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Lean production and ERP systems in small- and medium-sized enterprises: ERP support for pull production

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It is generally accepted that lean production improves manufacturing processes through the systematic application of lean practices, and equally assumed that present day IT systems, particularly ERP systems, are essential for companies seeking efficiency through organisational integration. Though lean production and ERP co-exist in many companies today, there is an ongoing argument in the scientific literature as to whether or not ERP systems can be used to support lean production principles, particularly pull production. By applying a multiple-case-study approach, we assess the functionality offered by ERP systems to support pull production. We develop and apply a capability maturity model that can be used to assess the extent to which the usage of a company's current ERP system supports pull production practices and to suggest modifications to the ERP system in order to better serve the company’s pull system. We focus on the application of lean production and ERP within small- and medium-sized enterprises, as in these companies decisions on lean and ERP are generally made by the same decision maker, which improves construct validity.

Keywords: lean production; enterprise resource planning; small- and medium-sized enterprises; pull production; maturity model

1. Introduction

As low-cost economies grow rapidly, European Union (EU) manufacturers are under increasing pressure to be more innovative and flexible. Lean manufacturing is a proven method of increasing productivity, as is the application of enterprise resource planning (ERP) systems. In fact, lean production and ERP systems are consistently rated in manufacturing improvement surveys as the two most important strategies utilised by manufacturers attempting to compete for sales and profits in global markets (see Armbruster et al. 2005, Carroll 2007).

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 (Bruun and Mefford 2004, Bell 2006, Hicks 2007). For example, Piszczalski (2000) describes manufacturers as being “torn between two opposing camps.” Halgari et al. (2011) also suggest that ERP systems have been considered a hindrance to lean manufacturing efforts and have been criticised for encouraging large inventories and slow production. We suggest that one of the main reasons for the lean versus ERP debate is that ERP systems often gather data that is not used at all to control or improve processes. Another reason is the gap between the actual business processes and the way they are being modelled in the ERP system. Notwithstanding, there is no doubt that ERP and lean have emerged from fundamentally different approaches to production. 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.

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While large companies seem to have embraced manufacturing philosophies such as lean production, empirical evidence suggests this is not the case for small- and medium-sized enterprises (SMEs). For example, Shah and Ward (2003) suggest that despite organisational inertia effects, large firms are more likely to implement lean practices than their smaller counterparts. The same can be said for the application of ERP systems, which have also been applied successfully in large companies, though the scientific literature suggests that SMEs often struggle to apply ERP systems in an effective manner (see Buonanno et al. 2005, Snider et al. 2009). Although SMEs are increasingly embracing ERP, research indicates that many of them fail to achieve their goals in terms of ERP utilisation and expected improvement (Sun et al. 2005). This might be due to the quality of their ERP implementation, but also to the actual support offered by the ERP system for controlling the material and information flows.

This paper aims to examine ERP support functionality for lean production in SMEs through a multiple-case-study approach. We will specifically focus on lean practices that help to realise pull, one of the essential elements of lean production (Shah and Ward 2003, Hines 2010). This is because pull production – as a result of peer influence and the demands of the value chain – is often a main driver for the implementation of ERP and lean production practices in SMEs (Laukkanen et al. 2007).

The structure of this paper is as follows: Section 2 gives an overview of the theoretical background of lean and pull production and ERP systems, offers further rationale for our focus on SMEs, and defines the research questions. Section 3 introduces a five-stage capability maturity model concept in order to assess the level of ERP support for pull production within manufacturing companies. Section 4 describes methodological issues of the case study design, whilst Section 5 provides insight into four case studies through a within-case and cross-case analysis. Finally, Section 6 draws conclusions and offers suggestions for future research.

2. Theoretical background and research questions

2.1 Lean production

Lean production is based on the principles and working processes of the Toyota production system, 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. It was however Womack and Jones (1996) who provided the world with a vision of what lean is about, and summarised lean thinking as five principles: (1) precisely specify value by specific product; (2) identify the value stream for each product; (3) make value flow without interruptions; (4) let the customer pull value from the producer; and (5) pursue perfection (Hines 2010). In this paper we consider only the practices primarily associated with the operationalisation of the fourth lean principle – pull.

