ABSTRACT: *Lean production and enterprise resource planning systems are often quoted as being the two most important strategies for achieving competitive advantage in today's global manufacturing environments. Though IT has traditionally been viewed as a contributor to waste within lean production, we suggest that modern developments in IT and the onset of hybrid "push-pull" production control mechanisms have allowed ERP and lean approaches to converge towards a state where ERP systems can in fact be used to support the deployment of lean practices. This paper analyses typical lean and ERP implementation processes contained within the scientific literature, and by further examining a concurrent implementation process in real-time, we develop and propose a 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

1. 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?***

1.1. 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.

1.2. 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.

2. EXISTING METHODOLOGIES FOR THE IMPLEMENTATION PROCESS

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).

2.1. 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***

2.1.1. 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).

2.2. The 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.

2.2.1. 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. 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.

2.2.2. 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 2:

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.

2.2.3. 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 2:

Table 2: ***Lean Implementation Steps Vs Five Lean Principles*** **(Hobbs, 2004; Womack & Jones, 1996)**

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.

2.2.4. 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 Figure 3:

Figure 3: ***Hierarchical lean transformation framework*** **(adapted from Bicheno and Holweg, 2009)**

Common elements from each of the four lean implementation processes have been identified, and a subsequent comparison can be seen in Table 3:

Table 3: ***A Comparison of Lean Implementation Processes***

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 3 when we develop our proposed framework.

3. 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.

3.1. 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.

3.1.1. The ERP initiative

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 4:

Figure 4: ***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 5:

Figure 5: ***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.

3.1.2. 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 6), 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 6: ***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.

4. 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 others application. For example value stream mapping and standard work (as representive 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 7).

Figure 7: ***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. Where this is so, the relevant lean practices have been integrated within the ERP Proven Path framework. In order to accomplish the implementation in a reasonable time frame, the Proven Path strategy is two-fold:

1. Divide the total implementation project into several major phases to be done serially – one after the other.
2. Within each phase, accomplish a variety of individual tasks simultaneously.

Thus, in Figure 7, it can be seen that the ERP-based lean implementation process is divided into three major phases. Rather than maintaining the original four phases of Proven Path (Phases 0-3), we opt to merge Phases zero and one to become Phase I: Basic lean and ERP; Phase II becomes Advanced ERP-enabled lean production; and Phase III we call Continuous improvement. These phases are reflected on the horizontal axis, which represents time. The significance of the vertical axis is that it identifies the variety of individual tasks that should be accomplished simultaneously. The individual tasks are now described in more detail.

4.1. 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.

4.2. 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.

4.3. 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.

4.4. 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.

4.5. 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.

4.5.1. 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.

4.5.2. *Defining products and processes*

Defining 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 defined the products (and "value"), the next step is to identify and define the processes that contribute to creating the products. Therefore, the next step in our lean transformation framework is to define 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.

4.5.3. *Data integrity*

Systems are only as effective as the data they are based on (Louis, 1997). 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. This included bill-of-material data, inventory status data, and master file data. For example, as well as the deployment of quality management practices on the shop floor, Noca adopted an approach for the quality assurance for all data entered into the ERP system, including customer information, product information, bills of materials and process information. The role of "IT controller" was created, which carried the responsibility for ensuring that all data was correct and up-to-date. Random samples are regularly taken from the data files in order to check that data is always accurate and timely.

4.5.4. *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.

4.6. 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.

4.6.1. 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.

4.6.2. 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.

4.7. 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 shutdown on a Friday afternoon, with the new system taking over on the Monday morning. Ongoing software support was offered from the ERP vendor and delivery partner until handover and sign-off.

4.8. 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), which can be classed as a pull system as long as POLCA is used in a production environment where the primary demand represents an external customer order and not a forecast. 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).

4.9. 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.

4.10. 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 shop floor 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.

4.11. 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:

4.11.1. 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.

4.11.2. 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.

4.11.3. 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.

5. 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 complementary approaches.

