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A Review and Assessment of Enterprise Resource Planning for Make-To-Order Companies

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Abstract

Many vendors of Enterprise Resource Planning (ERP) systems claim that their products are widely applicable – configurable to meet the needs of any business, whatever the product or service offering. However, producers of high-variety and bespoke products, such as Make-To-Order (MTO) companies, present particular challenges to implementation; it remains unclear whether ERP systems can cater for their needs.. This paper provides a state-of-the-art review of ERP systems and an assessment of the applicability of ERP to the MTO sector. While several comprehensive reviews of the ERP literature have previously been presented, these either do not focus on the MTO sector, or seek to assess the applicability of ERP systems, or give sufficient attention to recent developments in the fast moving ERP industry. In assessing applicability, this paper considers factors such as the planning and control stages of relevance to MTO companies, the typical size and supply chain positioning of MTO companies, and market-related features. The assessment concludes that there is a significant gap between the requirements of MTO companies and the functionality of ERP systems. One such gap is between the customer enquiry management and design & engineering processes of MTO companies and those supported by ERP systems. Eight key areas in need of further research are described. These include: providing effective decision support tools for customer enquiry management activities in the MTO sector, linking ERP systems with production planning and control concepts of relevance to MTO companies, and conducting an in-depth empirical study into existing applications of ERP systems in MTO companies and their impact on performance.

Keywords: *Enterprise Resource Planning (ERP); Make-To-Order (MTO); Small and Medium sized Enterprise (SME); Literature Review.*

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1. Introduction

When implemented effectively, Enterprise Resource Planning (ERP) systems enable a company to integrate the information used throughout the organization, including operations and logistics, sales and marketing, human resources, finance and accounting (see, for example, Davenport, 1998). ERP systems can lead to business benefits such as real-time data, synchronised decision-making, reduced duplication of effort, improved visibility, increased automation of routine tasks, faster transaction processing times, and improved customer service levels. These systems have emerged from the Material Requirements Planning (MRP) and Manufacturing Resource Planning (MRP-II) systems of the past (see Plossl & Wight, 1971; Wight, 1981) but have wider scope and an improved platform. ERP systems have traditionally been implemented by large companies, arguably in most need of integrating mechanisms, but ERP vendors have begun to market their products towards Small and Medium sized Enterprises (SMEs), developing scaled-down versions and more flexible pricing/licensing schemes. This is coupled with increasing pressure on many SMEs by large customers to adopt ERP. Having improved efficiency and integration at the firm level, these large customers want to extend this to the supply chain level. Many ERP vendors claim that their systems are generic – configurable to meet the needs of any business, whatever the product or service offering. Nonetheless, producers of high-variety and bespoke products, such as in the Make-To-Order (MTO) sector, present particular challenges. Despite the wide applicability of ERP systems, it is unclear whether they can cater sufficiently for the needs of MTO companies.

Implementing an ERP solution is expensive, typically requiring investment in software, hardware, training and consultancy. Moreover, ERP has been criticized for causing deep changes in culture and organizational behaviour. There have been many well-publicized implementation failures that have threatened the future of a company. Given that many MTO companies are SMEs, with limited financial resources, they are particularly vulnerable if implementation is unsuccessful. As a result, choosing whether to implement an ERP system is a difficult but important decision, increasingly relevant to all firms.

Few reviews of planning and control concepts, such as ERP, have focussed specifically on the needs of the MTO industry. One exception is provided by Stevenson *et al*. (2005);

while valuable, this reviews and assesses a wide range of concepts and is therefore unable to go into great depth on any one concept. The paper suggests that ERP may be a suitable solution for MTO companies but that further research is required. Recent reviews which focus specifically on ERP include those by Esteves & Pastor (2001), Al-Mashari *et al*. (2003), Jacobs & Weston (2007), and Moon (2007). While these studies provide greater depth, they do not either: focus on the MTO sector, seek to assess the applicability of ERP systems, or give sufficient attention to recent developments in the fast moving ERP industry (e.g. the emergence of add-ons to ERP packages for supply chain and customer relationship management). Bertrand & Muntslag (1993) presented a review of the applicability of MRP-II to bespoke production environments, specifically the Engineer-To-Order (ETO) sector; however, given advancements in technologies and the scope of concepts, and an increasing focus on bespoke production and the wider supply chain, an update of this work is required. More recently, Deep *et al.* (2008) conducted a case study investigation of the factors affecting the selection of an ERP system by a MTO company. The paper demonstrates that assisting firms in determining the applicability of ERP is required but it does not in itself provide a sufficiently comprehensive review of the available literature or consider the full range of MTO company characteristics that are likely to affect ERP adoption.

It is argued that an in-depth review which focuses on exploring contemporary issues in ERP systems, which consolidates existing knowledge, and assesses the applicability of ERP to the MTO industry is therefore required. In response, this paper provides: a state-of-the-art review of the available literature on ERP systems and MTO production, and an assessment of the applicability of ERP to the MTO sector. The review has a particular interest in studies of the impact of company size or industry-specific characteristics on ERP, and recent developments, including add-ons to core ERP systems. We do not seek to focus on broad implementation issues or to provide a detailed historical description of the evolution of ERP systems. For an overview of implementation issues, see Umble *et al*. (2003); for a detailed historical perspective on ERP, see Rashid *et al*. (2002) and Jacobs & Weston (2007).

The remainder of this paper is organized as follows. Section 2 defines the characteristics and requirements of MTO companies before Section 3 provides an overview of ERP systems, including recent extensions to their core functionality. An evaluations of ERP systems is then presented in Section 4 before Section 5 assesses the fit between the characteristics of MTO companies and the functionality of these systems. Section 6 identifies gaps in the literature in need of further research before the paper concludes in Section 7.

