where as an active participant within the client system, I was able to discuss the NPS concept with the Noca team, with particular reference to the new ERP system. After much reflection, it was decided that the ERP system would be placed as a fundamental part of the NPS concept, as shown in the third version in Figure 14.

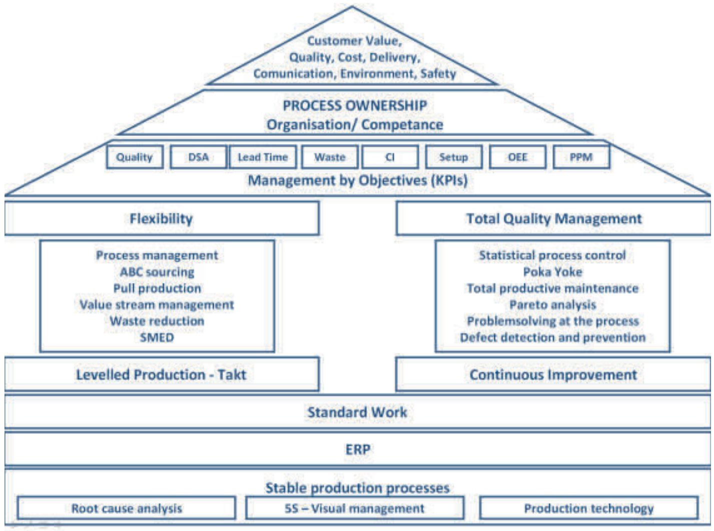

Figure 14: NPS Concept – Third Evolution

However, the process did not end there, and in December 2011, the fourth and final NPS concept was introduced to the Noca workforce (Figure 15).

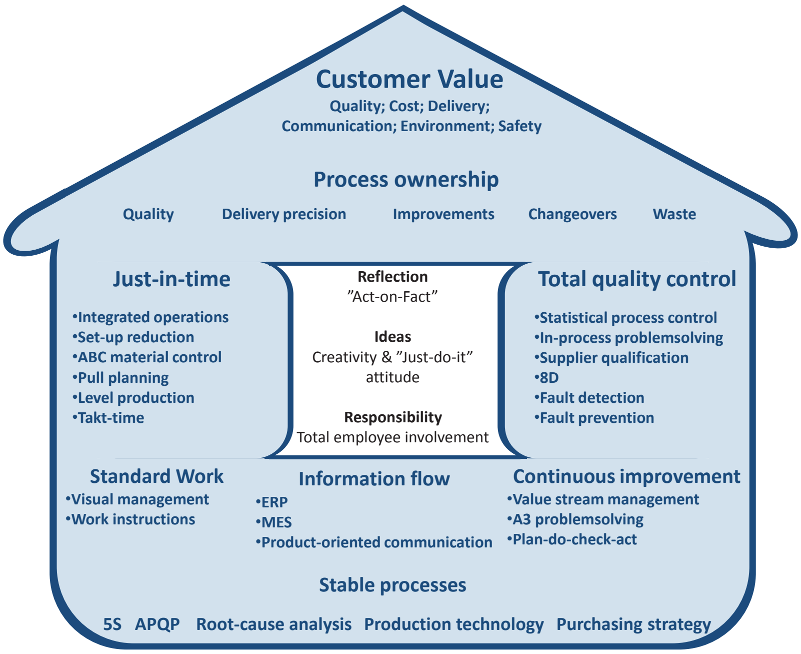

Figure 15: Final NPS Concept

4.3.4 Deployment of ERP-enabled lean production

Having developed the NPS concept, the next stage was to realise it in practice and deploy what we termed "ERP-enabled lean production". This phase of the action research project was all about change management, which required the correct balance amongst the organisation, processes, and system. Using a weekly "Noca lunch" and short educational workshops at the "Noca school" as the platform to introduce NPS to the employees, Noca was able to align its workers to a common vision of "*being the preferred supplier of electronic and electrical products in the Scandinavian industrial marketplace*". An implementation plan was created so that the basic principles of NPS could be learned first and then introduced in practice in an effective manner. Organizational learning such as this proved to be an effective way of managing such a complex change process.

Customer value

As the first lean principle (Womack and Jones, 1996) and most fundamental tenet of lean production, customer value is identified as the main goal of the NPS. Noca will strive to achieve the best quality, shortest lead time, and lowest cost in order to provide value to its customers. Excellence in communication is also identified as an objective of NPS, as well as corporate social responsibility through taking environmental, health and safety measures.

Reflection, Ideas, Responsibility

At the core of the NPS concept are the basic principles that will support the implementation and sustainability of NPS in practice – Reflection, Ideas, and Responsibility.

Noca employees are encouraged to "act-on-fact". Decisions should be made based on hard facts rather than assumptions. Employees' ideas are central to the creativity required for establishing a successful continuous improvement culture, where a "just-do-it" attitude is also favoured. Responsibility is the third and final core principle of NPS, where the involvement of everyone is fundamental.

Stable processes

NPS, like TPS (e.g. Liker, 2004) is built on the foundation of stable processes. Of particular relevance here are tools and methods such as 5S (Hirano, 1995); root-cause analysis, and an effective purchasing strategy. Reliable machines and processes (production technology) are also important for the success of NPS, as well as the basic product quality considerations that will instil a zero defect mind set (e.g. APQP).

Standard work

In order to maintain stable processes, NPS aims to apply standard work through the use of standard operating procedures and work instructions. In following with the basics of 5S, procedures and work instructions will be maintained through the application of visual management.

Continuous improvement

The basic tools for continuous improvement are also a fundamental part of NPS. Value stream management will be used to identify and carry out systematic improvements through the use of the plan-do-check (PDCA) cycle (Deming, 1986), and A3 problem solving will be used to support root-cause analysis in a visual manner.

Information flow

This part of the NPS concept is where the real essence of the ERP support functionality comes into play. Having identified customer value and excellence in communication as two of the main objectives of NPS, the ERP system can be used to automate some of the necessary non-value added activities (Powell, 2011), as well as provide channels for effective communication within the company and externally amongst supply chain partners (Koh *et al.*, 2008). Thus, the new ERP system is a key enabler of improved information flow.

Just-in-time & Total quality control

For the materialization of the TPS concept, Toyota attached special importance to just-in-time (JIT) production as well as "Jidoka", a term that means "to make equipment or operations stop whenever an abnormal or defective condition arises" (Sugimori *et al.*, 1977). Therefore, Noca also choose to emphasize these two aspects, and make JIT and "Total quality control" the two pillars of the NPS concept. On one hand, Noca will aim for JIT production through the application of such tools as the single minute exchange of dies (SMED) methodology (Shingo, 1985) for set-up reduction, Takt-time and Heijunka (Ohno, 1988) for levelled production; and pull-oriented production planning for small batches on the surface-mount technology machines. Additionally, Noca will apply quality management approaches such as statistical process control (SPC), supplier qualification, and 8 disciplines for problem solving (8D). By systematically integrating and synchronising the production operations, and by using ABC inventory classification for material control, Noca can achieve more streamlined material flow; which, when combined with improved quality performance, will lead to even greater customer satisfaction.

Because pull production in the traditional sense of one-piece flow and the deployment of the Kanban system have often been shown to be inapplicable in make-to-order, low volume, high variety environments, Noca are currently considering the application of a proven alternative in the form of quick response manufacturing (QRM) and POLCA (Suri, 1998; Suri, 2003). In the meantime, by applying value stream management and reorganizing the shop floor, Noca are concentrating efforts to better realise synchronized "flow" production.

Process ownership

The final element of the NPS concept is process ownership. Noca has identified a set of key performance indicators (KPIs), which through visual management and empowered workers will help to achieve buy-in from employees and encourage process ownership. Examples of the KPIs are right first time; delivery schedule adherence; number of improvements realized; and critical (bottleneck) machine setup time.

So far, the deployment of ERP-enabled lean production has primarily involved the implementation of Jeeves Universal ERP which has facilitated structured and improved information flow. Following the initial 5S implementation in 2009, a system for controlling workplace organisation and ensuring sustainability has also been executed. This has included the roll-out of 5S to the office areas. During the project, it was noticed that the ERP implementation process itself acted as a catalyst for the application of many of the lean practices, particularly those based around establishing synchronized material flow, the focus on quality improvement, and the creation of a continuous improvement culture. For more information about the implementation of ERP and lean production practices at Noca, the reader is directed to Paper six, which is summarized in Chapter 5.6.

4.3.5 Concluding remarks

The core action research project, which consisted of three parts: ERP system design and analysis; development of Noca Production System (NPS); and deployment of ERP-enabled lean; gave valuable insights into the support functionality of ERP systems for lean production. Also, in terms of the thesis action research project, it can be concluded that the action research process was a very useful and rewarding method for addressing the research question.

Having negotiated an appropriate role within the client system, I was able to influence and actively participate in the change process, simultaneously bringing about improvements at the client system and making a contribution to theory. Action research can often be compared to longitudinal field study research, which also observes processes of change and development in organizations over a period of time. It is however the role of the researcher that makes the vital difference between the two methods, as the involvement of the researcher is an important aspect of action research. For example Järvinen (2007) states that action research should include the researcher as an active participant rather than a passive observer. Comparing longitudinal field studies with clinical research, Karlsson (2009) suggests that a clinical researcher will always affect the studied organization, since it is also in the nature of the methodology. It can be concluded that all forms of inquiry into organizations entail intervention, as asking questions often entices people to think about things they possibly may not have thought of before. So long as the researcher is aware of what he is doing in the organisation and how it is being received, irresponsible interventions can be avoided (Czarniawska-Joerges, 1992).

Though the cyclic nature of the action research process was not so obvious early on in this example of action research, Hult and Lennung (1980) suggest that whilst the cyclical process is characteristic of some action research forms, it cannot be justified as a critical defining character of all action-based research. For example, some action-based research forms may assume that the first outcome will usually be satisfactory. With the intent of an explorative enquiry in order to build theory regarding ERP support for lean production, the outcome of the design and analysis phase is considered satisfactory in this respect. However, the development of the Noca Production System phase 2 was a very iterative process, consisting of several improvement cycles. This is shown in Figures 12-15.

During the start of the project, there was concern of how to address the combined difficulties of implementing both ERP and lean concurrently – each can be remarkably difficult in themselves. At one point, the lean initiative was even identified as a risk to the ERP project. However, it was quickly noted that a well-planned ERP implementation process can act as a catalyst for the application of lean practices, particular with reference to business process reengineering.

Though efforts were not taken to specifically quantify the effects of the action research project, since the project began Noca have seen a notable improvement in its key performance indicators (KPIs). For example, production lead times have been reduced by 65%, and inventory accuracy has improved by 15%. There has also been an evident improvement in quality levels.

Finally, Gummesson (2000) lays out ten characteristics of action research. Therefore, some aspects of the quality of this action research can be assessed by comparing to these characteristics. For example, Gummesson states that the researcher should take action in the client system through direct involvement in the project team. This was displayed over a twelve month period at Noca, where as an action researcher, I played an active role in the project team. The research must also involve two goals: to solve a problem and to contribute to science. This project has solved a problem and contributed to science by demonstrating how a contemporary ERP system can be used to support lean production practices. Gummesson suggests that the research project should be interactive, and should aim at developing holistic understanding. This was achieved through the collaborative development of a generalized framework for ERP support for lean production. This research has fundamentally been about change within the client system, where I have demonstrated an understanding of the ethical framework. The research has also included several types of data gathering methods, including interview, direct observation, and documentation. Through previous involvement with the client system, I already had a breadth of pre-understanding of the corporate environment, and the research was conducted in real-time. Finally, the research identifies its own quality criteria, as described in Chapter 3.4.

4.4 Multiple case study research: ERP support for pull production

The final part of the empirical work involved examining four case studies in the Northern part of the Netherlands. This work was carried out in order to evaluate the various levels of ERP support for pull production practices. As a result of the case studies, we were able to develop a capability maturity model (CMM) for ERP support for pull production (see Powell *et al.*, 2012b).

4.4.1 Case study one

Preferring to remain anonymous, the first of the case studies is an agricultural machinery manufacturer with 100 employees and an annual turnover of €20m. The company implemented the Microsoft Navision ERP system in 2001 (with an upgrade to current version in 2010), and implemented its assemble-to-order (ATO) pull system (lean assembly-line with production- and supplier Kanban) in 2008. When the lean line was implemented, the company stopped using the ERP system for planning and controlling production and inventory management tasks. Instead, it started using Kanban for controlling the supply of materials. This resulted in a number of issues, particular with the sourcing of long lead time items. For example, Kanban items were classified as Kanban-make (authorisation to make internally) or Kanban-buy (purchased items). However, there were often found to be stock-outs on the Kanban-buy items with long-lead times, due to an ineffective material management process. Therefore, since upgrading to the current version of Navision, the company has now re-parameterized the ERP system to procure long lead time items based on forecast, whilst short lead time items are procured (pulled) based on actual requirements (sales orders). The company also faces seasonal demand patterns, as it produces six types of harvesting machine for the summer season, and two types of planting machine for the spring (or winter) season. The product seasonality has resulted in a number of challenges with regard to pull production (particular with demand smoothing). However, by applying production levelling and through installing a second assembly line, they are currently producing machines at a steady rate of two per day, with the capability of at least doubling this output. A final problem experienced at the company was that the ERP system lacked the functionality of explicitly supporting the Kanban system. A modification has however been made which allows product-specific Kanban cards to be printed from the ERP system.

4.4.2 Case study two – Bosch Hinges

The second case study is a manufacturer of bespoke hinges with 30 employees and an annual turnover of €4m. The company implemented the Exact Globe ERP system in 2003 (with an upgrade to current version in 2005), and implemented a make-to-order / engineer-to-order (MTO / ETO) pull system (POLCA) in 2007. Due to the recent growth of the company, the POLCA system which first consisted of eight cells, is now in the process of being increased to twelve cells. The main issue encountered at this company is that the ERP system in all intents and purposes is just a simple accounting system, and as a result is very inflexible. An example of the inflexibility is that the company has had to invest in a custom solution (Bosch information system) for customer relationship management (CRM), as no functionality was offered to manage request for quotation (RFQ) through to sales order receipt. A complaint management system was also developed, as this task is not supported in the current Exact Globe system. During the transition to POLCA, the company made a strategic choice to invest in more machines so as to avoid the requirement of bottleneck control. A POLCA work cell is therefore defined as a cluster of machines and operators (not just one of each), thus a structural bottleneck is not encountered. In order to support this, tools in each cell are colour-coded to that specific cell, also reducing the chances of creating bottlenecks. This is in fact an area where the ERP system was modified to offer some support functionality, by illustrating a colour-coded work sequence (routing through cells) on the production order information. (The POLCA cards will be attached to the production order information and together with the material they will flow throughout several manufacturing operations, similar to the behaviour of a Kanban card).

In order to visualise production requirements and offer decision support functionality to shop floor personnel, an ERP bolt-on “production and POLCA observation system” (PROPOS) was created in 2011. This is another custom-developed solution, and can be considered as a type of manufacturing execution system (MES) that offers touch-screen functionality and which takes production order and routing information from the ERP system. PROPOS calculates planned start time based on due dates in the production and sales orders in the ERP system, and suggests a logical sequence for the processing of orders. It is possible for the production planner to override the system in order to adjust the sequence or block jobs, for example.

Bosch Hinges reported that lead times have been reduced by more than 60% and the quotation process for engineer-to-order products can now be completed within just 24 hours for 80% of the orders. The lead time reduction is a result of the POLCA system, and in the near future a further reduction will be possible due to the recent investments in the ERP bolt-on system PROPOS. The quotation process change is due both to the investment in IT support and the use of pull practices within the order management processes in the office.

4.4.3 Case study three – Variass Electronics
Case study three is a system supplier of integrated electronic and mechatronic equipment for industrial, medical and military applications. The company has 120 employees and an annual turnover of €20m. The company implemented SAP in 2006, and began implementing the assemble-to-order (ATO) POLCA pull system in 2011. The company chose to implement POLCA with an aim to improve flexibility by reducing throughput time, improve workload balancing, and to improve communication of the work order status and progress on the shop floor.

However, a major problem experienced at the company is that the number of POLCA cards in the system is difficult to ascertain. This is partly because it is difficult to define a standard time unit for each card. For example, jobs can vary from one hour to sixteen hours, but POLCA cards can represent any duration of work content up to a maximum time of eight hours, as extra operators are added to the cell when required thereafter.

Production in the POLCA system starts based on a production authorization list, which is directly linked to the planned start dates in SAP. Originally this start list was provided to all cells, but now it is only released at the first cell (production preparation). Other operations function on a first in, first out basis. As the company has only recently started to implement the POLCA pull system, a number of enquiries have been made to the SAP consultants mYuice, with regard to the support functionality offered. The results have been surprisingly pleasing. For example, the company requested to have the colour-coded cells identified on the production routing (similar to that at Bosch Hinges). mYuice has confirmed that this is possible and has made the modifications to the ERP system to allow this functionality. The ERP system has also been modified to allow for orderless rate-based planning, i.e., to calculate a number of transfer batches to be processed within an entire batch, based on the maximum volume/workload at the constraining cell (hand soldering), and the size of the transfer trolleys used on the shop floor.

Variass has reported a realised improvement of 25% on work in progress and shop floor lead time reduction after only 2 months of using POLCA. Unlike Bosch Hinges, the company has not invested in additional IT support, but instead focuses on making employees directly responsible for problem solving, worker reallocation, and material management.

4.4.4 Case study four – Altrex

The fourth and final case study in this investigation is a producer of step ladders and scaffolding equipment that has 150 employees and reports an annual turnover of €42m. The company has used an Infor ERP system (LN6 FP5) since 2008, and implemented a make-to-stock (MTS) pull system (with production- and supplier Kanban) in 2007.

The management team at the company suggests that ERP and lean are not yet an optimal combination. For example, the ERP system is not capable of effective demand smoothing due to seasonal demand patterns. Therefore, the company must use periods of free capacity to build up stock for promotional periods and seasonal demand as a manual countermeasure. This is organized using the rough cut capacity planning function of the ERP system. Also, in order to control and maintain the Kanban system, the company had to create a host of functionality outside of the central ERP-system, mainly as a bolt-on, Microsoft Access solution. This includes the creation of production priority reports; Kanban calculations (through a quarterly Kanban evaluation schema); seasonal stock building; stock turnover calculations; creating and printing Kanban cards; and the analysis of runners, repeaters, and strangers. Some functionality is however still missing, including unique Kanban identification for traceability and control; barcode scanning functionality; and "what-if" simulations (showing impact on working-capital, service level, and warehouse space, for example). A project is under way in order to develop a barcode solution to solve the traceability issue.

4.4.5 Concluding remarks

All in all, the cases that were selected in this investigation proved very helpful in addressing the research questions. The company contacts had a lot of knowledge that they were willing to share, and the different levels of integration between pull systems and ERP systems across the companies was distinctly useful in the development of the

CMM (see Chapter 5.5). Though a summary of all of the companies investigated as part of this research project is given in Table 11, the reader is directed to Papers 4-6 for a comprehensive overview of the action research and case studies.

Table 11: Summary of the companies investigated

	Kongsberg Automotive	Mark	Noca	Case study one	Bosch Hinges	Variass	Altrex
Industry:	Automotive	Mechanical	Electronics	Mechanical	Mechanical	Electronics	Mechanical
Major product:	Couplings	Climate control	Traffic cameras	Potato harvesters	Bespoke hinges	Climate control devices	Step ladders
Number of employees:	220	100	50	100	30	120	150
Annual turnover:	€67M	€24M	€12M	€20M	€4M	€20M	€42M
ERP system (Implementation year):	SAP (2006)	Exact Globe (2006)	Jeeves (2011)	Microsoft Navision (2001)	Exact Globe (2005)	SAP (2006)	Infor (2008)
Pull system (Implementation year):	-	-	-	Kanban (2009)	Polca (2007)	Polca (2011)	Kanban (2007)
Primary CODP:	MTS	ATO	ATO	ATO	ETO / MTO	ATO	MTS
Observations:	No pull system deployed. Kanban had previously been used in machining but did not work effectively. Vendor managed inventory (VMI) for O rings, and the external supplier visits everyday to inspect inventory level. If a replenishment order is required, a yellow flag is visible, and the supplier replenishes using a predetermined (fixed) order quantity.	No pull system deployed. Mark do not use ERP for production planning and control, Excel is preferred for planning, whilst handwritten schedules are used on the shopfloor.	No pull system deployed. Good knowledge and education strategy for basic lean foundations (5S; standard work; etc.). Development of company-specific Production System (NPS).	ERP functionality for printing kanban cards. Kanban cards are used between the assembly line and warehouse for replenishment of component parts.	ERP functionality for printing kanban cards. Feedback between pull system and ERP system. ERP system monitors performance of pull system. ERP system supports e-heijunka.	ERP functionality for printing kanban cards.	ERP functionality for printing kanban cards. Feedback between pull system and ERP system. ERP functionality for calculating kanban requirements & takt times.
CMM Level:	1	1	1	2	3 / 4	2	3

5 Results and Summary of the Papers

This research project makes contributions to theory and also has implications for practice. Although the findings and solutions may be specific to the particular cases, it is expected that the findings will be of interest to other companies that hold the same or similar positions in industry. There will also be general characteristics of the case companies that are likely to be applicable to others. In this section I evaluate the research papers that can be found in Part II of this thesis in terms of the contributions, and describe the results of the research project. A summary of the research papers and outcomes is made in Table 12:

Table 12: Summary of research papers and outcomes

Paper Number & Title:	Paper Type:	Research Method:	Research Questions	Outcome / Result:
1) The use of information technology in lean production: A transnational survey.	Conference paper	Survey	**RQ_i:** *What are the most commonly utilized IT solutions for manufacturing planning and control?* **RQ_{ii}:** *To what extent are lean practices adopted in manufacturing companies?* **RQ_{iii}:** *What are the influences of the most commonly utilized IT solutions on the adoption of lean practices?*	**RQ1**: *Are lean and ERP genuinely contradictory in nature?*
2) Lean production vs ERP systems: An ICT paradox?	Journal article	Literature review	**RQ1**: *Are lean and ERP genuinely contradictory in nature?*	**Lean-ERP Paradox**
3) ERP Systems in Lean Production: New insights from a review of Lean and ERP literature.	Journal article	Literature review	**RQ:** N/A	**Research framework for ERP systems in lean production** **RQ2**: *How can contemporary ERP systems be used to support lean production principles?*
4) ERP support for lean production.	Conference paper	Action research	**RQ2**: *How can contemporary ERP systems be used to support lean production principles?*	**Framework for ERP support for lean** **RQ3**: *How can contemporary ERP systems be used to support pull production practices in SMEs?* **RQ4**: *How can existing methodologies for the implementation of lean production and ERP systems be combined to develop a single "best-practice" process for ERP-based lean implementations?*
5) Lean and ERP in SMEs: Support for pull production.	Journal article	Multiple case study (4 cases)	**RQ3**: *How can contemporary ERP systems be used to support pull production practices in SMEs?*	**Capability maturity model (CMM) for ERP support for pull production**
6) The concurrent application of lean production and ERP: towards an ERP-based lean implementation process.	Journal article	Action research	**RQ4**: *How can existing methodologies for the implementation of lean production and ERP systems be combined to develop a single "best-practice" process for ERP-based lean implementations?*	**ERP-based lean implementation process**

Figure 16 shows the "red thread" through the collection of articles.

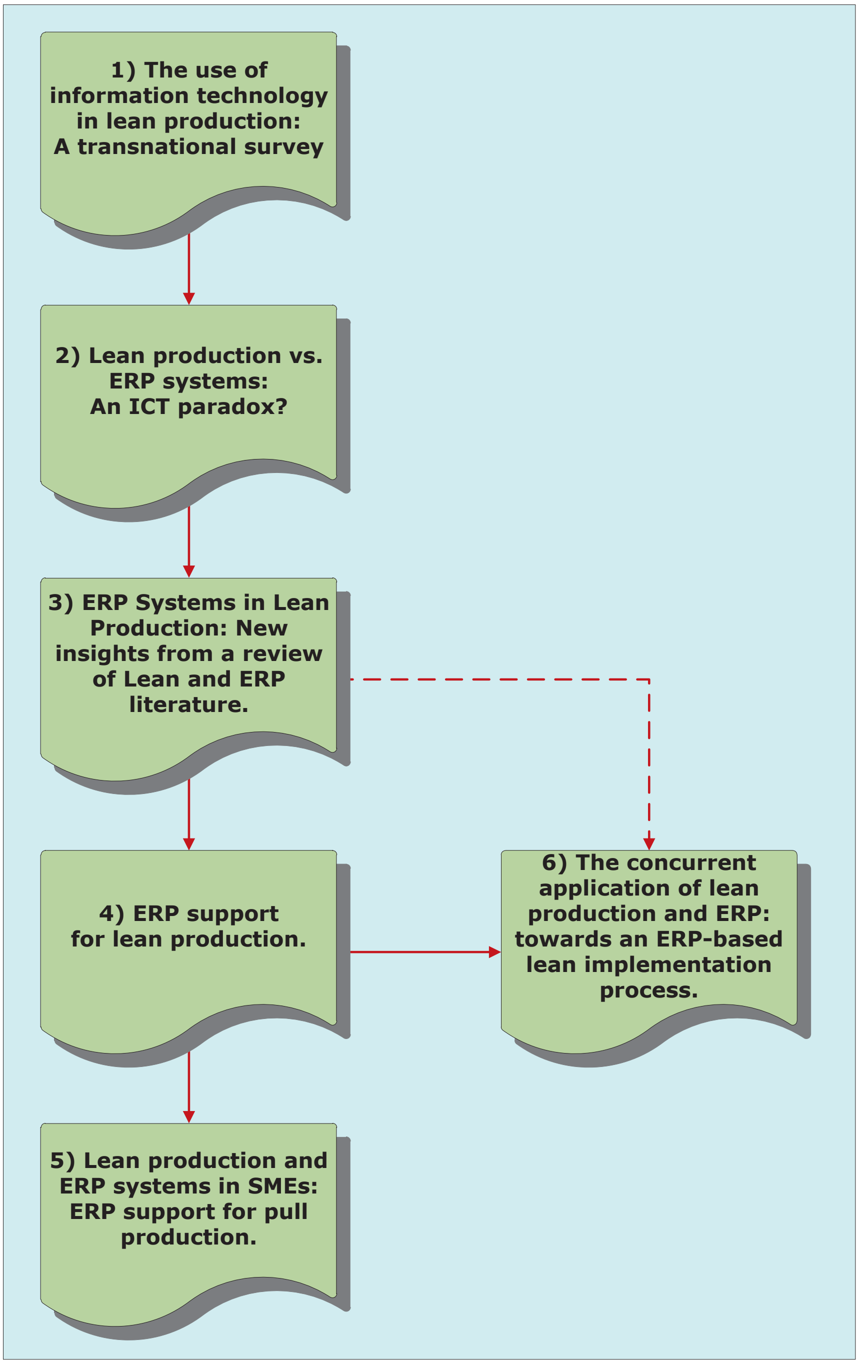

Figure 16: "Red Thread" Through the Collection of Articles

Figure 16 clearly shows how the project has developed. Paper one addresses three exploratory research questions (see RQ_{i-iii} in Table 12) and presents the results of an exploratory survey that was used to identify interesting topics within a broad area of study – Lean production and Information Technology (two exploratory case studies were also conducted to further investigate the relationships between lean and IT, though these are not included in any of the research papers). The results of the survey and the case studies were used to define the primary research topic – lean production and ERP systems.

Paper two was then used to set the context for the investigation, by investigating the research question that was formulated as a result of Paper one:

RQ1: Are lean and ERP genuinely contradictory in nature?

Following on from Paper two, Paper three set out to uncover pertinent factors and useful insights into the role and implications of ERP within lean production. The second research question was formulated as a result of Paper three:

RQ2: How can contemporary ERP systems be used to support lean production?

In an attempt to answer research question two, a framework for ERP support for lean production was developed in Paper four. During this stage of the work, the research also took a greater focus on pull production, and a third research question was formulated:

RQ3: How can contemporary ERP systems be used to support pull production practices in SMEs?

Therefore, paper five documents multiple case studies that were carried out to address this third research question, and presents a capability maturity model (CMM) for ERP support for pull production.

Finally, from the experiences encountered during the action research project, it was suggested that a process for ERP-based lean implementations could be developed. Therefore, a fourth and final research question was posed:

RQ4: How can existing methodologies for the implementation of lean production and ERP systems be combined to develop a single "best practice" process for ERP-based lean implementations?

By systematically working through these research questions, a number of contributions have been made as a result of this research project. Each of the research papers and the respective findings will now be summarised, before the contributions are discussed in more detail.

5.1 The use of IT in lean production

Purpose and overview – The purpose of this paper is to investigate modern applications of information technology and lean production in manufacturing companies. We evaluate whether there are any relationships between the use of IT and the deployment of specific lean practices. By using an online questionnaire, we conduct an exploratory survey of Norwegian and German manufacturing companies. We explore the types of IT used for manufacturing planning and control, including Microsoft Excel, MRP, MRP II, ERP, and APS. As lean aims for simplification, we also include pen and paper as the most basic type of IT. The lean practices that we consider are:

- Workplace organization
- Continuous improvement
- Total productive maintenance
- Total quality management
- Standardization
- Quick changeovers
- Levelled production
- Pull
- Supplier relationship management
- Customer relationship management

Each of the responding companies are rated into one of three classes in terms of the extent of its adoption of lean practices – best-in-class; industry average; and below industry average. Then, by examining each company's use of IT, we assess if there are any influences between the two.

Main findings – We show that while the companies which were using basic IT (such as pen and paper or Microsoft Excel) scored very low in the adoption of some lean practices (such as levelled production); those companies using more advanced IT (such as APS and MES) scored very high with the adoption of the same lean practices. We also conclude that the best-in-class lean companies applied ERP and APS more often than industry average or below industry average companies.

The most interesting findings can be seen in Tables 13 and 14. For example, Table 13 shows that whilst the basic lean practices associated with total quality management (TQM) and standardization have a high average implementation level in the companies investigated, the more advanced JIT practices such as pull and levelled production are the least implemented amongst respondents. Notably, the results in Table 14 illustrate that advanced IT such as APS and MES may in fact allow a company to attain a higher degree of implementation of levelled production.

These findings are somewhat contrary to the popular belief that Lean and IT are divergent, competing paradigms, particularly where ERP is concerned. Therefore, this exploratory study led us to formulate the first of the research questions addressed in this PhD project – Are lean and ERP genuinely contradictory in nature?

Table 13: Average Implementation Level and Standard Deviation for Lean Practices (Goeldner and Powell, 2011)

Lean Practice	Average Implementation Level	Standard Deviation
Customer relationship management	3,79	0,63
Total quality management	3,58	0,87
Standardization	3,36	0,83
Continuous improvement	3,27	0,75
Supplier relationship management	3,17	0,76
Workplace organization	3,10	0,73
Total productive maintenance	3,08	1,03
Quick changeovers	2,61	1,06
Pull	2,57	0,94
Levelled production	2,49	0,69

Table 14: Overview of the use of IT solutions with a significant or an almost significant influence on applied lean practices (Goeldner and Powell, 2011)

	Lean Score of company using IT solution	Lean Score of company not using IT solution	p-value
Pen and Paper			
TPM	2.63	3.50	*0.066*
Levelled production	2.08	2.80	*0.014*
CRM	3.55	3.95	*0.098*
Excel			
Continuous improvement	3.08	3.79	*0.03*
TPM	2.86	3.96	*0.02*
TQM	3.33	4.17	*0.02*
Levelled production	2.24	3.28	*0.01*
Pull	2.25	3.46	*0.01*
MRP			
TQM	3.42	3.92	*0.086*
ERP			
CRM	4.00	3.34	*0.041*
APS			
Levelled production	2.87	2.34	*0.046*
MES			
Levelled production	3.00	2.37	*0.085*

Limitations – Though the response rate of 17.4% was relatively low, we suggest that the results are acceptable for use as an exploratory survey, which is intended only to give useful insight into the formulation of the future direction of the study. For example, Forza (2002) suggests that there is no minimum response rate for an exploratory survey. However, for a descriptive or theory testing survey type, the suggested minimum response rate is 50%. Therefore, if the survey was to be repeated in order to test some of the theory developed during this PhD project, countermeasures should be deployed in order to ensure a greater rate of response. A larger sample size could be used, and more time given for the completion of the survey could be given.

5.2 Lean production vs ERP systems: An ICT paradox?

Purpose and overview – The purpose of this paper is to compare and contrast lean production principles with ERP systems in order to identify the challenges associated with the implementation of both approaches within today's manufacturing industry. Lean and ERP are analysed in the context of manufacturing planning and control (MPC) using theoretically grounded insights. Particular emphasis is placed on the recurring "push versus pull" debate (e.g. Alfnes, 2005; Benton and Shin, 1998; Stadtler, 2005)

Main findings – We conclude that although the suggested benefits of lean and ERP are almost identical, they continue to be identified in the scientific literature as competing paradigms. Thus, the contribution in this paper is the identification and formalisation of the lean-ERP paradox (Powell and Strandhagen, 2011). Whilst lean and ERP have emerged from fundamentally different approaches to production, on further investigation it appears that there is a synergetic impact to be realized by coordinating the two approaches and applying them in tandem. A summary of the paradox is shown in Table 15.

Table 15: **The Lean-ERP Paradox** (Powell and Strandhagen, 2011)

Lean	ERP
Production based on consumption (Pull)	Production based on forecasts and machine utilization (Push)
Decentralized control & empowerment (Bottom-up approach)	Centralized planning and control (Top-down approach)
Rate-based, mixed model production	Time-phased, batch production
Focus on maintaining flow	Focus on tracking material movements

Though at first both approaches appear to contradict each other, it is clear that nowadays they are both applied within industry to achieve reduced cost, reduced inventory, and increased productivity. Therefore this begs the question as to whether or not both approaches can be combined and coordinated so as to realize greater competitive advantage. These findings correspond to Slack *et al.* (2007), who suggest that though the operating philosophies of lean and ERP are fundamentally opposed, the irony is that they have similar objectives. Therefore, the next step in the research project was to examine more closely the role of ERP systems in lean production.

This paper was used to identify the broad area of study (lean production and information technology) and partially identifies the research topic (ERP systems in lean production). By considering the traditional view of lean production versus information technology in a modern day context, we highlight the paradoxical nature of the application of both ERP systems and lean production practices in a modern manufacturing environment.

Limitations – The main limitation of this paper was that it represents only a small sample of the extant operations management literature. However, the overall impact of such a small sample on the final results of this thesis, are marginal. This is because the paper again presents the results of exploratory research, which much like the exploratory survey described previously, was carried out to give useful insight into the research topic. Therefore the contribution of such a paper is significant in that it has helped to describe the research problem in more detail, and helped to further reduce the scope of the investigation, questioning the validity of the “so-called” contradictory nature of lean and ERP.

5.3 *ERP systems in lean production*

Purpose and overview – Faced with increasing global competition and growing customer expectations, manufacturers looking for significant performance improvements often look to one of two choices: implementing an ERP system, or applying the tools and techniques associated with lean production. In fact, many companies are today applying both approaches in an attempt to realise competitive advantage in the global marketplace. However, there seems to be an on-going debate within the academic literature as to whether lean and ERP are complimentary or contradictory technologies. This paper aims to present a thorough and critical review of literature with the objective of bringing out pertinent factors and useful insights into the role and implications of ERP systems in lean production, and to develop a research framework that can be used by researchers and practitioners for studying the value of integrating ERP with lean.

The research methodology used is literature survey. Literature was collected primarily through journals within the area of operations management. For rigorousness, textbooks, conference papers, white papers and dissertations were excluded from the subsequent analysis. Though older literature was considered to define the scope of the investigation; only literature published after the year 2000 was considered in the analysis in order to be current in the research field.