2.1.1 Pull production

Pull production is one of the most fundamental principles within lean (see Karlsson and Åström 1996, Womack and Jones 1996). Shah and Ward (2007) also characterise pull production as one of 10 distinct dimensions of a lean system. Where a push production system entails jobs being pushed from one workstation to the next upon completion, a pull system consists of jobs that are pulled by successive workstations, as and when required. 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). Two examples of pull systems are Kanban and POLCA.

Kanban – In this type of pull system, cards are used as production orders (Shahabudeen and Sivakumar 2008). Kanban is the Japanese word for tag, or signal. It is a simple form of communication that is always at the point where it is needed (Ohno 1988). Sugimori et al. (1977) describe the kanban system at Toyota in some detail. For the purpose of this paper, we classify kanban into two types: production kanban, used to communicate and authorise production requirements on the shop floor, and supplier kanban, used to communicate the requirement of raw materials and components to suppliers.

POLCA – An alternative type of pull system to kanban is POLCA. POLCA is an acronym for paired-cell overlapping loops of cards with authorisation (Suri 1998), and is a card-based control system for high variety or custom engineered products (Krishnamurthy and Suri 2009). Riezebos (2010) shows that POLCA is a pull system that is applicable in make-to-order (MTO) companies. It is a material control system that regulates the authorisation
of order progress on the shop floor in a cellular manufacturing environment. By strictly limiting work-in-process (WIP) inventory between cells, POLCA aims to increase the speed of job transfer and reduce the unbalances in the manufacturing system.

2.1.2 Elements of pull systems

Pull production is considered as a method of workload control. According to Fredendall et al. (2010), workload control can be divided into three main levels: job entry, job release, and priority dispatching/WIP control. The job entry level considers demand and capacity management, for example the decision as to whether to accept or reject orders, the setting of due dates, and the management of capacity. Job release determines the time of release for accepted orders, and short-term adjustments in capacity. Finally, priority dispatching/WIP control manages the flow of orders on the shop floor. We will now operationalise pull systems and describe them according to this framework for workload control.

2.1.2.1 Job entry – Demand and capacity management. The major mechanism associated with the job entry level can be identified as demand smoothing. Bicheno and Holweg (2011) show that arrival variation (demand variation) has a detrimental effect on queue length and therefore lead time. Thus, pull production requires a fairly stable and repetitive demand pattern (Karmarkar 1989). Demand smoothing is a method used as a prerequisite to pull production which aggregates demand and forecast data in order to allow for a smooth, steady master production schedule, thus reducing the detrimental effects of variations in demand.

Other elements of the job entry level are order acceptance, due date setting, and capacity management.

2.1.2.2 Job release – Order management. The major mechanisms associated with this level are production levelling (heijunka) and orderless rate-based planning (takt time). Following on from demand smoothing, heijunka is a production-levelling mechanism for pull environments (Shingo 1981). Often a heijunka board is used to gather cards which signal both the authorisation and the sequence for order release to the shop floor, and allows for operator reallocation. In contrast to the order-based, time-phased requirements of push production, pull production uses a mechanism of orderless, rate-based planning. Production orders are no longer required in pull production, as requirements are communicated using cards. However, the time buckets in the heijunka schedule are multiples of what is known as the takt time. Takt time is the pitch at which products should repeatedly emerge from production as finished goods. It is a method of synchronising production with the requirements of the customer (Shingo 1981). Takt time adjustments can be made at the job release level.

2.1.2.3 Priority dispatching and WIP control – Order control. At this level, the major mechanism is the card, as it is this that controls the level of WIP in the system. The size of the workload represented by the card, the number of cards, and the operations contained within the loop of the card are all decisions which should be made at this level. In addition to the card mechanism, rules for priority dispatching can be specified.