2. Characteristics of the Make-To-Order (MTO) Sector

Choosing whether to produce 'to-stock' or 'to-order' is a strategic decision (Amaro *et al*., 1999). Positions along the continuum (e.g., Make-to-Stock (MTS), Assemble-to-Order (ATO), MTO, ETO) are separated by the order penetration, or customer de-coupling, point (OPP, see Olhager & Ostlund, 1990; Olhager, 2003). In a MTS or ATO setting, finished goods or components are held in anticipation of demand while in an ETO or a MTO setting, design and production are driven by customer orders. The above are the most commonly referred to production strategies; however, many others exist. For example, Design-To-Order and Make-To-Print (DTO and MTP, e.g., Hill, 1993); Build-To-Order (BTO, e.g., Gunasekaran & Ngai, 2005); Configure-To-Order (CTO, e.g., Chen *et al.*, 2003); and, Finish-To-Order (FTO, e.g., Wikner & Rudberg, 2005) while Amaro *et al*. (1999) identify more specific sub-categories within 'to-order' production strategies (ATO_1, ATO_2, MTO_1, MTO_2, etc). In addition, Mass Customization (MC) can be described as a mid-volume and mid-variety strategy under which the ATO strategy can be categorized. Rudberg & Wikner (2004) attempt to unify MC with OPP, arguing that the resulting framework covers all strategies, including some situations previously neglected in the literature (e.g., companies which engineer-to-stock, referred to as adopt-to-order).

From the above, it follows that there are many definitions of the various production strategies presented in the literature. This paper therefore chooses to refer to only one - MTO – but uses this in a broad sense. In our definition (see also Hill, 2000, p. 379), MTO is an 'umbrella term' referring to companies that produce bespoke products and products customized to the specifications of a particular customer but not repeated on a regular basis or in a predictable manner. Hence, as illustrated in Figure 1, the definition incorporates DTO, MTP and ETO, but is separated from MTS, MC (and ATO), etc. The following subsections describe the characteristics and requirements of MTO companies as defined above, to be considered in determining ERP applicability.

[Take in Figure 1]

2.1 Planning and Control Stages of MTO Companies

The following Production Planning and Control (PPC) stages are critical to the order processing cycle in MTO companies:

- *Customer Enquiry Stage:* where a customer provides an invitation-to-tender for a particular product to prospective suppliers, requiring the determination of a price and due

date. For MTO companies, planning and control must begin here as each order may be different; decisions made here affect subsequent stages.

- *Design & Engineering Stage:* where more detailed design and engineering planning takes place for accepted orders. This stage is of particular relevance for DTO and ETO strategies.
- *Job Entry Stage:* where the production of a confirmed order is planned, including: material requirements, purchasing and shop floor routing.
- *Job Release Stage:* a decoupling phase, where the company decides when to start producing a particular job, to prevent confirmed orders at the job entry stage from entering the shop floor immediately.
- *Shop Floor Dispatching Stage:* where detailed shop floor scheduling is determined and jobs are sequenced on the shop floor, e.g., via job prioritization.

The particular importance of Customer Enquiry Management (CEM) for MTO companies has been identified by several authors (e.g. Hendry & Kingsman, 1993; Kingsman *et al.*, 1996; Moodie, 1999; Cakravastia & Nakamura, 2002; Calosso *et al.*, 2004; Stevenson, 2006; Zorzini *et al.*, 2008). Kingsman *et al*. (1996), for example, proposed the structure for a Decision Support System (DSS) to handle the quotation process and Park *et al*. (1999) implemented a CEM DSS, reporting improved due date adherence and reduced costs.

Little research has been conducted into the design and engineering stage, despite its impact on the total lead time. Wortmann (1995) makes a contribution by comparing the information system requirements of MTS and ETO companies. In a MTS context, complete, consistent and up-to-date basic product information is more likely to be available (as the product is likely to have been made before). The author highlighted an ability to be able to document aspects of product development throughout the order processing cycle as a key feature of an ETO-compliant system. While valuable, research has since failed to build on this contribution significantly. Bertrand & Sridharan (2001) suggest that, together with assembly, the design and engineering stage can be the bottleneck operation in aggregate planning - design and engineering are seen as scarce resources in a MTO company; however, the authors' study is limited to subcontract manufacturers. Rudberg & Wikner (2004) proposed a framework for MTO companies for this stage, including forecasting and order fulfilment mechanisms, for design and specification.

The need to control the job release stage was identified by Wight (1970), in order to avoid the 'untimely' release of jobs which can result in a 'vicious circle' of work-in-process

accumulation, known as the “lead time syndrome” (Mather & Plossl, 1978). This stage (in isolation) has received far more attention in the literature than preceding stages (see Wisner, 1995; Bergamaschi *et al.*, 1997); however, it is arguably the entire integrated PPC process from enquiry to delivery which determines the performance of a MTO company. Some Workload Control (WLC) methods have been developed to support many of the PPC stages important to MTO companies. Kingsman & Hendry (2002) conducted a simulation study which demonstrated that control at the customer enquiry and job entry planning levels can complement control at the job release stage. Stevenson & Hendry (2006) and Stevenson (2006) have since refined this methodology through case study research; however, Workload Control does not pay particular attention to the design and engineering stage.

2.2 Shop Floor Configuration of MTO Companies

Common shop floor configurations are Pure Flow Shop (PFS), General Flow Shop (GFS), General Job Shop (GJS) and Pure Job Shop (PJS), differing in terms of flow direction and processing flexibility. In a PFS, all jobs follow the same sequence of operations; in a GFS, all jobs flow in the same direction but can visit a subset of machines. In a PJS, jobs can start and finish at any work centre and no dominant flow direction dominates; in a GJS, routings are multi-directional but a dominant flow exists. Job shop configurations are suitable in customised production contexts, such as the MTO industry (Stevenson *et al*., 2005) but lead to complex planning problems. The PFS and GFS configurations are more suitable for continuous processes or assembly line manufacturing (i.e. MTS or ATO).