Main findings – I propose a classification scheme for current research on ERP and lean production, and identify six major areas in the extant literature. The literature survey is then used to find existing research gaps, and provides a research framework for future research directions regarding the applications and implications of ERP systems in lean production. The following issues can be considered to represent the most critical areas for further research into the role and implications of ERP systems in lean production:

- Combining lean and ERP for competitive advantage
- Methods for the concurrent application of lean and ERP
- ERP support for lean production
- Real-time information for intelligent planning and execution of lean manufacturing operations
- ERP systems for the extended lean enterprise
- e-Kanban as a platform for integrating ERP and pull systems

The research framework can be seen in Figure 17:

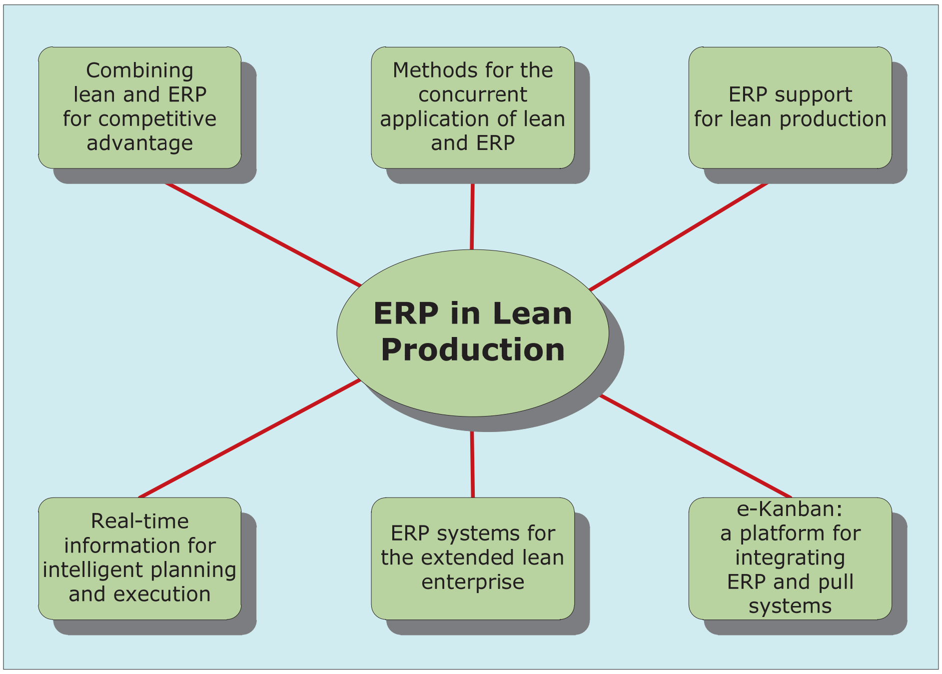

Figure 17: A Research Framework for ERP in Lean Production (Powell, 2012a)

Combining lean and ERP for competitive advantage
Firstly, both ERP systems and lean production were considered in the literature as enablers of competitive advantage. There was good evidence of the positive effects brought about by implementing either of the two approaches, but any measure of performance improvement realised by applying both approaches together is lacking in the current literature. Thus, the future research directions within this area should address the practicalities and respective quantification of how ERP and lean can be combined to realise competive advantage.

Methods for the concurrent application of lean and ERP
Secondly, the implementation processes of both approaches should be considered further. Gunasekaran and Ngai (2004) suggest that the implementation of an IT system requires a strong team that includes key, knowledgeable managers from all functional areas. A well-documented project plan is also required, addressing key implementation issues, and moreover, top management support and involvement are essential factors for success. The success criteria for the effective application of lean practices are almost identical to those for ERP implementations, for example team formation and top management support. However, although evidence of simultaneous implementations are lacking in the scientific literature, Masson and Jacobson (2007) suggest that ERP-based lean implementations will grow over time. Therefore, an interesting research topic within this area would be to investigate the potential of ERP-based lean implementations. Can the implementation methodologies of both approaches be integrated to develop a single best-practice model?

ERP support for lean production
Thirdly, the support functionality of each of the approaches should be considered. Although in the traditional sense ERP systems have been considered as a contributor to waste in lean production (Bruun and Mefford, 2004; Hicks, 2007), modern advances in IT and the improved capabilities of ERP have caused some authors to think differently (Riezebos *et al.*, 2009). Therefore, further research should address the support functionality of contemporary ERP systems for lean production. For example, how can contemporary ERP systems support lean production principles? It would also be interesting to evaluate how lean thinking can be used to support the successful deployment of modern ERP systems. These are some key issues which should be given further thought in order to improve the competitiveness of manufacturing organisations.

Real-time information for intelligent planning and execution
The fourth major issue identified in the literature was that of the role and value of information, which should be given close regard. If information is to replace inventory (Chen and Paulraj, 2004), the accuracy of the information becomes of significant importance, as does its timeliness. Of particular relevance here would be to address the capability of an ERP system to provide real-time information for intelligent planning and execution of lean manufacturing operations. This could be particularly relevant for applying pull production practices in engineer- and make-to-order environments, which have not typically been suited to the traditonal kanban approaches.

ERP systems for the extended lean enterprise
The fifth area identified was that of supply chain integration. Companies in the race for improving organizational competitiveness in the global markets of the 21st Century require their supply chains to be connected in an electronic and dynamic nature. These supply chains should also have a focus upon customer-centric value creation, removing non-value adding activities and contributing toward the lean supply chain. Empirical research within this area should investigate how ERP systems can be applied as a medium for extending lean practices throughout the supply chain, as an enabler of the extended lean enterprise.

e-Kanban as a platform for integrating ERP and pull systems
Finally, the development of kanban and the role of the Internet have a major part to play in the application of ERP within lean production. Godinho Filho (2010) reviewed 32 variations of kanban, though only two variants were significantly related with the field of IT (e-kanban and barcode-kanban). However, both of these variants showed signs of promise as enablers toward improved competitive advantage. Therefore, a final suggestion for future research directions would be to further examine applications of e-kanban as a platform for the integration of ERP and pull production. For example, how can a contemporary ERP system be configured to support a pull system?

I subsequently chose the third issue identified in the research framework - "ERP support for lean production" - as the research direction for the next research paper.

Limitations – This paper presents the results of a thorough and critical review of operations management literature published since the year 2000. Though one could consider it a disadvantage to disregard the extensive literature on MRP and JIT from the 1980s and 1990s, in order to remain current in the research community, I consider it more important to focus on the most recent developments in the field. After all, it seems that it was the early MRP and JIT literature that has led to the “contradictory” nature of ERP and lean production that we face today.

5.4 *ERP support for lean production*

Purpose and overview – The purpose of this paper is to evaluate the support functionality of a contemporary ERP system for lean production. By applying an action research approach and addressing the fundamental principles of lean production in the context of the capabilities and functionality of a modern ERP system, we develop a framework for ERP support for lean production, based on theoretical and practical insights.

Main findings – As a result of the first phase of the action research project (see Chapter 4.3.2), we develop "the 15 keys to ERP support for lean production". By operationalizing each of the five lean principles with practical examples, it was possible to identify the potential support functionality offered by a contemporary ERP system for lean production, thus making a contribution to the area "*ERP support for lean production*" identified in the research framework (Figure 17).

Table 16: The 15 keys to ERP support for lean production (Powell *et al.*, 2011)

No.	Principle	An ERP system for lean production should:	Reference:
1	Value	Support customer relationship management	(Chen and Popovich, 2003)
2		Automate necessary non-value adding activities (e.g. backflushing)	(Hamilton, 2009)
3	Value stream	Enable process-modelling to support standard work processes	(IFS, 2008; Prediktor, 2010)
4		Provide a source for easy-to-find product drawings and standard work instructions	(Houy, 2005; Tjahjono, 2009)
5		Support information sharing across the supply chain	(Bjorklund, 2009; Koh *et al.*, 2008)
6	Flow	Create synchronized and streamlined data flow (internal & external)	(Hamilton, 2003)
7		Support line balancing	(Steger-Jensen and Hvolby, 2008)
8		Support demand levelling	(Hamilton, 2009)
9		Support orderless rate-based planning (e.g. takt-time)	(IFS, 2010)
10		Provide decision support for shop floor decision making	(Hamilton, 2009)
11	Pull	Support Kanban control	(Hamilton, 2009; Masson and Jacobson, 2007)
12		Support production levelling (Heijunka)	(Masson and Jacobson, 2007)
13		Support JIT procurement	(Masson and Jacobson, 2007)
14	Perfection	Provide a system to support root-cause analysis and for the logging and follow-up of quality problems	(Bjorklund, 2009)
15		Provide highly visual and transparent operational measures (e.g. real time status against plan)	(Prediktor, 2010)

By combining the 15 keys for ERP support for lean production with the conceptual framework identified in Chapter 2.7, we propose a framework for ERP support for lean production as a result of this paper (Figure 18).

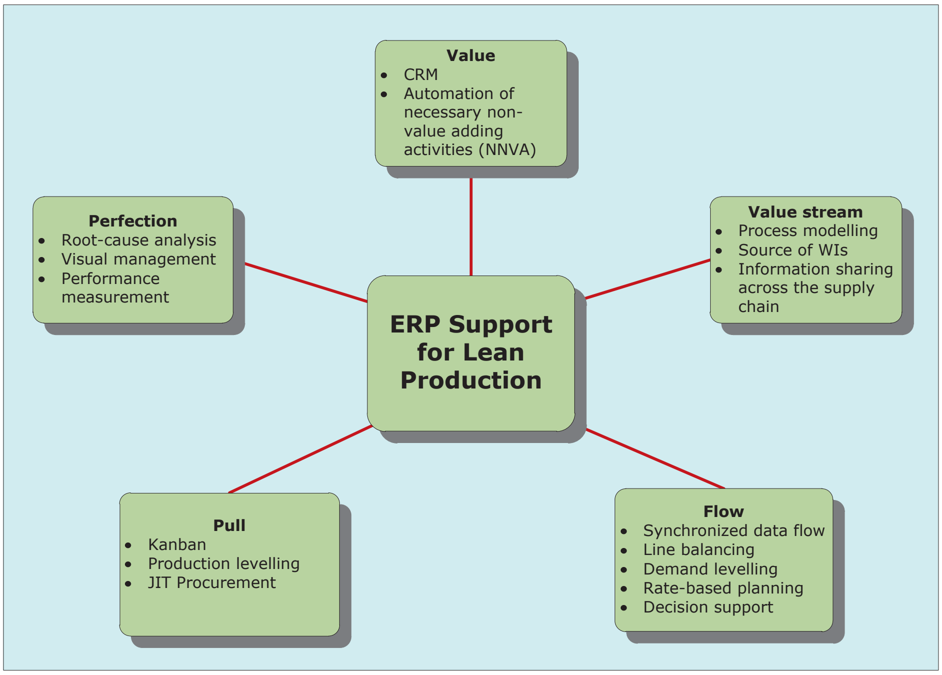

Figure 18: A Framework for ERP Support for Lean Production (Powell *et al.*, 2011)

In terms of manufacturing planning and control, some of the keys relate primarily to planning (e.g. support rate-based planning); some primarily to control (e.g. support kanban control); whilst others serve both planning and control (e.g. support customer relationship management; support information sharing across the supply chain). All of the 15 keys give good practical examples of potential ERP support functionality for lean production.

With reference to current thinking, Singleton (2011) suggests three ways in which manufacturing software can be used to support the lean manufacturing philosophy in comparing MRP and lean:

1. Incorporate support for value stream mapping
2. Continuously monitor lean metrics
3. Identify key places to add or subtract inventory

Though aspects of all three of these points are incorporated within the framework illustrated in Figure 18, we suggest that value stream mapping itself should still be carried out in the traditional sense – with pen and paper. When this technique was first developed, it was called big picture mapping. As such, it encouraged those carrying out the mapping task to "go to gemba" – i.e. to go to the shopfloor and learn to see the process of actual material and information flows. We suggest that there is a great risk of forgetting this basic lean principle by integrating value stream mapping functionality into the

ERP software. However, having first conducted the physical process mapping, we do suggest that the ERP system can be used more effectively to model the process flows, thus supporting value stream management.

As for the continuous monitoring of lean metrics, we identify "performance measurement" as part of the support functionality for *Perfection*. For example, as a part of the ERP system, a business intelligence (BI) module can be used to develop and manage lean metrics.

Identifying key places to add or subtract inventory is also covered by support for both *Flow* and *Pull*. For example, the relevant planning module can be used to support both demand levelling and production levelling (Heijunka), which involve decisions of where to locate strategic inventory so as to smooth out variations in demand.

In a Glovia whitepaper (Glovia, 2008), possible ERP support functionality for the technical elements of lean production (such as visual control and continuous flow), is also discussed. The white paper takes a much greater focus on which modules of the ERP system offer support for each of the technical elements of lean. For example, it states that *"the "glovia.com Shop Floor module" allows real-time data collection for continuous improvement"*. This falls within the realms of Item number 15 in Table 16, *"An ERP system for lean production should provide highly visual and transparent operational measures (e.g. real time status against plan)"*. Another example is *"the "glovia.com Factory Planning module" is able to smooth out variable demand, helping to establish and adjust takt-time"*. Again, this is similar to item numbers 8 and 9 in Table 16, which states that *"An ERP system for lean production should support demand levelling and orderless rate-based planning (e.g. takt-time)"*.

Limitations – This paper presents a framework for ERP support for lean production that has been developed by comparing a selection of authors' modern theoretical viewpoints with my own personal knowledge developed from my experiences gained in an action research project at a single case company. This may limit the generalizability of the findings, although measures have been taken to reduce any detrimental effects.

5.5 Lean production and ERP systems in SMEs

Purpose and overview – The purpose of this paper is to investigate potential ERP support functionality for pull production, in the context of SMEs. In the extant literature, it is suggested that SMEs often struggle with the applications of both lean and ERP, due to limited resources and knowledge (e.g. Achanga *et al.*, 2006; Buonanno *et al.*, 2005; Snider *et al.*, 2009). Therefore, we suggest that research in this area will have greatest impact for SMEs, as the potential synergy between both approaches may make the results more sustainable in the context of SMEs. Also, the decisions on lean and ERP are often made by the same decision maker in these companies, which improves the construct validity of the research.

Firstly, we develop a capability maturity model for ERP support for pull production, which can be used to benchmark a company's ERP system in respect to its support for the company's pull system. Then we apply the CMM to four case studies in the Northern part of the Netherlands.

Main findings – By investigating four case studies in the Netherlands, we propose a five stage capability maturity model (CMM) for ERP support for pull production (Figure 19). This model makes a direct contribution to the third area in the research framework "*ERP support for lean production*", previously identified in Figure 17. Rather than simply demonstrating examples of how a contemporary ERP system can be used to support pull production, the CMM defines five different levels of integration for ERP- and pull systems.

We developed the model by constantly comparing theory and data, thus iterating toward a theory which closely fitted the data (Eisenhardt, 1989). For example, the CMM was constructed based on other capability models in the scientific literature, and example criteria were classified at each level to fit the goal of each of the specific levels. The criteria were again constructed based on ideas in theory, as well as the data that was collected in practice.

With reference to existing theory, Wan and Chen (2008) highlight the problems and weaknesses of conventional card-based Kanban systems, such as lost Kanbans, problems over distance, and limited support for performance measurement. We suggest that as a manufacturer integrates the ERP system with its pull system, these problems and weaknesses can be systematically alleviated and removed from the system.

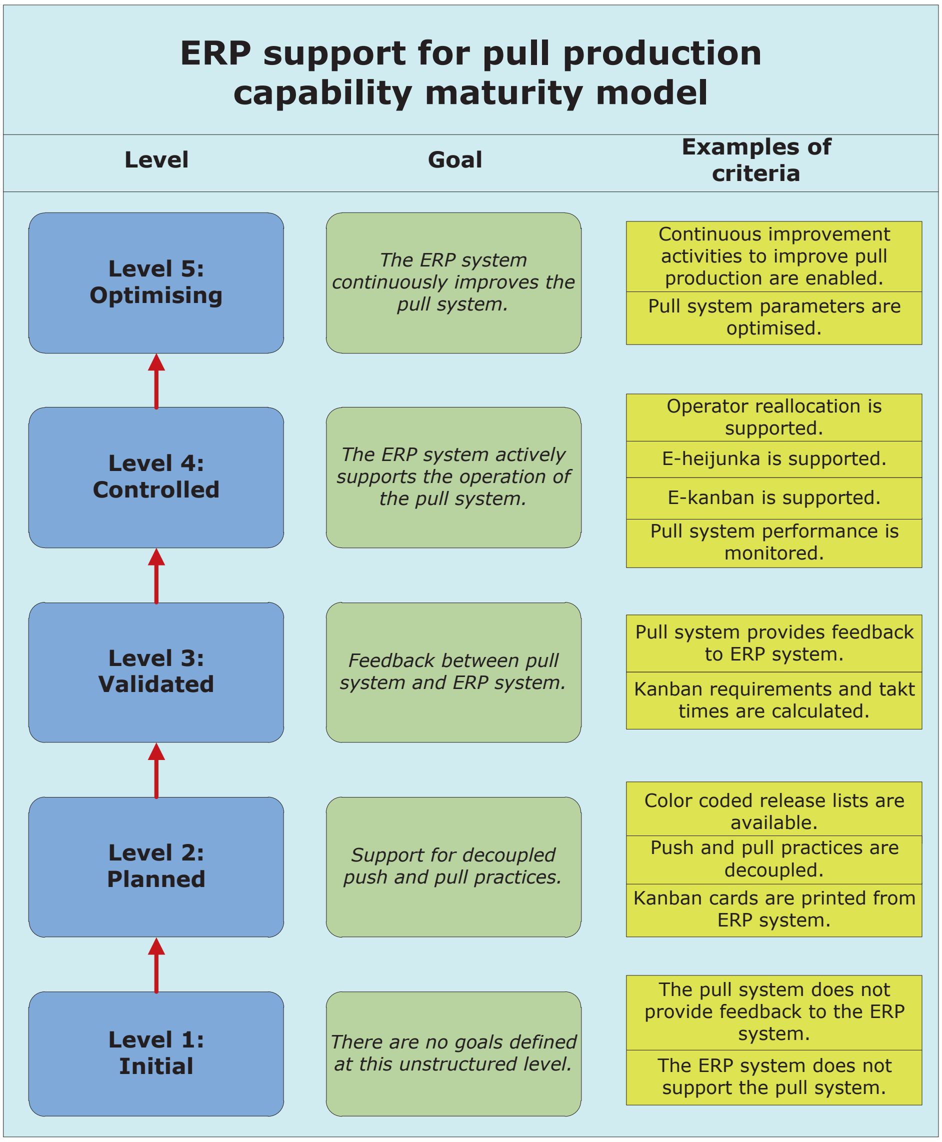

Figure 19: ERP Support for Pull Production: Capability Maturity Model (Powell *et al.*, 2012b)

Limitations – A limitation of the research is that the results from the cases considered in this investigation were limited to only stages two to four of our CMM. Note, however, that CMM level one was indeed outside of the scope of this paper, as all cases needed to have an ERP system and to have implemented a pull system. Hence, only a level five case was missing. We expect that SMEs located in the higher levels of the CMM-scale will be difficult to find as, in general, the implementation of lean practices and ERP implementations in SMEs is lagging behind that of their larger counterparts.

5.6 *The concurrent application of lean production and ERP*

Purpose and overview – The purpose of the final paper in this thesis is to examine existing methodologies for the implementation of lean production and ERP systems, in order to develop a single "best-practice" process for ERP-based lean implementations. By systematically integrating the application of lean production practices within a recognised ERP implementation methodology – ERP Proven Path (Wallace and Kremzar, 2001), and comparing this to the practical experience gathered through action research, we develop a process for ERP-based lean implementations.

Main findings – during the course of the action research project, it was suggested that the ERP implementation process served as a catalyst for the application of lean production practices. Therefore, the ERP Proven Path methodology (Wallace and Kremzar, 2001) was re-examined in light of the action research project in order to develop a process for ERP-based lean implementations, as shown in Figure 20.

The idea of an ERP-based lean implementation process can at first be considered quite controversial, as traditional thinking would suggest that both approaches should be dealt with separately. For example, Bell (2006) suggests that IT solutions are not a good place to start a lean initiative. After all, the implementation of ERP alone demands a vast amount of time and resources. However, we imply an alternative view, and suggest that the opportunities for business process reengineering that arrive with the onset of an ERP implementation present an interesting case for the application of lean practices. Nevertheless, we do state that first-cut lean education and training should be undertaken; and the basic lean foundations (e.g. zero defects; 7 wastes, 5S) should be implemented before the ERP system is selected, configured and installed.

This framework represents a contribution not only to "*ERP support for pull production*" in the research framework (Figure 17), but also to "*Methods for the concurrent application of lean and ERP*" as it addresses the supportive nature of the ERP implementation process for the application of lean practices.

Limitations – As in Powell *et al*., (2011), this paper is based only on the results of a single case. Though this would usually limit the generalizability of the contribution, we suggest that by keeping the contents of the ERP-based lean implementation process at a higher, more conceptual level, the generalizability of such a framework can be increased.

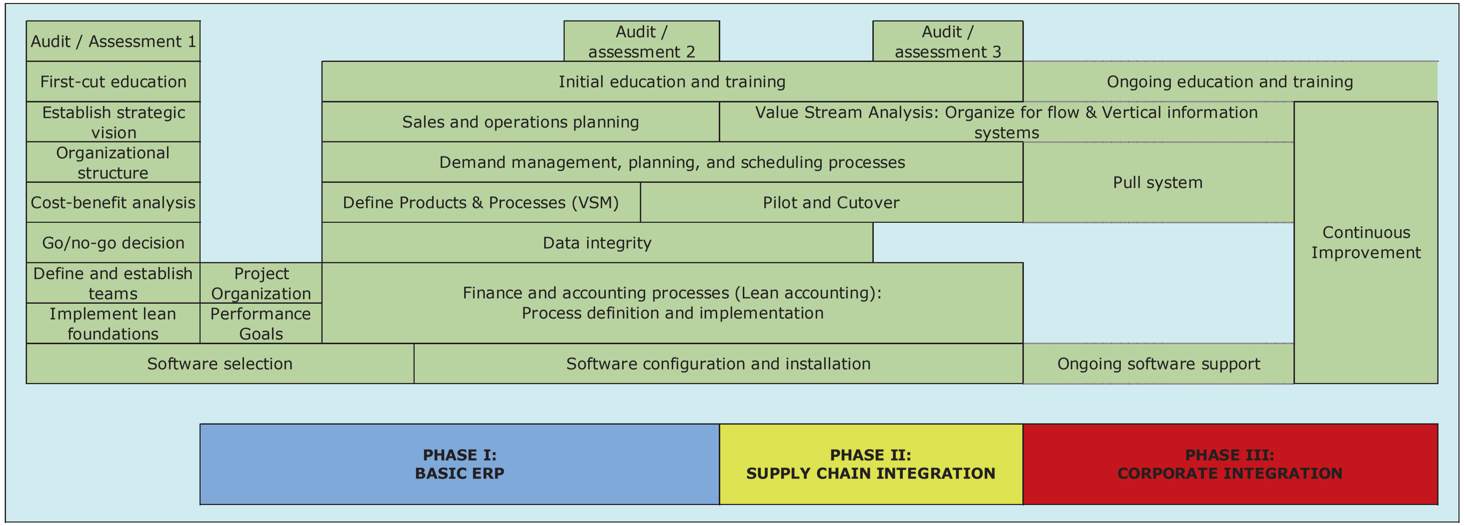

Figure 20: Framework for an ERP-Based Lean Implementation Process (Powell *et al.*, 2012a)

6 Discussion

Eisenhardt and Graebner (2007) clearly identify that sound empirical research begins with a strong grounding in related literature, through identifying a research gap and proposing research questions that address the gap. As such, this research project began by identifying several research gaps based on the results of an exploratory survey, two exploratory case studies, and through the development of a research framework grounded in the operations management literature. From the research framework, I opted to focus on investigating ERP support for lean production. In doing so, a number of research questions were formulated. This section addresses each of these research questions by listing propositions that have been developed as a result of the research. This section gives a clear illustration of an apparent movement towards a new paradigm: ERP-enabled lean production.

6.1 The contradictory nature of lean and ERP

The first research question set out to address the "contradictory" nature of lean and ERP:

RQ1: Are lean and ERP genuinely contradictory in nature?

In order to address the debate regarding the complimentary or contradictory nature of lean and ERP, a literature review was carried out which enabled the identification and definition of the lean-ERP paradox (Powell and Strandhagen, 2011). In light of this, as well as the other research activities that were involved in this PhD project, we are able to formulate a proposition in response to RQ1:

Proposition P1: Lean and ERP are not contradictory in nature. On the contrary, lean and ERP have evolved to become complimentary approaches to production management.

For instance, in our framework for ERP support for lean production (Figure 18), we present a broad set of examples of how a contemporary ERP system can be used to support lean production principles (Powell *et al.*, 2011). Through the use of four case studies in the Netherlands and the development of a capability maturity model (Figure 19), we also address the lean-ERP paradox by suggesting a number of areas where an ERP system can in fact be used to support a pull system (Powell *et al.*, 2012b).

6.2 ERP support for lean production

The second research question addresses ERP support functionality for lean production:

RQ2: How can contemporary ERP systems be used to support lean production?

The main objective of this research project was to investigate the support functionality of ERP systems for lean production. As such, the five lean principles of Womack and Jones (1996) were selected as the *a priori* constructs for investigation and were used to develop a conceptual framework that was used to guide the investigation. Smyth (2004) suggests that the fulfilment of certain conditions is necessary to ensure the credibility of a conceptual framework as a research tool. Smyth proposes four criteria for assessing the appropriateness of a conceptual framework:

1. Does the conceptual framework provide a common language for which to describe the situation under scrutiny and to report the research findings?
2. Does the conceptual framework act as a set of reference points from which to locate the research questions within contemporary theorising?
3. Does the conceptual framework develop a set of guiding principles against which judgements and predictions might be made?
4. Does the conceptual framework provide a structure within which to organise the content of the research and to frame conclusions within the research context?

Does the conceptual framework provide a common language for which to describe the situation under scrutiny and to report the research findings?

The situation under scrutiny can be defined as the contradictory nature of lean and ERP, and more precisely, ERP support for lean production. By using the five lean principles (Womack and Jones, 1996) in the conceptual framework, consistency in the discussion is ensured. The lean principles are well documented in the extant literature, and they provide a broad foundation for the investigation. By using the five lean principles as the constructs for investigation, the clarity of reporting can also be increased.

Does the conceptual framework act as a set of reference points from which to locate the research questions within contemporary theorising?

The process of deriving the framework gave broad scope to think about the research project and to conceptualise the problem. The outcomes of this research project, when considered together with the findings from additional contemporary literature, justify the usefulness of the conceptual framework as a set of reference points relative to contemporary theorising (see for example the 15 keys for ERP support for lean production).

Does the conceptual framework develop a set of guiding principles against which judgements and predictions might be made?

The very construction of the conceptual framework implies our assumption that contemporary ERP systems offer support for each of the five lean principles. This confirms that the framework develops a set of guiding principles against which judgement and predictions can be made. Examples of such judgements and predictions can be seen in the framework for ERP support for lean production (Chapter 5.4), where we operationalize the lean principles and evaluate them against the functionality of a contemporary ERP system.

Does the conceptual framework provide a structure within which to organise the content of the research and to frame conclusions within the research context?

The structure of the conceptual framework enabled the scope of the research project to develop at varying levels of investigation. First of all, the framework set out to evaluate ERP support for lean production at a more abstract level. Having gained insight from theory and practice at an overall level, it was decided to investigate ERP support for pull production in more detail. Therefore, we can conclude that the conceptual framework provided a structure within which to organise the content of the research, and to frame conclusions within the context of the research.

In general, the five lean principles proved to be highly relevant for this investigation, providing the basic theoretical grounding necessary for such a task, and also allowing the development of practical examples to guide the study. The major findings of this study suggest a number of ways in which the principles of lean production can be systematically supported by contemporary ERP systems. Thus, a proposition in response of RQ2 can be formulated:

P2: Developments in IT have enabled contemporary ERP systems to be used to support lean production by offering an array of support functionality for each of the five lean principles.

By combining a literature study with the first phase of an action research project, we were able to operationalize each of the five lean principles. In doing so, we were able to identify 15 keys for ERP support for lean production. These were used to populate the conceptual framework, which enabled us to develop a framework for ERP support for lean production (Powell *et al.*, 2011). We then opted to focus in more detail on specific ERP support for pull production.

6.3 ERP support for pull production in SMEs

Thirdly, we aimed to address the very essence of the lean vs. ERP debate, push vs. pull. We set out to investigate specific ERP functionality that is able to support the deployment and use of pull production. We also chose to focus on SMEs, as we suggest that it is this type of company that can benefit the most by integrating both approaches.

RQ3: How can contemporary ERP systems be used to support pull production practices in SMEs?

Through the use of case study research, a capability maturity model for ERP support for pull production was developed (Powell *et al.*, 2012b). Both the within-case and cross-case analyses provide interesting insights in terms of the potential ERP support functionality for pull production, particular when the observations were compared with the relevant theory in the literature. Our proposition in response of research question three is:

P3: Contemporary ERP systems can be used to support pull production practices in SMEs by providing functionality that actively supports and continuously improves the operation of pull systems at a number of levels.

This proposition strengthens our argument developed in P2, and also supports P1 by directly addressing the lean-ERP paradox and push vs. pull. Though level one of the CMM represents the traditional view of lean and ERP ("The pull system does not give feedback to the ERP system" and "the ERP system does not support the pull system"), the other levels demonstrate an incremental approach to optimizing the pull system through the systematic integration of the ERP system.

6.4 ERP-based lean implementations

Finally, by observing the concurrent application of lean and ERP in an SME, we began to think that an ERP-based lean implementation process would be very advantageous in the case of SMEs. The fourth research question targeted this problem in particular:

RQ4: How can existing methodologies for the implementation of lean production and ERP systems be combined to develop a single "best practice" process for ERP-based lean implementations?

By evaluating a number of well recognised implementation processes and methodologies for both lean and ERP, and by examining the concurrent application of lean and ERP in the action research project, we were able to propose a process for ERP-based lean implementations.

P4: Existing methodologies for the implementation of lean production and ERP systems can be combined to develop a single "best practice" process for ERP-based lean implementations by integrating the application of lean practices with the Proven Path Methodology for ERP implementation.

Using both theoretical and practical insights, we developed a model for a best-practice ERP-based lean implementation process (Figure 20). The Proven Path methodology is a well-recognised process for ERP implementation, and by systematically integrating lean production practices in the implementation process, we propose that our model can be used in practice for the effective application of lean and ERP (Powell *et al.*, 2012a). We imply that this is particularly useful for SMEs, who often struggle with both approaches. By integrating them in such a way, we suggest that the demanding tasks involved in applying lean and ERP can be simplified and used to greater effect.

6.5 General discussion

In Chapter two, the five lean principles (Womack and Jones, 1996) were identified, and some of the core capabilities of ERP systems (Borell and Hedman, 2000) were listed, of which many are reflected in the Jeeves Universal 2.0 system chosen by the client system in the action research project. Thus, by going back to basics and addressing the five lean principles in the context of the core capabilities of ERP, a number of interesting reflections can be made.

For example, in the traditional sense, information technology such as ERP systems has been classed as sources of waste within lean production. This can be traced back to Sugimori *et al.* (1977), who stated that the workshops at Toyota chose not to rely on electronic computers for production planning and control for three primary reasons:

1. Reduction of cost processing information;
2. Rapid and precise acquisition of facts;
3. Limiting surplus capacity of preceding shops.

By considering the results of this thesis in contrast to the old way of thinking, it is clear that in the modern manufacturing environment, it is no longer a case of "lean production versus ERP systems". It is time to move beyond the Lean-ERP paradox and use ERP systems more effectively in order to support the deployment of lean production practices, particularly when it comes to pull production. Through offering examples which point towards a new paradigm "ERP-enabled lean production", the results of this research project show that current applications of contemporary ERP systems challenge all three of the reasons given by Sugimori *et al.* (1977) as to why computerized systems have traditionally been classed as contributors to waste within lean production. For example, when used effectively, a contemporary ERP system can significantly reduce the cost of processing information. This is due to the ever increasing processing speed and capacity of modern IT solutions, which in turn invalidates Sugimori *et al.*'s second reason listed above, the rapid and precise acquisition of facts. The results of this project show that contemporary ERP systems are capable of collecting, analysing, and transferring facts in very short time periods, which can often be measured in seconds or less. Finally, the third reason for Toyota's choice of paper Kanban over computerized systems in the 1970s was limiting surplus capacity of preceding shops. We showed in Powell *et al.* (2012b) how this can be achieved through the use of contemporary ERP systems to provide active management of e-Kanban. Therefore, we suggest that the traditional view of ERP systems as the "antithesis" of lean production is null and void – this research project has shown how contemporary ERP systems can in fact be used to support lean production.

We do however emphasize that an ERP system is only a tool, which has indeed evolved from the MRP systems of the 1970s. We suggest that this is one of the primary obstacles that a manufacturer will meet during the deployment and realisation of ERP-enabled lean production. For example, though the ERP systems of today contain much more functionality of their predecessors, the "inventory and manufacturing" module (shown in Figure 6), is still used by placing heavy emphasis on the traditional MRP-logic. This must be approached with caution. For instance, in the case of lean production, it can be said that it is the result of effective application of lean tools and techniques that enable the realisation of improved performance, not the lean tools themselves. This is also true of the ERP system. We do not attempt to suggest that ERP is the solution. The system must be applied effectively, parameterized correctly, and aligned with lean thinking in order to realise the perceived benefits. Manufacturers will continue to face challenges and problems if they try to combine lean production principles with a traditional MRP approach. Contemporary ERP systems must be applied differently in order to realise the benefits of ERP-enabled lean production. We suggest that the CMM (Figure 19) is of particular relevance in helping manufacturing companies to align both approaches.

When we consider the entire production system in terms of the organisation-product-process ‘triad’ identified in Chapter 4.3.1, it is easier to see how the effective use of an ERP system serves to support the development of lean processes in a lean organisation. We can even suggest that some of the benefits of ERP systems (listed in Chapter 2.4.4) will not be realised in full unless lean thinking is also applied. For example, in order to realise inventory reduction, the company must be sure to set the parameters in the ERP system correctly so as to prevent overproduction, which will otherwise only lead to excessive inventory levels rather than stock reduction. This is also true with achieving reduced delivery times, as if unreasonably large batches are suggested due to excessive safety buffers being set in the production planning module, production lead times may actually increase.

Thus, this research indicates that it is no longer a question of either lean or ERP. If a company wants to realise the benefits of an ERP system, it should also make the necessary process- and organisational changes in line with the lean production philosophy. Also, if a company is considering applying lean production practices, it should also consider the support functionality offered by the application and use of a contemporary ERP system.

7 Conclusion

This chapter closes the research project by making conclusions regarding the implications for theory and practice, as well as clarifying its limitations. Finally, some areas for further work are identified.

By first addressing the "contradictory" nature of lean production and ERP systems, the overall aim of this research project was to investigate ERP support functionality for lean production. When each of the contributions is considered, it becomes apparent that contemporary ERP systems can be used to support lean production in a number of ways, giving examples and insights into a new concept: ERP-enabled lean production.

7.1 Implications for theory

By posing research questions that address relevant gaps in current theory regarding lean production and ERP systems, a number of theoretical contributions have been made which highlight an evolution in thinking since the rise of the Toyota Production System after the Second World War.

Though in the 1970s lean production and information technology were considered as divergent, competing approaches to production management; recent developments in ERP systems and the supporting technological infrastructures have enabled the two approaches to converge in a synergetic manner, enabling the creation of hybrid lean-ERP environments for improved competitive advantage of manufacturing enterprises. Figure 21 illustrates the divergent-convergent history of lean and ERP, starting in the 1970s when Sugimori *et al.* (1977) documented the reasoning for using Kanban instead of computer-based systems for production control. This divergence was largely due to the use (and often misuse) of the material requirements planning (MRP) approaches, that were based on bill-of-materials processors (BOMP) and subsequent MRP-logic, and that often used economies of scale and economic order quantity (EOQ) calculations to make production schedule- and purchase order proposals. Experiencing different market characteristics to the Western world, the Japanese auto producers, particularly Toyota, developed alternative approaches which deployed levelled production schedules and Kanban-based pull systems.