2.2 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, standardisation 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 organised record-keeping structures for such transactions (Jacobs and Bendoly 2003). An ERP system is built to manage all enterprise activities through independent software modules, while constantly updating a central database (Quiescenti et al. 2006). A simplified overview of an ERP system can be seen in Figure 1. Notice how the context of the term “ERP system” encapsulates much more than simply material 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 Figure 1. This is of great relevance for the research into ERP support for lean pull production, as we also include bolt-on solutions within the context of ERP systems.
Hopp and Spearman (1996) suggest that whilst ERP seemed (at least on the surface) to support lean production by providing modules with names like “repetitive manufacturing” that provided the capability to level load the master production schedule and to implement pull, the philosophical elements of continuous improvement, visual management, and mistake proofing were missing. However, developments are indeed moving in this direction, for example with the arrival of Microsoft Dynamics AX 2012, which claims to support lean production and flow manufacturing principles (see Hamilton 2009, Volkmann and Hietala 2011).

2.3 Small- and medium-sized enterprises

Small- and medium-sized enterprises are very important within Europe’s economic structure, but they are facing significant challenges to becoming suppliers of bigger customers due to the excessive costs associated with accessing a vast market of potential customers (Malhotra and Temponi 2010). Von Axelson (2007) suggests that SMEs are cornerstones of the industrial structure, whilst Ghobadian and Gallear (1996) suggest they are the lifeblood of modern economies. This is also acknowledged in various European Commission (EC) policies. For example, in the most recent annual SME report commissioned by the EC, the importance of SMEs is clear: 99% of all European businesses are in fact SMEs (European Commission 2010). These account for 67% of employment in the EU. SMEs are shown to have a lower labour productivity and lower profitability than their large counterparts, but are acknowledged as essential for economic growth, innovation, and knowledge transfer. While many large companies seem to have embraced manufacturing best practices such as lean production, empirical evidence suggests this is not the case for SMEs. Bell (2006) suggests that most SMEs must deal with a greater degree of uncertainty, and there are few that can claim to be as mature on the path to lean as Toyota. Despite organisational inertia effects, large firms are more likely to implement lean practices than their smaller counterparts (Shah and Ward 2003). This is also true for the application of ERP systems. Although literature that addresses the application of ERP systems in SMEs is limited, some valuable contributions have recently been made (see Shehab et al. 2004, Sun et al. 2005, Achanga et al. 2006, Blackwell et al. 2006, Quiescenti et al. 2006). For example, Quiescenti et al. (2006) suggest that the adoption of ERP systems is a crucial issue if referred to in the context of SMEs, and in their review of ERP, Shehab et al. (2004) indicate that SMEs have to tap the power of IT and integrative information systems (such as ERP) to stay competitive and customer-oriented. However, although SMEs are increasingly embracing ERP, research indicates that many of them fail to achieve their goals in terms of ERP utilisation and expected improvement (Sun et al. 2005). The reasons for such a lack of successful applications of lean and ERP in SMEs seem to be due to several key, defining characteristics (see Sun et al. 2005, Achanga et al. 2006):

Leadership and management – A large number of SMEs are hampered strategically due to a lack of quality strategic drives from good leadership traits, particularly in terms of top management commitment to improvement projects.

Figure 1. An overview of an ERP system (adapted from Mabert et al. 2001).
Financial capabilities – SMEs often lack financial capacity for the successful implementation of lean production practices and/or ERP systems.

Skills and expertise – Most SMEs employ people with low skill levels, and they do not foster the ideology of skill enhancement available resources and competence to develop and improve their production systems. This further impedes successful application of lean and/or ERP.

Organisational culture – Many SMEs are resistant to change, in the way that the companies reflect in their culture the personality of the owner/manager, and are constrained by this in terms of the changes they are able to undertake.

Obstacles aside, Koh and Saad (2006) suggest that many SMEs choose to combine an ERP system (as a planning and scheduling tool) with other production planning and control concepts, to control the flow of materials and manage the utilisation of resources. It is therefore of interest to both academics and practitioners to examine how ERP systems, as planning and scheduling tools, can be used to support pull production, particularly in the context of SMEs. To guide the study, we identify the following research questions:

RQ1: How can contemporary ERP systems support pull production in SMEs?
RQ2: What are the obstacles for using ERP systems to support pull production?

3. ERP support for pull production

Primarily through literature review, we now address the first research question and consider the support functionality offered by contemporary ERP systems for pull production in the context of small- and medium-sized enterprises. In order to assess the depth of support provided by ERP systems for pull production, we conceptualise a capability maturity model (CMM) for the use of ERP systems to support pull production practices.