2.3 MTO Companies and the Supply Chain

MTO companies are often positioned towards the upstream end of supply chains, serving large, powerful customers. Given this position, information about end-customer demand is limited and customers often outsource work to their upstream suppliers at short notice; hence, rush orders are common place. Stevenson *et al*. (2005) and Stevenson & Hendry (2007) explain that the presence of rush orders is likely to affect the type of PPC solution appropriate to MTO companies and highlight the importance of web-based practices that promote information and knowledge sharing within supply chains.

While a large proportion of MTO companies are at the upstream end of supply chains, it is also acknowledged that some supply chains consist exclusively of MTO companies, i.e., “MTO supply chains” - capital goods manufacturing is a common example (e.g. Hicks *et al.*, 2000; Sahin & Robinson, 2005). Sahin & Robinson (2005) conducted a simulation study of a two-stage MTO supply chain with a rolling schedule in a MRP environment, making use of

the supply chain coordination framework of Lee *et al*. (1997). The authors reported cost reductions of 47.58% when a fully integrated system (with information sharing and coordination) is compared with the 'traditional scenario' (i.e., no integrated system). The study highlighted the value of information sharing and coordination in MTO supply chains; similar results are presented by Robinson *et al*. (2005) and confirm the value of using web-based practices. Hence, developing buyer-supplier relationships built on information sharing and coordination can be an important part of an effective supply chain. The importance of effective Supply Chain Management (SCM) practices for MTO companies is demonstrated by the following examples:

- Information sharing and coordination along the supply chain can facilitate cost reduction and improved due date adherence (Sahin & Robinson, 2005);
- Effective knowledge sharing in the supply chain can be a competitive advantage (Hicks *et al*., 2000);
- Purchasing as a percentage of total cost has been argued to be higher for MTO companies than MTS companies; hence, relations with suppliers can be highly significant and this in turn has an effect on a firm's ability to satisfy customers (Jahnukainen & Lahti, 1999).

2.4 MTO Companies and Product Customization

The degree of customization is closely related to shop configuration and the positioning of the OPP (Hayes & Wheelwright, 1979). According to Lampel & Mintzberg's (1996) classification of product customization, MTO companies conduct *pure* and *tailored* customization practices which need a high degree of customer interaction and cause long and variable lead times. Many typologies, concepts and organizational issues regarding customization exist in the literature; for a comprehensive review, see Spring & Dalrymple (2000).

Amaro *et al*. (1999) define two types of MTO companies in relation to customisation: Repeat Business Customisers (RBCs) and Versatile Manufacturing Companies (VMCs). A RBC provides customised products on a continuous basis over the length of a contract while a VMC manufactures a high variety of products but competes for each order separately. Both types provide customisation, but the RBC is able to establish more stability by enticing customers into a more predictable and committed relationship (Stevenson & Hendry, 2007). In terms of their supply chain position, RBCs are generally located at the upstream sites of the supply chains, while VMCs operate in all levels of supply chains.

2.5 MTO Company Size

Many MTO companies are Small to Medium sized Enterprises (SMEs, see: Amaro *et al.*, 1999; Stevenson *et al.*, 2005). SMEs are a major contributor to supply chains and to the EU and UK economies, representing 99% and 99.9% of all enterprises, respectively (EU Commission, 2006; UK BERR, 2007). According to the EU Commission (2003), a medium-sized company has less than 250 employees or a turnover less than €50 million (and/or an annual balance sheet total less than €43 million); a small-sized company has less than 50 employees or a turnover of less than €10 million (and/or an annual balance sheet total of less than €10 million); and a micro-sized company has less than 10 employees or a turnover of less than €2 million (and/or an annual balance sheet total of less than €2 million). Micro-sized companies are argued to be too small to require the implementation of an ERP system and are therefore not considered further in this paper.

2.6 MTO Market Characteristics

Brown & Bessant (2003) refer back to Ford (1990) and Pine *et al.* (1993) in arguing that market demand for customized products is now greater than ever before. This growing market results in short product life cycles and requires a company to have a wide product range. Product specifications are often unpredictable and demand can be uncertain. MTO companies have to perform a continuous search for new business while simultaneously satisfying existing customers. The volatility of the MTO market is demonstrated by the strike rate (the percentage of tenders which become firm orders) which for MTO companies can be very low (e.g., 15% in the case described by Stevenson, 2006).

Table 1 provides a summary of key research contributions to the MTO literature. The table highlights the importance of the issues described in Sections 2.1 to 2.6 but illustrates that no previous studies have considered all of these issues at once. Bertrand & Muntslag (1993), for example, only considered the first four factors in assessing the applicability of MRP-II to ETO companies. This, however, is partly explained by the differences between MRP-II and ERP and the narrow focus of the authors on the production process.

[Take in Table 1]

3. Characteristics of Modern ERP Systems

Davenport *et al.* (2004) defined an ERP system as a "packaged software application that connects and manages information flows within and across a complex organization, allowing managers to make decisions based on information that truly reflects the current state of their business". Today's ERP systems stem from Material Requirements Planning (MRP) and Manufacturing Resource Planning (MRP-II) of the 1970s and 1980s.

MRP, developed by Plossl & Wight (1971), is quite straightforward and its calculations are 'mechanical', meaning MRP logic can be incorporated in the design of computer systems. However, this simplicity can lead to extreme "system nervousness" (Orlicky & Plossl, 1994). Moreover, the original MRP concept did not perform detailed and capacitated planning of resources. 'Closed Loop MRP' emerged to address capacity planning problems and to introduce a hierarchical planning structure. A three-tiered hierarchical structure is typically found within the planning systems provided by vendors, incorporating long-, mid- and short-term planning phases from forecasting to scheduling and dispatch (Vollmann *et al*., 1992). Available-To-Promise (ATP) functionality is an important element within this hierarchical structure, defined as a method of checking availability in response to a customer enquiry. 'Conventional' ATP systems have been in use since the emergence of MRP. Ball *et al*. (2004) describe ATP as a business function which is becoming increasingly important with the advent of e-business, MTO strategies and high-variety product offerings. Advanced ATP (AATP), a more sophisticated version of ATP, is an increasingly important concept in the era of SCM and will be described in Subsection 3.2. MRP was extended to include primary business functions (such as marketing, human resources, accounting and finance) and the data supporting these functions was integrated into a single, centralized database. This system became known as MRP-II (Wight, (1981).