Whilst one cannot overlook the significant contributions of the MRP and JIT literature of the 1980s and 1990s (e.g. Aggarwal, 1985; Discenza and MacFadden, 1988; Flapper *et al.*, 1991; Huq and Huq, 1994; Krajewski *et al.*, 1987), where various attempts were made to compare, contrast, and even integrate both approaches; much of this work was simplified simulation-based research that investigated inventory control, and often seemed to miss other empirical aspects one would expect to consider when investigating the integration of computer-based approaches with lean production. Thus, through the 1990s there was great divergence as lean production (Womack *et al.*, 1990) and ERP systems (Davenport, 1998) become two popular, competing approaches for production management. At the turn of the millennium, however, certain authors began to question the competitive nature of lean and ERP. For example, Bell (2006) suggested ways in which lean can be combined with information technologies for continuous improvement, and Sheldon (2005) named lean production as a central element of what he calls "*Class A ERP*". Finally it was Riezebos *et al.* (2009) who suggested several ways in which IT and ERP systems could be used to support lean production, which inspired us to investigate the role of ERP within lean production.

Our findings suggest that what may have once been two grossly divergent approaches to production management have now converged to form a highly competitive, hybrid model. For example, one of the contributions to theory which came as a result of this research project was a capability maturity model (CMM) which identifies various levels of ERP support functionality for pull production. This is contrary to the views of Sugimori *et al.* (1977), who gave good reasoning as to why Kanban was a much more suitable approach for controlling production in the Toyota workshops of the 1970s.

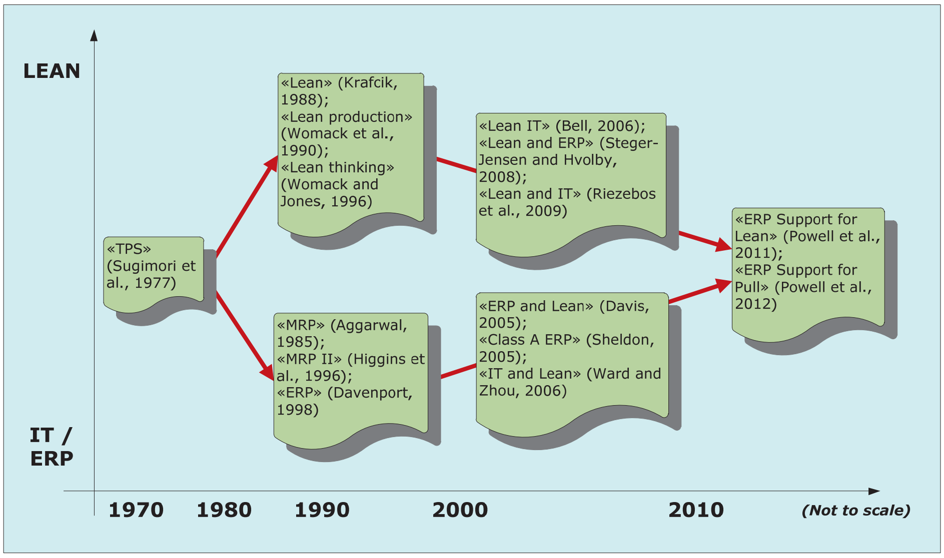

Figure 21: The Divergent-convergent History of Lean and ERP

7.2 Implications for practice

It is intended that the findings and outcomes of this research project can be applied in industry to increase the competitiveness of manufacturing companies. For example, practitioners can make use of the ERP-based lean implementation process (Figure 20) for the deployment of lean practices in parallel to the application of a contemporary ERP solution; and afterwards, can use the CMM (Figure 19) in order to develop effective ERP support mechanisms for pull production.

We suggest that the developments that have emerged from this research project are very applicable to two "target-audiences" in particular. Firstly, we suggest that SMEs can benefit greatly from the ways in which we suggest combining both lean and ERP. These types of companies often struggle with applying both approaches due to restrictions on resources, and limited knowledge, for example. Therefore, we suggest that by adopting a combined approach through the deployment of ERP-enabled lean production, smaller producers can realise the benefits of lean and ERP to a greater extent. Secondly, we suggest that those companies which do not exhibit the characteristics inherent to the

Toyota Production system such as relatively high and stable volumes and low variety products can also benefit from ERP-enabled lean production. These companies, for example make-to-order (MTO) and engineer-to-order (ETO) firms can utilise ERP systems in order to support the systematic application of lean production principles, in order to develop customised, company-specific production systems (such as the Noca Production System, see Chapter 4.3.3).

7.3 Limitations

By definition, the results of the qualitative approach adopted through the application of action research and case study research cannot be assumed to be typical. Thus, there is no way of being empirically certain of the extent to which the five SMEs represented in this study are similar or different from other manufacturers in Norway, the Netherlands, or indeed in Europe. Furthermore, because the sample is small and idiosyncratic, and because data is predominantly non-numerical, there is no way to establish the probability that the data is representative of a more generalized population. Nonetheless, it is never the main intention of an action research project to arrive at a generalizable contribution. Yet action research is often generalizable through theoretical abstraction. Scientific concepts "are produced on the basis of a mental and systemic analysis of the relations and connections amongst objects" (Davydov, 1990). Theoretical abstraction can occur when similar core features are recognised in pieces of "superficially different" information (Hiebert and LeFevre, 1986). This happens when the relationships amongst objects transcend the level at which knowledge is currently represented. Then, the common features of different-looking pieces of knowledge are pulled out, and then tied together to formulate new knowledge. This has been the case with the two fields of "different-looking" pieces of knowledge in lean production and ERP systems. Thus, even though the results of this research project do not represent "hard" proof that lean and ERP have become convergent in nature, it is fair to state that the results do indicate such a trend.

Action research is not limited to the understanding of the process and communicating it, but includes the participation of the researcher and using his understanding to suggest ways in which desirable change might take place (monitoring these attempts amounts to self-evaluation). The active participation of the researcher is in fact quite a controversial situation. Many researchers, particularly positivists, would in fact doubt the feasibility of insiders carrying out worthwhile, credible, and objective enquiries into a situation in which they are centrally involved, as this can quite easily result in bias, both in terms of the effects of the researcher on the case; and the effects of the case on the researcher (Miles and Huberman, 1994). In terms of mitigating bias in such a participative enquiry, a key approach is to combine retrospective and real-time cases (Leonard-Barton, 1990). This approach was supported within this research project through adopting both the case study and action research views. For example, where retrospective cases rely primarily on interviews (thus enabling the researcher to cover more informants and include more cases), the real-time case from the action research methodology employed in contrast a number of longitudinal data collection techniques, making use of interviews as well as real-time observations, which helped to mitigate retrospective sense-making and impression management. In order to increase the quality and validity of the results in this research project, a number of quality and validity criteria were also applied throughout the research process (examples of which can be seen in Chapter 3.4).

7.4 Further work

Finally, in terms of further work, Hines (2010) suggests that the five lean principles of Womack and Jones (1996) almost totally missed the importance of people. An interesting uncertainty that was identified during this research project was the role of ERP systems in supporting empowerment of workers and the establishment of multifunctional teams. Therefore, it is suggested that future research should address the role of ERP systems in connection with the respect-for-human aspect of TPS (e.g. Sugimori *et al.*, 1977). The other research areas identified in Figure 17 should also be investigated, for example using ERP systems as an enabler for the extended lean enterprise, and using ERP for real-time intelligent planning and control of lean manufacturing operations.

I suggest that it would be beneficial to conduct another survey, this time with a greater sample size and possibly covering a number of different countries. For example, in a recent feature entitled "*North Stars*" in "*Lean Management Journal*", a comparison was made as to the extent of lean adoption in Scandinavia – Norway (Powell, 2012b); Sweden (Hillberg, 2012); and Denmark (Jørgensen, 2012). This was carried out through the use of several case studies in each country. It would certainly be interesting to conduct a survey which could be used to examine in more detail the extent to which lean and ERP had been integrated within these countries, as well as further afield. Such a survey could be based upon the CMM developed in Powell *et al*. (2012b).

Also, though some improvement in performance was indicated following the implementation of lean practices at Noca AS, and likewise at a select few of the case companies in the Netherlands; the effects of combining lean and ERP have not been quantified in this research project. Therefore, by adopting a survey approach, an attempt could be made to study the quantitative effects of the integration of lean and ERP.

Future work could also involve carrying out further case studies, either by use of case study research, or through a wider application of action research. This would enable the contributions identified in this project, and generalizability of such, to be tested in the context of other companies and in other industries, for example.

7.5 Concluding remarks

In order to draw this thesis to a close, I will now summarize the results of the PhD thesis and make some final reflections.

Through the course of this research project, we have:

- Conducted an exploratory survey to investigate the relationships between lean production and information technology;
- Carried out two exploratory case studies in order to gain empirically grounded insights into the use of lean and ERP;
- Critically examined recent operations management literature to identify interesting research gaps that exist in current knowledge of ERP and lean production;

- Actively participated in a twelve month action research project at an SME in Trondheim, Norway to investigate ERP support for lean production; and
- Carried out four case studies in the Netherlands in order to examine the application of both ERP and pull systems, and to classify ERP support functionality for pull production.

This has enabled us to develop several contributions to theory and practice, namely:

- The identification and formalisation of the lean-ERP paradox (Powell and Strandhagen, 2011);
- A research framework for ERP systems in lean production (Powell, 2012a);
- A framework for ERP support for lean production (Powell *et al.*, 2011);
- A capability maturity model for ERP support for pull production (Powell *et al.*, 2012b);
- A framework for an ERP-based lean implementation process (Powell *et al.*, 2012a).

We suggest that by the very nature of these theoretical contributions, they are highly relevant and useful for developments in practice concerning the integration of lean and ERP.

Finally, by way of closure, having spent much of the past three years studying theoretical and practical applications of lean production and ERP systems, we have seen a clear need to develop generalized solutions that can help companies combine the best of both approaches in order to secure competitive advantage for the future. We suggest that the results and contributions that have arisen from this research project certainly indicate a trend towards the use of ERP systems to support lean production principles and practices. In response of this trend, ERP vendors have begun to offer their own take on "lean modules", for example Microsoft Dynamics AX 2012 and its "*Lean Manufacturing*" software (Volkmann, 2011). Though it was never the intention of this research project to quantify the "leanness" of ERP systems, we suggest that the move towards ERP-enabled lean production should be examined closer in order to attempt to quantify the effects of such an approach.

The continuous development of IT will only increase the capabilities of contemporary ERP systems, which will in turn enable these systems to become even more effective in supporting the practices associated with lean production. Though neither lean production nor ERP can be considered as a panacea, indications suggest that through the systematic integration of both approaches, manufacturers are able to overcome a number of problems that neither can prevail in isolation. This has been illustrated for example in addressing the problems associated with traditional paper Kanban (such as lost cards and long-distance, long lead-time suppliers); and with the consequences of using poorly thought-out parameters in the ERP system (such as excessive buffers in safety stocks and production lead-times). We suggest that the advent of real-time and web-enabled ERP in combination with the application of lean thinking will enable manufacturers in high-cost countries to increase their competitive edge in light of the challenges they face from globalization and rivals in low-cost regions.

8 References

Achanga, P., Shehab, E., Roy, R. & Nelder, G. 2006. Critical success factors for lean implementation within SMEs. *Journal of Manufacturing Technology Management,* 17 (4)**,** 460-471.

Adler, N., Shani, A. B. & Styhre, A. 2004. *Collaborative Research in Organizations,* Thousand Oaks, Sage.

Aggarwal, S. C. 1985. MRP, JIT, OPT, FMS? Making sense of production operating systems. *Harvard Business Review,* 63 (5)**,** 8-16.

Al-Mashari, M. 2002. Enterprise Resource Planning (ERP) Systems: a research agenda. *Industrial Management and Data Systems,* 102 (3)**,** 165-170.

Alfnes, E. 2005. *Enterprise Reengineering - A strategic framework and methodology,* Trondheim, Norway, Doctoral Thesis, Norwegian University of Science and Technology.

Apics 2009. *APICS Operations Management Body of Knowledge Framework,* Chicago, APICS The Association for Operations Management.

Arbnor, I. & Bjerke, B. 2009. *Methodology for Creating Business Knowledge,* London, SAGE Publications.

Arnold, J. R. T., Chapman, S. N. & Clive, L. M. 2008. *Introduction to Materials Management,* Upper Saddle River, NJ, Pearson Prentice Hall.

Bartholomew, D. 1999. Lean vs ERP. *Industry Week,* 248 (14)**,** 24-30.

Beckhard, R. & Harris, R. 1987. *Organizational Transitions: Managing Complex Change,* Reading, MA, Addison-Wesley.

Bell, S. 2006. *Lean Enterprise Systems: Using IT for Continuous Improvement,* Hoboken, NJ, Wiley and Sons.

Benbasat, I., Goldstein, D. K. & Mead, M. 1987. The Case Research Strategy in Studies of Information Systems. *MIS Quarterly,* 11 (3)**,** 369-386.

Benhabib, B. 2003. *Manufacturing: Design, Production, Automation and Integration,* New York, Marcel Dekker.

Benton, W. C. & Shin, H. 1998. Manufacturing Planning and Control: The evolution of MRP and JIT integration. *European Journal of Operational Research,* 110 411-440.

Bicheno, J. & Holweg, M. 2009. *The Lean Toolbox,* Buckingham, PICSIE Books.

Bjorklund, J. 2009. 10 Ways to Use ERP to Lean the Manufacturing Supply Chain. *Managing Automation* [Online]. Available: http://www.managingautomation.com/uploadedimages/downloads/10_Ways_ERP_Lean_Manuf.pdf [Accessed September 2010].

Blackstone, J. H. & Cox, J. 2005. *APICS Dictionary,* Chicago, IL, APICS.

Borell, A. & Hedman, J. 2000. CVA Based Framework for ERP Requirements Specification. *In:* SVENSSON, L., SNIS, U., SØRENSEN, C., FAGERLIND, H., LINDROTH, T., MAGNUSSON, M. & OSTLAND, C. (eds.) *Proceedings of IRIS 23.* Laboratorium for Interaction Technology, University of Trollhattan Uddevalla.

Bradbury-Huang, H. 2010. What is good action research? *Action Research,* 8 (1)**,** 93-109.

Browne, J., Harhen, J. & Shivnan, J. 1988. *Production Management Systems: A CIM Perspective,* New York, Addison-Wesley.

Browne, J., Harhen, J. & Shivnan, J. 1996. *Production Management Systems: an Integrated Perspective,* Harlow, Addison-Wesley.
Bruun, P. & Mefford, R. N. R. N. 2004. Lean production and the Internet. *International Journal of Production Economics,* 89 (3)**,** 247-260.
Bryman, A. 1988. *Doing Research in Organisations,* London, Routledge.
Buonanno, G., Faverio, P., Pigni, F., Ravarini, A., Sciuto, D. & Tagliavini, M. 2005. Factors affecting ERP system adoption: A comparative analysis between SMEs and large companies. *Journal of Enterprise Information Management,* 18 (4)**,** 384-426.
Buxey, G. 1989. Production scheduling: Practice and theory. *European Journal of Operational Research,* 39 17-31.
Carroll, B. J. 2007. Lean VS ERP: Can't We All Just Get Along? [Online]. [Accessed September 2009].
Chase, R. B., Jacobs, F. R. & Nicholas, J. A. 2004. *Operations Management for Competitive Advantage*, McGrawHill Irwin.
Chen, I. J. & Popovich, K. 2003. Understanding customer relationship management (CRM). People, process and technology. *Business Process Management Journal,* 9 (5)**,** 672-688.
Coghlan, D. & Brannick, T. 2005. *Doing Action Research in Your Own Organization,* London, Sage.
Coghlan, D. & Brannick, T. 2010. *Doing Action Research in Your Own Organization,* London, Sage.
Collier, D. A. & Evans, J. R. 2006. *Operations Management: Goods, Service, and Value Chains,* Mason, Cengage Learning.
Cooney, R. 2002. Is “lean” a universal production system?: Batch production in the automotive industry. *International Journal of Operations & Production Management,* 22 (10)**,** 1130-1147.
Coughlan, P. & Coghlan, D. 2009. Action Research for Operations Management. *In:* KARLSSON, C. (ed.) *Researching Operations Management.* New York, NY: Taylor & Francis.
Croom, S. 2009. Introduction to Research Methodology in Operations Management. *In:* KARLSSON, C. (ed.) *Researching Operations Management.* New York: Routledge.
Cunningham, J. & Jones, D. 2007. *Easier, simpler, faster: systems strategy for lean IT,* New York, Productivity Press.
Czarniawska-Joerges, B. 1992. *Exploring Complex Organizations: A Cultural Perspective,* Newbury Park, California, Sage.
Davenport, T. H. 1998. Living with ERP. *CIO Magazine,* 12 (5)**,** 30-32.
Davydov, V. V. 1990. Types of generalisation in instruction: Logical and psychological problems in the structuring of school curricula. *In:* KILPATRICK, J. (ed.) *Soviet studies in mathematics education.* Reston, VA: National Council of Teachers of Mathematics.
Deming, W. E. 1986. *Out of the Crisis,* Cambridge, Massachusetts Institute of Technology.
Dickmann, P. 2006. *Schlanker Materialfluss: mit Lean Production, Kanban und Innovationen* Berlin,, Springer Verlag.

Discenza, R. & Macfadden, F. R. 1988. The integration of MRP II and JIT through software unification. *Production and Inventory Management,* 29 49-53.
Drejer, A., Blackmon, K. & Voss, C. 2000. Worlds apart? - a look at the operations management area in the US, UK and Scandinavia. *Scandinavian Journal of Management,* 16 (2000)**,** 45-66.
Eisenhardt, K. M. 1989. Building Theories from Case Study Research. *Academy of Management: The Academy of Management Review,* 14 (4)**,** 532-549.
Eisenhardt, K. M. & Graebner, M. E. 2007. Theory building from cases: opportunities and challenges. *Academy of Management Journal,* 50 (1)**,** 25-32.
European Commission 2007. *FP7 NMP-2007-3.1-1 Beyond Lean Manufacturing*.
European Commission. 2010. *Small and medium-sized enterprises (SMEs): Fact and figures about the EU´s Small and Medium Enterprise (SME)*. 2010. Available: http://ec.europa.eu/enterprise/policies/sme/facts-figures-analysis/index_en.htm.
Flapper, S. D. P., Miltenburg, G. J. & Wijngaard, J. 1991. Embedding JIT into MRP. *International Journal of Production Research,* 29 (2)**,** 329-341.
Flegel, H. 2006. MANUFUTURE Strategic Research Agenda. *Report of the High-Level Group* [Online]. Available: http://www.manufuture.org/manufacturing/wp-content/uploads/Manufuture-SRA-web-version.pdf [Accessed 27 February 2012].
Flyvbjerg, B. 2006. Five Misunderstandings About Case-Study Research. *Qualitative Inquiry,* 12 (2)**,** 219-245.
Forza, C. 2002. Survey Research in Operations Management: a Process-based Perspective. *International Journal of Operations & Production Management,* 22 (2)**,** 152-194.
Gibbons-Paul, L. 2008. Lean manufacturing and ERP not mutually exclusive, experts say. *SearchManufacturingERP.com* [Online]. Available: http://searchmanufacturingerp.techtarget.com/news/1333817/Lean-manufacturing-and-ERP-not-mutually-exclusive-experts-say [Accessed January 2011].
Gill, J. & Johnson, P. 1991. *Research Methods for Managers,* London, Paul Chapman Publishing.
Glovia. 2008. Supporting Lean Manufacturing with ERP. *Fujitsu Glovia International* [Online]. Available: http://www.glovia.com/whitepapers/getPDF/O72f6UvAw.aspx [Accessed 1 February 2012].
Goeldner, T. & Powell, D. 2011. The Use of Information Technology in Lean Production: Results of a Transnational Survey. *In:* DREYER, H. C., STRANDHAGEN, J. O. & BJARTNES, R. (eds.) *13th International Conference on Modern Information Technology in the Innovation Processes of Industrial Enterprises (MITIP).* Trondheim: SIT Tapir.
Guba, E. G. & Lincoln, Y. S. 1989. *Fourth Generation Evaluation,* Thousand Oaks, CA, Sage.
Guba, E. G. & Lincoln, Y. S. 1994. Competing Paradigms in Qualitative Research. *In:* DENZIN, N. K. & LINCOLN, Y. S. (eds.) *Handbook of qualitative research.* Thousand Oaks, CA: Sage.
Gummesson, E. 2000. *Qualitative Methods in Management Research,* Thousand Oaks, California, Sage Publications.

Halgari, P., Mchaney, R. & Pei, Z. J. 2011. ERP Systems Supporting Lean Manufacturing in SMEs. *In:* CRUZ-CUNHA, M. M. (ed.) *Enterprise Information for Systems Business Integration in SMEs: Technological, Organizational, and Social Dimensions* Hershey, PA: Business Science Reference.
Halldórsson, Á. & Aastrup, J. 2003. Quality criteria for qualitative inquiries in logistics. *European Journal of Operational Research,* 144 (2)**,** 321-332.
Hamilton, S. 2003. *Maximizing your ERP system: a practical guide for managers* New York, McGraw Hill.
Hamilton, S. 2009. *Managing Lean Manufacturing using Microsoft Dynamics AX,* New York, McGraw Hill.
Hayes, R. H. & Wheelwright, S. C. 1979. Link manufacturing process and product life cycles. *Harvard Business Review,* 57 (1)**,** 133-140.
Herr, K. & Anderson, G. L. 2005. *The Action Research Dissertation: A guide for students and faculty,* Thousand Oaks, Ca., Sage.
Hicks, B. J. 2007. Lean information management: Understanding and eliminating waste. *International Journal of Information Management,* 27 (4)**,** 233-249.
Hiebert, J. & Lefevre, P. 1986. Conceptual and procedural knowledge in mathematics: An introductory analysis. *In:* HIEBERT, J. (ed.) *Conceptual an procedural knowledge: The case of mathematics.* Hillsdale, NJ: Lawrence Erlbaum.
Higgins, P., Le Roy, P. & Tierney, L. 1996. *Manufacturing Planning and Control Beyond MRP II,* London, Chapman and Hall.
Hill, T. 2005. *Operations Management,* New York, Palgrave Macmillan.
Hillberg, J. 2012. Sweden's take on lean. *Lean Management Journal,* 2 (2)**,** 32-36.
Hines, P. 2010. *The Principles of the Lean Business System* [Online]. S A Partners. Available: http://www.sapartners.com/images/pdfs/the%20principles%20of%20the%20lean%20business%20system.pdf [Accessed February 2011].
Hirano, H. 1995. *5 Pillars of the Visual Workplace - The Sourcebook for 5S Implementation,* New York, Productivity Press.
Hitt, L. M., Wu, D. J. & Zhou, X. 2002. ERP Investment: Business Impact and Productivity Measures. *Journal of Management*.
Hofmann, P. 2008. ERP is Dead, Long Live ERP. *IEEE Internet Computing,* 2008 (July/August)**,** 80-84.
Holweg, M. 2007. The genealogy of lean production. *Journal of Operations Management,* 25 (2)**,** 420-437.
Hopp, W. J. & Spearman, M. L. 2004. To Pull or Not to Pull: What is the Question? *Manufacturing & Service Operations Management,* 6 (2)**,** 133-148.
Houy, T. 2005. ICT and Lean Management: Will They Ever Get Along? Available: http://mpra.ub.uni-muenchen.de/2502/ [Accessed September 2010].
Hult, M. & Lennung, S.-Å. 1980. Towards a definition of action research: A note and bibliography. *Journal of Management Studies,* 17 (2)**,** 241-250.
Huq, Z. & Huq, F. 1994. Embedding JIT in MRP: The case of job shops. *Journal of Manufacturing Systems,* 13 (3)**,** 153-164.
Ifs. 2008. Going Lean, Step by Step, with IFS Applications. Available: http://www.manmonthly.com.au/Article/Going-Lean-Step-by-Step-with-IFS-Applications [Accessed September 2009].

Ifs 2010. IFS Applications for Lean manufacturing. *IFS AB.*
Imai, M. 1986. *Kaizen: The Key to Japan's Competitive Success,* New York, McGraw Hill.
Jacobs, F. R. & Bendoly, E. 2003. Enterprise resource planning: Developments and directions for operations management research. *European Journal of Operational Research,* 146 (2), 233-240.
Jina, J., Bhattacharya, A. K. & Walton, A. D. 1997. Applying lean principles for high product variety and low volumes: some issues and propositions. *Logistics Information Management,* 10 (1), 5-13.
Jonsson, P. 2008. *Logistics and Supply Chain Management,* London, McGraw-Hill.
Järvinen, P. 2007. Action Research is Similar to Design Science. *Quality & Quantity,* 41 (1), 37-54.
Jørgensen, J. K. 2012. Denmark: fairytale lean. *Lean Management Journal,* 2 (2), 37-40.
Karlsson, C. 2009. *Researching operations management,* New York, Routledge.
Katayama, H. & Bennett, D. 1996. Lean production in a changing competitive world: a Japanese perspective. *International Journal of Operations & Production Management,* 16 (2), 8-23.
Kidder, L. & Judd, C. M. 1986. *Research Methods in Social Relations,* New York, Holt, Rinehart & Winston.
Kochan, T., Lansbury, R. & Macduffie, J. 1997. *After Lean Production. Evolving Employment Practices in the World Auto Industry,* Ithica, ILR Press.
Koh, S. C. L., Gunasekaran, A. & Rajkumar, D. 2008. ERP II: The involvement, benefits and impediments of collaborative information sharing. *International Journal of Production Economics,* 113 (1), 245-268.
Krafcik, J. F. 1988. Triumph of the lean production system. *Sloan Management Review,* 30 (1), 41-52.
Krajewski, L. J., King, B. E., Ritzman, L. P. & Wong, D. S. 1987. Kanban, MRP, and Shaping the Manufacturing Environment. *Management Science,* 33 (1), 39-57.
Laukkanen, S., Sarpola, S. & Hallikainen, P. 2007. Enterprise size matters: objectives and constraints of ERP adoption. *Journal of Enterprise Information Management,* 20 (3), 319-334.
Lee, H. L., Padmanabhan, V. & Whang, S. 1997. Information distortion in a supply chain: The Bullwhip effect. *Management Science* 43 (4), 546-558.
Leonard-Barton, D. 1990. A dual methodology for case studies: Synergistic use of a longitudinal single site with replicated multiple sites. *Organization Science,* 1 1-19.
Liker, J. K. 2004. *The Toyota Way: 14 Management Principles From the World's Greatest Manufacturer,* New York, McGraw-Hill.
Loureiro, G., Leaney, P. G. & Hodgson, M. 2004. A systems engineering framework for integrated automotive development. *Systems Engineering,* 7 (2), 153-166.
Mabert, V. A., Soni, A. & Venkataramanan, M. A. 2001. Enterprise resource planning: Common myths versus evolving reality. *Business Horizons,* 44 (3), 69-76.
Mabert, V. A., Soni, A. & Venkataramanan, M. A. 2003. Enterprise resource planning: Managing the implementation process. *European Journal of Operational Research,* 146 (2), 302-314.

Marchwinski, C. & Shook, J. 2006. *Lean Lexicon,* Cambridge, The Lean Enterprise Institute.
Martin, J. W. 2010. *Measuring and Improving Performance: Information Technology Applications in Lean Systems,* New York, Productivity Press.
Masson, C. & Jacobson, S. 2007. Lean Planning and Execution Software: Extending Lean Thinking Across the Enterprise. Available: http://www.oracle.com/corporate/analyst/reports/industries/aim/amr-20378.pdf [Accessed September 2010].
Matsui, Y. 2007. An empirical analysis of just-in-time production in Japanese manufacturing companies. *International Journal of Production Economics,* 108 (1-2)**,** 153-164.
Mcniff, J. & Whitehead, J. 2009. *Doing and Writing Action Research,* Los Angeles, Sage.
Meredith, J., Raturi, A., Amoako-Gyampah, K. & Kaplan, B. 1989. Alternative Research Paradigms in Operations. *Journal of Operations Management,* 9 (4)**,** 297-326.
Miles, M. B. & Huberman, A. M. 1994. *Qualitative data analysis: an expanded sourcebook,* Thousand Oaks, CA, SAGE Publications.
Murphy, K. E. & Simon, S. J. 2002. Intangible benefits valuation in ERP projects. *Information Systems Journal,* 12 301-320.
Nakashima, B. & Berger, D. 2000. Can lean and ERP work together? *Advanced Manufacturing* [Online]. Available: http://www.automationmag.com/component/option,com_staticxt/Itemid,344/staticfile,informationtech.htm [Accessed September 2010].
Nicholas, J. M. 1998. *Competitive Manufacturing Management,* New York, McGraw Hill.
Ohno, T. 1988. *Toyota Production System: Beyond large-scale production* New York, Productivity Press.
Olhager, J. & Rudberg, M. 2002. Linking manufacturing strategy decisions on process choice with manufacturing planning and control systems. *International Journal of Production Research,* 40, no. 10 2335-2351.
Olhager, J. & Östland, B. 1990. An integrated push-pull manufacturing strategy. *European Journal of Operational Research,* 45 135-142.
Omar, M., Mears, L., Kurfess, T. & Kiggans, R. 2011. Organizational learning in automotive manufacturing: a strategic choice. *Journal of Intelligent Manufacturing,* 22 (5)**,** 709-715.
Orlicky, J. A. 1973. Net change material requirements planning. *IBM Systems Journal,* 12 (1)**,** 2-29.
Pettigrew, A. M. 1990. Longitudinal field research on change: Theory and practice *Organization Science,* 1 (3)**,** 267-292.
Philips, M. E. 2004. Action research and development coalitions in health care. *Action Research,* 2 (4)**,** 349-370.
Piszczalski, M. 2000. Lean vs. Information Systems. *Automotive Manufacturing & Production* [Online], 2000. Available: http://findarticles.com/p/articles/mi_m0FWH/is_8_112/ai_65073436/ [Accessed May 2011].

Pollock, N. & Cornford, J. 2001. Customising Industry Standard Computer Systems for Universities: ERP Systems and the University as a 'Unique' Organisation. *The Critical Management Studies Conference.*

Powell, D. 2011. Understanding customer value. *Lean Management Journal,* 2011 (13), 24-27.

Powell, D. 2012a. ERP Systems in Lean Production: New insights from a review of Lean and ERP literature. *International Journal of Operations & Production Management,* Accepted for publication.

Powell, D. 2012b. Norway, a lean champion. *Lean Management Journal,* 2 (2), 41-44.

Powell, D., Alfnes, E. & Semini, M. 2009. The Application of Lean Production Control Methods within a Process-Type Industry: The Case of Hydro Automotive Structures. *APMS 2009: International Conference on Advances in Production Management Systems.* University of Bordeaux, Bordeaux, France: Springer.

Powell, D., Alfnes, E., Strandhagen, J. O. & Dreyer, H. 2011. ERP support for lean production. *APMS 2011: International Conference on Advances in Production Management Systems.* Stavanger, Norway. 26-28 September 2011: Springer.

Powell, D., Alfnes, E., Strandhagen, J. O. & Dreyer, H. 2012a. The concurrent application of lean production and ERP: Towards an ERP-based lean implementation process. *Computers in Industry,* In Review.

Powell, D., Riezebos, J. & Strandhagen, J. O. 2012b. Lean production and ERP systems in SMEs: ERP support for pull production. *International Journal of Production Research,* Available online 23 January 2012.

Powell, D. & Strandhagen, J. O. 2011. Lean Production Vs. ERP Systems: An ICT Paradox? *Operations Management,* 37 (3), 31-36.

Prasad, S. & Babbar, S. 2000. International operations management research. *Journal of Operations Management,* 18 (2), 209-247.

Prediktor. 2010. Lean. Available: http://www.prediktor.no/business_solutions/lean/Pages/default.aspx [Accessed February 2011].

Ptak, C. A. 2004. *ERP: tools, techniques, and applications for integrating the supply chain,* Boca Raton, FL., St Lucie Press.

Reason, P. & Bradbury, H. (eds.) 2006. *Handbook of Action Research,* London: Sage Publications.

Reichel, M. & Ramey, M. A. 1987. *Conceptual frameworks for bibliographic education: Theory into practice,* Littleton, Colorado, Libraries Unlimited Inc.

Riezebos, J., Klingenberg, W. & Hicks, C. 2009. Lean Production and information technology: Connection or contradiction? *Computers in Industry,* 60 237-247.

Rother, M. & Shook, J. 2003. *Learning to See,* Cambridge, Lean Enterprise Institute.

Schein, E. H. 1995. Process consultation, action research and clinical inquiry: Are they the same? *Journal of Managerial Psychology,* 10 (6), 14-19.

Schonberger, R. J. 1982. *Japanese manufacturing techniques: nine hidden lessons in simplicity,* New York, Free Press.

Schonberger, R. J. 2007. Japanese production management: An evolution - with mixed success. *Journal of Operations Management,* 25 (2), 403-419.

Schonberger, R. J. 2012. Lean's Western beginnings: The JIT era and the transition to lean. *Lean Management Journal,* 2 (2), 26-30.

Shah, R. & Ward, P. T. 2003. Lean manufacturing: context, practice bundles, and performance. *Journal of Operations Management,* 21 (2), 129-149.
Shang, S. & Seddon, P. B. 2000. A comprehensive framework for classifying the benefits of ERP systems. *Proceedings of America's Conference on Information Systems (AMCIS 2000).*
Sheldon, D. H. 2005. *Class A ERP Implementation,* Boca Raton, FL., Ross.
Shingo, S. 1981. *A Study of the Toyota Production System,* New York, Productivity Press.
Shingo, S. 1985. *A Revolution in Manufacturing: The SMED System,* New York, Productivity Press.
Silverman, D. 2001. *Interpreting Qualitative Data: Methods for Analysing Talk, Text and Interaction,* London, Sage Publications.
Singleton, D. 2011. How Manufacturing Software Should Adapt to Support Lean Principles. *Software Advice* [Online]. Available: http://blog.softwareadvice.com/articles/manufacturing/how-manufacturing-software-should-adapt-to-support-lean-principles-1121511/ [Accessed 10 January 2012].
Slack, N., Chambers, S. & Johnston, R. 2007. *Operations Management,* Harlow, FT Prentice Hall.
Smyth, R. 2004. Exploring the usefulness of a conceptual framework as a research tool: A researcher's reflections. *Issues in Educational Research,* 14 (2), 167-180.
Snider, B., Silveira, G. J. C. D. & Balakrishnan, J. 2009. ERP implementation at SMEs: Analysis of five Canadian cases. *International Journal of Operations & Production Management,* 29 (1), 4-29.
Spathis, C. & Constantinides, S. 2003. The usefulness of ERP systems for effective management. *Industrial Management & Data Systems,* 103 (9), 677-685.
Stadtler, H. 2005. Supply chain management and advanced planning: basics, overview and challenges. *European Journal of Operational Research,* 163 (3), 575-588.
Steger-Jensen, K. & Hvolby, H.-H. 2008. Review of an ERP System Supporting Lean Manufacturing. *In:* KOCH, T. (ed.) *IFIP International Federation for Information Processing: Lean Business Systems and Beyond.* Boston: Springer.
Sugimori, Y., Kusunoki, K., Cho, F. & Uchikawa, S. 1977. Toyota production system and Kanban system Materialization of just-in-time and respect-for-human system. *International Journal of Production Research,* 15 (6), 553 - 564.
Suri, R. 1998. *Quick response manufacturing: a companywide approach to reducing leadtimes,* Portland, OR, Productivity Press.
Suri, R. 2003. *How to implement Polca: A Material Control System for High Variety or Custom Engineered Products* [Online]. Available: http://www.apics-nwie.org/images/uploads/polca.pdf [Accessed May 2009].
Tjahjono, B. 2009. Supporting shop floor workers with a multimedia task-oriented information system. *Computers in Industry,* 60 (4), 257-265.
Tsai, W. H., Cheng, J. M. S., Leu, J. D., Fan, Y. W., Hsu, P. Y., Chou, L. W. & Yang, C. C. 2007. The relationship between implementation variables and performance improvement of ERP systems. *International Journal of Technology Management,* 38 (4), 465-474.
Volkmann, C. 2011. Lean Manufacturing: Kanban and Pull Based Manufacturing. *Microsoft Dynamics® AX 2012* [Online]. Available:

http://www.microsoft.com/download/en/confirmation.aspx?id=26918 [Accessed March 23rd 2012].