3.1 Capability maturity model

A maturity model aims to aid companies in benchmarking the maturity of their operations relative to an industry best practice (Netland and Alfnes 2011). In the field of IT system implementation, several models are available. For example, Holland and Light (2001) present a maturity model for the use of ERP systems based on five theoretical constructs: strategic use of IT; organisational sophistication; penetration of the ERP system; vision; and drivers and lessons. They divide a company’s maturity into three levels: management of existing legacy systems; post-implementation exploitation of the ERP system; and strategic (innovative) exploitation of the ERP system. For our purpose of assessing the level of support for pull production, this is too strategic and specific. Therefore, we develop a model which focuses on maturity stages similar to the quality management maturity grid (QMMG) (Crosby 1980), the capability maturity model for software (CMMS) (Curtis and Paulk 1993), and the capability maturity model integration (CMMI) (Software Engineering Institute 2010). A summary of each of these models can be found in Table 1.

Our capability maturity model of ERP support for pull production provides a framework for identifying five levels of maturity that lay successive foundations for continuous process improvement. The five levels of our CMM define an ordinal scale for assessing the maturity level of an organisation’s use of ERP to support pull production. Each maturity level represents an evolutionary plateau on the path toward the full integration of pull production
within an ERP system infrastructure. The five levels of our CMM are illustrated with examples of criteria in Figure 2.

**Level 1** – the first level of all three of the previously described maturity models shown in Table 1 reflects a somewhat ad-hoc approach to production planning and control. Thus we maintain “initial” as the name for the first level of our maturity model, and suggest that a company operating at this level would show uncertainty in applications of lean and ERP, both of which would function in an ad-hoc manner.

**Level 2** – At this level, for which we use the term “planned”, we suggest a company would have a systematic approach to planning and controlling production with either lean production principles (pull production) or the ERP system. A disciplined approach to standardised business processes is the key. There will, in any case, be a clear decoupling of the two concepts, and a push–pull point (Karlsson and Ålström 1996) will be identifiable – this is the point at which the push planning of the ERP system ceases, and the control of the pull system takes over on the shop floor. At the job entry level, this means the demand and forecast data is available for the pull system in order to allow for manual demand smoothing. At the job release level, the ERP system should support both orderless and order-based production, as this is a requirement for firms who are just starting lean implementations (Hamilton 2003). At the order control level, we expect ERP functionality such as manual printing of cards and colour-coded release lists.

![Figure 2. ERP support for pull production: Capability maturity model.](image-url)
Level 3 – We choose the term “validated” to describe the level known as “enlightenment” in Crosby’s (1980) model and “defined” in the other two models, and suggest that companies operating at this level will have established feedback loops between the pull system and the ERP system. Cho and Prabhu (2007) suggest that a gap exists between the resource control and shop floor control in many ERP systems. For example, Zijm (2000) states that although ERP systems provide an information backbone that is needed for sound planning procedures, there is still a lack of intelligent planning and decision support functions. At this level of the CMM, this gap is closed as activities on the shop floor are systematically tracked and monitored in the ERP system. This allows the ERP system to be used in a more intelligent manner. At the job entry level, the ERP system is used automatically for demand smoothing through the systematic aggregation of demand and forecast information. At the job release level, ERP can be used to calculate takt times in support of orderless, rate-based planning. Finally, card requirements (size and quantity) are calculated to support the order control level.

Level 4 – Labelled as “quantitatively managed” in the CMMI, we choose the term “controlled” to describe this level of maturity, as the ERP system takes a more controlling role over the pull system in order to improve performance. For example, by shifting from a manual kanban system to an e-kanban system, production and delivery lead-times can be reduced (Kotani 2007). Also, by actively monitoring performance (for example, inventory levels), the ERP system is able to dynamically adjust the number and size of cards required in the system – reactive kanban systems such as this are explained in Takahashi (2003). Also at Level 4, the ERP system is able to actively support customer relationship management by calculating expected lead times, for example. The ERP system is also used to support visual management through the allocation of visual dashboards at production locations. Powell and Olesen (2011) conceptualise such a dashboard solution and call it e-heijunka (demand smoothing at the job entry level is a prerequisite for levelled production at the job release level). Use of e-heijunka further enables shop floor decision making, such as the prioritising and re-sequencing of orders. This function can also be used to visualise where operators are required on the shop floor and to make adjustments in capacity thus supporting line balancing. Holsapple and Sena (2005) suggest that the decision-support capabilities of ERP systems are often overlooked due to a more intense focus on transaction handling through standardised business processes. Therefore, with standardised business processes the main focus at Levels 2 and 3, Level 4 allows a more systematic focus on the decision support functionality of the ERP system.