The term "Enterprise Resource Planning (ERP) System" was coined by The Gartner Group (Chen, 2001). The key difference between this integrated software system and MRP-II is that ERP is not only designed for the needs of the manufacturing sector – it is intended for any company in any sector, whatever the product or service offering, with applications in, for example, healthcare, banking and education. The development of ERP was aided by technological advances and increased computing power. Its widespread introduction into companies was accelerated, for example, by: its ability to enable managers and planners to minimize time spent on manual tasks; a number of large-scale mergers and acquisitions, with the resulting enterprises requiring a means of integrating the fragmented organizational

structure together; and, concerns over the year 2000 (Y2K) and euro currency compliancy of previous legacy systems.

Huge growth in ERP adoption was followed by disappointment. Some companies noted only marginal benefits from ERP adoption incommensurate with investment (Millman, 2004) and several highly publicized implemented failures were reported, e.g., FoxMeyer Drug Co. and Hershey Food Co. (Scott, 1999; Stedman, 1999). In response, many executives cut back their IT expenditure, especially in 2002 (Gartner Group Dataquest, 2003). More recently, the ERP market has been revived and many successful applications have been reported (e.g. Scheer & Habermann, 2000; Davenport & Harris, 2007). The ERP market is now dominated by a small number of ERP vendors. Today, the top three ERP vendors dominate nearly half of the market share for enterprise systems; according to Gartner Dataquest (Bailor, 2006), the largest ERP vendors worldwide are SAP AG, Oracle Corporation and The Sage Group, with 28.7 %, 10.2% and 7.4 % of the market share, respectively.

As predicted by Davenport (2000), the functionality of ERP systems has continued to grow and their scope has begun to extend from internal processes (e.g. transaction automation and internal planning) to collective and external processes in the wider network. This trend has led to the term "Extended ERP" or "ERP-II" (Rashid *et al*., 2002; Botta-Genoulaz *et al*., 2005) to refer to add-ons to the core internally-facing ERP system and a shift from transaction-oriented systems to more analytical systems. ERP adopters, having realized the benefits of ERP, are beginning to explore extensions provided by ERP vendors to core-ERP functionality (Moon, 2007).

To conclude the above discussion, the following defines MRP, MRP-II, ERP and Extended ERP. Extensions to ERP will then be explored. SCM software is described in Section 3.1, advanced planning and scheduling in 3.2, customer relationship management in 3.3, and other extensions in 3.4. Section 4 provides an evaluation of ERP and its extensions.

- "MRP": the core material requirements planning system, achieving step-by-step netting, lot-sizing, time phasing and BOM explosion.
- "MRP-II": the hierarchical capacity-constrained manufacturing planning system with automated primary business functions.
- "ERP": the company-wide system designed to plan and control all business functions across an enterprise.
- "Extended ERP": the combination of ERP with one or more analytical add-ons, extending the functionality of ERP beyond internally-oriented processes. It is a broad term; therefore, the particular extension to ERP should be specified.

3.1. Supply Chain Management Software

Many companies have focussed on their core competencies, outsourcing other operations to firms in the supply chain. This has increased the reliance on supply chain partners, blurring the boundaries of the firm. As a result, firms are taking an increasing interest in the wider supply chain; software to support SCM has thus been demanded. ERP is becoming the process-oriented transaction backbone for intra- and inter-company SCM (de Kok & Graves, 2003).

Early examples of SCM software supported logistics functions and aided the management of inventory in the supply chain but were not well-integrated with other applications. Today, both ERP and specialized SCM software vendors provide a variety of solutions for managing the supply chain, for transactional processing, forecasting and planning purposes. Furthermore, the Internet, data sharing specifications (e.g., XML), automatic identification systems (e.g., RFID) and other technological advancements have accelerated small and large-scale SCM software developments to address supply chain-wide problems. Consequently, SCM software can facilitate information integration with supply chain partners. The main role of supply chain information integration is in cost reduction and improved efficiency, service and relationships with customers (Davenport & Brooks, 2004).

3.2 Advanced Planning and Scheduling Software

Despite its name, an Enterprise Resource *Planning* system does not concentrate on resolving planning issues, but rather business process management and transactional activities (Fleischmann *et al.*, 2002). In contrast, Advanced Planning and Scheduling (APS) systems address manufacturing planning and scheduling problems based on hierarchical planning principles (Stadtler & Kilger, 2002). Stadtler (2005) describes APS as a company-wide software system making use of analytical approaches to address supply chain and company-wide planning problems (e.g., plant location or supplier selection problems in the long term, and production and demand planning problems in the mid- to short-term). It is comprised of several independently implementable modules at different time levels (e.g., long-term) and production stages (e.g., procurement). Meyr *et al.* (2002) reported that, in most cases, all the modules offered by an APS vendor are not installed and that a best-of-breed integration is occasionally adopted. APS has similarities with the planning and scheduling in MRP-II, e.g., in terms of hierarchical planning and capacity-constrained structure; the “advanced” part of APS appears to come from addressing the decision support insufficiency of ERP (Stadtler, 2002).

Stadtler & Kilger (2002) emphasized the collaborative planning functionality of APS systems for supply chain planning. In an APS supported supply chain, the sales plans of one company (the supplier) are connected to the procurement plans of a downstream customer (the buyer) (Meyr *et al*., 2002). Available-to-Promise (ATP) and Capable-to-Promise (CTP) functionality is also incorporated in APS systems. ATP refers to determining the availability of 'uncommitted' finished goods inventory (FGI) at certain points of time in the planning horizon; CTP indicates remaining slack capacity after available capacity has been matched with committed customer orders (Ball *et al*., 2004). Akkermans *et al*. (2003) suggest that, in the future, an ATP/CTP system should not only check the ability to meet customer orders (based on availability or capability) but also offer to build a 'specific supply chain' for the incoming customer enquiry. Fleischmann & Meyr (2003) and Kilger & Schneeweiss (2005) stress the influence of the order penetration point on the applicability of ATP. ATP handles MTS order promising issues with a 'yes-or-no answer'; however, CTP and ATP are equally important in ATO order promising. Fleischmann & Meyr (2003) and Pibernik (2005) stress the necessity of detailed production planning and order promising integration in a complex MTO case. However, Kilger & Schneeweiss (2005) argue only for the use of CTP; the authors do not highlight a need to integrate these modules together.