Vollmann, T. E., Berry, W. L., Whybark, D. C. & Jacobs, R. F. 2005. Manufacturing Planning and Control for Supply Chain Management. *McGraw-Hill, Boston*.

Voss, C. A., Tsikriktsis, N. & Frohlich, M. 2002. Case Research in Operations Management. *International Journal of Operations & Production Management,* 22 (2)**,** 195-210.

Wallace, T. F. & Kremzar, M. H. 2001. *ERP : Making IT Happen. The implementers' guide to success with enterprise resource planning,* Hoboken, NJ, John Wiley and Sons.

Waller, D. L. 1999. *Operations management: a supply chain approach,* London, UK, International Thomson Business Press.

Wan, H.-D. & Chen, F. F. 2008. A web-based kanban system for job dispatching, tracking, and performance monitoring. *International Journal of Advanced Manufacturing Technologies,* 38 995-1005.

Wan, H.-D. & Chen, F. F. 2009. Decision support for lean practitioners: A web-based adaptive assessment approach. *Computers in Industry,* 60 (4)**,** 277-283.

Ward, P. T. & Zhou, H. 2006. Impact of IT Integration and Lean/JIT Practices on Lead time Performance. *Decision Sciences,* 37 (2)**,** 177-203.

Wight, O. W. 1984. *Manufacturing Resource Planning: MRP II: Unlocking America's Productivity Potential,* Brattleboro, Vermont, The Book Press.

Williams, D. 2010. Grasp growth not pennies. *Lean Management Journal,* 2010 (7)**,** 7-9.

Womack, J. P. & Jones, D. T. 1996. *Lean Thinking: Banish Waste and Create Wealth in Your Corporation,* New York, Simon and Schuster.

Womack, J. P., Jones, D. T. & Roos, D. 1990. *The Machine that Changed the World,* New York, Harper Perennial.

Woods, J. 2008. Modernizing ERP: How to Make Users Fall in Love With ERP All Over Again. *Gartner Research* [Online]. Available: http://www.sdn.sap.com/irj/scn/go/portal/prtroot/docs/library/uuid/a0a93876-a35b-2b10-5583-b04ab7fa32a0?QuickLink=index&overridelayout=true&32220844666643 [Accessed March 8th 2012].

Yin, R. K. 2009. *Case study research: design and methods,* Thousand Oaks, California, Sage Publications.

Zhang, Z., Lee, M. K. O., Huang, P., Zhang, L. & Huang, X. 2005. A framework of ERP systems implementation success in China: An empirical study. *International Journal of Production Economics,* 98 (1)**,** 56-80.

Zuber-Skerritt, O. & Fletcher, M. 2007. The quality of an action research thesis in the social sciences. *Quality Assurance in Education,* 15 (4)**,** 413-436.

Zuber-Skerritt, O. & Perry, C. 2002. Action research within organizations and university thesis writing. *The Learning Organization,* 9 (4)**,** 171-179.

Zäpfel, G. 1996. Production planning in the case of uncertain individual demand - extension for an MRP II concept. *International Journal of Production Economics,* 46-47 153-164.

Zäpfel, G. & Missbauer, H. 1993. New concepts for production planning and control. *European Journal of Operational Research,* 67 297-320.

Part II: Collection of Articles

Paper I

PAPER 1

Goeldner, T. & Powell, D.J. (2011) **The use of information technology in lean production: Results of a transnational survey.** *13th International MITIP Conference, 22-24 June 2011*. Trondheim, Norway: Tapir.

THE USE OF INFORMATION TECHNOLOGY IN LEAN PRODUCTION:

RESULTS OF A TRANSNATIONAL SURVEY

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ABSTRACT:

Today, companies are faced with several new challenges such as globalization, increasing competitive pressures, and shorter product life cycles. Two possible ways to cope with these challenges are the implementation of lean practices and the integration of IT systems. This paper presents results of a transnational survey that was conducted amongst manufacturing companies in Norway and Germany. Through the development and application of an online questionnaire, we compare the use of lean practices and ITs within the companies, and draw conclusions between the use of IT in the best-in-class lean companies compared with those used in below-industry-average companies. Results show that companies using advanced ITs such as ERP are more successful with lean practices, for example standardization, levelled production, quick changeovers, and customer relationship management.

KEYWORDS:

Information technology, Lean production, Enterprise resource planning (ERP) systems

INTRODUCTION

Today companies are faced with several new challenges such as globalization, increasing competitive pressure, shorter product life cycles, and shorter technology innovation cycles. Customers are demanding more variety and increased quality, delivered in shorter lead times and at a lower price. Never before have companies faced a greater need to become more agile and responsive (Pope, 2008). In order to survive, companies have had to develop strategies to deal with these challenges. Two popular ways are the implementation of lean practices and the integration of information technology (IT).

Lean production is a strategy that aims for the production of high quality products at the pace of customer demand and with little waste (Ward and Zhou, 2006). Womack and Jones (1996) identified five basic underlying principles for the elimination of waste: Specifying value, identifying the value stream, creating flow, establishing pull, and continuously seeking perfection. While these principles are quite constant, there are many different practices that are mentioned in connection with lean production. Thus, a standard definition for lean production does not exist.

Alternatively, by transmitting information electronically, ITs precipitate the information exchange speed between employees and enhance the quality of within company communication. Furthermore, they underpin the processing of information in the form of data (Houy, 2005).

Although IT integration and lean practices have a similar (if not the same) aim, they are often considered to be competing (Ward and Zhou, 2006). Several authors (e.g. Ward and Zhou, 2006; Bruun and Mefford, 2004; Pope, 2008) speak of an ideological battle between two opposing camps. Other authors have analysed the origins for this conflict (e.g. Riezebos *et al.*, 2009; Riezebos and Klingenberg, 2009). The explanations they offered are manifold and range from historical causes to shortcomings of modern IT integrations.

In order to further evaluate this conflict, we develop an online questionnaire addressing the use of ITs and lean practices within manufacturing companies. The rest of the paper is presented as follows: Chapter two describes the methodology chosen for the research, and the development of the survey instrument, whilst chapter three presents the results. Chapter four evaluates the analyses that were carried out. Finally, chapter five summarizes the results and draws conclusions to the work, and also identifies areas for future research.

METHODOLOGY

The chosen methodology for this paper is survey. A survey is an information collection method that aims to describe, compare, or explain individual and societal knowledge, feelings, values, preferences, and behaviour (Bradburn *et al.*, 2004). An internet-based (online) questionnaire was selected as the survey instrument. The aim of the questionnaire was to answer the following research questions:

1. What are the most commonly utilized IT solutions for manufacturing planning and control?

2. To what extent are lean practices adopted in manufacturing companies?

3. What are the influences of the most commonly utilized IT solutions on the adoption of lean practices?

An online questionnaire was selected on the grounds of several distinct reasons. Firstly, the selected companies are not in one precise geographical location but there is a long distance between them. Therefore, making an in-person interview or an on-site self-administered questionnaire with each company would require excessive resources. In comparison to postal questionnaires, online surveys have two substantial advantages. Firstly there is no cost for postage, and secondly the participant can transmit data direct from his or her computer with little or no effort in returning the completed questionnaire.

Designing a questionnaire requires the development of questions which are appropriate to accomplish the determined goals. Therefore, it has to be decided about the direction of impact of each question and how they should be asked. Generally, three different question types can be identified: multiple-choice, numerical open-ended and text open-ended. For the final survey instrument, multiple-choice was chosen as the preferred question type.

The online questionnaire consisted of three sections. The first acquired data about the general profile of the participating companies. It gathered information such as company size, type of industry, and type of production. The second section consisted of questions about the application of within-firm IT solutions, which would be used to answer RQ1. Finally, the questions in the third section gathered information about the extent of adopted lean practices in order to answer RQ2. RQ3 was answered by simultaneous analysis of the results of the first two questions.

RESULTS

For the survey, 138 emails were sent to different manufacturing companies in Norway and Germany. The companies were selected on the basis that they had been involved in previously conducted online questionnaires. The emails contained an introduction to the subject, an invitation for participating in the survey, and a link leading to the online questionnaire. 31 companies participated in the survey but only 24 submitted a complete questionnaire. The 7 companies that submitted an incomplete questionnaire were therefore removed from the following analyses. This gave a response rate of 17.4%. In accordance with Yusof and Aspinwall (1999), the normal response rate for a mailed survey is between 20-25%. On the other hand, some highly regarded publications were faced with even lower response rates. For example Shah and Ward (2003) had a response rate of only 6.7%. Therefore, a response rate of 17.4% can be regarded as acceptable.

The first aspect that was investigated was the general profile of the participating companies. This includes industry sector, number of employees and primary type of production. All analysed companies belonged to the manufacturing industry. The largest proportion with 25% of all respondents was the machinery and equipment sector. Companies that did not belong to one of the predefined selectable sectors ("Other") are the second largest proportion with 20.83%, followed by the electrical machinery and apparatus sector and the automotive sector with 12.5% each. The next biggest group is the fabricated metals and the chemical sector with 8.33% each. Companies producing textiles, measurement and test engineering and furniture were the smallest proportion with only 4.17% each.

Most of the companies that submitted a response (50%) had less than 250 employees. The second largest proportion (20.83%) was represented by companies with less than 500 employees, followed by companies with less than 50 employees (16.67%). Only three companies (12.5%) had more than 1000 employees.

The final part of the first section evaluated the companies' primary production strategy. The largest proportion of the companies (45.33%) had "make to order" as the primary production strategy. The second largest category (20.83%) was represented by those companies that "make to stock" or "assemble to order". The smallest portion consisted of companies that "engineer to order" (12.5%).

MOST COMMONLY UTILIZED IT SOLUTIONS FOR MANUFACTURING PLANNING AND CONTROL

In order to evaluate the most commonly utilized IT solutions for manufacturing planning and control (MPC), each of the respondents selected which solution(s) was(were) used for each of the MPC tasks. For our investigation, MPC tasks included sales and operations planning (SOP); master production scheduling (MPS); material planning; capacity planning; and production activity control (PAC). The IT solutions considered in this study and available as multiple-choice answers were: Pen & paper; Microsoft Excel; MRP; MRP II; ERP; APS; MES; and Custom (company specific) software. There was also an option for "Another kind of IT". Results can be seen in Figure 1. It appears that Microsoft Excel (79%) and ERP systems (67%) are the two most utilized IT solutions for manufacturing planning and control.

EXTENT OF IMPLEMENTED LEAN PRACTICES

One of the main aims of this study was to develop a survey instrument that could be used to assess the type and extent of lean practices that have been implemented within companies.

Therefore, the extent of implementation was determined for all companies by calculating an average score and standard deviation for each of ten selected lean practices. The ten lean practices chosen in this study are as follows, and are considered to be a representative sample of the lean practices identified in the literature:

- Workplace organization (Hirano, 1995)
- Continuous improvement (Imai, 1986)
- Total productive maintenance (Nakajima, 1988)
- Total quality management (Shah and Ward, 2003)
- Standardization (Ohno, 1988)
- Quick changeovers (Shingo, 1985)
- Levelled production (Bicheno and Holweg, 2009)
- Pull (Womack and Jones, 1996)
- Supplier relationship management (Nicholas and Soni, 2006)
- Customer relationship management (Simchi-Levi *et al.*, 2008)

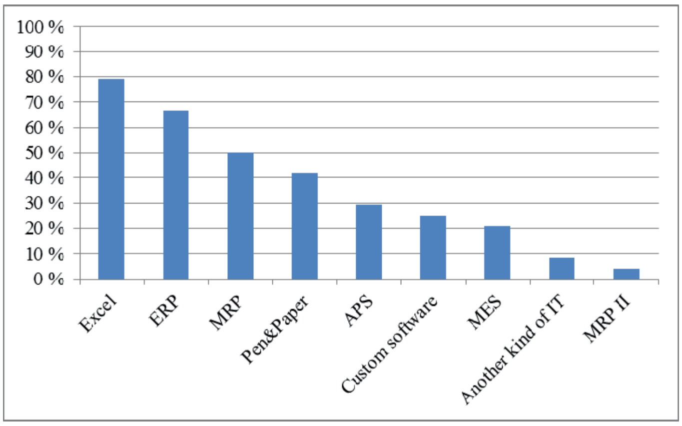

Figure 1: Most commonly utilized IT solutions for manufacturing planning and control

Using a Likert scale (1-5), the respondents scored themselves for the level of implementation of four sub-practices for each of the ten lean practices, where a score of one indicates (a perception of) no evidence of implementation, and a score of five indicates (a perception of) strong evidence of implementation. The implementation score was then measured by averaging the level of implementation for the four sub-practices associated with the ten main lean practices. Higher scores indicate a higher level of implementation. Table 1 summarizes the results. Customer relationship management and continuous improvement practices received the highest average scores (3.79 respectively 3.58). The categories lean production planning and scheduling and pull production received the lowest average score (2.49 and 2.57 respectively). The Standard Deviation was smallest for the category customer relationship management (0.63) and largest for quick changeovers (1.06).

Table 1: Average Implementation Level and Standard Deviation for Lean Practices

Lean Practice	Average Implementation Level	Standard Deviation
Customer relationship management	3,79	0,63
Total quality management	3,58	0,87
Standardization	3,36	0,83
Continuous improvement	3,27	0,75
Supplier relationship management	3,17	0,76
Workplace organization	3,10	0,73
Total productive maintenance	3,08	1,03
Quick changeovers	2,61	1,06
Pull	2,57	0,94
Levelled production	2,49	0,69

ANALYSIS

Based on the information about the extent of implemented lean practices provided by the respondents, the average score of lean implementation was used to distinguish the companies in three groups. Stratifying the data allows a better comparison between companies with high and low scores of lean implementation. For the following analyses, the respondents were segmented into three categories: "Best-in-class" (BIC - top 33.33% of companies with the highest implementation rate of lean practices), "Industry Average" (IA - the middle 33.33%) and "Below Industry Average" (BIA - the bottom 33.33%). Figure 2 displays the average lean score of these three groups. BIC companies have an average lean implementation score of 3.73. Companies that belong to the category of IA or BIA have implemented lean practices within their plant with scores of 3.19 and 2.51 respectively.

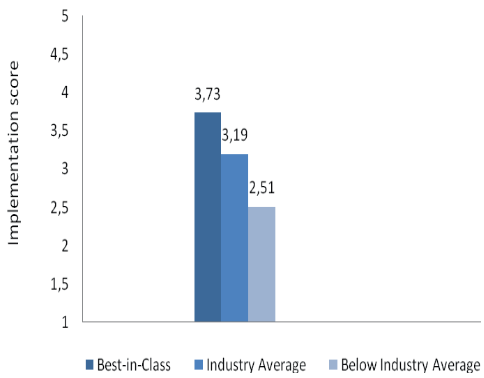

Figure 2: Average Lean Implementation Score (All Practices)

A Kruskal Wallis test was performed in order to determine if it was viable to separate the companies in accordance to their lean performance. The p-value for this test was calculated and is displayed in Table 2. Eight out of ten p-values show significance (p-value < 0.05).

Only the p-values for customer relationship management (0.078) and total quality management (0.077) are slightly higher than 0.05, but are therefore, however, not significant.

Table 2: Lean score of BIC-, IA- and BIA-companies

Lean Practice	BIC Lean Score	IA Lean Score	BIA Lean Score	p-value
Customer relationship management	4,16	3,63	3,59	0,07
Total productive maintenance	4,09	3,16	2,00	0,00
Standardization	4,06	3,16	2,88	0,04
Total quality management	4,03	3,66	3,06	0,08
Continuous improvement	3,91	3,38	2,53	0,01
Workplace organization	3,61	3,31	2,31	0,03
Supplier relationship management	3,52	3,19	2,81	0,04
Pull	3,16	2,75	1,81	0,01
Quick changeovers	3,06	2,98	1,78	0,00
Levelled production	3,05	2,53	1,88	0,00
Mean	3,665	3,175	2,465	

COMPARING THE USE OF IT SOLUTIONS BETWEEN BEST-IN-CLASS, INDUSTRY AVERAGE, AND BELOW INDUSTRY AVERAGE LEAN COMPANIES

This section analyses the results of the utilization of various IT solutions between BIC, IA, and BIA lean companies at the manufacturing planning and control (MPC) level.

Sales and Operations Planning

Table 3 shows what tools BIC, IA and BIA lean companies were using for sales and operation planning (SOP) and how many of each group were using them. (Note that multiple answers were possible).

While companies of the BIC group mainly used ERP (50%) and MRP (25%) software for this task, companies of the IA and BIA group were mainly using Excel (75% and 88% respectively). The analysis of the collected data revealed that BIC companies used only one single solution for SOP while companies of the other two groups often used two or more different solutions for this task.

Table 3: Tools for SOP

Tools for SOP	Best-in-Class	Industry Average	Below Industry Average
Pen & paper	0%	0%	25%
Excel	0%	75&	88%
MRP	25%	13%	13%
MRP 2	0%	0%	13%
ERP	50%	25%	50%
APS	13%	0%	0%
MES	0%	0%	0%
Custom software	13%	38%	25%
Another kind of IT	0%	13%	0%

Master Production Scheduling

Table 4 shows that BIC companies are using mainly ERP systems (75%) for master production scheduling (MPS) followed by MRP (38%) and APS (38%) systems. Though companies of the IA group were also mainly using ERP (50%) and MRP (50%) systems, companies of the BIA group were found to be mainly using Excel (88%) for this task.

Table 4: Tools for MPS

Tools for MPS	Best-in-Class	Industry Average	Below Industry
Pen & paper	0%	0%	0%
Excel	13%	38%	88%
MRP	38%	50%	38%
MRP 2	0%	0%	0%
ERP	75%	50%	25%
APS	38%	13%	0%
MES	0%	0%	0%
Custom software	0%	13%	0%
Another kind of IT	0%	0%	0%

Capacity Planning

Most of the BIC companies were using ERP (88%) systems for capacity planning, followed by APS (38%) systems. In the IA group, the tools used were Excel (63%), MRP (50%) and ERP (50%) systems. Companies of the BIA group were all using Excel (100%) with only sporadic use of MRP (38%) and ERP (25%) systems. Table 5 summarizes these findings:

Table 5: Tools for capacity planning

Tools for capacity planning	Best-in-Class	Industry Average	Below Industry
Pen & paper	0%	0%	13%
Excel	13%	63%	100%
MRP	25%	50%	38%
MRP 2	0%	0%	0%
ERP	88%	50%	25%
APS	38%	25%	0%
MES	0%	13%	13%
Custom software	0%	13%	13%
Another kind of IT	0%	13%	0%

Material Planning

Both the companies in the BIC group and the IA group were mainly using ERP (88% and 50% respectively), MRP (38% and 63% respectively) and APS (both 38%) for material planning. Additionally, IA companies were also often using Excel (50%). The group of BIA companies were mainly using MRP (50%), Excel (38%) and ERP (38%) software, which can be seen in table 6.

Table 6: Tools for material planning

Tools for MRP	Best-in-Class	Industry Average	Below Industry
Pen & paper	0%	0%	13%
Excel	0%	50%	38%
MRP	38%	63%	50%
MRP 2	0%	0%	13%
ERP	88%	50%	38%
APS	38%	38%	0%
MES	0%	0%	0%
Custom software	0%	13%	0%
Another kind of IT	0%	13%	0%

Production Activity Control

Finally, Table 7 shows the percentage use of IT solutions for production activity control (PAC) for the companies in the BIC, IA and BIA groups. The analysis revealed that BIC companies were mainly using ERP systems for this task, followed by pen and paper, MRP, APS and MES (each 25%). The preferred tools for PAC in the IA group were pen and paper (50%), Excel (38%) and ERP, MES and Custom software (each 25%). Companies of the BIA group chose for this task mainly Excel (63%), pen and paper (38%) and ERP (38%).

Table 7: Tools for PAC

Tools for PAC	Best-in-Class	Industry Average	Below Industry
Pen & paper	25%	50%	38%
Excel	13%	38%	63%
MRP	25%	0%	13%
MRP 2	0%	0%	0%
ERP	75%	25%	38%
APS	25%	0%	0%
MES	25%	25%	0%
Custom software	0%	25%	13%
Another kind of IT	0%	13%	0%

CONCLUSION

Table 8 gives an overview of the IT solutions with a significant or an almost significant influence on lean implementation scores. Based on the survey results it appears that the utilization of several within-firm IT solutions have an influence on the category of lean production planning and scheduling (leveled production). While companies which are using pen and paper and Excel have a very low score in this area, companies using APS and MES software have a very high lean score. Moreover, companies which are using pen and paper had a comparatively low score in total productive maintenance (TPM) and customer relationship management (CRM). Enterprises which did not used Excel had a much higher score in continuous improvement, TPM, total quality management (TQM), leveled production and pull practices than companies which used Excel.

The statistical analysis also showed that the implementation of MRP systems appears to have a negative influence on TQM score, whilst the implementation of an ERP system is shown to have a positive influence on the CRM score. Companies using APS and MES systems also had a significantly higher score in the application of levelled production than companies not using them.

Table 8: Overview of the use of IT solutions with a significant or an almost significant influence on applied lean practices

	Lean Score of company using IT solution	Lean Score of company not using IT solution	p-value
Pen and Paper			
TPM	2.63	3.50	*0.066*
Levelled production	2.08	2.80	*0.014*
CRM	3.55	3.95	*0.098*
Excel			
Continuous improvement	3.08	3.79	*0.03*
TPM	2.86	3.96	*0.02*
TQM	3.33	4.17	*0.02*
Levelled production	2.24	3.28	*0.01*
Pull	2.25	3.46	*0.01*
MRP			
TQM	3.42	3.92	*0.086*
ERP			
CRM	4.00	3.34	*0.041*
APS			
Levelled production	2.87	2.34	*0.046*
MES			
Levelled production	3.00	2.37	*0.085*

In the category sales and operation planning there exists no significant difference in the application of IT systems beside the fact that IA and BIA companies were using Excel more often for this task whilst none of the BIC companies used such software. For the task of master production scheduling, BIC companies were using ERP and APS systems more often than companies in the other two groups. The same result was found for capacity planning, where companies of the BIC group were again using ERP and APS systems more often than companies of the other two groups. In comparison with the other two groups, companies of the BIC class applied ERP systems more often. Additionally, it is worth mentioning that BIC and IA companies utilized APS systems whilst none of the BIA companies appeared to use this kind of IT solution. Also, for the task of production activity control, BIC companies were using ERP more often. To summarize, it can be said that BIC companies applied ERP and APS systems more often than the IA and BIA companies. On the other hand, companies of the IA and BIA group appeared to be using Excel and pen and paper for these planning tasks much more often.

In the literature, several authors discuss an ideological battle between the use of IT solutions and lean practices. This study marks an empirical effort to examine the influence of IT integration on lean adoption. The overarching goal of this work was to reveal whether or not these two approaches are complementary or competing. Therefore, a questionnaire was developed to evaluate the extent to which several IT solutions were adopted and for what they were used. Additionally, the extent of implemented lean practices was also measured. Afterwards, the extent of implemented lean practices was analyzed as a function of IT integration.

The analyses suggest that it would be misleading to say that the utilization of modern IT solutions should be minimized in order to achieve a high lean implementation rate, as this study revealed that companies using IT solutions did not have a lower lean implementation rate. Actually, the companies with best lean score were found to be using modern within-firm IT solutions to a much larger extent than companies with only a low lean implementation score. The individual consideration of each within-firm IT solution in connection with the extent of the implemented lean practices had revealed that companies which were using ERP, APS and MES systems had a higher perceived level of implementation in most of the lean practices than companies without these IT systems. On the other hand, companies which were using pen and paper, Excel and MRP had on the contrary a lower score in most of the lean practices. Dividing the companies into three groups relative to the extent of implemented lean practices and comparing the different utilization of within firm IT solutions between these groups confirmed this observation.

On one hand, this study revealed that the integration of modern IT solutions has a positive influence on the extent of implemented lean practices, whilst on the other hand it was shown in which way companies with BIC, IA, and BIA lean implementation scores differentiate in their use of IT solutions.

The main limitation of this study was the low response rate. Only 17% of 138 companies responded to the survey with usable results. A further limitation could be the terminology used for the IT solutions that were investigated. For example, it may be that the terms MRP, MRP II, and ERP were in fact confusing and could have resulted in misleading results (the survey was also set up so that respondents could select all three at any one time). Lean practices were also limited to ten areas. Though these give a representative sample of lean practices, future studies could expand this investigation to consider other lean practices, and indeed other IT solutions.

In terms of further research, as mentioned above, this study considered only ten lean practices. Further research could analyse the influence of IT on other facets of lean. Moreover, further research could concentrate on the way in which IT solutions and lean practices work together. In this paper, only the influence of IT integration on the extent of adopted lean practices was analysed. Further research could therefore concentrate on analysing in which manner IT solutions can facilitate lean practices. In this context it would be important to get to know in which way both approaches have to be combined for best results. In further research, one should also extend the scope of the study and gather additional financial and productivity measures. Implementing modern IT systems and lean practices costs time and money thus no company would do this if it cannot see or measure the results of these investments.

It is also interesting to observe that pull production and levelled scheduling had the lowest score as regards lean implementation (Table 1). Though companies that were using Microsoft Excel appeared to have implemented pull to a lesser extent than those not using Excel, there were no observations as to the role of ERP. Therefore, further work should investigate the role of ERP systems in lean production, particularly in terms of its support functionality for pull production.

REFERENCES

Bicheno, J. & Holweg, M. 2009. *The Lean Toolbox,* Buckingham, PICSIE Books.

Bradburn, N., Sudman, S. & Wansink, B. 2004 *Asking Questions: The Definitive Guide to Questionnaire Design- For Market Research, Political Polls, and Social and Health Questionnaires* San Francisco, Jossey-Bass.

Bruun, P. & Mefford, R. N. R. N. 2004. Lean production and the Internet. *International Journal of Production Economics,* 89 (3)**,** 247-260.

Hirano, H. 1995. *5 Pillars of the Visual Workplace - The Sourcebook for 5S Implementation,* New York, Productivity Press.

Houy, T. 2005. ICT and Lean Management: Will They Ever Get Along? Available: http://mpra.ub.uni-muenchen.de/2502/ [Accessed September 2010].

Imai, M. 1986. *Kaizen: The Key to Japan's Competitive Success,* New York, McGraw Hill.

Nakajima, S. 1988. *Introduction to TPM: Total Productive Maintenance,* New York, Productivity Press.

Nicholas, J. & Soni, A. 2006. *The Portal to Lean Production: Principles and Practices for Doing More with Less,* Boca Raton, FL, Auerbach Publications.

Ohno, T. 1988. *Toyota Production System: Beyond large-scale production* New York, Productivity Press.

Pope, C. 2008. Lean's last hand: information technology ready to lead manufacturing. *Industrial Engineer.*

Riezebos, J. & Klingenberg, W. 2009. Advancing lean manufacturing, the role of IT. *Computers in Industry,* 60 (4)**,** 235-236.

Riezebos, J., Klingenberg, W. & Hicks, C. 2009. Lean Production and information technology: Connection or contradiction? *Computers in Industry,* 60 237-247.

Shah, R. & Ward, P. T. 2003. Lean manufacturing: context, practice bundles, and performance. *Journal of Operations Management,* 21 (2)**,** 129-149.

Shingo, S. 1985. *A Revolution in Manufacturing: The SMED System,* New York, Productivity Press.

Simchi-Levi, D., Kaminsky, P. & Simchi-Levi, E. 2008. *Designing and Managing the Supply Chain. Concepts, Strategies, and Case Studies,* Boston, Massachusetts, McGraw-Hill/Irwin.

Ward, P. T. & Zhou, H. 2006. Impact of IT Integration and Lean/JIT Practices on Lead time Performance. *Decision Sciences,* 37 (2)**,** 177-203.

Womack, J. P. & Jones, D. T. 1996. *Lean Thinking: Banish Waste and Create Wealth in Your Corporation,* New York, Simon and Schuster.

Yusof, S. M. & Aspinwall, E. 1999. Critical success factors for total qualitymanagement implementation in small and medium enterprises *Total Quality Management & Business Excellence,* 10 (4)**,** 803-809.

PAPER 2

Powell, D. & Strandhagen, J.O. (2011) **Lean production vs. ERP systems: An ICT paradox?**
Operations Management 37 (3)

Paper II

LEAN PRODUCTION VS. ERP SYSTEMS: AN ICT PARADOX?

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ABSTRACT:

Lean production has lead to substantial improvements in performance across many industries and is widely implemented today. The development of ICT support for manufacturing has also led to substantial improvements in production effectiveness. While certain aspects of lean such as the focus on workplace organisation (5S) and total productive maintenance (TPM) have been applied to all types of industrial processes, the lean production control principles (i.e. JIT and kanban) have simply been avoided in the presence of ERP systems. With a focus on manufacturing planning and control, this paper aims to compare and contrast the differences between lean production control principles and ERP systems in order to identify the challenges of implementing both approaches within the manufacturing industry of today. The challenges will form areas for further research.

KEYWORDS:

Lean production; Enterprise resource planning; Manufacturing planning and control.

INTRODUCTION

Lean production and enterprise resource planning (ERP) systems are consistently rated in manufacturing improvement surveys as the two most important strategies being utilized by manufacturers attempting to compete for sales and profits in global markets (Carroll, 2007). Lean production, which is often described as a journey of waste reduction, has lead to substantial performance improvements across many industries and is widely implemented today. Although the development of advanced information and communication technology (ICT) support for manufacturing (i.e. ERP systems), has also led to improvements in production effectiveness, in lean thinking, technology has often been viewed as part of the non-value adding activity to be eliminated, rather than as a tool to help achieve and sustain positive change (Bell, 2006). Sugimori et al. (1977) stated that the use of computer systems for organising production logistics would introduce unnecessary cost, overproduction and uncertainty. However, describing the synergistic impact of technology and lean practices, Bell (2006) suggests that no longer is it possible to exclude technology from the lean approach. Goddard (2003) states that it is disappointing to find a lack of academic interest in the interactions between lean and ERP. Therefore, by employing a literature review methodology, this paper aims to compare and contrast the two production management methods, lean production and ERP systems.

LEAN PRODUCTION

Lean production is based on the manufacturing principles and work processes known as the Toyota Production System (TPS), which is built on two fundamental concepts, Just-in-time (JIT), and Jidoka. Shingo (1981) states that at Toyota, JIT means producing parts or products in exactly the required quantity – just when they are needed, and not before. Jidoka is the foundation to Toyota's philosophy of building in quality to products and processes, rather than inspecting it out (Liker, 2006). Bicheno and Holweg (2009) suggest that the driving force behind the Toyota production system (TPS) was the vision of Taiichi Ohno – of one at a time, completely flexible, no waste flow. It was in fact Ohno's vision that led to the development of the principles and practices that we now know as lean production.

ENTERPRISE RESOURCE PLANNING (ERP) SYSTEMS

Enterprise Resource Planning (ERP) systems are widely used by large corporations around the world (Pollock and Cornford, 2001) and have evolved from a technique used to plan dependant demand materials, known as Materials Requirement Planning (MRP), via a coherent set of best practices for the planning and control of resources, known as Manufacturing Resources Planning (MRP II). The root of all three of these concepts is a product's bill of material (BOM).

MRP was developed in the USA in the early 1960s and was widely implemented during the 1970s (Browne et al., 1988). Higgins et al. (1996) suggest that MRP thinking has revolutionized manufacturing planning and control. Applications of MRP were built around a bill of material processor (BOMP) which converted the aggregated plan of production for a parent item into a discrete plan of production or purchasing for individual component items content within the BOM. MRP logic can be summarised as an iteration of three consecutive steps (Higgins et al., 1996):

1. Netting against available inventory.
2. Calculation of planned orders.
3. Bill of materials explosion to calculate gross requirements for dependant items.

The main objective of MRP is to determine what and how much to order (both purchase and production orders). The input to this is the master production schedule (MPS). As the MRP calculation process makes no consideration of available capacity, a separate capacity requirements plan (CRP) must also be created. In the 1980s, the three separate key modules (MRP, MPS and CRP) were combined and coined as manufacturing resource planning (MRP II). In the 1990s, other functions were also added to this package, including product design, warehousing, human resources, and accounting, and enterprise resource planning (ERP) was born.

Companies are increasingly using off-the-shelf ERP solutions (Al-Mashari, 2002). But what about the future of ERP? Weston Jr. (2003) suggests that tomorrow's extended enterprise systems will comprise of technological changes that affect not only business strategies, but will also shape our fundamental ideas as to how to best serve customers and compete more efficiently, effectively and profitably, with a central emphasis on a clear flow of consistent, real-time information.

MANUFACTURING PLANNING AND CONTROL (MPC) SYSTEMS

To effectively consider ERP systems and lean production control on the same platform, it is important to define what is meant by an MPC system. A widely used MPC system framework is the centralized, hierarchical planning system suggested by Vollman et al. (2005), which is illustrated in Figure 1. Vollman et al. (2005) suggest that it is now most typical to find the MPC system embedded within the ERP system, as shown in the framework. For example, it is nowadays quite common to find a module for each planning mechanism (i.e. master production schedule; material planning; capacity planning) within the ERP system. The framework itself is divided into three phases – front end, engine, and back end.

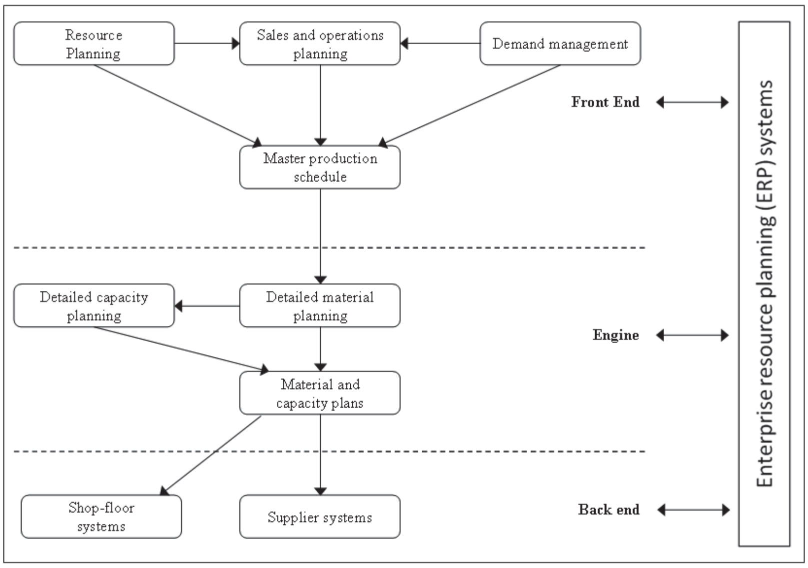

Figure 1: MPC System (Vollman et al., 2005)

The front end phase is the strategic level of the planning system, and aligns the long term production plans with the overall business plan. Included in this phase one would typically find the aggregate level sales and operations plan (SOP) and a long-term resources plan. Demand management is an integral part of the SOP, and encompasses the forecasting of customer (end-product) demand, order entry and order promising. Resource planning provides the basis for matching production forecasts with capacity. The SOP then balances sales and marketing plans with available production resources. The lowest level of the front end phase is the master production schedule (MPS). This is the disaggregated version of the SOP, and states which end items or product options will be produced in the future. The engine phase can be considered as the tactical level, encompassing all decisions for detailed material and capacity planning. First of all, the MPS contributes directly toward the detailed material plan, or the materials requirement plan (MRP). This breaks down the MPS into all of the component parts and raw materials required for production. The material plan can then be used to carry out the detailed capacity requirement plan. Finally, the back end phase represents the operational level, namely supplier systems (procurement) and shopfloor systems (production activity control, or PAC), and also includes performance measurement.