Level 5 – In line with the CMMS and the CMMI, the top level of our maturity model is called “optimising”. The ERP system truly supports continuous improvement activities by optimising the pull system parameters and characteristics. By using real-time performance measurement information, the ERP system can optimise the pull system for greatest performance with respect to lead-times and inventory levels. The ERP system is also used to track processing times in order to identify and systematically eliminate bottlenecks (Bendoly and Kaefer 2004). It is also possible that the ERP system is used for modelling and optimisation of the supply chain (Botta-Genoulaz and Millet 2005), with emphasis on lean procurement and distribution. For example, Diaz and Ardalan (2010) discuss the advantage of including information about customer waiting lines in the production scheduling decision. By optimising supply chain performance at this level of maturity, the ERP system can make more informed decisions in terms of e-heijunka scheduling. This level of the CMM also reflects the observations of Quiescenti et al. (2006), who suggest that business processes which are managed by ERP systems should not be considered as static; once they are defined, a monitoring activity is needed during the process operation and improvements should be made whenever possible.

The proposed capability maturity model shows various types of support for pull production that contemporary ERP systems might be able to provide. It also suggests examples of criteria for each of the levels. In order to assess the depth of support provided by ERP systems for pull production in practice, we now analyse multiple case studies in terms of our proposed CMM. The next section will describe the methodological choices we have made in the research design process.

4. Research methodology

A qualitative approach has been adopted in this study, as we aim to provide an in-depth analysis of the support functionality for pull production offered to SMEs by contemporary ERP systems. Silverman (2001) argues that qualitative data has the ability to provide a deeper understanding of certain phenomena than quantitative, therefore we select this approach by applying a multiple case study research methodology. Yin (2009) suggests that case study
research is the most appropriate overall research methodology if how or why questions are being posed, if the researcher has little control over events, and if the focus is on contemporary phenomenon within a real life context. As the research questions are how-type questions and as the focus of the project is on contemporary phenomenon within a real life context (ERP support functionality for pull production in SMEs), we chose to carry out multiple-case-study research. The goal in case study research is analytic generalisation and not statistical generalisation (Yin 2009). One drawback of this methodology is however its time-consuming nature, which makes it necessary to limit the number of studies. We therefore restrict 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):

1. The phenomenon must be “transparently observable”;
2. Cases must represent “polar types... which illustrate high and low performance”;
3. 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 fit the European Commission (2010) definition of an SME (less than 250 employees and less than €50 million annual turnover). In order to be current in the research field, we also selected cases on the basis that both the ERP system and the pull system had been implemented at the company within the past 10 years. For practical reasons we limited the set of cases to locations in the northern part of the Netherlands. Within the group of cases, we also aimed for polar types with respect to the successful integration of the companies’ ERP and pull production systems, based on our CMM.

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. One of the researchers was identified as the primary interviewer and was present at all interviews. This enabled the interview activity to be consistent across all cases. Triangulation was carried out by direct observation and through use of documentation in order to strengthen construct validity.

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 categorisation is useful for both within-case and cross-case analysis.

5. Case studies
We now consider the four case studies, to which we apply the capability maturity model of ERP support for pull production.

5.1 Within case analysis
Within the individual cases, there is strong evidence of the obstacles that are encountered when an SME attempts to use an ERP system to support pull production.

5.1.1 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 €20 m. The company implemented the Microsoft Navision ERP system in 2001, with an upgrade to the current version in 2010, and implemented their 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 for 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-parameterised 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 machines for the summer season, and two types of planting machines 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 within the ERP system.