6. 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. In this paper, we have combined existing methodologies for lean production and ERP systems in order to propose a single best practice approach which we call an "ERP-based lean implementation process". We have also used data gathered from an action research project at an electronics producer in Trondheim, Norway, to develop the suggested methodology. Our findings suggest that the ERP implementation process can in fact 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. We also suggest that this type of methodology has practical implications for SMEs, as these types of company often struggle to implement either of the approaches independently. By using the

ERP implementation process as a platform and catalyst for the deployment of lean practices, an SME can gain advantage from both approaches to production management.

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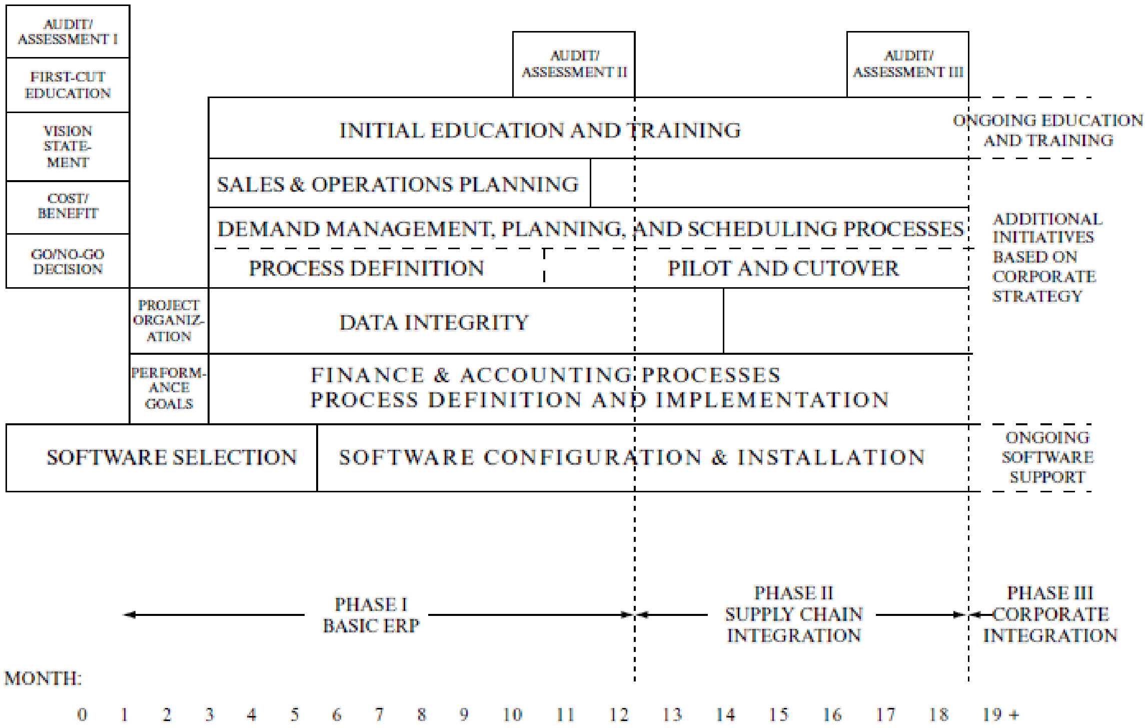

Figure 1: ***ERP Proven Path*** **(Wallace and Kremzar, 2001)**

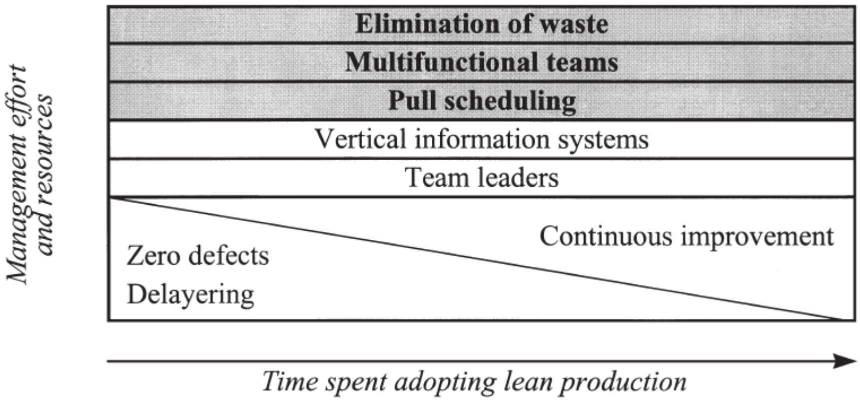

Figure 2: ***Sequences in the Implementation of Lean Production*** **(Åhlström, 1998)**