Figure 1 is designed in a way that makes it clear how an ERP system encompasses the tasks of the MPC system. But how does the implementation of lean production principles impact the MPC system? To answer this question, the Just-in-Time (JIT) concept must be addressed. JIT is the core lean principle which has the greatest impact on the MPC system, and has often been considered to be an alternative to MRP. JIT changes manufacturing practices, which requires a new way of thinking in the MPC system. The primary impact of JIT is on the back end, providing greater streamlined execution in both shop floor and purchasing systems (Vollman et al., 2005). However, JIT also impacts the front end, as it requires a levelled and stable MPS, as well as a level capacity load. The engine phase is also affected by JIT as bills of material become flatter due to cellular manufacturing, time buckets can be reduced (typically to one day or less), and no MRP netting logic is required in a true JIT environment, as order quantity logic in JIT is to make exactly what is required (Arnold et al., 2008).

Though there is a lack of a generalizable framework in current literature that illustrates a lean MPC system, we make reference to Sugimori et al. (1977), who demonstrate the use of kanban to indicate and fulfil material requirements at the back end phase. They suggest that by utilizing the kanban system, the workshops of Toyota no longer need to rely upon an 'electronic computer'. However, as kanban is used only at the operational level, it is unclear as to how the other levels of the MPC system are carried out, either with or without the application of ICT.

Shingo (1981) also describes production planning and schedule control at Toyota. He suggests that production planning in a JIT environment occurs in three stages: long-term master schedule (annual, biannual or quarterly), intermittent schedule (monthly), and detailed schedule (one week, three days, or one day):

> *Toyota's master schedule is based on extensive market research and yields a rough production number for sales. Unofficial monthly production numbers are given to the plant and to parts suppliers two months in advance and then firmed up a month later. These firm numbers are used to plan detailed daily and weekly schedules and to level the production sequence. Approximately two weeks before actual production, each line is given projected daily production numbers for each model. A single levelled schedule is sent to the end of the final assembly line, as are all daily changes, to match the schedule to actual orders. Changes are communicated back down the line through the kanban system.*
>
> (Shingo, 1981)

In his description of the system, Shingo suggests that kanban is used only to communicate requirements and changes back down the line throughout the day, as the daily levelled schedule is only sent to one point in the production system, the end of the final assembly line. By adjusting the intended schedule to actual customer orders through the use of kanban, a true pull system is created.

Lean Production vs. ERP Systems: an ICT Paradox?

A paradox can be defined as a statement or proposition that seems contradictory or absurd, but in reality expresses a possible truth (dictionary.com, 2009). This describes rather well the combination of lean production principles with ERP systems. Whereas in the past, ICTs such as ERP systems were regarded as waste by lean purists, in the current climate, the majority of manufacturers are using ERP systems to plan manufacturing operations whilst also developing a desire to move toward JIT production. ERP systems have become a requirement for modern manufacturers, whose customers demand an ever-increasing portfolio of products, resulting in 100s if not 1000s of stock keeping units (SKUs). Managing such a wide range of parts is not a simple task, hence the growing number of ERP systems available today. In order to manage such an array of products also makes the elimination of non-value added activity even more appealing to producers, hence the big question, ERP, lean, or both?

A common argument arising between lean production and ERP systems is that of pull vs. push. Benton and Shin (1998) suggest that there is a common agreement among researchers that a lean, kanban controlled production system functions as a pull system, whereas those systems using MRP logic (for example, within an ERP platform) are predominantly push. Rother and Shook (2003) suggest that to qualify as pull, parts must not be produced or conveyed when there is no kanban, and the quantity produced must be the same as specified on the kanban.

When defined in terms of information flow, in a pull system, the physical flow of materials is triggered by the local demand from the subsequent customer (via kanban). On the contrary, a push system uses global and centralized information stored within the central ERP system in order to drive all production stages (Olhager and Östland, 1990). This leads to the next contrast between lean and ERP. Where lean strives for decentralised control of production through empowered workers, ERP remains a centralised planning and control database. Stadtler (2005) suggests that ERP systems are incapable of performing real time control of production operations at the shopfloor. Rother and Shook (2003) also suggest that for lean production, a producer should get rid of those elements of an MRP system that try to schedule the different areas of a plant. A further contrast between the two approaches is that of the time-phased vs. rate-based argument (Alfnes, 2005). With lean, the aim is to achieve a level schedule of mixed-model production, synchronised with the rate of customer demand (takt-time). With ERP, the system often calculates an 'economic batch quantity' which is often based on machine utilization.

It becomes apparent that the main disconnect between lean production and ERP systems is that lean flow methods are used to control production activity over the short-term time horizon, and ERP in the form of the master production schedule (MPS) and materials requirement plan (MRP) work over the medium- to long-term.

According to Shingo (1981), MRP does not address itself to improving the basic production system in the same way as the Toyota Production System, which he suggests makes fundamental improvements in the system of control and management by:

- Drastically shortening setup and changeover times
- Using the shortened setups in the relentless pursuit of small lot production
- Carrying out coherent one-piece flow operations from parts processing to the assembly process
- Aiming to achieve order-based production through a pull system

However, these improvements within the manufacturing processes must also be reflected through simplification of the support processes. This means that lean thinking should also be applied to the ERP system.

Riezebos et al. (2009) suggest that ERP systems can dramatically reduce the amount of time required to obtain information relating to products and processes, as well as helping to increase the speed and quality of management decisions, whilst simultaneously reducing costs. Al-Mashari (2002) also states that the use of ERP can stimulate the adoption of standardised business processes throughout an organisation. These motivations and benefits are clearly well aligned with the principles of lean production. Furthermore, many lean companies are using ERP based approaches for communicating demand through the supply chain in order to facilitate just-in-time delivery, to the point where lean control principles (such as kanban) take over. Such hybrid situations (ERP-kanban) have in fact become quite common in modern industry.

Although traditional ERP systems were developed for internal company planning and optimisation only, ERP II (Koh et al., 2008) and Class A ERP (Sheldon, 2005) have more recently been developed to take a more holistic view of integration across whole supply chains by allowing direct external links over a web-based architecture (i.e. electronic data interchange, EDI). This is important for future developments of the lean paradigm, as we shift from lean production to the lean supply chain. For example, one area in which modern ERP systems could support lean is in enabling improved demand forecasting ability. Bjorklund (2009) states that the better the demand forecasting tool in the ERP system, the leaner the supply chain can be. However, Koh et al. (2008) state clearly that there is currently a lack of research on the subject of ERP II.

CONCLUSION

The suggested benefits of lean and ERP systems are almost identical, and include reduced cost, reduced inventory, and increased productivity (Womack et al., 1990; Goldratt, 2000; Falk, 2005; SAP, 2009). However, they are often considered to be mutually exclusive management principles. With this in mind, we aimed to address the paradox that exists between lean production and enterprise resource planning (ERP) systems, by taking an MPC system view in order to compare and contrast the two production management methods – see Table 1.

Table 1: A summary of the Lean-ERP Paradox

Lean	ERP
Production based on consumption (Pull)	Production based on forecasts and machine utilization (Push)
Decentralized control & empowerment (Bottom-up approach)	Centralized planning and control (Top-down approach)
Rate-based, mixed model production	Time-phased, batch production
Focus on maintaining flow	Focus on tracking material movements

Though in the traditional sense the two approaches have been labelled as contradictory, there does appear to be a synergistic impact to be gained as a result of combining and synchronizing the two. This is because of the increased processing speed, capacity, and visibility of contemporary ERP systems that allows for closer coordination between shopfloor activities and the supply chain, as well as the continuous elimination of waste within lean production.

The lean-ERP paradox leads itself nicely into several areas for future research. For example, the combination of both production management approaches will allow opportunities for development in several areas: Firstly, lean thinking can be applied to not just manufacturing processes but also to ERP systems, in order to effectively align lean production control principles within the MPC system. Secondly, other emerging advanced ICTs can be applied within the MPC system in order to take advantage of the ability of ICTs to increase processing speed, capacity and visibility. Further work will therefore address the combination and alignment of lean production control principles with both ERP systems and other advanced ICTs, such as manufacturing execution systems (MES) and radio frequency identification (RFID), in order to design an effective MPC system which is able to increase the competitiveness of manufacturing organisations. Of particular relevance here of course will be further research into the ERP II concept, as Koh et al. (2008) point out that no significant research is available on the subject. We suggest that further work should take the form of case study research, giving empirical results and contributing to fresh knowledge in the academic literature. The support offered by ERP systems for the DBR principle could also be explored.

REFERENCES

Alfnes, E. (2005) Enterprise Reengineering: A Strategic Framework and Methodology. *Doctoral Thesis (NTNU).* 2005:153, Tapir, Trondheim.

Al-Mashari, M. (2002) Enterprise resource planning (ERP) systems: a research agenda. *Industrial Management and Data Systems* 102 (3) pp. 165-170.

Arnold, J.R.T., Chapman, S.N. and Clive, L.M. (2008) *Introduction to Materials Management.* Pearson Prentice Hall, New Jersey.

Bell, S. (2006) *Lean Enterprise Systems: Using IT for Continuous Improvement*. Wiley, New Jersey.
Benton, W.C. and Shin, H. (1998) Manufacturing Planning and Control: The evolution of MRP and JIT integration. *European Journal of Operational Research* 110 (1998) pp. 411-440.
Bicheno, J. and Holweg, M. (2009) *The Lean Toolbox (4th Ed.)*. PICSIE Books, Buckingham.
Bjorklund, J. (2009) *10 Ways to use ERP to lean the manufacturing supply chain.* IFS white paper.
Browne, J., Harhen, J. and Shivnan, J. (1988) *Production Management Systems.* Addison-Wesley, New York.
Carroll, B.J. (2007) *Lean Performance ERP Project Management*. (2nd Ed.) Auerbach, Florida.
dictionary.com (2009) *paradox* [online]. Available: http://dictionary.reference.com/browse/paradox (accessed October 2009).
Goddard, R.W. (2003) The Role of Information Technology in the Lean Enterprise. *IE 780S – Lean Manufacturing*, Spring 2003
Goldratt, E. M. & Cox, J. (1986) *The Goal.* North River Press, Great Barrington, MA.
Goldratt, E. M. (2000) *Necessary but not Sufficient.* North River Press, Great Barrington, MA.
Higgins, P., Le Roy, P. and Tierney, L. (1996) *Manufacturing Planning and Control Beyond MRP II.* Chapman and Hall, London.
Koh, S.C.L., Gunasekaran, A. and Rajkumar, D. (2008) ERP II: The involvement, benefits and impediments of collaborative information sharing. *International Journal of Production Economics* 113 (1) pp. 245-268.
Liker, J.K. (2006) *The Toyota Way Fieldbook.* McGraw-Hill, New York.
Olhager, J. and Östland, B. (1990) An integrated push-pull manufacturing strategy. *European Journal of Operational Research* 45 (1990) pp. 135-142.
Pollock, N. and Cornford, J. (2001) Customising Industry Standard Computer Systems for Universities: ERP Systems and the University as a 'Unique' Organisation. *Proceedings of the Critical Management Studies Conference, 2001.*
Riezebos, J., Klingenberg, W. and Hicks, C. (2009) Lean Production and Information Technology: Connection or Contradiction? *Computers in Industry* 60 (4) pp. 237-247
Rother and Shook (2003) *Learning to See.* The Lean Enterprise Institute, Brookline MA.
SAP (2009) *ERP: Business Benefits* [online]. Available: http://www.sap.com/solutions/business-suite/erp/businessbenefits/index.epx (accessed October 2009).
Shingo, S. (1981) *A Study of the Toyota Production System.* Productivity Press, New York.
Sheldon, D.H. (2005) *Class A ERP Implementation.* Ross, Boca Raton, FL.
Slack, N., Chambers, S. & Johnston, R. (2007) *Operations Management.* FT Prentice Hall, Harlow.
Stadtler, H. (2005) Supply chain management and advanced planning – basics, overview and challenges. *European Journal of Operational Research* 163 (2005) pp. 575-588.
Sugimori, Y.K., Kusunoki, F.C. and Uchikawa, S. (1977) Toyota production system and kanban system materialization of just-in-time and respect-for-human system. *International Journal of Production Research* 15 pp. 553-564
Vollman, T.E., Berry, W.L., Whybark, D.C. and Jacobs, F.R. (2005) *Manufacturing Planning and Control Systems for Supply Chain Management.* McGraw-Hill, New York.
Weston Jr. F.C. (2003) ERP II: The Extended Enterprise System. *Business Horizons* 46 (6) pp. 49-55.

PAPER 3

Powell, D. (2012) **ERP Systems in Lean Production: New insights from a review of Lean and ERP literature**

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Paper III

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ERP Systems in Lean Production: New insights from a review of Lean and ERP literature

Structured Abstract

Purpose *– Faced with increasing global competition and growing customer expectations, manufacturers looking for significant performance improvements often look to one of two choices: implementing an ERP system, or applying the tools and techniques associated with lean production. In fact, many companies are today applying both approaches in an attempt to realise competitive advantage in the global marketplace. However, there seems to be an on-going debate within the academic literature as to whether lean and ERP are complimentary or contradictory technologies. This paper aims to present a thorough and critical review of literature with the objective of bringing out pertinent factors and useful insights into the role and implications of ERP systems in lean production, and to develop a research framework that can be used by researchers and practitioners for studying the value of integrating ERP with lean.*

Design/methodology/approach *– The research methodology employed is literature survey. Literature has been collected primarily through journals within the area of operations management. For rigorousness, textbooks, conference papers, white papers and dissertations have been excluded from the subsequent analysis. Though older literature has been considered to define the scope of this investigation; only literature published after the year 2000 has been considered in the analysis in order to be current in the research field.*

Findings *– The paper proposes a classification scheme for current research on ERP and lean production, which identifies six major areas in the extant literature. The literature survey is used to find existing research gaps, and provides a research framework for future research directions regarding applications and implications of ERP systems in lean production.*

Originality/value *– This paper fulfils an identified need to study the interactions between ERP systems and lean production.*

Keywords: *Lean Production; Enterprise Resource Planning*

Article Type*: Literature review*

1. Introduction

It is generally accepted that lean production improves manufacturing processes with the application of recognized tools and techniques, and equally assumed that contemporary enterprise resource planning (ERP) systems are essential for companies seeking efficiencies through organizational integration. Traditionally, ERP systems have been implemented in order to integrate business processes and support managerial decision making. While the integration objective seems to fit with the holistic approach that is typical for lean, ERP systems have often been classed as sources of waste within lean production literature (Bell, 2006; Bruun and Mefford, 2004; Hicks, 2007; Sugimori *et al.*, 1977). For example, Piszczalski (2000) describes manufacturers as being "torn between two opposing camps", and Halgari *et al.* (2011) suggest that ERP systems have been considered a hindrance to lean manufacturing efforts and have been criticized for encouraging large inventories and slow production.

Based primarily on the working practices of the Toyota Production System (TPS), lean production is an increasingly applied operations paradigm for enhancing production effectiveness. It can be described as both a philosophy and a set of tools and techniques that aim to systematically identify and eliminate all waste in processes, with an underlying vision of one-piece flow (Bicheno and Holweg, 2009). Just-in-time (JIT) is a key area of the lean production paradigm, and has been one of the hottest research areas in operations management since the 1980s (Matsui, 2007). Cooney (2002) states that the importance of just-in-time flow is what is distinctive about the lean production concept, and that JIT is seen to be a superior value-adding practice. Lean has been described by Shah and Ward (2003) as a collection of practice bundles, consisting of JIT, total quality management (TQM), total preventive maintenance (TPM), and human resource management (HRM). This is equivalent to the Schonberger's (1986) concept of world class manufacturing.

ERP systems are commercial software packages that promise seamless integration of all information flowing through a company – financial, human resources, supply chain, and customer information (Davenport, 1998). They are designed to provide the information backbone to cope with the complexities of modern business and the global nature of today's markets (Hill, 2005). The origins of ERP can be traced back to the material requirements planning (MRP) systems that were developed in the 1970s with a focus purely on materials planning, inventory accounting, and purchasing. In the 1980s, manufacturing resource planning (MRP II) was born when capacity and financial planning capabilities were added to the MRP system. Finally, the integration of planning, management and the use of all resources within an entire enterprise gave rise to ERP in the 1990s.

Ward and Zhou (2006) suggest that although proponents of IT integration and lean/JIT practices often appear to be at odds, there is no technical reason for such competition. Information systems such as ERP systems are generally higher level planning systems, whilst lean/JIT practices are primarily related to shopfloor control and execution activities (Vollmann *et al.*, 2005). The aim of this paper is therefore to identify the research gaps in the literature on lean and ERP, in order to provide a research framework that can be used to direct further research efforts within the realm of lean production and ERP systems.

The paper is organised as follows: Section 2 describes the chosen research methodology, whilst Section 3 presents the classification scheme used to review the selected literature. A brief review of the literature is presented in Section 4. In Section 5, the classification scheme identified in Section 3 has been used to develop a research framework which contains useful research topics that should be investigated for the application of ERP within lean production. Finally, conclusions are drawn and areas for further work are identified in Section 6.

2. Research Methodology

The research methodology employed for investigating the application of ERP within lean production is literature survey. Literature has been collected primarily through journals within the area of operations management. For rigorousness, textbooks, conference papers, white papers and dissertations have been excluded from the analysis. A list of journals and the number of articles from each journal is presented in Table 1.

The literature search has been conducted using electronic journal databases (e.g. Science Direct, ISI Web of knowledge, and EBSCO), and the search terms “lean production” and “enterprise resource planning”. Though there is extensive literature regarding MRP and JIT from the 1980s and 1990s, Botta-Genoulaz *et al.* (2005) suggest that it is important for researchers interested in ERP systems to continually refer to the most recent literature on the subject. ERP has evolved considerably and has almost ceased to exist as we knew it years ago (Deis, 2006). Therefore, with an effort to be current on the research field, only literature published after the year 2000 has been considered in this review. The literature search returned 82 useful results, of which four journals, *Computers in Industry, European Journal of Operations Research, International Journal of Production Economics,* and *Journal of Operations Management* accounted for 50% of the citations. The search was aimed primarily at helping both researchers and practitioners in addressing the applications and implications of ERP in lean production.

Table 1: *Article Resources – Journals*

Title of the Journal	Number of Articles
Advanced Engineering Informatics	1
Accounting, Organizations and Society	1
Annual Reviews in Control	2
Business Horizons	2
CIRP J. of Manufacturing Science and Technology	1
Computers and Industrial Engineering	2
Computers in Industry	9
Decision Sciences	1
Design Studies	1
European J. of Operational Research	8
European Management Journal	1
International Federation for Information Processing	1
Information and Management	2
Information and Organization	1
Int. J. of Accounting Information Systems	1
Int. J. of Advanced Manufacturing Technology	1
Int. J. of Industrial Ergonomics	1
Int. J. of Information Management	1
Int. J. of Mechanical Systems Science and Engineering	1
Int. J. of Operations and Production Management	2
Int. J. of Physical Distribution & Logistics Management	1
Int. J. of Production Economics	12
Int. J. of Production Research	4
J. of Engineering and Technology Management	1
J. of International Management	1
J. of Operations Management	11
J. of Manufacturing Systems	1
J. of Materials Processing Technology	1
J. of Purchasing and Supply Management	1
J. of Strategic Information Systems	1
Omega	2
Production and Inventory Management Journal	1
Production Planning and Control	1
Research Policy	1
Robotics and Computer Integrated Manufacturing	1
Technovation	2

3. Classification of the Literature on ERP Systems in Lean Production

In this section, a classification scheme is proposed that can be applied by researchers and practitioners for studying the applications and implications of ERP in lean production. By closely examining the scientific literature on ERP systems and lean production, a number of recurrent themes were identified. These themes form the areas for the classification of the literature:

(a) *Enablers for Competitive Advantage*
Manufacturers looking for performance improvements and a vision to gain competitive advantage often consider the application of an ERP system or the implementation of lean production. The articles in this category evaluate how both approaches can realise competitive advantage.

(b) *Modes of implementation*
Much literature focuses on the implementation of either one of the approaches; however there is a lack of academic literature reporting the effects of the implementation of both.

(c) *Support Functionality*
Some of the literature suggests how either of the approaches supports the other. However, the supporting evidence is often anecdotal.

(d) *The Role and Value of Information*
A key area in the literature is that on the role and value of information, namely information sharing and accuracy of data. If an ERP system is to support lean, this is where it must demonstrate strength and integrity.

(e) *Supply Chain Integration*
Perhaps as an extension to the information argument, some literature explores the concept of supply chain integration as an extension of the lean production paradigm. Research here can is often labelled as lean supply chain.

(f) *Development of Kanban and the Role of the Internet*
Though these two aspects could be categorised separately, most of the literature documents them together. Therefore an analysis is made simultaneously.

4. Review of the Literature on ERP Systems in Lean Production

In this section, the literature available on ERP and lean production has been reviewed based on the previously described classification scheme. A summary of the literature is given in Table 2:

Table 2: *A Summary of the Literature*

Theme	Authors
Enablers of Competitive Advantage	Bayou and de Korvin (2008); Bottani (2010); Dowlatshahi and Cao (2006); Hendricks *et al.* (2007); Matsui (2007); Narasimhan *et al.* (2006); Seppälä (2004); Swamidass and Winch (2002)
Modes of Implementation	Aloini *et al.* (2007); Botta-Genoulaz *et al.* (2005); Cua *et al.* (2001); Herron and Hicks (2008); (Hong and Kim (2002); Jacobs and Bendoly (2003); Mabert *et al.* (2003); Manjunatha and Shivanand (2008); Morabito *et al.* (2005); Motwani *et al.* (2005); Newell *et al.* (2003); Ngai *et al.* (2008); Nicolaou (2004); Scherrer-Rathje *et al.* (2009); Umble *et al.* (2003); Xue *et al.* (2005); Yusuf *et al.* (2004); Zhang *et al.* (2005)
Support Functionality	Bayo-Moriones *et al.* (2008); Botta-Genoulaz and Millet (2005); de Menezes *et al.* (2010); Gunasekaran and Ngai (2004); Howcroft *et al.* (2004); Kalay (2006); Mo (2009); Parry and Turner (2006); Riezebos *et al.* (2009); Steger-Jensen and Hvolby (2008); Tjahjono (2009); Ward and Zhou (2006); Zuehlke (2010)
The Role and Value of Information	Chen and Paulraj (2004); Chryssolouris *et al.* (2008); Doolen and Hacker (2005); Forza and Salvador (2001); Hicks (2007); Kisperska-Moron and de Haan (2011); Robert Jacobs and Weston Jr. (2007); Zhou and Benton Jr (2007)
Supply Chain Integration	Akkermans *et al.* (2003); Cagliano *et al.* (2004); Dias *et al.* (2009); Falk (2005); Gunasekaran *et al.* (2008); Jonsson and Kjellsdotter (2007); Kinder (2003); Koh *et al.* (2008); Mefford (2009); Naim *et al.* (2002); Rondeau and Litteral (2001); Schonberger (2007); Stadtler (2005); Weston Jr. (2003)
Development of Kanban and the Role of the Internet	Bruun and Mefford (2004); Cooney (2002); Dechow and Mouritsen (2005); Gunasekaran *et al.* (2002); Ho and Chang (2001); Jonsson and Mattsson (2008); Kotani (2007); Lage Junior and Godinho Filho (2010); Mabert (2007); New (2007); Olhager and Selldin (2004); Parry and Turner (2006); Pettersen and Segerstedt (2009); Riezebos and Klingenberg (2009); Shah and Ward (2003); Shah and Ward (2007); Shen *et al.* (2010); Takahashi and Nakamura (2002); Teo *et al.* (2009); Wan and Chen (2008); Wan and Chen (2009)

4.1 Enablers of Competitive Advantage

The first strand of the literature identifies lean production and ERP systems as enablers of competitive advantage. For example, Zhang *et al.* (2005) suggest that ERP systems are one of the most widely accepted choices for manufacturing companies to obtain competitive advantage. By employing a survey approach, Hendricks *et al.* (2007) observe evidence of improved profitability from a sample of 186 ERP system implementations. They also suggest other benefits of ERP, stating that ERP systems replace complex, manual interfaces between different systems with standardized, cross-functional transaction automation, thus enabling order cycle time reduction, as well as improvements in throughput, customer response times, and delivery speed. Bayou and de Korvin (2008) also suggest that advances in information technology facilitate improved competitive advantage.

In the perspective of lean production, Matsui (2007) describes the contribution of just-in-time (JIT) systems to improved competitive performance, and suggests that MRP systems and accounting practices (ERP) should be adapted to JIT production systems. His findings, again through a survey approach, suggest that JIT contributes to improved competitive performance. Bayou and de Korvin (2008) suggest that although information technology can facilitate gains in competitive advantage, lean production has become a key approach in managing the complexity of fast moving global markets.

Swamidass and Winch (2002) suggest that appropriately implemented manufacturing technologies provide competitive advantage to manufacturers, and distinctly categorise both JIT and MRP/MRP II as examples of such technologies. They indicate that the benefits of technology use include increased return-on-investment and market share, and reductions in manufacturing cost and cycle time. Seppälä (2004) summarizes this theme rather well by suggesting that companies increasingly adopt new organizational (e.g. lean) and technological (e.g. ERP) innovations in order to enhance their competitiveness.

4.2 Modes of Implementation

An organization's people and processes must undergo significant change in response to the introduction and implementation of an ERP system or lean production practices. Therefore, the second key area explored in the literature is that of the implementation of either ERP systems lean practices. Much of the existing operations management research has primarily focussed on key factors for successful implementation of ERP systems (Hendricks *et al.*, 2007; Hong and Kim, 2002; Jacobs and Bendoly, 2003; Mabert *et al.*, 2003; Newell *et al.*, 2003; Ngai *et al.*, 2008; Umble *et al.*, 2003) and lean (Achanga *et al.*, 2006; Motwani, 2003; Scherrer-Rathje *et al.*, 2009). However, simultaneous implementations and the impacts of ERP systems on lean production, or vice-versa, are not present in the current literature.

Botta-Genoulaz and Millet (2005) synthesize three ERP implementation surveys (Labruyere *et al.*, 2002; Moulin, 2002). Common to all three surveys were the identification of a company's motive to implement ERP, identification of which ERP modules or functionality were implemented, and identification of the benefits and obstacles. Of particular relevance to this study, one key motive for implementation was "to simplify and standardise systems". Simplification and standardisation are important aspects of lean production.

In their analysis of IT systems for supply chain management, Gunasekaran and Ngai (2004) distinguish between three types of implementation issue: Organizational, e.g. demanding the support of top management; Methodological, e.g. the project management approach taken; and Human Resource, e.g. behavioural attitudes of the workforce.

In terms of failed implementations, Ngai *et al.* (2008) list some challenges with the ERP implementation process, consisting of cultural issues; functionality requirements; expertise and people; and ERP practices, whilst Xue *et al.* (2005) identify eight factors that have contributed to the failure of ERP implementations in China, including cultural, environmental, and technical aspects. Umble *et al.* (2003) list reasons why ERP implementations fail in ten categories:

1. Strategic goals are not clearly defined;
2. Top management is not committed to the system;
3. Project management is poor;
4. The organization is not committed to change;
5. A great implementation team is not selected;
6. Inadequate education and training results in unable users;
7. Data accuracy is not ensured;
8. Performance measures are not adapted;
9. Multi-site issues are not properly resolved;
10. Technical difficulties can lead to implementation failures.

Though the success factors and reasons for failure when implementing lean production practices can be likened to those of ERP implementations (e.g. top management commitment; organizational commitment to change; and education and training), the successes and failures of the implementation of lean practices are less represented in the most recent academic literature. However, Scherrer-Rathje *et al.* (2009) draw comparisons between a failed first attempt at lean implementation and a successful second attempt. The contributing factors to success are identified as a top-down rather than bottom-up implementation approach ("the bottom-up approach produced a cascading effect of problems"), senior management commitment, increased team autonomy, organizational communication, and continuous evaluation. Herron and Hicks (2008) identify reasons for the successful (and unsuccessful) transfer of lean manufacturing techniques in the UK, all of which relate to the total support of top management and desire for change.

4.3 Support Functionality

This area of the literature addresses the potential support functionality of ERP systems for lean production. For example, though lean purists suggest that lean production does not mix well with information technology (Sugimori *et al.*, 1977), Steger-Jensen and Hvolby (2008) state that ERP systems can be used to successfully support lean manufacturing, particularly in the case of highly variable demand for a large number of low volume products. Also, de Menezes *et al.* (2010) list the most popular lean production practices, in which they include integrated computer-based technology. This would suggest that ERP is capable of supporting lean production.

Speaking in terms of a company's long-term performance, Gunasekaran and Ngai (2004) suggest that a lack of information technology in an organisation can make the organisation obsolete. For example, they state that it would be difficult for a company to survive in a global market without support from IT systems, as IT helps to improve collaborative-supported work within the supply chain. This may also be true of IT support for lean production, as the lean paradigm expands to take a supply chain approach. Because ERP systems can help increase the speed and quality of management decisions, Riezebos *et al.* (2009) suggest that they offer a satisfactory level of support for lean production, making computer-aided production management and lean manufacturing complementary technologies. Howcroft *et al.* (2004) also suggest that enterprise systems can support lean by streamlining work flow in order to increase productivity, reduce costs, and improve decision making, thus enabling leaner production.

Tjahjono (2009) presents an alternative means of supporting lean production with an information system approach, by investigating the extent to which a multimedia based information system developed for shopfloor workers has contributed to the increased efficiency and productivity of manufacturing operations. Such a system could be incorporated within a contemporary ERP system and can be used both as a training tool as well as a task support tool or memory aid (i.e. as a source for quality standards, work instructions, and standard operating procedures), in support of lean principles such as visualization and standardization. Parry and Turner (2006) also illustrate a novel visual solution for communicating production schedules from the ERP system to the shopfloor production cells at Rolls Royce.

Mo (2009) takes a different approach by evaluating how lean production principles can be used to successfully implement IT systems, and also suggests that although the application of IT is key to supporting lean manufacturing activities, it is not the cause of productivity improvement. A similar message is communicated by Zuehlke (2010), who suggests that the philosophy of lean production has traditionally been directed on the organization and less on the technologies, and implies that lean technologies should be created and used now in the same way as lean organizations were created before.

4.4 The Role and Value of Information

Perhaps one of the most important themes in the literature is that which explores the role and value of information, both within the ERP system and as part of the lean enterprise. Forza and Salvador (2001) suggest that the pressure for reducing costs and shortening lead times requires the development of leaner process control structures, which run faster and consume fewer resources. Chryssolouris *et al.* (2008) suggests that recent developments in IT have enabled modern ERP systems to incorporate all planning and business processes, making communication and information exchange much more effective.

Excess inventory is one of the seven wastes identified by the Toyota Production System (Shingo, 1981). Chen and Paulraj (2004) suggest that the goal of ERP systems is to replace inventory with perfect information. However, in Doolen and Hacker (2005), it becomes apparent that no previous lean assessment models have considered the impact of information exchange and the planning models utilized in a lean environment, rather they have focussed purely upon the lean practices identified in the literature (e.g. Shah and Ward, 2003). Continuing with the subject of waste, Hicks (2007) evaluates the application of lean to information management within an ERP system architecture, and characterises the seven wastes specifically for the management of information.

Zhou and Benton Jr (2007) suggest that effective information sharing enhances effective supply chain practice, and hypothesize that effective JIT production practice has a positive impact on delivery performance. They also suggest that increased investment in information sharing support technology improves delivery performance. However, their findings suggest that JIT production does not have a significant direct impact on delivery performance. Unfortunately, the potential of the effective use of ERP in order to enhance JIT capability was not considered.

Kisperska-Moron and de Haan (2011) suggest that if a company wants to be lean, it has to communicate with its supply chain partners on a continuous basis, and the sequencing for producing products on a JIT basis requires timely and adequate information sharing among partners. They state that electronic data interchange (EDI) is a tool that can be used to ensure that information is available online and in real-time. Forza and Salvador (2001) suggest that EDI links enhance the speed at which customer order information is gathered. This leads nicely into the next strand of the literature, supply chain integration.

4.5 Supply Chain Integration

Supply chain integration is the fifth strand identified in the literature survey. There is a rich literature in operations management on the benefits of improved supply chain planning and coordination (Cachon and Fisher, 2000; Cagliano *et al.*, 2004; Zhou and Benton Jr, 2007). Naim *et al.* (2002) suggest that the migration from single businesses with functional units towards seamless market driven supply chain processes is a common theme in many management paradigms, including lean production. Although many authors do not consider supply chain management as part of the lean production paradigm, when the Japanese phenomena of zaibatsu and keiretsu are examined, it becomes apparent exactly how important integration within the supply chain is to the success of lean production (Koh *et al.*, 2008; Schonberger, 2007). Zaibatsu is an old Japanese term that refers to the industrial and financial business conglomerates that existed in Japan before World War II. The influence and size of zaibatsu allowed for control over significant parts of the Japanese economy until they were dissolved under the occupation of America at the end of WWII. Keiretsu on the other hand is a Japanese term used for a set of companies with interlocking business relationships and shareholdings. The keiretsu has maintained dominance over the Japanese economy for the greater half of the twentieth century. Keiretsu exist as both horizontal and vertical, where horizontal keiretsu centre around a major bank, and vertical keiretsu are based around a major manufacturer. As an example, Toyota was affiliated with the Mitsui zaibatsu until the end of World War II, and the Mitsui keiretsu thereafter. Toyota also has its own vertical keiretsu, owning between 15 and 30% of each of its main parts suppliers, some of which are spin-offs from Toyota Motors (Morck and Nakamura, 2005). Toyota's other parts suppliers are independent firms that find it advantageous to secure their alliances with Toyota by selling a controlling share to Toyota, thus joining the Toyota keiretsu. This exhibits tight integration, with no superfluous firms that are not direct parts of the production chain leading to the final products of Toyota.

In exploring the benefits and impediments of information sharing within an ERP II framework, Koh *et al.* (2008) ask whether a parallel can be drawn between the implications of ERP II and the existing keiretsu structures in Japan. Weston Jr. (2003) defines ERP II as an integrated extended enterprise planning and execution system (IEEP/ES), which includes everything related to front- and back-office systems (ERP), systematically integrated with customer relationship management (CRM) and supplier relationship management (SRM) software. He suggests that the future of extended enterprise systems will include companies, customers, and suppliers all linked electronically.

Schonberger (2007) suggests that supplier partnership is a basic element of the Toyota Production System. He suggests that Western industry pursued this idea under the broadened name supply chain management, with strong support from IT. However, Schonberger states that front-end and continuing collaborations that must break down many human, functional, and company-to-company barriers are more essential than any computer systems within lean production. He suggests that lean management is only skin-deep at many companies, and that manufacturers are too focused on local, in-plant improvements whilst avoiding the tougher issues of inter-company collaboration.

Cagliano *et al.* (2004) make an interesting generalisation and suggest that customer-supplier integration can be considered both as operational integration (JIT) and technological integration (ERP). They describe the lean supply model as a close integration of physical flows and information flows within long term customer-supplier relationships.

Kinder (2003) also makes the link between JIT and supply chain management, suggesting that JIT has widened its scope from simple leanness into wider inter-organizational relationships, where IT is an important enabler towards inter-organizational functional integration. Dias *et al.* (2009) also define IT as an enabler for supply chain integration, and suggest that supply chain integration with transparent information flow is one of the key parameters in achieving lean production and JIT.

Supply chain integration is often cited as one of the benefits of an ERP system (e.g. Falk, 2005). Jacobs and Bendoly (2003) suggest that the concept of ERP represents a significant step in the long history of technology assisted business-process integration. Rondeau and Litteral (2001) state that ERP systems are designed to optimize an organization’s underlying business processes in an effort to create a seamless, integrated information flow from suppliers, through manufacturing and distribution. Botta-Genoulaz *et al.* (2005) suggest that ERP is a driver for more efficient internal and external supply chain operations. They state that an important role of ERP is to serve as a platform for other applications, such as CRM and SRM.