5.1.2 Case study two – Bosch Hinges

The second case study is a manufacturer of custom-made hinges with 30 employees and an annual turnover of €4 m. The company implemented the Exact Globe ERP system in 2003, with an upgrade to the 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 12 cells. The main issue encountered at this company is that the ERP system for 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 – and thus 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 are attached to the production order information and together with the material they flow through 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.

5.1.3 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 €20 m. The company implemented SAP in 2006, and began implementing its 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 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 16 hours, but POLCA cards represent a 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 authorisation 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 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, that is to say 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 two 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.

5.1.4 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 €42 m. The company has been using 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 organised 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, for example, impact on working-capital, service level, and warehouse space. A project is under way in order to develop a barcode solution to solve the traceability issue.

Table 2 summarises the main characteristics of the four cases and identifies the problems and solutions encountered in each case.

A host of different problems and solutions are identified that give useful insight into the role and functionality of ERP systems for the support of pull production.

5.2 Cross-case analysis
Cross-case analysis was also carried out to improve understanding and explanation, and to increase the generalisability of the findings. One particular reflection from cross-case analysis is that the intended application area of ERP systems (for example, industry type) is critical when considering the specific ERP support for pull production.

In terms of the CMM for ERP support for pull production, Table 3 shows the results of the cross-case analysis.

6. Conclusion and further research
This study has explored the support functionality offered by contemporary ERP systems for pull production in the context of SMEs and has made two main contributions. Firstly, we have developed a capability maturity model of ERP support for pull production based on workload control theory. This can be used to evaluate the level of support offered by contemporary ERP systems for pull production and also to identify improvement areas.
<table>
<thead>
<tr>
<th>Case:</th>
<th>Bosch Hinges</th>
<th>Variass Electronics</th>
<th>Altrex</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industry</td>
<td>Machine building</td>
<td>Mechanical</td>
<td>Electronic</td>
</tr>
<tr>
<td>Number of employees</td>
<td>100</td>
<td>30</td>
<td>120</td>
</tr>
<tr>
<td>Annual turnover</td>
<td>€20 m</td>
<td>€4 m</td>
<td>€20 m</td>
</tr>
<tr>
<td>Customer order decoupling point</td>
<td>ATO</td>
<td>ETO/MTO</td>
<td>ATO</td>
</tr>
<tr>
<td>Seasonal demand</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Obstacles encountered</td>
<td>P1.1: Product seasonality; P1.2: Supplier kanbans are not suitable for long lead time component parts; P1.3: No pull functionality in the ERP system.</td>
<td>P2.1: ERP system did not offer a CRM module to control RFQ through to sales order receipt; P2.2: Basic ERP system is “only an accounting system.”</td>
<td>P3.1: The ERP system is too static, and proposes to build batches based on historical batch sizes; P3.2: Difficult to visualise production routings.</td>
</tr>
<tr>
<td>Solutions developed</td>
<td>S1.1: An additional assembly line was constructed in order to increase capacity and flexibility. S1.2: MRP is parameterised to procure long lead time items based on forecast, and short lead time items are procured based on actual requirements (sales orders). S1.3: Functionality added to the ERP system for printing of kanban cards.</td>
<td>S2.1: An external module was developed (Bosch Information System) to control RFQ through to sales order receipt. S2.2: Bolt-on “PROPOS” system developed to visualise real-time requirements on the shop floor.</td>
<td>S3.1: Modification made to SAP with regard to parameterisation and logic used for the calculation of batch sizes. S3.2: Creation of “colour-coded” production map.</td>
</tr>
</tbody>
</table>
Secondly, we saw that few (if any) previous studies have focused on ERP and pull production in the context of SMEs. By applying our CMM to a selection of SMEs, we have identified the difficulties that are endured when attempting to integrate pull production with ERP systems in the context of SMEs.

Through the development of a conceptual CMM, we identified five maturity levels of ERP support for pull production: initial, planned, validated, controlled, and optimising. Aside from the basic functionality of, for example, that which is required to print cards, we have proposed several advanced mechanisms where ERP can be used to fully support pull production, particularly with the use of real-time information and traceability for the subsequent optimisation and continuous improvement of the pull system (stages four and five of the CMM). Furthermore, our CMM can be used to identify types of decision support that should be contained within the ERP system itself rather than as bolt-on modules. The main advantage of integrating this type of support within the ERP system itself is seen when the ERP system requires updating to a newer version, as there is a potential risk of failure for bolt-on modules during system upgrades.