'Advanced' ATP (AATP) broadens the functionality and scope of ATP from production capacity planning and support for order quotation activities to also include raw material and distribution capacities (Chen *et al*., 2002). ERP and APS vendors provide both AATP and CTP since it is important to consider both quantity and due date quotation issues based on the resources of the whole supply chain rather than on the finished goods inventory of a firm (Pibernik, 2005). In this study, the term ATP refers to the entire order promising procedure.

3.3 Customer Relationship Management Software

Customer relationship Management (CRM) software has emerged more recently than ERP and SCM but the original concept was introduced as "one-to-one marketing" by Peppers & Rogers (1993). Buttle (2004) describes it as a business practice centred around customer needs. Using CRM software, a company can compile data on customers and analyze it in order to sell more goods or services, and to do so more efficiently (Bose, 2002).

CRM - like SCM - is a business strategy, and can be an independent enterprise-wide IT system. CRM possesses its own infrastructure and can be implemented and utilized without enterprise system support; however, ERP is thought to be a supportive structure for the growing needs of CRM. Chen & Popovich (2003) outlined three infrastructures that significantly affect the running of CRM applications. Firstly, the Internet brings cost-

effectiveness and speed; secondly, data warehousing enables data quality and rapid access to information; finally, ERP's back-office functionality (i.e. manufacturing, inventory and financial applications) supports CRM's front-office functionality (i.e. Sales and Distribution and Service applications). As a result, many ERP vendors have invested in CRM add-ons; many ERP vendors are now also major CRM vendors. According to the Gartner Group (2006a, b), the top three major CRM vendors are SAP, Siebel (the only single specific CRM system vendor, acquired by Oracle since 2006) and Oracle (including PeopleSoft) in both Europe and worldwide.

3.4 Other Software Extensions to ERP

In addition to the three key extensions to ERP described above, the following are also reported in the literature and may be of relevance to MTO companies:

- *Collaborative Planning, Forecasting and Replenishment (CPFR) software:* both a strategy and a supply chain solution for joint decision making via information sharing, marketing, sales, and production. CPFR is mostly restricted to fast moving consumer goods and the retail industry. The main goal is to optimize the replenishment of a retailer's products through supply network coordination. The grocery industry was the first to utilize it, preceding the pharmaceutical and apparel industries. CPFR verifies the importance of information exchange in retail supply networks, in which information and product flows are faster than in fabrication and assembly supply networks.
- *Customer Enquiry Management (CEM) software:* focuses on due date and price estimation. SAP R/3 is said to contain a CEM-like component within its order management module (Knolmayer *et al*., 2002; Xiong *et al*., 2006). It is also reportedly used for automating order entry, processing customer orders and tracking order status.
- *Product Configuration (or 'Variant Generator') software:* an increasingly used add-on to ERP. Even many small-sized ERP vendors now provide this via the Internet. The typical example is a computer retailer's website being used as an interface between the end-customer and suppliers; the customer selects the components they would like and the suppliers receive the order simultaneously (e.g., the computer assembly case in Fleischmann & Meyr, 2003). Related software includes Product Tailoring systems, an application similar to product configuration software but distinguished by its high flexibility and responsiveness to customer requirements.
- *Product Lifecycle Management (PLM) software*: enables a company to bring innovative products to market effectively (Møller, 2005). PLM incorporates: Product Design Support (PDS), including cost estimation, product development, and prototyping; and, Product

Data Management (PDM), enabling a company to manage product-related information more effectively throughout the lifecycle of a product.

Figure 2 provides a conceptual representation of the evolution of ERP from MRP and incorporates extensions like SCM software and smaller add-ons such as PLM software.

[Take in Figure 2]

4. Critical Evaluation of ERP and Extensions to ERP

One of the strengths of MRP has been its simplicity; however, as manufacturing has become increasingly complex with high variety, customized production and wide-ranging bills-of-material, it is unclear whether MRP remains feasible. Lead times for each component are assumed to be deterministic, which in many contexts is unrealistic, and processes are assumed to be independent of each other which is likely to be impractical, especially for industries employing configurations other than an assembly line or a mass production strategy. MRP-II has a more complex structure but most MRP-II packages do not fully integrate all the processes of a typical manufacturing company; for example, features missing include transportation and distribution planning and dynamic scheduling of production resources in real-time. ERP differs from MRP-II in terms of wider functionality and its applicability beyond a manufacturing context. The strengths and weakness of ERP are summarised in Table 2 as a starting point for the following discussion which evaluates recent studies of ERP systems.

[Take in Table 2]

4.1 Evaluation of ERP Literature

Since the late 1990s, many papers have been published on ERP and its implementation process (e.g. Davenport, 1998; Klaus *et al*., 2000; Mabert *et al*., 2001; Umble *et al*., 2003). Moon (2007) analyzed papers published on "ERP" between 2000 and 2006 and found that 40% of 313 articles taken from 79 journals focussed on implementation issues, of which only seven studies focussed on a particular sector (e.g., public and educational organizations, service and manufacturing sectors). The large number of articles overall reflects the difficulties companies have experienced in implementing ERP in the past and the small number of these articles that focus on particular sectors demonstrates a need to further explore sector-specific issues in ERP adoption.

Rashid *et al*. (2002) and Jacobs & Weston (2007) provided historical reviews of ERP systems. Rashid *et al*. (2002) highlighted the need to explore ERP in small companies.