Though Ward and Zhou (2006) suggest that ERP systems are an example of IT designed to achieve high levels of internal integration, they also state that, as an exemplar of JIT production, Toyota implemented SAP R/3 in the late 1990s to help manage its supply chains. Mefford (2009) suggests that while improvements in ERP systems have enabled companies to integrate their purchasing, production scheduling, inventory, logistics, and product design functions, other technologies such as barcodes and RFID have also contributed to tracking materials across entire supply chains.

4.6 Development of Kanban and the Role of the Internet

The final strand of the literature, and perhaps the one with the greatest coverage, is that of the development of Kanban and the role of the Internet within lean production. Though these could have been classified separately, the two areas are so closely linked that it is more valuable to consider them simultaneously.

The Kanban system is one of the most important components of the Toyota Production System, and is a simple and effective tool for accomplishing the pull concept of lean production (Monden, 1998). Jonsson and Mattsson (2008) identify Kanban as a variant of the traditional re-order point (ROP) method, and Pettersen and Segerstedt (2009) also suggest that Kanban is basically a ROP system but with a more visible re-order point. Since the original Kanban system was developed in the 1940s, many variations of Kanban have been developed. For example, Lage Junior and Godinho Filho (2010) review 32 variations of Kanban, suggesting the advantages and disadvantages of each. In terms of IT applications, they suggest that electronic Kanban (e-Kanban), which substitutes the physical signal with electronic signals, improves supplier relationships, allows instantaneous assessment of supplier performance, and reduces the amount of the company's paperwork. They also briefly mention the concept of bar-coding Kanban (Landry *et al.*, 1997), and suggest that the conditions overcome by the use of this type of Kanban are item variability and unstable demand. Some ERP systems linked with MES seek to replace physical Kanban cards with a visual on-screen display. However, Dechow and Mouritsen (2005) suggest that although present technology can perform Kanban type control, a Kanban screen on a PC terminal does not have the same effect as physical cards.

On the other hand, Lage Junior and Godinho Filho (2010) summarize the restrictions of the traditional card-based Kanban system, and state that it is not adequate in situations with unstable demand, processing time instability, non-standardized operations, long setup times, wide variety of items, and uncertainty in raw material supply. An e-Kanban system can minimize human error as well as facilitate product tracking and performance measurement. Wan and Chen also present advantages, limitations, and challenges of web-based Kanban systems. They suggest that lost cards are the most common problem with a paper-based Kanban system, which leads to material shortages, waiting, extra costs, and lower service level. They also state that visibility is another critical issue with the conventional Kanban system, as visibility is completely lost when the paper-based Kanban are sent to distant suppliers. "Seeing" the flow of the value stream is the key to lean production (Rother and Shook, 2003), and Wan and Chen suggest that IT can provide the tools that will greatly enhance the visibility of a Kanban system.

Though they suggest that the impact of IT on lean production has not been as significant as the initial development of the original lean tools, Wan and Chen (2009) present a web-based decision support tool for the implementation of lean manufacturing. They suggest that the tool provides a new direction for computer applications for lean implementation. In a similar manner to how Tjahono (2009) implies that a multimedia based information system developed for shopfloor workers could be incorporated within a contemporary ERP framework and can be used both as a training tool as well as a task support tool or memory aid, Wan and Chen's decision support tool could also be incorporated within the ERP system for assisting in the coordination of a company's lean implementation.

To summarize the developments of Kanban, Mabert (2007) suggests that while developments like lean manufacturing and JIT concepts have enriched and provided an opportunity to debate the benefits of push vs. pull systems for materials management, MRP basics and its contribution to the business and material planning functions should continue to be a fundamental part of the operations management body of knowledge for many years to come.

Shen *et al.* (2010) suggest that with the rapid advancement of information and communication technologies, particularly the Internet, various systems integration and collaboration technologies have been developed that enable greater integration of people, processes, business systems, and information. Also, according to Gunasekaran and Ngai (2004), the Internet has the scope to transfer complex information accurately and to reduce delays as information passes up and down the supply chain. Rondeau and Litteral (2001) also suggest that ERP systems must interface with and capitalize on the Internet as a major conduit of new business growth. As such, Olhager and Selldin (2004) suggest that the ways in which companies communicate with customers and suppliers will undergo major changes in the near future. Telephone, fax and e-mail are the prevalent ways of communicating within supply chains today. They suggest that electronic communication such as e-mail, EDI, and Internet based extranets will increase in importance, as will Kanban.

Bruun and Mefford (2004) explore the implications of the Internet for lean production, and question whether the Internet will allow lean production concepts to be more fully applied, or whether it might actually serve as an alternative way to increase operational efficiency. They argue that the Internet is a facilitator to the implementation of lean production, and that a synergy exists between the two. For example, in discussing pull production, they suggest that the Internet has a much greater potential to link a supply chain together in order to allow for pull production planning. In comparing the Internet with EDI, they suggest that the open and inexpensive nature of the Internet is much more attractive than a closed, inflexible EDI system that requires substantial investment in software and hardware.

Finally, in order to demonstrate the application of a Kanban system that utilizes the Internet, Kotani (2007) presents the e-Kanban system used at Toyota. This system establishes a communication network amongst its suppliers, and shows how it can be implemented and used more efficiently and effectively than the original Kanban system. Kotani shows how modern IT and intelligent algorithms are involved for adaptive control of the supply chain system (Riezebos and Klingenberg, 2009).

5. A Research Framework for ERP in Lean Production: Towards a Concept for ERP-enabled Lean

A critical evaluation and categorisation of the literature has helped to identify six major areas which should be considered when investigating the application of ERP systems in lean production. The literature review has also provided theoretically grounded insights which have been used for the development of a research framework that identifies future research directions regarding the application of ERP systems in lean production (Figure 1). We suggest that the framework can be used to assist researchers and practitioners in identifying the potential areas of development for the successful application of ERP systems as an enabler of leaner production, or ERP-enabled Lean.

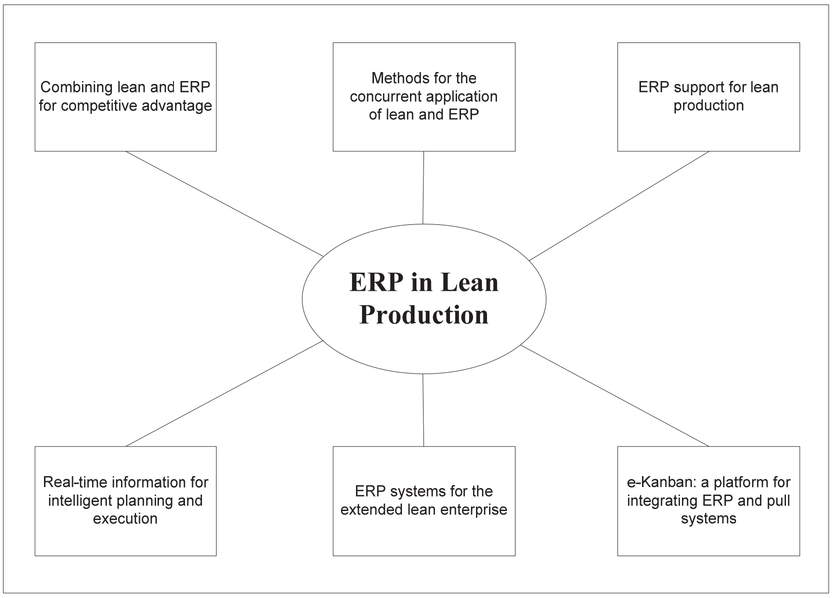

Figure 1: *A Research Framework for ERP Systems in Lean Production*

5.1 Combining lean and ERP for competitive advantage

Firstly, both ERP systems and lean production were considered in the literature as enablers of competitive advantage. There was good evidence of the positive effects brought about by implementing either of the two approaches, but any measure of performance improvement realised by applying both approaches together is lacking in the current literature. Thus, the future research directions within this area should address the practicalities and respective quantification of how ERP and lean can be combined to realise competive advantage.

5.2 Methods for the concurrent application of lean and ERP

Secondly, the implementation processes of both approaches should be considered further. Gunasekaran and Ngai (2004) suggest that the implementation of an IT system requires a strong team that includes key, knowledgeable managers from all functional areas. A well documented project plan is also required, addressing key implementation issues, and moreover, top management support and involvement are essential factors for success. The success criteria for the effective application of lean practices are almost identical to those for ERP implementations, for example team formation and top management support. However, although evidence of simultaneous implementations are lacking in the scientific literature, Masson and Jacobson (2007) suggest that ERP-based lean implementations will grow over time. Therefore, an interesting research topic within this area would be to investigate the potential of ERP-based lean implementations. Can the implementation methodologies of both approaches be integrated to develop a single best-practice model?

5.3 ERP support for lean production

Thirdly, the support functionality of each of the approaches should be considered. Although in the traditional sense ERP systems have been considered as a contributor to waste in lean production (Bruun and Mefford, 2004; Hicks, 2007), modern advances in IT and the improved capabilities of ERP have caused some authors to think differently (Riezebos *et al.*, 2009). Therefore, further research should address the support functionality of contemporary ERP systems for lean production. For example, how can contemporary ERP systems support lean production principles? It would also be interesting to evaluate how lean thinking can be used to support the successful deployment of modern ERP systems. These are some key issues which should be given further thought in order to improve the competitiveness of manufacturing organisations.

5.4 Real-time information for intelligent planning and execution

The fourth major issue identified in the literature was that of the role and value of information, which should be given close regard. If information is to replace inventory (Chen and Paulraj, 2004), the accuracy of the information becomes of significant importance, as does its timeliness. Of particular relevance here would be to address the capability of an ERP system to provide real-time information for intelligent planning and execution of lean manufacturing operations. This could be particularly relevant for applying pull production practices in engineer- and make-to-order environments, which have not typically been suited to the traditonal Kanban approaches.

5.5 ERP systems for the extended lean enterprise

The fifth area identified was that of supply chain integration. Companies in the race for improving organizational competitiveness in the global markets of the 21st Century require their supply chains to be connected in an electronic and dynamic nature. These supply chains should also have a focus upon customer-centric value creation, removing non-value adding activities and contributing toward the lean supply chain. Empirical research within this area should investigate how ERP systems can be applied as a medium for extending lean practices throughout the supply chain, as an enabler of the extended lean enterprise.

5.6 e-Kanban as a platform for integrating ERP and pull systems

Finally, the development of Kanban and the role of the Internet have a major part to play in the application of ERP within lean production. Godinho Filho (2010) reviewed 32 variations of Kanban, though only two variants were significantly related with the field of IT (e-Kanban and barcode-Kanban). However, both of these variants showed signs of promise as enablers toward improved competitive advantage. Therefore, a final suggestion for future research directions would be to further examine applications of e-Kanban as a platform for the integration of ERP and pull production. For example, how can a contemporary ERP system be configured to support a pull system?

6. Conclusion

This paper has presented a thorough and critical review of literature with the objective of bringing out pertinent factors and useful insights into the role and implications of ERP systems in lean production. The academic literature available on ERP and lean production was critically reviewed and classified into the most prominent subject areas, which were (i) competitive advantage; (ii) modes of implementation; (iii) support functionality; (iv) the role and value of information; (v) supply chain integration; and (vi) the developments of Kanban and the role of the Internet. By analysing each of these areas, some specific directions for further research have been identified, and were used to develop the research framework (shown in Figure 1). Although the literature survey may not be exhaustive, this paper serves as a scientifically grounded and comprehensive base for understanding the application and implications of ERP systems in lean production.

In the academic literature, it is clear that both ERP systems and lean production offer vast opportunities for manufacturers to improve their competitiveness. We suggest that through the use of the research framework, researchers and practitioners can investigate how synergies can be realised by combining ERP systems with lean production. This can and should also be extended to take a supply chain perspective, as in today's economic climate, it is supply chains that compete, not companies (Christopher, 2005). In order to make a wider impact on the supply chain, lean production and in particular the JIT concept should make use of information technology, such as ERP systems and the Internet. This becomes even more important in ensuring the effectiveness of a Kanban system within a global setting.

Several avenues for further work have been specified in the research framework. The search for promising combinations of practices has been a dominant subject of empirical research (Cua *et al.*, 2001; Narasimhan *et al.*, 2006; Shah and Ward, 2003). Therefore, further work should evaluate the combination of ERP systems with lean production principles. The following issues can be considered to represent the most critical areas for further research into the role and implications of ERP systems in lean production:

- *Combining lean and ERP for competitive advantage*
- *Methods for the concurrent application of lean and ERP*
- *ERP support for lean production*
- *Real-time information for intelligent planning and execution of lean manufacturing operations*
- *ERP systems for the extended lean enterprise*
- *e-Kanban as a platform for integrating ERP and pull systems*

Hendricks *et al.* (2007) suggest that future research on ERP systems should move beyond the key factors for successful implementation. By addressing the six critical areas identified in the research framework, research efforts on ERP (and lean) can move far beyond just the success factors for implementation. Hendricks *et al.* also state that objective performance criteria need to be applied when assessing the benefits, which should provide a clearer picture of how ERP influences both operational and financial performance. This is also true of the influences of lean production practices, and especially interesting for simultaneous implementations. For example, Cua *et al.* (2001) investigated the simultaneous implementation of JIT, TQM and TPM, and the relative effects on manufacturing performance. They demonstrated that the components of each manufacturing program are mutually supportive in achieving higher levels of manufacturing performance. It would be interesting to see if a similar result is achieved from the simultaneous implementation of lean production practices with a contemporary ERP system.

It is also clear that when future research explores the applications of lean and ERP, other technologies should also be considered, such as advanced planning and scheduling systems (Akkermans *et al.*, 2003); manufacturing execution systems (Stadtler, 2005); and RFID (Dias *et al.*, 2009; Mefford, 2009). Therefore, in combining lean production principles with contemporary ERP systems, integrated throughout the supply chain with the support of the Internet and other information technologies, it is possible to move closer to a new paradigm: ERP-enabled Lean.

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References

Achanga, P., Shehab, E., Roy, R. & Nelder, G. 2006. Critical success factors for lean implementation within SMEs. *Journal of Manufacturing Technology Management,* 17 (4)**,** 460-471.

Akkermans, H. A., Bogerd, P., Yücesan, E. & Van Wassenhove, L. N. 2003. The impact of ERP on supply chain management: Exploratory findings from a European Delphi study. *European Journal of Operational Research,* 146 (2)**,** 284-301.

Aloini, D., Dulmin, R. & Mininno, V. 2007. Risk management in ERP project introduction: Review of the literature. *Information & Management,* 44 547-567.

Bayo-Moriones, A., Bello-Pintado, A. & Merino-Díaz De Cerio, J. 2008. The role of organizational context and infrastructure practices in JIT implementation. *International Journal of Operations and Production Management,* 28 (11)**,** 1042-1066.

Bayou, M. E. & De Korvin, A. 2008. Measuring the leanness of manufacturing systems--A case study of Ford Motor Company and General Motors. *Journal of Engineering and Technology Management,* 25 (4)**,** 287-304.

Bell, S. 2006. *Lean Enterprise Systems: Using IT for Continuous Improvement,* Hoboken, NJ, Wiley and Sons.

Bicheno, J. & Holweg, M. 2009. *The Lean Toolbox,* Buckingham, PICSIE Books.
Botta-Genoulaz, V. & Millet, P.-A. 2005. A classification for better use of ERP systems. *Computers in Industry,* 56 (6)**,** 573-587.
Botta-Genoulaz, V., Millet, P. A. & Grabot, B. 2005. A survey on the recent research literature on ERP systems. *Computers in Industry,* 56 (6)**,** 510-522.
Bottani, E. 2010. Profile and enablers of agile companies: An empirical investigation. *International Journal of Production Economics,* 125 (2)**,** 251-261.
Bruun, P. & Mefford, R. N. R. N. 2004. Lean production and the Internet. *International Journal of Production Economics,* 89 (3)**,** 247-260.
Cachon, G. P. & Fisher, M. 2000. Supply Chain Inventory Management and the Value of Shared Information. *MANAGEMENT SCIENCE,* 46 (8)**,** 1032-1048.
Cagliano, R., Caniato, F. & Spina, G. 2004. Lean, Agile and traditional supply: how do they impact manufacturing performance? *Journal of Purchasing and Supply Management,* 10 (4-5)**,** 151-164.
Chen, I. J. & Paulraj, A. 2004. Towards a theory of supply chain management: the constructs and measurements. *Journal of Operations Management,* 22 (2)**,** 119-150.
Christopher, M. 2005. *Logistics and Supply Chain Management: Creating Value Adding Networks*, FT Prentice Hall, London.
Chryssolouris, G., Papakostas, N. & Mavrikios, D. 2008. A perspective on manufacturing strategy: Produce more with less. *CIRP Journal of Manufacturing Science and Technology,* 1 (1)**,** 45-52.
Cooney, R. 2002. Is “lean” a universal production system?: Batch production in the automotive industry. *International Journal of Operations & Production Management,* 22 (10)**,** 1130-1147.
Cua, K. O., Mckone, K. E. & Schroeder, R. G. 2001. Relationships between implementation of TQM, JIT, and TPM and manufacturing performance. *Journal of Operations Management,* 19 (6)**,** 675-694.
Davenport, T. H. 1998. Living with ERP. *CIO Magazine,* 12 (5)**,** 30-32.
De Menezes, L. M., Wood, S. & Gelade, G. 2010. The integration of human resource and operation management practices and its link with performance: A longitudinal latent class study. *Journal of Operations Management,* In Press, Corrected Proof.
Dechow, N. & Mouritsen, J. 2005. Enterprise resource planning systems, management control and the quest for integration. *Accounting, Organizations and Society,* 30 (7-8)**,** 691-733.
Deis, P. 2006. Lean and Erp - Can They Co-exist? *Proaction* [Online]. Available: http://www.articlesbase.com/strategic-planning-articles/lean-and-erp-can-they-coexist-47604.html [Accessed 10 February 2012].
Delone, W. H. & Mclean, E. R. 1993. Information Systems Success: The Quest for the Dependent Variable. *INFORMATION SYSTEMS RESEARCH,* 3 (1)**,** 60-95.
Dias, J. C. Q., Calado, J. F. M., Osorio, A. L. & Morgado, L. F. 2009. RFID together with multi-agent systems to control global value chains. *Annual Reviews in Control,* 33 185-195.
Doolen, T. L. & Hacker, M. E. 2005. A review of lean assessment in organizations: An exploratory study of lean practices by electronics manufacturers. *Journal of Manufacturing Systems,* 24 (1)**,** 55-67.

Dowlatshahi, S. & Cao, Q. 2006. The relationships among virtual enterprise, information technology, and business performance in agile manufacturing: An industry perspective. *European Journal of Operational Research,* 174 (2)**,** 835-860.
Falk, M. 2005. ICT-linked firm reorganisation and productivity gains. *Technovation,* 25 (11)**,** 1229-1250.
Forza, C. & Salvador, F. 2001. Information flows for high-performance manufacturing. *International Journal of Production Economics,* 70 (1)**,** 21-36.
Gunasekaran, A., Lai, K. H. & Cheng, T. C. E. 2008. Responsive supply chain: A competitive strategy in a networked economy *Omega,* 36 549-564.
Gunasekaran, A. & Ngai, E. W. T. 2004. Information systems in supply chain integration and management. *European Journal of Operational Research,* 159 (2)**,** 269-295.
Gunasekaran, A., Tirtiroglu, E. & Wolstencroft, V. 2002. An investigation into the application of agile manufacturing in an aerospace company. *Technovation,* 22 (7)**,** 405-415.
Halgari, P., Mchaney, R. & Pei, Z. J. 2011. ERP Systems Supporting Lean Manufacturing in SMEs. *In:* CRUZ-CUNHA, M. M. (ed.) *Enterprise Information for Systems Business Integration in SMEs: Technological, Organizational, and Social Dimensions* Hershey, PA: Business Science Reference.
Hendricks, K. B., Singhal, V. R. & Stratman, J. K. 2007. The impact of enterprise systems on corporate performance: A study of ERP, SCM, and CRM system implementations. *Journal of Operations Management,* 25 65-82.
Herron, C. & Hicks, C. 2008. The transfer of selected lean manufacturing techniques from Japanese automotive manufacturing into general manufacturing (UK) through change agents. *Robotics and Computer-Integrated Manufacturing,* 24 524-531.
Hicks, B. J. 2007. Lean information management: Understanding and eliminating waste. *International Journal of Information Management,* 27 (4)**,** 233-249.
Hill, T. 2005. *Operations Management,* New York, Palgrave Macmillan.
Ho, J. C. & Chang, Y.-L. 2001. An integrated MRP and JIT framework. *Computers & Industrial Engineering,* 41 (2)**,** 173-185.
Hong, K.-K. & Kim, Y.-G. 2002. The critical success factors for ERP implementation: an organizational fit perspective. *Information and Management,* 40 25-40.
Howcroft, D., Newell, S. & Wagner, E. 2004. Understanding the contextual influences on enterprise system design, implementation, use and evaluation. *The Journal of Strategic Information Systems,* 13 (4)**,** 271-277.
Jacobs, F. R. & Bendoly, E. 2003. Enterprise resource planning: Developments and directions for operations management research. *European Journal of Operational Research,* 146 (2)**,** 233-240.
Jacobs, F. R. & Weston Jr., F. C. T. 2007. Enterprise resource planning (ERP) - A brief history. *Journal of Operations Management,* 25 357-363.
Jonsson, P. & Kjellsdotter, L. 2007. Applying advanced planning systems for supply chain planning: three case studies. *International Journal of Physical Distribution & Logistics Management,* 37 (10)**,** 816-834.
Jonsson, P. & Mattsson, S.-A. 2008. Inventory management practices and their implications on perceived planning performance. *International Journal of Production Research,* 46 (7)**,** 1787 - 1812.

Kalay, Y. E. 2006. The impact of information technology on design methods, products and practices. *Design Studies,* 27 (3), 357-380.

Kinder, T. 2003. Go with the flow--a conceptual framework for supply relations in the era of the extended enterprise. *Research Policy,* 32 (3), 503-523.

Kisperska-Moron, D. & De Haan, J. 2011. Improving supply chain performance to satisfy final customers: "Leagile" experiences of a polish distributor. *International Journal of Production Economics,* 133 (1), 127-134.

Koh, S. C. L., Gunasekaran, A. & Rajkumar, D. 2008. ERP II: The involvement, benefits and impediments of collaborative information sharing. *International Journal of Production Economics,* 113 (1), 245-268.

Kotani, S. 2007. Optimal method for changing the number of Kanbans in the e-Kanban system and its applications. *International Journal of Production Research,* 45 (24), 5789-5809.

Labruyere, E., Sebben, P. & Versini, M. 2002. L'ERP a-t-il tenu ses promesses? *Deloitte & Touche report,* June 2002 45pp.

Lage Junior, M. & Godinho Filho, M. 2010. Variations of the Kanban system: Literature review and classification. *International Journal of Production Economics,* 125 (1), 13-21.

Landry, S., Duguay, C. R., Chausse, S. & Themens, J. 1997. Integrating MRP, Kanban, and bar-coding systems to achieve JIT procurement. *Production and Inventory Management Journal,* 38 (1), 8-12.

Mabert, V. A. 2007. The early road to material requirements planning. *Journal of Operations Management,* 25 (2), 346-356.

Mabert, V. A., Soni, A. & Venkataramanan, M. A. 2003. Enterprise resource planning: Managing the implementation process. *European Journal of Operational Research,* 146 (2), 302-314.

Manjunatha, H. K. & Shivanand, C. A. 2008. A New Paradigm of Implementation of Lean Manufacturing through SAP R/3. *International Journal of Mechanical Systems Science and Engineering,* 2 (3), 187-192.

Masson, C. & Jacobson, S. 2007. Lean Planning and Execution Software: Extending Lean Thinking Across the Enterprise. Available: http://www.oracle.com/corporate/analyst/reports/industries/aim/amr-20378.pdf [Accessed September 2010].

Matsui, Y. 2007. An empirical analysis of just-in-time production in Japanese manufacturing companies. *International Journal of Production Economics,* 108 (1-2), 153-164.

Mefford, R. N. 2009. Increasing productivity in global firms: The CEO challenge. *Journal of International Management,* 15 (3), 262-272.

Mo, J. P. T. 2009. The role of lean in the application of information technology to manufacturing. *Computers in Industry,* 60 (4), 266-276.

Monden, Y. 1998. *Toyota Production System: an Integrated Approach to Just-in-Time,* Norcross, GA, Institute of Industrial Engineers.

Morabito, V., Pace, S. & Previtali, P. 2005. ERP Marketing and Italian SMEs. *European Management Journal,* 23 (5), 590-598.

Morck, R. & Nakamura, M. 2005. A Frog in a Well Knows Nothing of the Ocean: A History of Corporate Ownership in Japan. *In:* MORCK, R. (ed.) *A History of*

Corporate Governance Around the World: Family Business Groups to Professional Managers. Chicago: University of Chicago Press.

Motwani, J. 2003. A business process change framework for examining lean manufacturing: A case study. *Industrial Management & Data Systems,* 103 (5/6), 339-346.

Motwani, J., Subramanian, R. & Gopalakrishna, P. 2005. Critical factors for successful ERP implementation: Exploratory findings from four case studies. *Computers in Industry,* 56 529-544.

Moulin, C. 2002. Enquete ERP 2002: les principaux resultats. *21eme Journee regionale de la Productique, Pole Productique Rhone-Alpes, France*.

Naim, M. M., Childerhouse, P., Disney, S. M. & Towill, D. R. 2002. A supply chain diagnostic methodology: determining the vector of change. *Computers & Industrial Engineering,* 43 (1-2), 135-157.

Narasimhan, R., Swink, M. & Kim, S. W. 2006. Disentangling leanness and agility: An empirical investigation. *Journal of Operations Management,* 24 (5), 440-457.

New, S. J. 2007. Celebrating the enigma: the continuing puzzle of the Toyota Production System. *International Journal of Production Research,* 45 (16), 3545-3554.

Newell, S., Huang, J. C., Galliers, R. D. & Pan, S. L. 2003. Implementing enterprise resource planning and knowledge management systems in tandem: fostering efficiency and innovation complementarity. *Information and Organization,* 13 (1), 25-52.

Ngai, E. W. T., Law, C. C. H. & Wat, F. K. T. 2008. Examining the critical success factors in the adoption of enterprise resource planning. *Computers in Industry,* 59 548-564.

Nicolaou, A. I. 2004. Quality of postimplementation review for enterprise resource planning systems. *International Journal of Accounting Information Systems,* 5 25-49.

Olhager, J. & Selldin, E. 2004. Supply chain management survey of Swedish manufacturing firms. *International Journal of Production Economics,* 89 (3), 353-361.

Parry, G. C. & Turner, C. E. 2006. Application of lean visual process management tools. *Production Planning & Control: The Management of Operations,* 17 (1), 77 - 86.

Pettersen, J.-A. & Segerstedt, A. 2009. Restricted work-in-process: A study of differences between Kanban and CONWIP. *International Journal of Production Economics,* 118 (1), 199-207.

Piszczalski, M. 2000. Lean vs. Information Systems. *Automotive Manufacturing & Production* [Online], 2000. Available: http://findarticles.com/p/articles/mi_m0FWH/is_8_112/ai_65073436/ [Accessed May 2011].

Riezebos, J. & Klingenberg, W. 2009. Advancing lean manufacturing, the role of IT. *Computers in Industry,* 60 (4), 235-236.

Riezebos, J., Klingenberg, W. & Hicks, C. 2009. Lean Production and information technology: Connection or contradiction? *Computers in Industry,* 60 237-247.

Robert Jacobs, F. & Weston Jr., F. C. 2007. Enterprise resource planning (ERP)--A brief history. *Journal of Operations Management,* 25 (2), 357-363.

Rondeau, P. J. & Litteral, L. A. 2001. Evolution of Manufacturing Planning and Control Systems: from Reorder Point to Enterprise Resource Planning. *Production and Inventory Management Journal,* 42 (2)**,** 1-7.
Rother, M. & Shook, J. 2003. *Learning to See,* Cambridge, Lean Enterprise Institute.
Scherrer-Rathje, M., Boyle, T. A. & Deflorin, P. 2009. Lean, take two! Reflections from the second attempt at lean implementation. *Business Horizons,* 52 79-88.
Schonberger, R. J. 1986. *World Class Manufacturing: The Lessons of Simplicity Applied,* New York, Free Press.
Schonberger, R. J. 2007. Japanese production management: An evolution - with mixed success. *Journal of Operations Management,* 25 (2)**,** 403-419.
Seppälä, P. 2004. Flat organizations and the role of white-collar employees in production. *International Journal of Industrial Ergonomics,* 33 (1)**,** 15-27.
Shah, R. & Ward, P. T. 2003. Lean manufacturing: context, practice bundles, and performance. *Journal of Operations Management,* 21 (2)**,** 129-149.
Shah, R. & Ward, P. T. 2007. Defining and developing measures of lean production. *Journal of Operations Management,* 25 (4)**,** 785-805.
Shen, W., Hao, Q., Mak, H., Neelamkavil, J., Xie, H., Dickinson, J., Thomas, R., Pardasani, A. & Xue, H. 2010. Systems integration and collaboration in architecture, engineering, construction, and facilities management: A review. *Advanced Engineering Informatics,* 24 (2)**,** 196-207.
Shingo, S. 1981. *A Study of the Toyota Production System,* New York, Productivity Press.
Stadtler, H. 2005. Supply chain management and advanced planning: basics, overview and challenges. *European Journal of Operational Research,* 163 (3)**,** 575-588.
Steger-Jensen, K. & Hvolby, H.-H. 2008. Review of an ERP System Supporting Lean Manufacturing. *In:* KOCH, T. (ed.) *IFIP International Federation for Information Processing: Lean Business Systems and Beyond.* Boston: Springer.
Sugimori, Y., Kusunoki, K., Cho, F. & Uchikawa, S. 1977. Toyota production system and Kanban system Materialization of just-in-time and respect-for-human system. *International Journal of Production Research,* 15 (6)**,** 553 - 564.
Swamidass, P. M. & Winch, G. W. 2002. Exploratory study of the adoption of manufacturing technology innovations in the USA and the UK. *International Journal of Production Research,* 40 (12)**,** 2677 - 2703.
Takahashi, K. & Nakamura, N. 2002. Decentralized reactive Kanban system. *European Journal of Operational Research,* 139 (2)**,** 262-276.
Teo, T. S. H., Lin, S. & Lai, K.-H. 2009. Adopters and non-adopters of e-procurement in Singapore: An empirical study. *Omega,* 37 (5)**,** 972-987.
Tjahjono, B. 2009. Supporting shop floor workers with a multimedia task-oriented information system. *Computers in Industry,* 60 (4)**,** 257-265.
Umble, E. J., Haft, R. R. & Umble, M. M. 2003. Enterprise resource planning: Implementation procedures and critical success factors. *European Journal of Operational Research,* 146 241-257.
Vollmann, T. E., Berry, W. L., Whybark, D. C. & Jacobs, R. F. 2005. Manufacturing Planning and Control for Supply Chain Management. *McGraw-Hill, Boston*.
Wan, H.-D. & Chen, F. F. 2008. A web-based Kanban system for job dispatching, tracking, and performance monitoring. *International Journal of Advanced Manufacturing Technologies,* 38 995-1005.

Wan, H.-D. & Chen, F. F. 2009. Decision support for lean practitioners: A web-based adaptive assessment approach. *Computers in Industry,* 60 (4)**,** 277-283.

Ward, P. T. & Zhou, H. 2006. Impact of IT Integration and Lean/JIT Practices on Lead time Performance. *Decision Sciences,* 37 (2)**,** 177-203.

Weston Jr., F. C. 2003. ERP II: The Extended Enterprise System. *Business Horizons,* 46 (6)**,** 49-55.

Xue, Y., Liang, H., Boulton, W. R. & Snyder, C. A. 2005. ERP implementation failures in China: Case studies with implications for ERP vendors. *International Journal of Production Economics,* 97 279-295.

Yusuf, Y., Gunasekaran, A. & Abthorpe, M. S. 2004. Enterprise information systems project implementation: A case study of ERP in Rolls-Royce. *International Journal of Production Economics,* 87 251-266.

Zhang, Z., Lee, M. K. O., Huang, P., Zhang, L. & Huang, X. 2005. A framework of ERP systems implementation success in China: An empirical study. *International Journal of Production Economics,* 98 (1)**,** 56-80.

Zhou, H. & Benton Jr, W. C. 2007. Supply chain practice and information sharing. *Journal of Operations Management,* 25 (6)**,** 1348-1365.

Zuehlke, D. 2010. SmartFactory - Towards a factory-of-things. *Annual Reviews in Control,* 34 (2010)**,** 129-138.

PAPER 4

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Paper IV

ERP Support for Lean Production

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Abstract

In the traditional sense, IT has often been viewed as a contributor to waste within lean production. However, as the business world changes and competition from low-cost countries increases, new models must be developed which deliver competitive advantage by combining contemporary technological advances with the lean paradigm. By applying an action research approach, this paper evaluates the support functionality of ERP systems for lean production. We address the fundamental principles of lean production in comparison with the functionality and modules of a contemporary ERP system.

Key Words: *Lean production, Enterprise resource planning, Action research*

Introduction

Though the theory of lean production is nowadays well understood, the relationship between information technology (IT) and lean production remains a controversial and far less explored topic. While lean is often characterized by decentralized coordination and control, ITs such as enterprise resource planning (ERP) systems are typically best suited to support centralized production planning. However, Powell and Strandhagen (2011) identify and explore the lean-ERP paradox, and suggest that there is a synergistic impact to be realised in combining ERP systems within the lean paradigm. Riezebos et al. (2009) also argue that modern IT can indeed be tailored to support lean, but state that further research is required to evaluate the combination of lean production principles and ERP. Therefore, the purpose of this paper is to evaluate the support functionality of a contemporary ERP system for lean production by addressing the following research question:

How can a contemporary ERP system be used to support lean production principles?

Theoretical Background

The term lean production was popularized by Womack et al. (1990) when they compared the mass production principles of the Western world to the very simple production principles of Toyota. However, this philosophy was primarily directed at the organization and less on information technologies (Zuehlke, 2010). As such, IT has since been viewed as a contributor to the waste to be eliminated, rather than as a tool to help achieve and sustain positive change (Bell, 2006). The increasing rate of development of IT today is constantly increasing manufacturing companies' ability to react quickly and reliably to demand through increased transparency, visualization and processing capabilities. Moody (2006) suggests that, although profitability can be enhanced in any number of ways, one of the most rewarding and direct avenues is through the use of technology. Riezebos et al. (2009) suggest that modern IT (such as contemporary ERP systems) can be tailored to support lean production.

ERP is one of the most widely accepted choices to obtain competitive advantage for manufacturing companies (Zhang et al., 2005). ERP systems are designed to provide seamless integration of processes across functional areas with improved workflow, standardization of various business practices, and access to real-time data (Mabert et al., 2003). The fundamental benefits of ERP systems do not in fact come from their inherent "planning" capabilities but rather from their abilities to process transactions efficiently and to provide organized record keeping structures for such transactions (Jacobs and Bendoly, 2003).

In order to evaluate the support functionality offered by ERP systems for lean production, we use the fundamental principles of lean manufacturing identified by Womack and Jones (1996): *"precisely specify **value** by specific product; identify the **value stream** for each product; make value **flow** without interruptions; let the customer **pull** value from the producer; and pursue **perfection**"* (Hines, 2010).