By adopting a multiple case study approach, we were also able to highlight a selection of the problems/obstacles that can be encountered when attempting to combine ERP and pull production, as well as the solutions that have been developed in order to overcome them. For example, the ERP systems that were used in the SMEs lacked support for demand smoothing, production levelling, order quotation, process planning, and kanban/POLCA configuration. There were however different ways in approaching these problems. Some of the companies chose to focus on either the pull system or the ERP system. In this respect, the company in case study one chose to refocus on ERP system improvements in order to better manage the material flow to the company, while Variass Electronics decided to focus purely on the POLCA pull system without further investments in connection with their ERP system. Both companies achieved a lower level on the CMM scale, and were assessed at maturity Level 2. On the other hand, the other two companies aimed to integrate pull production with their ERP systems, and found new ways to improve the support functionality of the ERP systems by developing bolt-on solutions that provide value to the customer in terms of reduced lead times and improved service levels. This resulted in a higher maturity level on our CMM, particular in the case of Bosch Hinges, where a specific bolt-on ERP solution (PROPOS) had been designed and implemented to monitor and support the POLCA pull system.

It is also interesting to observe that three out of four cases had in fact implemented the ERP system before the pull system – see Table 2. This goes against the conclusion of Schniederjans and Kim (2003), who found that the best ERP implementations involved the reengineering of processes before the introduction of ERP, rather than after. This may also be a contributing factor to the low CMM scores achieved in this study (the ERP systems were not selected on the basis of supporting pull production).

From the majority of the case studies identified in this investigation, we can conclude that production managers, particularly in SMEs, would like to proceed to use ERP more effectively both with and without bolt-on applications in order to plan and support pull production practices. Our message is that if companies use an ERP system and

<table>
<thead>
<tr>
<th>CMM Level</th>
<th>Criteria</th>
<th>Case study one</th>
<th>Bosch Hinges</th>
<th>Variass Electronics</th>
<th>Altrex</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No specific requirement</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>2</td>
<td>Identifiable decoupling of push and pull practices</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Colour-coded release lists available</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>ERP functionality for printing of cards</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>3</td>
<td>Feedback between pull system and ERP system</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ERP functionality for calculating kanban requirements and takt times</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>ERP system monitors performance of pull system</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>ERP system supports e-kanban</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>ERP system supports e-heijunka</td>
<td></td>
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<tr>
<td></td>
<td>ERP system can be used to reallocate operators</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>ERP system optimises pull system parameters</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ERP supports continuous improvement</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

CMM level achieved: 2 3/4 2 3
would like to implement a pull system, then the two systems should coincide. This is particularly true in the case of SMEs, where the rate of success for the application of lean production practices and ERP systems are both very low. We have seen that, in terms of developments with lean and ERP in SMEs, it is often the same people (owners/managers) who make decisions in both areas. This is in contrast to larger organisations, where decisions regarding ERP systems are usually made by the IT function, and decisions regarding lean are more often related to the production and quality departments. Therefore, we suggest that the application of a suitable ERP system may indeed have a catalytic effect on the implementation of pull systems and/or other lean production practices. However, as witnessed specifically in case study two, certain types of ERP systems do not intrinsically support either the lean journey or the decision making required for pull systems.

The quality of a case study research design can be judged through a range of tests, including construct validity, internal validity, and external validity (Kidder and Judd 1986, Yin 2009). In order to strengthen our construct validity, we made use of triangulation by using three sources of evidence: interviews, direct observations, and documentation. We also increased our external validity by using replication logic in our multiple case studies: the same terminology was used, the same constructs were investigated, and so on. Finally, internal validity was supported through the use of pattern matching in the cross-case analyses. 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 in order to uncover the potential contained within our capability maturity model of ERP support for pull production. Further work should also evaluate contemporary ERP systems against the CMM concept, in order to assess the leanness of ERP systems.

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