Mabert *et al*. (2003) and Muscatello *et al*. (2003) have since conducted pioneering studies on the impact of company size on ERP adoption. Jacobs & Weston (2007) emphasize the need to minimize implementation cycle times and suggest increasing the number of pre-configured sector and industry-specific packages; some such packages are now readily available (e.g., for healthcare and the automotive industry) but there is a need to explore the ERP requirements of other sectors, such as MTO manufacturing. Moreover, academia has an important part to play in the future development of ERP systems and frameworks for their implementation, e.g., through theoretical work, surveys, Delphi studies, and case studies.

4.2 Evaluation of Literature on Extensions to ERP

ERP and its extension into SCM, CRM, APS, etc, is a growing area; what follows demonstrates that there remains much scope for further research. Bowersox *et al*. (1998) found that the scope and flexibility of ERP systems is insufficient to support supply chain functionality. Akkermans *et al*. (2003) were sceptical of the practical value of combining ERP with SCM. The authors conducted a Delphi study with 23 executives from various industries and concluded that ERP systems have an inappropriate structure and are too rigid to support SCM activities. Given advancements in technology, future research should reapply the Delphi method adopted by Akkermans *et al.* (2003) and assess whether the criticisms remain valid.

Hendricks *et al*. (2007) studied the impact of SCM, CRM and ERP investments on the long-term stock price performance and profitability of firms. The authors found evidence to support the claim that ERP can improve profitability but not stock price. SCM systems, on average, led to improvements in both stock price and profitability while CRM showed no evidence of an improvement in either measure. While valuable, the study explored each system independently. Exploring the impact on performance of combinations of the three approaches would also be valuable.

The available literature on APS systems is scarce. There are two edited books on APS systems which provide a general overview of the field (i.e. Stadtler & Kilger, 2002; de Kok & Graves, 2003). While valuable, these contributions, and others (e.g. Tempelmeier, 2001; David et al., 2006) lack sufficient detail on several aspects of the methodology. A much greater body of literature, e.g., on the inner-working of APS systems and the application of APS in practice, is required.

Pibernik (2005) classified ATP (and AATP) methods according to their characteristics and explored their applicability to different production strategies. The author found AATP to be of relevance to a MTO production strategy but failed to explore this issue in detail.

Similarly, Fleischmann & Meyr (2003) considered AATP to be suitable for a MTO strategy and suggested coordinating AATP with a firm's production planning and scheduling modules. Again, while this is suggested, the authors did not explore this issue in detail.

Meyr *et al*. (2002) explained that planning tasks vary from industry to industry, especially for short-term planning. As a result, there remains a need to conduct further research into industry- and sector-specific APS solutions. Such a study was conducted by David *et al*. (2006), who explored the applicability of APS systems to managing production in the aluminium conversion industry. A similar study on the applicability of ERP in the same industry was earlier conducted by (David *et al*., 2005). Both studies found major limitations in the fit with the aluminium conversion industry; expected benefits were not fully realized in either case. Studies of the fit between APS and the requirements of the MTO sector should be conducted, comparing the planning and scheduling requirements of the sector with the functionality of APS systems to increase the competitiveness of MTO companies through greater analytical capabilities.

In summary, while a vast amount of literature exists on ERP and its predecessors, literature is only now beginning to emerge which explores extensions to ERP. More research is required which explores combining ERP with the various add-ons and which focuses on particular industry sectors.

Section 2 above defined the requirements of the MTO sector before Sections 3 and 4 described and evaluated ERP and its extensions. Following this, Table 3 summarizes the requirements and characteristics of MTO companies, lists the functionality provided by ERP, and raises a series of research questions (RQ1A- RQ6A) to be considered in what follows:

[Take in Table 3]

5. Assessing the Relevance of ERP to the MTO sector

This section seeks to explore the available literature on ERP, and its extensions, in contexts which demonstrate one or more of the characteristics of the MTO sector, as outlined in Sections 2.1 to 2.6. Firstly, with a focus on SMEs, the impact of company size on ERP adoption is explored (Section 5.1); then, the characteristics and requirements of MTO companies (whatever their size) are compared with the business processes supported by core ERP systems (Section 5.2); finally, the relevance of ERP extensions to the characteristics of MTO companies are considered (Section 5.3).

5.1 ERP Adoption in SMEs

Company size is a factor influencing a wide range of issues, which has been explored in many different streams of the Operations Management literature, including Total Quality Management and logistics (e.g., Ghobadian & Gallear, 1997; de Haan *et al.*, 2007, respectively). Similarly, company size is an important issue within the ERP literature. The large company market for ERP systems is arguably reaching saturation point – many large organizations have either implemented ERP or are in the process of implementing ERP.

Mabert *et al.* (2003) studied the impact of company size on ERP adoption through a series of case studies and interviews with representatives from 18 companies. In addition, the authors presented five propositions on the impact of company size on ERP adoption. For example, large firms intend to employ more of the functionality offered by ERP systems and customise the software more than smaller firms; and, large firms think more strategically about ERP adoption than small firms, which have more tactical concerns. The authors conducted a survey to test the propositions using statistical inference; however, the propositions are relatively straightforward and do not advance our understanding of the impact of company size on ERP adoption substantially. Moreover, it is difficult to have confidence in the results due to a small sample size. Nonetheless, the work is important as it emphasized the need to study the impact of company size on ERP adoption, leading to several other studies and national perspectives on ERP adoption in SMEs. Later studies (e.g., Buonanno *et al.*, 2005) have been conducted with larger sample sizes.

Studies of ERP adoption in SMEs in several different countries have been conducted in recent years with similar results. For example, the findings of Morabito *et al*.'s (2005) survey of Italian SMEs are consistent with the earlier findings of Mabert *et al*.'s (2003) survey among North American companies. Similarly, Argyropoulou *et al*. (2007) surveyed the importance of the operational requirements, logistics fulfilment and financial capabilities of Greek SMEs on ERP adoption with many similarities with the study of Finnish SMEs by Laukkanen *et al*. (2007). Laukkanen *et al*. (2007) also found that the expected impact of ERP on intra-firm processes is high for all firms but that midsize and large organizations expect more from ERP in terms of outward-oriented processes than small firms.