Figure 3: ***Hierarchical lean transformation framework*** **(Bicheno and Holweg, 2009)**

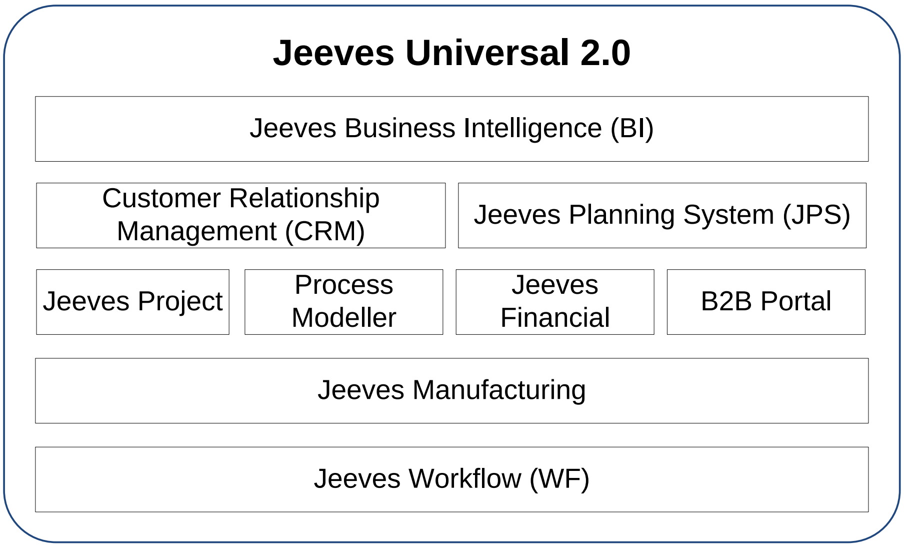

Figure 4: ***The "Jeeves Universal" ERP system and included module***

Figure 5: ***Jeeves Project Model***

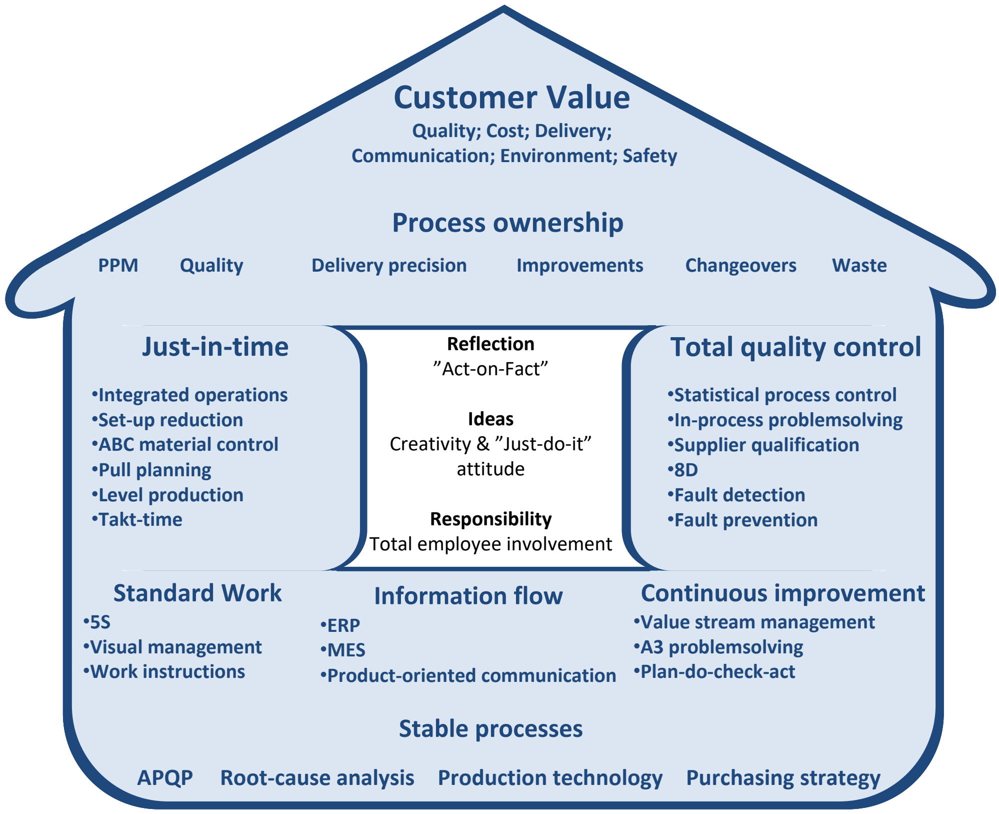

Figure 6: ***Noca Production System "House"***

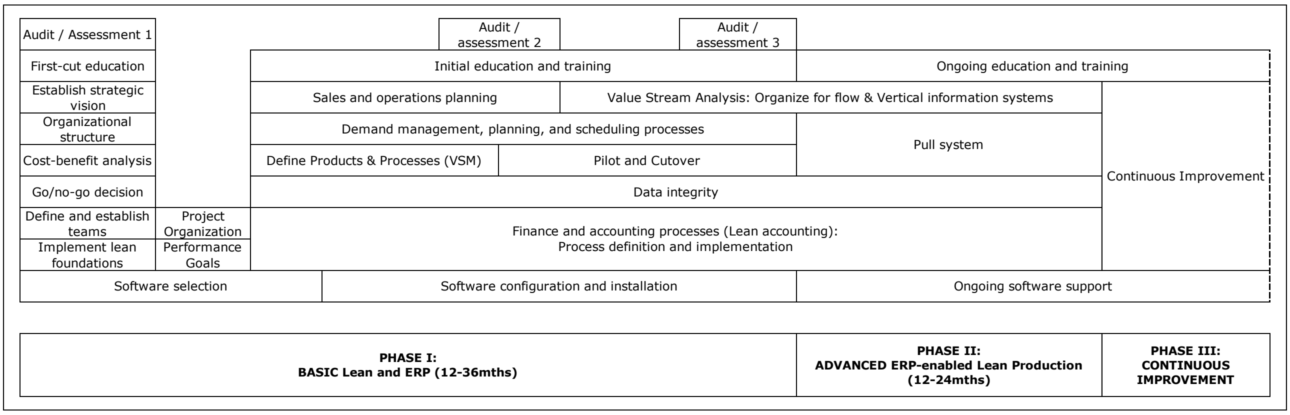

Figure 7: ***Framework for an ERP-Based Lean Implementation Process***

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

Table 2: ***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*** – *"…must be defined jointly for each product family (along with a target cost) based on the customer's perception of value"* (p.277)
4) Identify processes	***Value Stream*** – *"the specific activities required to design, order and provide a specific product, from concept to launch, order to delivery, and raw materials into the hands of the customer"* (p.353)
5) Review factory layout	***Flow*** – *"rethink specific work practices and tools to eliminate backflows, scrap and stoppages (of all sorts) so that the design, order and production of the specific product can proceed continuously"* (p.52)
6) Select appropriate Kanban (Pull) strategy	***Pull**** – *"flow only when pulled by the next step"* (p.70)
7) Continuously improve	***Perfection*** – *"the complete elimination of muda (waste) so that all activities along a value stream create value"* (p.350)

*perhaps a more appropriate definition for pull is that of Schönsleben (2007) – "*value-adding takes place only on customer demand (or to replace a use of items)"*

Table 3: ***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