By conducting a study of the extant literature in the form of academic journals, trade journals, textbooks, and white papers; we identify 15 fundamental areas in which an ERP system could be configured to support lean production principles. The 15 areas, which we call the 15 keys to ERP support for lean, are summarized in Table 1:

Table 1: ***15 keys to ERP support for lean production***

No	Principle	An ERP system for lean production should:	Reference:
1	Value	Support customer relationship management	(Chen and Popovich, 2003)
2		Automate necessary non-value adding activities (e.g. backflushing)	(Hamilton, 2009)
3	Value stream	Enable process-modelling to support standard work processes	(IFS, 2008, Prediktor, 2010)
4		Provide a source for easy-to-find product drawings and standard work instructions	(Houy, 2005, Tjahjono, 2009)
5		Support information sharing across the supply chain	(Bjorklund, 2009, Koh et al., 2008)
6	Flow	Create synchronized and streamlined data flow (internal & external)	(Hamilton, 2003)
7		Support line balancing	(Steger-Jensen and Hvolby, 2008)
8		Support demand levelling	(Hamilton, 2009)
9		Support orderless rate-based planning (e.g. takt-time)	(IFS, 2010)
10		Provide decision support for shop floor decision making	(Hamilton, 2009)
11	Pull	Support kanban control	(Hamilton, 2009, Masson and Jacobson, 2007)
12		Support production levelling (Heijunka)	(Masson and Jacobson, 2007)
13		Support JIT procurement	(Masson and Jacobson, 2007)
14	Perfection	Provide a system to support root-cause analysis and for the logging and follow-up of quality problems	(Bjorklund, 2009)
15		Provide highly visual and transparent operational measures (e.g. real time status against plan)	(Prediktor, 2010)

Research Methodology

In this study we adopt an action research approach by following an ERP implementation project at a case company in Trondheim, Norway. One of the authors has been actively involved at the case company during the introduction of lean practices since 2009, and has also been present during the design and analysis phase of the ERP implementation process since January 2011.

Action research

Philips (2004) suggests that there is a broad Scandinavian tradition for action research. Action research can be defined as a participatory, democratic process concerned with developing practical knowing in the pursuit of worthwhile human purposes, grounded in a participatory worldview (Reason and

Bradbury, 2006). Essentially, it focuses on bringing about change (action) and contributing to knowledge (research). McNiff and Whitehead (2009) suggest that doing action research involves the following:

1. Taking action (changing something);
2. Doing research (evaluating both the change and the change process);
3. Telling the story and sharing your findings (disseminating the results).

Action research is considered as an appropriate methodology for this study as both lean production and ERP systems are very much applied in industry, thus a "learning by doing" approach is very suitable.

Client System: Noca AS

Noca is a manufacturing and service supplier within electronics and electronics development. Established in 1986, Noca delivers development, prototypes, batch production, and assembly for customers within innovation and entrepreneurs in high-tech industries. Noca has 50 employees and an annual turnover of €11.5m (2010). The company is currently actively applying lean practices to their operations, having started with value stream mapping (VSM) in 2009, followed by 5S in 2010. Noca has also identified a need to enhance their supporting processes, such as production planning and control, and have therefore chosen to implement a new ERP system, Jeeves Universal (Figure 1). Recognised as "Sweden's most popular ERP system – 2009", Jeeves Universal is claimed to be a flexible (customized) standard ERP system (ERPResearch.org, 2010). The ERP implementation process at Noca will consist of three phases – a design and analyse phase (phase zero); an implementation phase (phase one); and an improvement phase (phase two). This paper considers phase zero only.

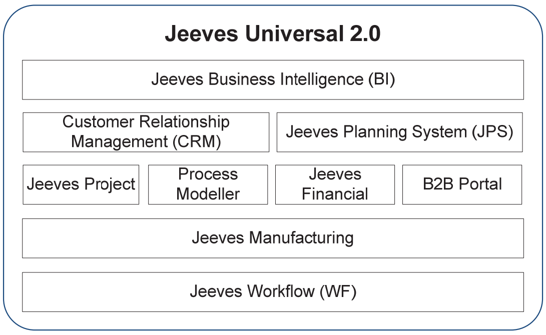

Figure 1: ***The "Jeeves Universal" ERP system and selected modules***

Results

This paper presents preliminary findings following phase zero of the ERP implementation project, which we call the design and analysis phase. By evaluating the functionality of the chosen ERP system and selected modules (Figure 1) against the lean principles identified by Womack and Jones (1996), we are able to propose a theoretical framework for ERP support for lean production (Figure 2). This framework can be used by researchers and practitioners when combining lean and ERP.

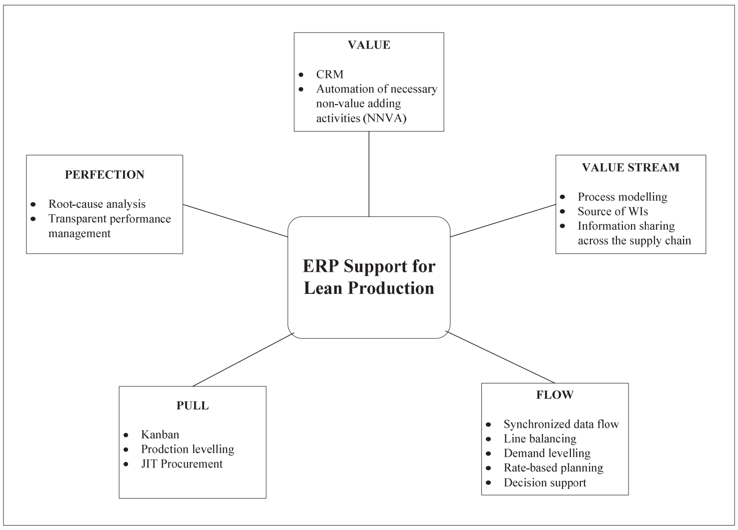

Figure 2: ***ERP Support for Lean Production – a Conceptual Framework***

Value

It was identified that a significant element of the ERP system that helps contribute to value creation from the point of view of the customer was the application of a customer relationship management (CRM) module. The ERP system also offered select functionality to automate the necessary, non-value adding activities, such as backflushing (e.g. Hamilton, 2003).

Value Stream

In terms of supporting the value stream, it was shown that the ERP system offered process modelling functionality to support the creation of standard work processes, as well as providing a source for easy-to-find product drawings and work instructions. Functionality that enables the sharing of information across the supply chain is also offered with the B2B Portal. The ERP system also supports a number of different levels within the factory, ranging from the individual operation (process level), through production group (work cell level), to flow group (value stream level).

Flow
The main module of the ERP system supporting flow manufacturing was identified as the Workflow (WF) module, which integrated all functions of the enterprise and aided the creation of a "paperless" paper-trail for continuous flow of information supporting the production processes. Functionality is also offered to support line balancing; demand levelling; and orderless rate-based planning through the use of Jeeves planning system (JPS). Finally, and particularly through the use of business intelligence (BI), decision support for shopfloor decision making allows shopfloor workers to become even more empowered in the lean environment.

Pull
Even though the client system is too early in its lean journey to implement a pull system, ERP support for pull production was still taken into consideration. It was noted in particular that the JPS is a very useful visual tool that can be used to support production levelling (heijunka). It is also anticipated that the WF module can be used to support pull production through enabling and supporting material and information flow. JIT procurement can be supported through integrating a product's BOM within both Jeeves Project (for prototyping and ramp-up) and Jeeves manufacturing (for volume production).

Perfection
Finally, in terms of perfection and continuous improvement, it was highlighted how the ERP system can make use of both BI and JPS (as a visual tool) to provide a system for logging and follow-up of quality problems, and to provide a system for highly visual and transparent operational measures.

Conclusion
By considering the functionality of the Jeeves Universal ERP system against the five lean principles, we conceptualized a framework for ERP support for lean production, which we call *"the 15 keys to ERP support for lean production"*. The framework (shown in Table 1) has been used to highlight the theoretical support functionality of the Jeeves Universal ERP system for lean production. The framework can also be used by other researchers and practitioners for the future integration of ERP systems within the lean paradigm.

Though measures have been taken to increase the validity of this research, a number of limitations do however exist. For example, a commonly cited limitation of the action research approach is the focus upon only one company. Though it is often not the main goal of action research to generalise results, the results herein can be used as a template for reflecting on new experience (Friedman, 2010). We also only considered an ERP system of a single vendor, Jeeves. We therefore suggest that further investigation with other case companies and/or other ERP system vendors would help to make our framework more generalizable.

A particularly interesting subject that arose as a result of the work was ERP support for pull production. Therefore, the authors suggest that a greater focus should be taken on the role of ERP systems in helping manufacturers to realise JIT production, one of the most important dimensions of lean. Further work should therefore investigate ERP support for pull production, helping to strengthen the validity and contribution of this work.

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References

Bell, S. 2006. *Lean Enterprise Systems: Using IT for Continuous Improvement,* Hoboken, NJ, Wiley and Sons.

Bjorklund, J. 2009. 10 Ways to Use ERP to Lean the Manufacturing Supply Chain. *Managing Automation* [Online]. Available: http://www.managingautomation.com/uploadedimages/downloads/10_Ways_ERP_Lean_Manuf.pdf [Accessed September 2010].

Chen, I. J. & Popovich, K. 2003. Understanding customer relationship management (CRM). People, process and technology. *Business Process Management Journal,* 9 (5)**,** 672-688.

Erpresearch.Org. 2010. *What is Jeeves Universal ERP?* [Online]. Available: http://octavesolutions.com/erpresearch/?p=5 [Accessed June 2011].

Friedman, V. J. 2010. Action Science: Creating Communities of Inquiry in Communities of Practice. *In:* REASON, P. & BRADBURY, H. (eds.) *The Handbook of Action Research.* London: Sage.

Glenday, I. & Sather, R. 2005. *Breaking Through to Flow* [Online]. Available: http://www.leanuk.org/downloads/LFL_2005/Day2_Plenary_Glenday_Sather.pdf [Accessed May 2009].

Hamilton, S. 2003. *Maximizing your ERP system: a practical guide for managers* New York, McGraw Hill.

Hamilton, S. 2009. *Managing Lean Manufacturing using Microsoft Dynamics AX,* New York, McGraw Hill.

Hines, P. 2010. *The Principles of the Lean Business System* [Online]. S A Partners. Available: http://www.sapartners.com/images/pdfs/the%20principles%20of%20the%20lean%20business%20system.pdf [Accessed February 2011].

Houy, T. 2005. ICT and Lean Management: Will They Ever Get Along? Available: http://mpra.ub.uni-muenchen.de/2502/ [Accessed September 2010].

Ifs. 2008. Going Lean, Step by Step, with IFS Applications. Available: http://www.manmonthly.com.au/Article/Going-Lean-Step-by-Step-with-IFS-Applications [Accessed September 2009].

Ifs 2010. IFS Applications for Lean manufacturing. *IFS AB.*

Jacobs, F. R. & Bendoly, E. 2003. Enterprise resource planning: Developments and directions for operations management research. *European Journal of Operational Research,* 146 (2)**,** 233-240.

Koh, S. C. L., Gunasekaran, A. & Rajkumar, D. 2008. ERP II: The involvement, benefits and impediments of collaborative information sharing. *International Journal of Production Economics,* 113 (1)**,** 245-268.

Mabert, V. A., Soni, A. & Venkataramanan, M. A. 2003. Enterprise resource planning: Managing the implementation process. *European Journal of Operational Research,* 146 (2)**,** 302-314.

Masson, C. & Jacobson, S. 2007. Lean Planning and Execution Software: Extending Lean Thinking Across the Enterprise. Available: http://www.oracle.com/corporate/analyst/reports/industries/aim/amr-20378.pdf [Accessed September 2010].

Mcniff, J. & Whitehead, J. 2009. *Doing and Writing Action Research,* Los Angeles, Sage.

Moody, P. E. 2006. With Supply Management, Technology Rules! *Supply Chain Management Review,* May/June 2006.

Philips, M. E. 2004. Action research and development coalitions in health care. *Action Research,* 2 (4)**,** 349-370.

Powell, D. & Strandhagen, J. O. 2011. Lean Production Vs. ERP Systems: An ICT Paradox? *Operations Management,* 37 (3)**,** 31-36.

Prediktor. 2010. Lean. Available: http://www.prediktor.no/business_solutions/lean/Pages/default.aspx [Accessed February 2011].

Reason, P. & Bradbury, H. (eds.) 2006. *Handbook of Action Research,* London: Sage Publications.

Riezebos, J., Klingenberg, W. & Hicks, C. 2009. Lean Production and information technology: Connection or contradiction? *Computers in Industry,* 60 237-247.

Steger-Jensen, K. & Hvolby, H.-H. 2008. Review of an ERP System Supporting Lean Manufacturing. *In:* KOCH, T. (ed.) *IFIP International Federation for Information Processing: Lean Business Systems and Beyond.* Boston: Springer.

Tjahjono, B. 2009. Supporting shop floor workers with a multimedia task-oriented information system. *Computers in Industry,* 60 (4)**,** 257-265.

Womack, J. P. & Jones, D. T. 1996. *Lean Thinking: Banish Waste and Create Wealth in Your Corporation,* New York, Simon and Schuster.

Womack, J. P., Jones, D. T. & Roos, D. 1990. *The Machine that Changed the World,* New York, Harper Perennial.

Zhang, Z., Lee, M. K. O., Huang, P., Zhang, L. & Huang, X. 2005. A framework of ERP systems implementation success in China: An empirical study. *International Journal of Production Economics,* 98 (1)**,** 56-80.

Zuehlke, D. 2010. SmartFactory - Towards a factory-of-things. *Annual Reviews in Control,* 34 (2010)**,** 129-138.

PAPER 5

Powell, D., Riezebos, J. & Strandhagen, J.O. (2012) **Lean production and ERP systems in SMEs: ERP support for pull production.** *International Journal of Production Research* (Available online 23 January 2012)

Paper V

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PAPER 6

Powell, D., Alfnes, E., Strandhagen, J.O. & Dreyer, H.C. (2012) **The concurrent application of lean production and ERP: towards an ERP-based lean implementation process**
(*submitted to Computers in Industry*)

Paper VI

THE CONCURRENT APPLICATION OF LEAN PRODUCTION AND ERP: TOWARDS AN ERP-BASED LEAN IMPLEMENTATION PROCESS

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ABSTRACT: *In the traditional sense, information technology has often been viewed as a contributor to waste within lean production. However, as the business world changes and competition from low-cost countries increases, new models must be developed which deliver competitive advantage by combining contemporary technological advances with the lean paradigm. This paper presents a framework for the concurrent implementation of ERP and lean production by applying an action research approach. Through analysing the typical implementation processes of both approaches, we develop a combined process for ERP-based lean implementations. Our findings suggest that the implementation of a contemporary ERP system can act as a catalyst for the application of lean production practices.*

KEYWORDS:
Enterprise resource planning; Lean production; ERP-based lean implementation

INTRODUCTION

There seems to be a continuous debate in the literature as to whether or not lean production and information technology can be successfully combined in an enterprise (e.g. Bell, 2006; Bruun and Mefford, 2004; Halgari *et al.*, 2011). However, in practice, companies have been building hybrid environments in which they take advantage of lean production practices facilitated by developments in information technology for quite some time (Riezebos *et al.*, 2009). This article attempts to shed light on the argument by addressing the parallel application of both approaches. By adopting an action research methodology, we examine the concurrent application of ERP and lean production practices within a single organization, in order to develop an ERP-based lean implementation process. Though coverage of such dual-implementations is currently very low, Masson and Jacobson (2007) suggest that ERP-based lean implementations will grow over time. We draw parallels between the ERP and lean implementation processes, and show how the ERP implementation process can in fact behave as a catalyst for lean implementation. In order to guide our inquiry, we pose the following research question:

RQ: ***How can existing methodologies for the implementation of lean production and ERP systems be combined to develop a single "best-practice" process for ERP-based lean implementations?***

THEORETICAL BACKGROUND

Enterprise Resource Planning (ERP) Systems

ERP is one of the most widely accepted choices to obtain competitive advantage for manufacturing companies (Zhang *et al.*, 2005). ERP systems are designed to provide seamless integration of processes across functional areas with improved workflow, standardization of various business practices, and access to real-time data (Mabert *et al.*, 2003). The fundamental benefits of ERP systems do not in fact come from their inherent "planning" capabilities but rather from their abilities to process transactions efficiently and to provide organized record keeping structures for such transactions (Jacobs and Bendoly, 2003). Hopp and Spearman (1996) suggest that whilst (at least on the surface) ERP seemed to contain aspects of just-in-time (JIT) by providing modules with names like "repetitive manufacturing" that provided the capability to level load the MPS and to implement pull, the philosophical elements of continuous improvement, visual management, and mistake proofing were missing.

Lean Production

Lean production is based on the principles and working processes of the Toyota Production System (TPS), and has been defined as doing more with less (Womack *et al.*, 1990). In its simplest terms, lean production can be described as the elimination of waste (Liker, 2004). It has been most prominent in discrete, repetitive assembly-type operations (Powell *et al.*, 2009). Liker (2004) suggests that the goals of lean production are highest quality, lowest cost, and shortest lead time. Lean production can be considered as a philosophy and as a set of tools and practices for the continuous improvement of operations.

Implementation Processes

The extant literature in the form of international academic journals and educational textbooks was examined in order to identify existing processes and methodologies for the implementation of ERP systems and lean production. The most frequently cited implementation processes were selected for further analysis. The main criterion for selection was that the identified implementation process should have a definite sequence (i.e. a step-by-step implementation process).

ERP Implementation Process

Implementing an ERP system is an expensive and time consuming process (Sarkis and Gunasekaran, 2003). In the world of ERP, the term implementation is often used to describe a well-defined project, spaning from the choice of the system, through its configuration and training of users, to "go-live" (Bancroft *et al.*, 1998). However, Kraemmergaard et al. (2003) show that go-live only really marks the start of the actual implementation, which is often an infinite process of correcting software errors, adding new functionality and new modules, and implementing updated versions. Needless to say, a formalized project approach and methodology have been identified in the literature as a critical success factor for the ERP implementation process (Doom and Milis, 2009; Holland and Light, 2001). Several researchers have developed process models of ERP implementation (Parr and Shanks, 2000). The implementation processes examined herein are Markus and Tanis's (2000) four phase model; Berchet and Habchi's (2005) five-stage model; Rajagopal's (2002) six-stage model (which is based on Cooper and Zmud's (1990) "Model of the IT Implementation Process"), Jacobs and Whybark's (2000) accelerated implementation process for SAP R/3, Harwood's (2003) ERP implementation cycle, and Wallace and Kremzar's (2001) "ERP Proven Path" methodology for ERP implementation. Common elements from each of these methodologies have been identified, and a comparison is made in Table 1. Due to the prominent nature of Proven Path, and the fact that it is by far the most comprehensive methodologies of the five studied, we select the ERP Proven Path model as the basis for the development of a best-practice process for ERP-based lean implementations.

Table 1: ***A Comparison of ERP Implementation Processes***

	Berchet and Habchi (2005)	Harwood (2003)	Jacobs and Whybark (2000)	Markus and Tanis (2000)	Rajagopal (2002)	Wallace and Kremzar (2001)
Building a business case		X		X		X
First-cut education						X
Establish strategic goals and vision	X				X	X
Investment decisions and cost-benefit analysis	X	X			X	X
Define and establish project organization		X	X			X
Define performance goals		X				X
Define system requirements	X	X	X		X	X
Software and vendor selection	X	X		X	X	X
Define processes	X	X	X	X	X	X
Business process reengineering (BPR)		X		X	X	
Data cleanup and conversion (data integrity)			X	X		X
Software configuration		X	X	X		X
Software installation	X					X
Software customization				X	X	X
System integration				X	X	X
Ongoing training / learning	X	X	X	X		X
ERP system Go-live	X	X	X	X	X	X
Continuous improvement	X	X	X	X	X	X
Evolution (Software upgrades; additional modules etc)	X			X	X	X

Wallace and Kremzar's (2001) ERP Proven Path

The most comprehensive and also perhaps the most well-known framework for ERP implementation is that of *ERP Proven Path* (Wallace and Kremzar, 2001). This section will give a brief overview of the methodology. For a more in depth account, see Wallace and Kremzer (2001).

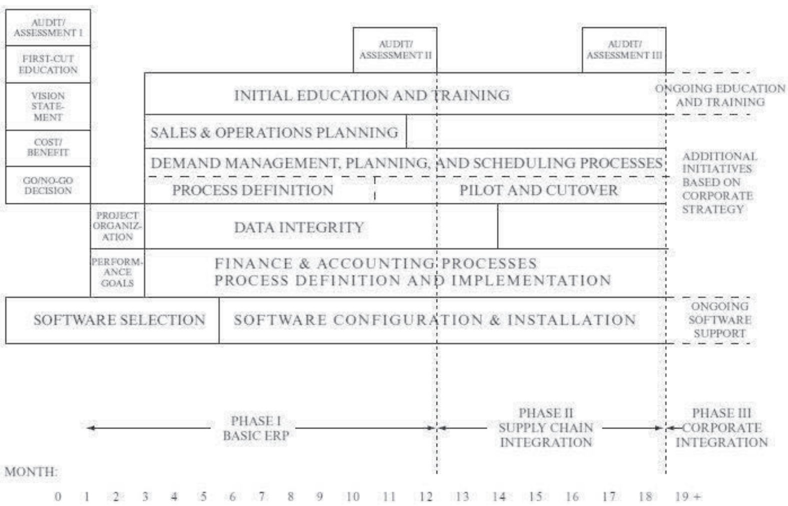

Figure 1: ***ERP Proven Path*** **(Wallace and Kremzar, 2001)**

Though ERP Proven Path appears at first to be a significantly complex framework, it consists of only three main phases: Phase I (Basic ERP); Phase II (Supply chain integration); and Phase III (Corporate integration). Though it is not identified in the figure, Proven Path also has a Phase 0 that describes the various elements that must logically occur before Phase I.

Phase 0

The starting point of ERP Proven Path is to conduct an analysis of the company's current situation, for example in order to assess current problems, opportunities, and strategies. Wallace and Kremzer (2001) suggest that executives and top managers should then learn the basics of how ERP works, and what is required for its effective implementation. They also suggest that a vision statement should be created, in the form of a written document that defines the desired environment to be achieved with the ERP implementation. A cost-benefit analysis is the final part of Phase 0, and this activity will end with a Go/No-go decision.

Phase I: Basic ERP

Phase I of the Proven Path methodology begins with creating the project team and executive steering committee, and consists of project planning and setting of performance goals. Phase I includes the selection, configuration and installation of the basic ERP package, including sales and operations planning, demand management, rough-cut capacity planning, master scheduling, material requirements planning, and the necessary applications for finance and accounting; and ends with ERP system "Go-live", or what Wallace and Kremzer call "cutover". This phase will normally take between nine and twelve months to complete.

Phase II: Supply chain integration

Phase II consists of all of the processes that extend ERP backwards and forwards in the suply chain: back to the suppliers (e.g. B2B e-commerce) and forward to customers (e.g. CRM; VMI). Wallace and Kremzar suggest that this phase will usually take three to six months, depending on the scope and intensity of the applications.

Phase III: Corporate integration

The final phase of Proven Path consists of the extensions and enhancements that are made to support corporate strategy, and can include completion of any finance and accounting elements not yet implemented, linkages to other business units within the global organization, HR applications, maintenance, product development, etc. (Wallace and Kremzar, 2001). This phase could also involve the implementation of other modules not absolutely necessary for Phases I & II, such as advanced planning and scheduling (APS) systems, and manufacturing execution systems (MES).

Lean Implementation Process

Though there exists an abundance of documented ERP implementation processes, this is unfortunatley not the case with lean production. After examining the extant literature, only four frameworks showing a sequential process for lean implementation were uncovered: Womack and Jones (1996); Åhlström (1998); Hobbs (2004); and Bicheno and Holweg (2009).

Åhlström (1998) suggests that existing research on the implementation of manufacturing improvement initiatives supports the idea that there are sequences for improvement activities in manufacturing. For example, Roos (1990) suggests that it is first necessary to change employees' attitudes to quality, in order to achieve material flow which contains only value adding operations. Storhagen (1993) suggests that job rotation and teamwork are required early on in order to support continuous improvement and change. This section considers the four frameworks for lean implementation with the aim of identifying the pertinent factors which should be combined with the Proven Path methodology (Wallace and Kremzar, 2001) in order to develop a process for ERP-based lean implementations.

Time Frame for the Lean Leap (Womack and Jones, 1996)

Womack and Jones (1996) present an outline for lean implementation, which they call a time frame for the lean leap (see Table 2). The "lean leap process" begins with identifying a change agent, who should acquire lean knowledge to share with the rest of the organisation before mapping value streams in order to create a new "lean" organisation. Once a lean function and a strategy for lean growth have been created, Womack and Jones suggest that the next phase is to install business systems to support the lean organization and encourage lean thinking. They suggest that the transformation is completed by applying lean thinking to suppliers and customers, developing a global strategy, and transitioning from a top-down to a bottom-up continuous improvement program.

Table 2: *Time Frame for the Lean Leap* (adapted from Womack and Jones, 1996)

Phase	Specific Steps	Time frame
Get started	Find a change agent Get lean knowledge Find a lever Map value streams Begin kaikaku Expand your scope	First six months
Create a new organisation	Reorganise by product family Create a lean function Devise a policy for excess people Devise a growth strategy Remove anchor-draggers Instill a "perfection" mindset	Six months through year two
Install business systems	Introduce lean accounting Relate pay to performance Implement transparency Initiate policy deployment Introduce lean learning Find right-sized tools	Years three and four
Complete the transformation	Apply these steps to suppliers/customers Develop global strategy Transition from top-down to bottom-up improvement	By end of year five

Sequences in the Implementation of Lean Production (Åhlström, 1998)

Åhlström studied the sequence in which eight lean production principles (Karlsson and Åhlström, 1995) were implemented during a longitudinal case study at Office Machines (a fictitious name of a Sweden-based company that implemented lean production). The eight lean principles are shown in Figure 4:

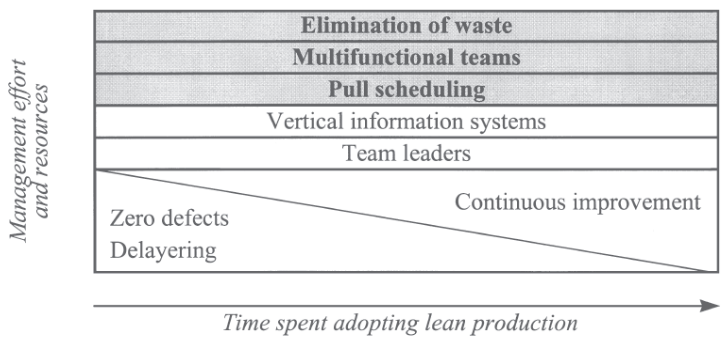

Figure 2: *Sequences in the Implementation of Lean Production* (Åhlström, 1998)

Although Åhlström concludes that zero defects and delayering of the organizational structure are important early on in the implementation of lean production, a so-called "step-by-step" guide for the implementation of the other lean production principles was not presented due to the identified interdependencies between them. For example, elimination of waste, multifunctional teams, and pull scheduling (the three "core principles") required management effort and resources throughout the whole implementation process. It was also found that vertical information systems and team leaders were also related to the three core principles throughout the entire implementation process. Åhlström did conclude, however, that the principle "continuous improvement" should be implemented late during the process, as it benefits from the prior establishment of the other principles.

Lean Manufacturing Implementation (Hobbs, 2004)

Hobbs (2004) describes a step-by-step process for the implementation of lean manufacturing that clearly consists of seven consecutive elements, and which hypothetically reflect the five lean principles (Womack and Jones, 1996), as shown in Table 3:

Table 3: *Lean Implementation Steps Vs Five Lean Principles* (Hobbs, 2004; Womack & Jones, 1996)

Implementation Step (Hobbs, 2004)	Relevant lean principle (Womack & Jones, 1996)
1) Establish strategic vision	
2) Identify and establish teams	
3) Identify products	***Value*** *– "…can only be defined by the ultimate customer. And is only meaningful when expressed in terms of a specific product"*
4) Identify processes	***Value Stream*** *– "all of the specific actions (processes) required to bring a specific product from concept into the hands of the customer"*
5) Review factory layout	***Flow*** *– "make the value-creating steps flow"*
6) Select appropriate Kanban (Pull) strategy	***Pull*** *– no one upstream should produce a good or service until the customer downstream asks for it"*
7) Continuously improve	***Perfection*** *– "the complete elimination of muda (waste)"*

Though steps three to seven are clearly connected to the five lean principles, steps one and two are more difficult to assign to the original lean principles. However, Hines (2010) states that the classic lean principles almost totally missed the importance of people. Thus, if we introduce an additional lean principle, People, then the step for establishing multifunctional teams (Hobbs 2004; Åhlström 1998) can also be attributed to a fundamental principle of lean production. Finally, step one (establish strategic vision) is a recommended starting point for any strategic implementation project, and can be considered as a 'pre-step' in this case.

Hierarchical lean transformation framework (Bicheno and Holweg, 2009)

Finally, a further alternative to the lean implementation approaches of Womack and Jones (1996), Åhlström (1998), and Hobbs (2004) is the hierarchical lean transformation framework presented in Bicheno and Holweg (2009). This is a more conventional, step-by-step approach developed to suit a longer-term implementation. The framework is summarized in Table 4:

Table 4: ***Hierarchical lean transformation framework*** **(adapted from Bicheno and Holweg, 2009)**

Step	Activity
1	Understand the lean principles
2	Understand your customers
3	Strategy, planning, and communication (e.g. establish and communicate strategic vision)
4	Understand the system
5	Product rationalization and lean design
6	Implement foundation stones
7	Value stream implementation cycle
8	Build a lean culture (people and teamwork)
9	Implement lean supply
10	Implement lean distribution
11	Performance measures and costing
12	Improve and sustain
13	Design the lean scheduling system
14	Cell and line design

Common elements from each of the four lean implementation processes have been identified, and a subsequent comparison can be seen in Table 5:

Table 5: ***A Comparison of Lean Implementation Processes***

	Bicheno and Holweg (2009)	Hobbs (2004)	Womack and Jones (1996)	Åhlström (1998)
Initial education	X		X	
Establish strategic vision	X	X	X	
Organizational structure for change			X	X
Define and establish teams	X	X	X	X
Define performance goals	X		X	
Implement basic foundations of lean	X			
Define products	X	X	X	
Define processes	X	X	X	
Establish zero defect mentality	X			X
Ongoing training / learning	X		X	
Vertical information systems	X		X	X
Layout for flow	X	X		
Lean accounting	X		X	
Pull system	X	X		X
Continuous improvement	X	X	X	X

Because all of the lean implementation processes studied were very similar and none of them stood out from the rest, and because we aim to create a process for ERP-based lean implementations, we choose to consider all of the elements identified in Table 5 when we develop our proposed framework.

RESEARCH METHODOLOGY

Due to the qualitative nature of this investigation and the type of research question, the selected research methodology is action research, which can also be compared to longitudinal, participative case study research. Philips (2004) suggests that there is a broad Scandinavian tradition for action research, which can be defined as a participatory, democratic process concerned with developing practical knowing in the pursuit of worthwhile human purposes, grounded in a participatory worldview (Reason and Bradbury, 2006). Essentially, it focuses on bringing about change (action) as well as contributing to knowledge (research). Reason and Bradbury go on to say that action without reflection and understanding is blind, just as theory without action is meaningless. McNiff and Whitehead (2009) suggest that doing action research involves the following elements:

1. Taking action (changing something);
2. Doing research (analyzing and evaluating both the change and change process);
3. Telling the story and sharing your findings (disseminating the results).

In an action research project, the researcher is required to take a participatory role in the change process at what we will call the client system. This makes bias somewhat inherent to the action research process. Herr and Anderson (2005) state that while bias and subjectivity are natural and acceptable in action research as long as they are critically examined rather than ignored, other mechanisms may need to be put in place to ensure that they do not have a distorting effect on the outcomes. Self-reflexivity is one such mechanism for reducing the effects of bias, allowing the researcher to examine his own subjectivity. Involving a group of people in the action research project also reduces the bias in a study, by having the group challenge the opinions of the researcher. Both of these approaches were taking so as limit the possible effects of bias in the study, thus increasing the quality and reliability of the findings.

Client System: Noca AS

Based in Trondheim, Norway, Noca is a manufacturing and service supplier within electronics and electronics development. Established in 1986, Noca delivers development, prototypes, batch production, and assembly for customers within innovation and entrepreneurs in high-tech industries. Noca has 50 employees and an annual turnover of €11.5m (2010). The company has recently begun applying lean practices to their operations, having started with value stream mapping (VSM) in late-2009, followed by 5S in 2010. Also in 2010, Noca management decided that the existing information system could no longer support efficient facility operation and proposed that it be replaced with a contemporary ERP system. After critically reviewing several available options which included Microsoft Dynamics Navision amongst others, Noca selected the Jeeves Universal ERP system.
In October 2010, one of the authors was contacted by Noca management and was informed that the company would like to combine the ERP implementation project with the application of lean production practices. The researcher was subsequently invited to join the implementation process, with an active role in the implementation project team – responsible for lean production. The ERP implementation process at Noca was to consist of three phases – a design and analyse phase; an implementation phase; and a Go-live phase. The two initiatives will now be described in more detail.

<u>The ERP initiative</u>

Company's motive to implement ERP

Due to increasing complexity in product requirements, more extensive and comprehensive supply chain requirements, and a greater mix of product offerings, there was a clear need to replace the current ageing MRP system. Therefore, in order to enable improvements and to increase the efficiency of its supporting IT solutions, Noca opted to begin the process of selecting and implementing a new ERP system.

ERP system and modules implemented

After a comprehensive selection process that included several major ERP vendors, Noca selected the Jeeves Universal ERP system in December 2010. The chosen system and included modules are shown in Figure 3:

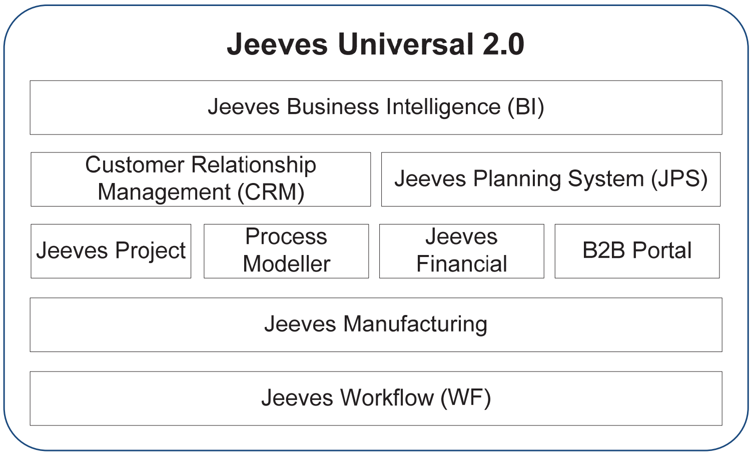

Figure 3: ***The "Jeeves Universal" ERP system and included modules***

Implementation strategy

The ERP implementation project team consisted of the following key stakeholders: Noca management team; representatives from Jeeves (ERP vendor - Sweden); representatives from Logit group (Norwegian delivery partner of Jeeves); and the researcher (NTNU / SINTEF). Logit group took the lead role in the ERP implementation project. The "Jeeves Project Model" implementation process is shown in Figure 4:

Figure 4: ***Jeeves Project Model***

As can be seen in the figure, the Jeeves Project Model consists of three main phases. The phases consist of the following elements:

1. Planning phase
   a. Project planning and start-up
   b. System selection
   c. Data conversion
   d. Training of super-users
2. Implementation phase
   a. Process design
   b. Configuration
   c. Verification
   d. Installation
   e. Training of users
3. Go-live/Close phase
   a. Go-live
   b. Support
   c. Hand-over
   d. Project close-out and evaluation

Obstacles
The main obstacle for the ERP implementation project was timing. Following the Jeeves Project Model, it was planned that the ERP implementation process would consist of the three main phases – design and analyse phase; implementation phase; and Go-live phase. The design and analysis phase was planned to run from January 2011 through February 2011, so as to realise a "go-live" (marking completion of the implementation phase) in the summer of 2011. However, increasing demands on both Noca and Logit saw the project delayed by six months, with a realised "go-live" date in January 2012.

The lean initiative

Company's motive to implement lean
Due to rising levels of international competition and increasing demands from the customer, Noca decided to implement lean production principles to improve its operational performance. For example, the company was experiencing significantly long production lead times and unsatisfactory levels of customer complaints; and these are two areas where lean production practices have been proven to deliver good results.

Lean practices implemented
Noca began its lean initiative as part of a project called NCEi Lean with a value stream mapping exercise in 2009, followed by 5S implementation in 2010 (see http://www.noca.no/Nyheter/LEAN). Positive results are already starting to show, such as a 17% improvement in delivery schedule adherence, as well as more than a 10% reduction in production leadtime (Langva, 2011). In fact, more recent indicators show a reduction in leadtime of 35%. Noca has also deployed a focus on zero defects, for example by delivering training to all operators in root-cause analysis; statistical process control (SPC); and A3 problem solving.

Implementation strategy
Noca's lean implementation strategy is based on the development of the Noca Production System (Figure 5), which much like the Toyota Production System (TPS) is built on the basis of stable processes and establishing the basic foundations of lean (5S, visual management, plan-do-check-act, and standard work),. Also like TPS, the Noca Production System rests on two fundamental pillars: Just-in-time (JIT) and total quality control (TQC).

In order to achieve JIT production, Noca aims to apply lean tools and techniques such as single minute exchange of dies (SMED) for set-up reduction, level production, and pull planning. Likewise, for TQC, Noca will deploy quality tools such as statistical process control (SPC), supplier quality assurance, in-process problem solving, and the eight disciplines to problem solving – 8D (e.g. Arnott, 2004).

The Noca Production System (NPS) has the overall goal of customer value through realising excellence in quality, cost, delivery, communication, environment and safety. NPS also aims for process ownership through the use of well-defined key performance indicators (KPIs), and has at its core three supporting principles: reflection; ideas; and responsibility. Interestingly, NPS also identifies ERP as a key underpinning element for creating and sustaining effective information flow:

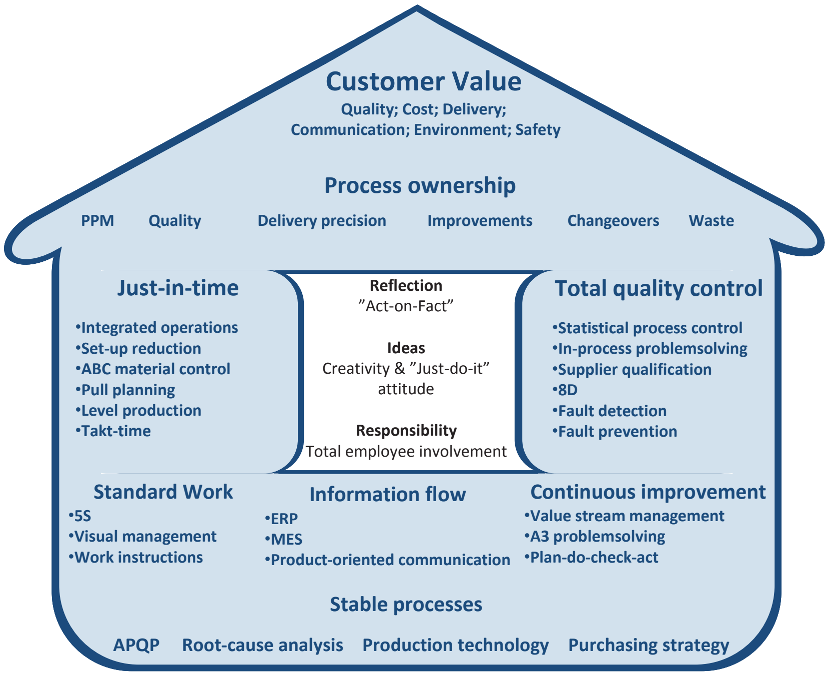

Figure 5: ***Noca Production System "House"***

Obstacles

The main challenges experienced during the lean implementation efforts were finding the time and resources for learning, development, and deployment of the lean practices. The availability of resources is identified as a key success criteria for lean implementation in SMEs (e.g. Achanga *et al.*, 2006), and as such, the development of an ERP-based lean implementation process is considered a key enabler for applying lean in SMEs, as time and resource requirements are reduced through applying a concurrent course of action.

Towards an ERP-Based Lean Implementation Process

By examining the relevant theory on the implementation of lean production and ERP systems, and through following a concurrent application process, we aim to propose a single best-practice process for ERP-based lean implementations. During the action research project, it was observed first-hand that the ERP implementation process can act as a catalyst for the implementation of lean practices, as many of the tasks are the same or similar, or they support each other's application. For example value stream mapping and standard work (as representative lean practices) support the development of process definition for the ERP implementation.

By applying the implementation of various lean practices to the Proven Path ERP implementation process, and by taking the findings of the action research project into consideration, a generalized process framework for ERP-based lean implementations can be proposed (see Figure 6).

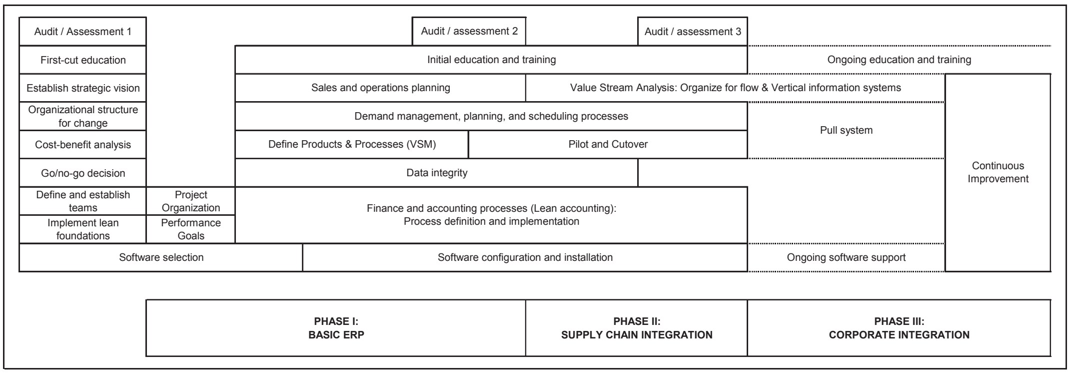

Figure 6: ***Framework for an ERP-Based Lean Implementation Process***

Many of the activities involved in the ERP implementation process were found to be highly influential for the implementation of lean practices. Were this is so, the relevant lean practices have been integrated within the ERP Proven Path framework.

Leadership, education, and training

First-cut education is one of the first steps in the Proven Path model. The journey to lean manufacturing also begins with top management education which develops the leadership so that lean learning can eventually flow to everyone in the company. Therefore, we suggest that that the initial education programme should include the basic elements of both lean and ERP, in order for top management to build a good business case for embarking on an ERP-based lean implementation process. Buker (2010) suggest that the lean implementation process should typically begin with a two-day lean course for top management. This could be integrated within a basic ERP course, and will help top management to become actively engaged in the implementation process. It also enables the development of the strategic vision to guide the implementation process. This type of strategic vision is an essential element for the type of corporate leadership required throughout the lean journey, as top management support is often cited as one of the critical success factors for lean implementation (e.g. Achanga *et al.*, 2006). The education process should then continue for operations management down to first-line supervisors and support staff (Buker, 2010), and finally for everyone else in the company, so that everyone can understand the lean principles (Bicheno and Holweg, 2009), and everyone has a common vision Hobbs (2004).

Learning then becomes a continuous process throughout the implementation of both lean and ERP. Multifunctional teams are developed, and focussed groups of people learn how to use ERP, as well as how to apply lean manufacturing principles to their specific jobs, often with the support of the ERP system (e.g. for decision support).

At Noca, the process of lean learning began when the researcher (having an active role in the project team) delivered an interactive presentation which gave an introduction to the theory behind lean, and gave an overview of the 7 wastes. A basic mapping workshop was also conducted, with participants including managers, team leaders and shopfloor operators. This helped identify immediate sources of waste in the production proceses, and gave useful insight into the relevance for the application of lean production practices at Noca.
In terms of learning for ERP, Noca have seven "super-users" who were trained up at least three months prior to go-live. Other users (such as production operators) were given initial training just before go-live.

Cost-benefit analysis and go/no-go

A cost-benefit analysis is the final part of initial implemention phase, and in our ERP-based lean implementation process, should consider the relevance of the application of both ERP and lean for the company. This activity will then end with a Go/No-go decision, as in the original Proven Path framework. At Noca, the cost-benefit analysis was carried out before selecting the ERP vendor.

Define and establish teams

Besides continuous improvement, the establishment of teams is the only other element of a lean implementation process to be identified by all four of the implementation processes studied in this investigation (Bicheno and Holweg, 2009; Hobbs, 2004; Womack, 2006; Åhlström, 1998). Teams are an essential element for the successful deployment of lean practices (Mueller *et al.*, 2000), and this is also the case with ERP implementation. For example, Snider et al. (2009) identify small internal teams as a critical success factor for implementing ERP systems in SMEs.

Senior management input is very important when selecting a suitable ERP vendor (Welti, 1999), as well as throughout the implementation process (Sun *et al.*, 2005). Likewise, top management commitment is also a critical success factor in any lean project (Scherrer-Rathje *et al.*, 2009). The commitment of top management was demonstrated at Noca through attendance at all team meetings, for both lean and ERP initiatives. It is also important to involve active personnel from the shopfloor, such as operators and team leaders, in the management of a lean change process (Bicheno and Holweg, 2009). As the establishment and formation of an effective "lean-ERP" team was a distinguishing part the implementation processes at Noca, with common team members for both the ERP and lean processes, we place the establishment of teams as an initial stage of the ERP-based lean implementation process.

Implement lean foundations

Having decided on a concurrent ERP and lean implementation process, at this stage in the implementation process the company takes a greater focus on the basic lean elements, and the real essence of the lean toolbox comes into play. Systematic improvements should be made (using lean-learning) in order to eliminate wastes – one such example would be to adopt a total quality control (TQC) approach in order to support a zero defects quality program, as Åhlström (1998) suggests that zero defects should come early on in the lean implementation process. This type of program would involve operators being given necessary quality management training, for example in the use of SPC techniques and root-cause-analysis (RCA) tools. The other key basic lean foundations include for example 7 wastes (Ohno, 1988); 5S (Hirano, 1995); plan-do-check-act (Deming, 1986); and standard work (Ohno, 1988). We also suggest the use of basic process mapping as a fundamental part of the lean process. Though we suggest that the basic elements of lean be instilled before ERP implementation, a catalytic effect can be had by applying some elements concurrently. As an example, following an introduction to lean production and the 7 wastes, Noca began implementing 5S prior to starting the software selection process for the ERP implementation. Noca then chose to educate its workforce in TQC techniques (SPC & RCA) whilst the ERP vendor was configuring the ERP solution to Noca's specification. Having also carried out basic process mapping, Noca also had a better understanding of the necessary process information for the ERP implementation.

Wallace and Kremzar (2001) suggest that total quality initiatives and ERP projects should not be seen as competing, but rather complementary. They suggest that the two processes support, reinforce, and benefit each other, and state that the total quality project leader would ideally also be a member of the ERP project team.

ERP system selection and implementation

This is the most important part of our ERP-based lean implementation methodology. This is because, in the traditional sense, lean and ERP would be treated remotely, often by different people in different functions. However, during the concurrent implementation process, it was identified that the ERP implementation can and should be used as a catalyst for the application and sustainability of lean production practices. As such, members of the team selected to manage the lean implementation at Noca were also members of the ERP project team, and included management personnel and team leaders.

Software selection

Noca selected the Jeeves Universal ERP system as it was one of the most flexible systems on the market. An interesting property of the Jeeves system is its infrastructure, which uses metadata-based technology that makes the system simple to modify without being affected by future system upgrades. This means that any modifications to the software, be it lean-related or otherwise, will not be lost or overwritten in the event of software upgrades. We consider this to be a key strength that should be considered by any company that is considering using ERP to support the deployment of lean practices.

By comparing the five lean principles (Womack and Jones, 1996) with the modules of the Jeeves Universal ERP system selected by Noca, Powell et al. (2011) present 15 key areas where the ERP system can be used to support lean production. They suggest that a contemporary ERP system such as Jeeves can:

1. Support customer relationship management
2. Automate necessary non-value adding activities (e.g. backflushing)
3. Enable process-modelling to support standard work processes
4. Provide a source for easy-to-find product drawings and standard work instructions
5. Support information sharing across the supply chain
6. Create synchronized and streamlined data flow (internal & external)
7. Support line balancing
8. Support demand levelling
9. Support orderless rate-based planning (e.g. takt-time)
10. Provide decision support for shop floor decision making
11. Support kanban control
12. Support production levelling (Heijunka)
13. Support JIT procurement
14. Provide a system to support root-cause analysis and for the logging and follow-up of quality problems
15. Provide highly visual and transparent operational measures (e.g. real time status against plan)

We suggest that each of these 15 areas should also be considered when selecting an ERP system that will be used for an ERP-based lean implementation.

Identify products and processes

Identifying products, especially product families, is critical to any ERP or lean implementation. This is because it is essential to define the correct product structure in the ERP system, and equally important to define value from the perspective of the customer, which is only meaningful in terms of a specific product (Womack and Jones, 1996). Product family analysis should be part of this stage, in order to support process identification and value stream analysis that follows.

Having identified the products (and defined value), the next step is to identify the processes that contribute to creating the products. Therefore, the next step in our lean transformation framework is to identify the processes, or what Bicheno and Holweg call "the value stream implementation cycle". Basic mapping should already have been carried out to identify the various processes during the implementation of the basic lean foundations. This can be used to help formalize and structure the various processes in the ERP system, and applies to the physical operational processes (machines and work centres) as well as the business (e.g. transactional) processes (demand management, planning and scheduling processes; and finance and accounting processes). The sales and operations planning (S&OP) process should also be formalized in the ERP system, as this is an essential part of demand levelling as a pre-step for pull production (Shingo, 1981). Wallace and Kremzar (2001) state that S&OP is an essential part of ERP, and suggest that one of the major reasons for ERP's poor success rate is that many companies do not include S&OP in their ERP implementation. Wallace and Kremzar also state that S&OP is all about balancing supply and demand at the volume level, where volume refers to rates – rates of sales, rates of production, etc. Having a rate-based view will also set the company in good stead for the implementation of rate-based planning required for pull production. Often the identification and formalization of business processes will result in business process reengineering (e.g. Davenport, 2000). Therefore, it is logical that this activity be carried out alongside value stream analysis, such that improvements can be made for material and information flows.

Noca made a concerted effort to identify and define products and processes for both the lean and ERP initiatives. The company also formalized its S&OP process, which is greatly supported by the new ERP system through automated data capture and automation of manual tasks. However, none of Noca's processes were reengineered, as Noca wanted to use the out-of-the-box ERP system as much as possible. This calls for accurate process data, which is covered in the next step of the process – data integrity.

Data integrity

From the initial lean-learning stage, it was suggested that a zero defects culture be created whereby errors in the system are no longer acceptable. This does not just apply to the production system, but also to the supporting ERP system. Therefore, the integrity of the data in the ERP must be assured. As with any information technology (IT) solution, particularly true of ERP systems is "garbage in = garbage out" (GIGO). A significant amount of time was spent ensuring data integrity at Noca in order that the ERP system can be used most effectively.

Software configuration and installation

Having assured the integrity of the basic data in the ERP system, it must then be configured to the client specifications and installed at the client's location/s before go-live. This stage took in excess of six months in the case of the Jeeves configuration for Noca, which actually gave the company opportunity to investigate other lean principles whilst the vendor configured the ERP system remotely.

Value stream analysis

Having previously identified and defined the products (product families) and processes, a more detailed value stream analysis should be carried out so as to identify waste in processes and to improve material and information flows (Rother and Shook, 2003). This step is directly linked to the "organize for flow" step, which focuses on effective material flows, and the "visual management and vertical information systems" step which places emphasis on efficient information flows.

Organize for flow

Having laid the basic foundations for lean production and set the ball rolling with the ERP implementation, we suggest that the next step is to create continuous flow. This step requires an assessment of the current shopfloor layout. Machines and work cells should be located as close as possible so as to reduce the need for transportation (one of the 7 wastes), thus supporting the systematic and logical flow of materials. The flow concept should also be reflected in the ERP system. Wallace and Kremzar (2001) state that a good transaction system should, to the greatest extent possible, mirror the reality of how material actually flows. This is one of the reasons why Noca has selected a Workflow module in its ERP system.

Having optimized the shopfloor layout, operations should be synchronised in order to realise continuous flow, and changeover times of the machines should be reduced by applying single minute exchange of dies – SMED (Shingo, 1985). The lean implementation team at Noca evaluated the current shopfloor layout, and made relevant changes in order to support material flow through the plant. SMED was also applied, and Noca was able to reduce the changeover times of its surface mount technology (SMT) machines from a number of hours to less than 30 minutes.

Vertical information systems

In order to support the effective flow of materials and products, vertical information systems should be used for the effective flow of information. Åhlström (1998) suggests that vertical information systems are simple information systems relying on direct information flows to the relevant decision-makers. This allows for rapid feedback and corrective action. Such an information system also enables the multifunctional teams to perform according to the company's goals, thus reducing the need for managers to micromanage the manufacturing process, and allowing empowered workers.

The vertical information systems that were introduced at Noca consist of performance and demand information displayed on notice boards in the production areas. However, this information is often outdated. As such, it is anticipated that in the future the ERP system will be configured to provide direct information to the relevant decision-makers, in the relevant locations, in real-time.

Cutover

ERP cutover, or go-live, marks the point at which the new system is switched on to take-over from any existing system. As is suggested by Wallace and Kremzar (2001), this step should usually be carried out in a small pilot area first; however it can also be executed as a "big-bang" switchover.
The ERP go-live at Noca was a big-bang cutover with a pre-test, or what Wallace and Kremzar called the pilot approach. Firstly, a test was carried out which compared two months' worth of system data (net-requirements planning; production orders; purchase orders etc.) from the old system with the suggestions of the new Jeeves system. The purpose of this was to prove that master production scheduling (MPS) and material requirement planning (MRP) were working properly. Once the ERP team were happy with the outcome, the cutover was planned, and the old system was shut down on a Friday afternoon, with the new system taking over on the Monday morning. On-going software support was offered from the ERP vendor and delivery partner until handover and sign-off.

Pull system

Once the new ERP system is running smoothly, having overcome any teething problems at cutover, and products are flowing continuously through the value stream, the company can begin to think about an appropriate pull strategy (Hobbs, 2004). Though pull systems have traditionally been designed and deployed without support from the ERP system, Powell et al. (2012) suggest a number of ways in which an ERP system can be used to support a pull system. This will of course depend upon the type of products and processes the company has, for example a company producing standardised, high volume and low variety products may select a Kanban system (Ohno, 1988), whereas a company with low volume, high variety, customised products may opt for a POLCA system (Suri, 1998). On the other hand, a company may not produce discrete products at all, and will need to select a solution that is suitable for the process-type industries, e.g. Process Wheel (King, 2009) or every product every – EPE (Powell *et al.*, 2009).

As part of the Noca Production System, our case company is considering the application of pull planning and level production (based on takt-time), for its products, and are very interested in the concept of quick response manufacturing (QRM) and Polca (Suri, 1998).

Lean accounting

Bicheno and Holweg (2009) distinguish between lean accounting, whereby the number of transactions are minimised in order to increase the efficiency of the accounting process; and accounting for lean, which attempts to improve decision making to enable lean operations. Here, the term "lean accounting" covers both ideas. Bicheno and Holweg also suggest that a lean accounting system should ideally work towards direct costs, and overhead allocation should be directly associated with work cells or product lines. This is similar to the suggestions of Womack and Jones (1996), who state that when implementing lean, a company should create a lean accounting system, based on either activity based costing (ABC), or value-stream/product-based costing that takes into account product development costs as well as production and supplier costs.

Though Noca has chosen to use standard cost accounting rather than ABC, the deployment of a Workflow module in the ERP system will nevertheless support lean accounting by reducing the number of transactions, and increasing the speed and quality of transactions. Noca has suggested that an alternative accounting system will be considered as the company moves closer to achieving continuous flow and pull production.

Continuous improvement

Womack and Jones' (1996) fifth and final lean principle is perfection. A central element on the journey towards perfection is a concept known as kaizen (Imai, 1986). Kaizen is the Japanese term for continuous improvement. In fact, a culture of continuous improvement should already be present within the company since day one of the lean implementation. Though continuous improvement is the final step in our ERP-based lean implementation process, it has been present from the very start. For example, from the moment that a company chooses to embark on a lean implementation project, continuous improvement should be at the forefront of such a change process. This is why plan-do-check-act (PDCA) improvement cycle (Deming, 1986) is included as a basic lean foundation at the start of the ERP-based lean implementation process.

Noca has identified PDCA and continuous improvement as a fundamental part of the Noca Production System, and implemented a continuous improvement program that uses information boards on the shopfloor to gather improvement suggestions from the employees. Noca has also established routines for dealing with improvement suggestions, and ensuring that improvement becomes a continuous process.

The audit and assessment process

Throughout the implementation process, a number of assessments should be made in order to monitor and control the success of the project. The ERP Proven Path framework has three audit and assessment points. In our ERP-based lean implementation framework, we maintain the three assessment points as our implementation milestones, as follows:

Audit/assessment 1

Audit/assessment 1 contains all elements of the initial preparation phase, first cut education; strategic vision; organizational structure; cost-benefit analysis; go/no-go decision; team formation; and the implementation of the lean foundations (e.g. 7 wastes, 5S, PDCA, basic process mapping). This first assessment should mark that all of these tasks are accomplished, and ensures that the initiatives to be pursued by the company through the ERP-based lean implementation match the company's true needs, generate competitive advantage, and are consistent with the company's long-term strategy.

Audit/assessment 2

This step is an "in-process" check, and assesses the status and success of the implementation to date. The assessment includes the verification of performance to the goals that were set at the start of the process, and formally reviews what has been achieved so far in the project. The vision statement can also be reviewed and modified at this stage, and the company should assess its readiness to pursue the implementation into phase II.

Audit/assessment 3

This is the final formal assessment of the ERP-based lean implementation process. Wallace and Kremzar (2001) suggest that whilst this assessment is the maybe the most critical to the company's growth and survival, it is often the easiest to overlook.

The first task at this stage is to assess what has been completed to date. Have the lean foundations that were implemented at the start of the process been sustained? Does the performance of the ERP system meet the goals that were originally set by the team? Are the benefits that were projected in the cost-benefit analysis being realized? Having answered these questions, the company can plan the road ahead in terms of the lean-ERP process. For example, should additional ERP modules be installed to further support lean production principles? We conclude that the third assessment should identify on what to do during phase III: corporate integration. This is an ideal phase in the dual-implementation process to begin to deploy a pull system, carefully tuning the rate of production to the rate of customer demand (takt-time). The pull system can be supported by further developing the ERP system (e.g. Powell *et al.*, 2012). A plan should also be made at this stage for ongoing education and training for the workforce.

DISCUSSION

Though there is an abundance of documented ERP implementation methodologies and processes, this is not the case with lean production. Thus, it is no surprise that a methodology for ERP-based lean implementations is absent from the scientific literature. By comparing the various approaches for ERP and lean implementation, and by studying the concurrent application of lean production and a contemporary ERP system at Noca AS, we have been able to propose a framework for ERP-based lean implementations.

Motwani (2003) suggests that the role of IT in a business process change project could either be dominant or as an enabler. Through applying an action research approach, we have developed a framework for an ERP-based lean implementation process, where the role of IT is both dominant and as an enabler. By comparing the theoretical approaches to lean implementation and ERP implementation projects, we propose a best-practice approach for ERP-based lean implementations.
Both approaches tend to begin with setting the strategic vision and values of the company. Therefore, we suggest that after top management has been educated in the basics of lean production, a clear strategic vision should be communicated to the entire company. This was in fact one of the first steps in developing the Noca production system, when the management team defined and communicated a clear strategic vision to the workforce.

Evidence suggests that IT-lead projects are often unsuccessful in capturing the business and human dimensions of processes, and are likely to fail (Markus and Keil, 1994). Therefore, in developing a process for ERP-based lean implementations, we emphasize the importance of capturing the human dimensions at an early stage, by ensuring initial lean education for all, and continuous lean-learning throughout the entire implementation process (for example, in group improvement activities).

Schniederjans and Kim (2003) and Snider et al. (2009) show that it is often necessary to carry out improvements prior to enforcing standardized procedures brought in by ERP. Therefore we suggest that before the ERP system "go-live", at least the basic foundations of lean are established (e.g. zero defects; 5S; standard work).

Wallace and Kremzar (2001) suggest that lean manufacturing is arguably the best thing that ever happened to ERP. They state that if a company does lean properly, it will not be able to neglect its ERP system. This is because pull production requires accurate data in order to function correctly. Also, as lean practices are applied to improve and simplify processes, data integrity and planning also become easier. Thus lean and ERP are very much complimentary approaches.

Conclusion and Further Work

Many managers feel that one of the benefits of ERP implementation is the chance to re-engineer their operations (Hopp and Spearman, 1996). Similarly, Wallace and Kremzar (2001) also state that ERP can be used to provide the foundation upon which additional productivity and quality enhancements can be built, whilst Abbas et al. (2006) suggest that an ERP system can be used as a mechanism to effect enterprise-wide change with the long term goal of significant business improvement. We therefore suggest that the ERP implementation process can be considered as a catalyst for the implementation of lean production in an enterprise. For example, Nauhria et al. (2009) suggest that a well implemented ERP system is the foundation on which an effective lean (six sigma) program can be built. We go a step further and suggest that future perspectives of lean manufacturing should consider the ERP system as one of the tools in the lean toolbox, as the results of this research has placed the ERP implementation process as an imperative element of the lean implementation process.

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References

Abbas, S. A., Pinedo-Cuenca, R., Badak, Z. & Ahmad, M. 2006. A Three-Step Methodology for ERP. *Production and Operations Management Society (POMS) Conference "The World of Operations Management"*. Shanghai.

Achanga, P., Shehab, E., Roy, R. & Nelder, G. 2006. Critical success factors for lean implementation within SMEs. *Journal of Manufacturing Technology Management,* 17 (4), 460-471.

Arnott, B. 2004. The 8 Discipline Approach to Problem Solving. *IRINFO* [Online]. Available: http://www.irinfo.org/articles/article_9_1_2004_arnott.pdf [Accessed 2 January 2012].

Bancroft, N. H., Seip, H. & Sprengel, A. 1998. *Implementing SAP R/3 - How to Introduce a Large System into a Large Organization,* Greenwich, Manning Publications.

Bell, S. 2006. *Lean Enterprise Systems: Using IT for Continuous Improvement,* Hoboken, NJ, Wiley and Sons.

Berchet, C. & Habchi, G. 2005. The implementation and deployment of an ERP system: An industrial case study. *Computers in Industry,* 56 588-605.

Bicheno, J. & Holweg, M. 2009. *The Lean Toolbox,* Buckingham, PICSIE Books.

Bruun, P. & Mefford, R. N. R. N. 2004. Lean production and the Internet. *International Journal of Production Economics,* 89 (3)**,** 247-260.

Buker. 2010. Seven Steps to Lean Manufacturing. Available: http://buker.com/files/uploads/2010/01/LM.pdf [Accessed November 2011].

Cooper, R. B. & Zmud, R. W. 1990. Information Technology Implementation Research: A Technological Diffusion Approach. *Management Science,* 36 (2)**,** 123-139.

Davenport, T. H. 2000. *Mission critical: realizing the promise of enterprise systems,* Boston, Harvard Business School Press.

Deming, W. E. 1986. *Out of the Crisis,* Cambridge, Massachusetts Institute of Technology.

Doom, C. & Milis, K. 2009. CSFs of ERP Implementations in Belgian SMEs: A Multiple Case Study. *European and Mediterranean Conference on Information Systems 2009.* Izmir.

Halgari, P., Mchaney, R. & Pei, Z. J. 2011. ERP Systems Supporting Lean Manufacturing in SMEs. *In:* CRUZ-CUNHA, M. M. (ed.) *Enterprise Information for Systems Business Integration in SMEs: Technological, Organizational, and Social Dimensions* Hershey, PA: Business Science Reference.

Harwood, S. 2003. *ERP: The Implementation Cycle,* Oxford, Butterworth Heinemann.

Herr, K. & Anderson, G. L. 2005. *The Action Research Dissertation: A guide for students and faculty,* Thousand Oaks, Ca., Sage.

Hines, P. 2010. *The Principles of the Lean Business System* [Online]. S A Partners. Available: http://www.sapartners.com/images/pdfs/the%20principles%20of%20the%20lean%20business%20system.pdf [Accessed February 2011].

Hirano, H. 1995. *5 Pillars of the Visual Workplace - The Sourcebook for 5S Implementation,* New York, Productivity Press.

Hobbs, D. P. 2004. *Lean Manufacturing Implementation: a complete execution manual for any size manufacturer,* Boca Raton, FL, Ross Publishing.

Holland, C. P. & Light, B. 2001. A Stage Maturity Model for Enterprise Resource Planning Systems Use. *The DATA BASE for Advances in Information Systems,* 32 (2)**,** 34-45.

Hopp, W. J. & Spearman, M. L. 1996. *Factory Physics,* Boston, McGraw-Hill.

Imai, M. 1986. *Kaizen: The Key to Japan's Competitive Success,* New York, McGraw Hill.

Jacobs, F. R. & Bendoly, E. 2003. Enterprise resource planning: Developments and directions for operations management research. *European Journal of Operational Research,* 146 (2)**,** 233-240.

Jacobs, F. R. & Whybark, D. C. 2000. *Why ERP? A Primer on SAP Implementation,* Boston, McGraw-Hill.

Karlsson, C. & Åhlström, P. 1995. Change processes towards lean production: The role of the remuneration system. *International Journal of Operations & Production Management,* 15 (11)**,** 80-100.

King, P. L. 2009. *Lean for the Process Industries: Dealing with Complexity,* New York, Productivity Press.

Kraemmergaard, P., Møller, C. & Boer, H. 2003. ERP implementation: An integrated process of radical change and continuous learning. *Production Planning & Control,* 14 (4)**,** 338-348.

Langva, N. E. 2011. Nye veier til forbedring med SINTEF i forstavnen. *Logistikk & Ledelse,* 5 (2011) 28-32.

Liker, J. K. 2004. *The Toyota Way: 14 Management Principles From the World's Greatest Manufacturer,* New York, McGraw-Hill.

Mabert, V. A., Soni, A. & Venkataramanan, M. A. 2003. Enterprise resource planning: Managing the implementation process. *European Journal of Operational Research,* 146 (2)**,** 302-314.

Markus, M. & Keil, M. 1994. If we build it they will come: designing information systems that users want to use. *Sloan Management Review,* 35 11-25.

Markus, M. L. & Tanis, C. 2000. The enterprise system experience - from adoption to success. *In:* ZMUD, R. W. (ed.) *Framing the domains of IT management.* Cincinnatti: Pinnaflex.

Masson, C. & Jacobson, S. 2007. Lean Planning and Execution Software: Extending Lean Thinking Across the Enterprise. Available: http://www.oracle.com/corporate/analyst/reports/industries/aim/amr-20378.pdf [Accessed September 2010].

Mcniff, J. & Whitehead, J. 2009. *Doing and Writing Action Research,* Los Angeles, Sage.

Motwani, J. 2003. A business process change framework for examining lean manufacturing: A case study. *Industrial Management & Data Systems,* 103 (5/6)**,** 339-346.

Mueller, F., Procter, S. & Buchanan, D. 2000. Teamworking in its context(s): Antecedents, nature and dimensions. *Human Relations,* 53 (11)**,** 1387-1424.

Nauhria, Y., Wadhwa, S. & Pandey, S. 2009. ERP Enabled Lean SIx Sigma: A Holistic Approach for Competitive Advantage. *Global Journal of Flexible Systems Management,* Jul-Sep.

Ohno, T. 1988. *Toyota Production System: Beyond large-scale production* New York, Productivity Press.

Parr, A. & Shanks, G. 2000. A model of ERP project implementation. *Journal of Information Technology,* 15 289-303.

Philips, M. E. 2004. Action research and development coalitions in health care. *Action Research,* 2 (4)**,** 349-370.

Powell, D., Alfnes, E. & Semini, M. 2009. The Application of Lean Production Control Methods within a Process-Type Industry: The Case of Hydro Automotive Structures. *APMS 2009: International Conference on Advances in Production Management Systems.* University of Bordeaux, Bordeaux, France: Springer.

Powell, D., Alfnes, E., Strandhagen, J. O. & Dreyer, H. 2011. ERP support for lean production. *APMS 2011: International Conference on Advances in Production Management Systems.* Stavanger, Norway. 26-28 September 2011: Springer.

Powell, D., Riezebos, J. & Strandhagen, J. O. 2012. Lean production and ERP systems in SMEs: ERP support for pull production. *International Journal of Production Research,* Available online 23 January 2012.

Rajagopal, P. 2002. An innovation—diffusion view of implementation of enterprise resource planning (ERP) systems and development of a research model. *Information & Management,* 40 (2)**,** 87-114.

Reason, P. & Bradbury, H. (eds.) 2006. *Handbook of Action Research,* London: Sage Publications.

Riezebos, J., Klingenberg, W. & Hicks, C. 2009. Lean Production and information technology: Connection or contradiction? *Computers in Industry,* 60 237-247.

Roos, L.-U. 1990. *Japanisering inom produktionssystem: Några fallstudier av Total Quality Management i brittisk tillverkningsindustri, (Japanisation in Production Systems: Some Case Studies of Total Quality Management in British Manufacturing Industry). Swedish,* Göteborg, Handelshögskolan vid Göteborgs Universitet.

Rother, M. & Shook, J. 2003. *Learning to See,* Cambridge, Lean Enterprise Institute.

Sarkis, J. & Gunasekaran, A. 2003. Enterprise resource planning—modeling and analysis. *European Journal of Operational Research,* 146 (2)**,** 229-232.

Scherrer-Rathje, M., Boyle, T. A. & Deflorin, P. 2009. Lean, take two! Reflections from the second attempt at lean implementation. *Business Horizons,* 52 79-88.

Schniederjans, M. J. & Kim, G. C. 2003. Implementing enterprise resource planning systems with total quality control and business process reengineering: survey results. *International Journal of Operations & Production Management,* 23 (4)**,** 418-429.

Shingo, S. 1981. *A Study of the Toyota Production System,* New York, Productivity Press.

Shingo, S. 1985. *A Revolution in Manufacturing: The SMED System,* New York, Productivity Press.

Snider, B., Silveira, G. J. C. D. & Balakrishnan, J. 2009. ERP implementation at SMEs: Analysis of five Canadian cases. *International Journal of Operations & Production Management,* 29 (1)**,** 4-29.

Storhagen, N. G. 1993. *Management och flödeseffektivitet i Japan och Sverige. (Management and Flow Efficiency in Japan and Sweden). Swedish,* Linköping, Linköping University.

Sun, A. Y. T., Yazdani, A. & Overend, J. D. 2005. Achievement assessment for enterprise resource planning (ERP) system implementations based on critical success factors (CSFs). *International Journal of Production Economics,* 98 (2)**,** 189-203.

Suri, R. 1998. *Quick response manufacturing: a companywide approach to reducing leadtimes,* Portland, OR, Productivity Press.

Wallace, T. F. & Kremzar, M. H. 2001. *ERP : Making IT Happen. The implementers' guide to success with enterprise resource planning,* Hoboken, NJ, John Wiley and Sons.

Welti, N. 1999. *Successful SAP R/3 Implementation: Practical Management of ERP projects.,* Reading, MA, Addison Wesley.

Womack, J. P. 2006. Back to its Roots. *IET Manufacturing Engineer,* October/November 2006 (8-9).

Womack, J. P. & Jones, D. T. 1996. *Lean Thinking: Banish Waste and Create Wealth in Your Corporation,* New York, Simon and Schuster.

Womack, J. P., Jones, D. T. & Roos, D. 1990. *The Machine that Changed the World,* New York, Harper Perennial.

Zhang, Z., Lee, M. K. O., Huang, P., Zhang, L. & Huang, X. 2005. A framework of ERP systems implementation success in China: An empirical study. *International Journal of Production Economics,* 98 (1)**,** 56-80.

Åhlström, P. 1998. Sequences in the Implementation of Lean Production. *European Management Journal,* 16 (3)**,** 327-334.