National perspectives on ERP adoption enrich the literature in many ways. In addition to supporting proposed theory and highlighting the impact of company size, they also uncover cultural and national issues previously over-looked in the literature. Olhager & Selldin (2003) report that, unlike in some other countries, Swedish companies generally prefer European and Swedish ERP vendors over huge global vendors. Sheu *et al*. (2004) conducted a study on

national differences in ERP adoption through case study research of companies using ERP systems provided by global vendors. The authors found that ERP adoption can be more difficult in Europe than in North America due to complex European corporate and national cultures. Hence, it appears as though the universal solutions of global ERP vendors have created additional implementation problems. Perhaps the reason why Olhager & Selldin (2003) found that Swedish firms prefer local vendors is that, by doing so, these firms seek to eliminate these cultural and national obstacles. To the best of our knowledge, there is no research which explores ERP adoption in UK SMEs; while Koh & Simpson (2007) questioned the suitability of ERP for SMEs in the UK, the survey and interviews conducted by the authors have a different focus - diagnosing uncertainty in SMEs using ERP. Developing a body of knowledge from different national perspectives, including the UK, would help to further our understanding of the impact of company size, and cultural and national differences on ERP adoption.

Buonanno *et al*. (2005) investigated the relationships between business complexities, organizational change and ERP adoption by surveying 366 firms and explored the impact of seven factors (including company size and the level of diversification) on ERP adoption. The authors found company size to be the only significant factor affecting ERP adoption. The authors use 'level of diversification' (whether a firm considers diversification as a source of competitive advantage) as an indicator of market strategy. Previous research had found this to have a significant effect on the complexity of information flows, thereby affecting ERP adoption; however, the authors did not find this in their study. This contradiction could be as a result, for example, of further national or cultural issues or due to differences in questionnaire design.

To conclude the above discussion, company size has recently been recognized as a factor that affects ERP adoption. This is a topical area of research, given that ERP vendors have begun to market their products towards SMEs. At present the fit between ERP and SMEs appears inconclusive. Company size influences the structure of many company-wide activities, affecting a company's internal and external dynamics; therefore, it is understandable that this is an important factor in the adoption of integrating mechanisms such as an ERP system. Although there have been several recent studies of the relationship between company size and ERP adoption, most of these have ignored the impact of the order penetration point. However, the order penetration point has a substantial impact on planning at the firm and supply chain level (Fleischmann & Meyr, 2003). It would be valuable to revisit the data collected in the studies reviewed in this subsection and acquire further

information from the respondents on the order penetration point and manufacturing strategy of the companies in order to provide a richer insight into this topic for MTO SMEs.

5.2 ERP and MTO Production

ERP systems contain a wide variety of modules and subcomponents for various decision support and transaction automation purposes. The MTO sector comprises of companies with idiosyncratic processes specific to an industry or individual firm. Therefore, it is important to explore whether ERP systems are able to meet the requirements of MTO companies (e.g., through flexibility). ERP systems provide transaction automation which lightens the administrative burden and is a feature considered broadly beneficial to all companies. However, to automate processes, the system needs a 'good enough' model of the processes (Davenport, 2000). The successful adoption of ERP in a MTO company relies on an ability to customize the system and set appropriate parameters in each of the major primary ERP modules such as accounting, finance and human resources. This is an important issue that makes ERP systems internally consistent and externally reliable but, to date, there is no literature available which focuses on this issue. The key characteristic that differentiates MTO companies from producers of more standard products is the production process; therefore, what follows focuses on the applicability of ERP functionality to a MTO company from a production perspective.

Reviews of the literature which consider PPC applicability to the MTO sector are conducted by Hendry & Kingsman (1989) and Stevenson *et al.* (2005) in which MRP-II and ERP were investigated, respectively. Despite considering the planning modules of MRP-II systems unsuitable for MTO companies, Hendry & Kingsman (1989) found them useful for the integration of production and marketing functions. However, a lack of functionality to support the customer enquiry stage was highlighted as a significant gap. Stevenson *et al.* (2005) evaluated the applicability of ERP systems to the MTO sector according to shop configuration and contract type (i.e. RBC or VMC). Again, despite some gaps, ERP was found to be generally suitable due to its wide availability and e-business capabilities. The authors did not, however, provide a sufficiently in-depth analysis of the fit between ERP and MTO companies at each planning and control stage. Deep *et al.* (2008) conducted a case study investigation of the factors affecting a ERP selection by a MTO company. While this provides a useful insight, it fails to provide a comprehensive review of the relevant literature or to consider the full range of order processing activities of relevance to MTO companies. The following is an attempt to address this issue:

- *Customer Enquiry Stage:* As previously described, customer enquiry management is a key planning and control phase for MTO companies – if due dates are to be adhered to, it is important that they are determined appropriately. Given high-variety and bespoke production, quoting standard lead times is considered inappropriate. CEM systems have been presented in the literature by Hendry & Kingsman (1993), Park *et al*. (1999) and Xiong *et al*. (2006); other relevant studies conducted by the authors include: (e.g. Hendry, 1992; Kingsman et al., 1996; Kingsman, 2000; Park, 2002; Xiong et al., 2003a; Xiong et al., 2003b). No attempt has been made to incorporate the functionality of these particular contributions within an ERP system. Stevenson *et al*. (2005) suggested that MRP does not provide sufficient support for managing customer enquiries in a MTO context, despite its Rough Cut Capacity Planning (RCCP) and Capacity Requirements Planning (CRP) modules. However, it has also been argued that the effectiveness of customer enquiry management depends on coordination across departments (Hendry & Kingsman, 1989) - this is a requirement which ERP systems are able to support. The major tool contained within ERP systems to support customer enquiry management is AATP/CTP; however, there is a need to explore the effectiveness of AATP/CTP in practice and to consider the MTO sector in the design of AATP/CTP systems (Pibernik, 2005).
- *Design and Engineering Stage:* The design and engineering stages are especially important for ETO and DTO companies (incorporated in the broad definition of MTO used in this paper). The importance of this stage has been described in the literature but little research has been conducted to explore this phenomenon or to explicitly incorporate design and engineering within planning and control structures. Rudberg & Wikner (2004) provided a rare contribution, proposing a framework to forecast the lead time required for design and engineering activities using a database of historical activities and by considering the current workload. While valuable, discussion of the framework is limited; there is insufficient detail for others to apply the method in practice. A second contribution is made by Olsen & Sætre (2007b). The authors conducted an action research project in a growing ETO company which was experiencing typical problems of bespoke production (e.g., setting reliable prices, determining realistic due dates, coping with increasing demand, and accommodating the customization requirements of each order). The company considered a number of ERP systems but was unable to find a system suitable for this set of problems. In particular, an inability to cope with product customization at the design and engineering stage was noted. ERP implementation in the company was unsuccessful – the vendor offered to build a ‘product configurator’ but this

was considered unsuitable and the company developed their own in-house design and engineering solution. This suggests that the ERP systems available provide insufficient support for tailored and pure customization.

- *Job Entry and Release Stages:* Control at job entry and job release supports adherence to the due dates negotiated at the customer enquiry stage. Breithaupt *et al*. (2002) reported that the job release mechanism of Load-oriented Manufacturing Control (LOMC), a particular Workload Control methodology developed in Hanover and described by Bechte (1988), was previously included in the SAP R/2 system and the systems of other local ERP vendors in Germany. However, to our knowledge, contemporary ERP systems (including those provided by SAP) do not contain this mechanism or other variants of Workload Control and no further information on this issue is available in the literature. Research should be conducted to understand how the job release mechanism was embedded into SAP R/2 and why it is no longer available. If the function was removed due to poor performance, this may be explained by the use of job release independent of other tiers of hierarchical Workload Control methodologies. Kingsman (2000) emphasizes the importance of incorporating all planning and control stages in the design of concepts for a MTO context. If contemporary ERP systems incorporated all the planning and control phases important to MTO companies within their design, including at job entry and release, the fit between ERP systems and the MTO sector could be improved.
- *Shop Floor Dispatching Stage:* The dispatching phase can be considered the least important stage in the planning and control hierarchy, if sufficient control is provided at the higher levels. Several authors have stressed this, suggesting that with job release, dispatching can be decentralized to the shop floor supervisor (Tobin *et al.*, 1988; Stevenson & Hendry, 2006). Jonsson & Mattsson (2003) agree that this is a suitable method for MTO companies but also suggested implementing a 'dispatching list' method, where advised priorities are given to the shop floor. Meanwhile, Kingsman (2000) suggested a simple prioritization rule like first-come-first-served is sufficient. Although the effectiveness of these policies may vary, providing a sophisticated dispatching mechanism within an ERP system is arguably not necessary for MTO production if prior stages are controlled.

To conclude the above discussion, in order to be suitable for the MTO sector, a system must be based on a concept which provides support throughout most of the production planning and control stages and is suitable for the general job shop (Stevenson *et al.*, 2005).

One such approach is Workload Control; therefore, if ERP systems provide a good fit with the needs of MTO companies in other respects (e.g., integrating departments) then research should be conducted which seeks to embed Workload Control within the structure of ERP systems. This would not only increase the applicability of ERP to MTO companies but could also improve the implementation of Workload Control. For example, Hendry *et al*. (2008) conducted comparative case study analysis on Workload Control implementations, highlighting the need to improve information flows and to align Workload Control with the existing IT infrastructure of a company. The authors suggested embedding WLC within an ERP system as an area for future research to explore. The case study by McKay & Black (2007) could provide a starting point for embedding PPC concepts such as Workload Control within an ERP system. The authors took a simple decision support tool which sequenced operations using a Gantt chart, developed it into a PPC system over ten years and integrated it with an ERP system. The authors noted that embedding the tool within an ERP system improved the functionality of the system and resolved information availability related issues that had previously been experienced when using the tool. While valuable, the company's manufacturing strategy and size are unknown.

5.3 Extended ERP and MTO Production

The available literature on supply chain effects on MTO companies, and on MTO supply chains is limited. As a result of the typical supply chain position and leverage of MTO companies, 'last minute' requests are commonplace. This requires responsive supply chain practices, including in purchasing, and a planning and control system capable of handling rush orders. Stevenson *et al*. (2005) and Stevenson & Hendry (2007) stressed the importance of web-based SCM practices and referred to Cagliano *et al*. (2003) in arguing that the Internet can be feasible for SMEs. Hence, aligning the core ERP system of an organization with software for SCM may be beneficial but further research is required.

A rare contribution to the literature of MTO supply chains is made by Jahnukainen & Lahti (1999) who explained that the overall performance of a MTO supply chain may suffer if supply chain control practices and information management are inadequate, even if firm-level performance is good. Subsequent findings appear to support this view. Sahin & Robinson (2005) and Robinson *et al*. (2005) perform simulation studies which show significant cost reduction for the supply chain as a result of information sharing, coordination and e-replenishment. Information sharing may also serve to reduce negative supply chain effects at the upstream end of the supply chain, e.g., the rush order arrival rate. APS can support collective planning through planning and optimizing the supply chain (Fleischmann

& Meyr, 2003). This is yet to be studied sufficiently in a MTO context; however, Deep *et al.* (2008) recently found APS to be relevant to MTO companies due to its capacity management structure and analytical planning functionality. APS systems are generally considered to be broadly applicable packages that provide company-wide planning and scheduling as well as supply chain planning. The above suggests that SCM software may be of benefit to MTO companies in general and to MTO supply chains but APS appears to lack sufficient support for due date and price determinations in a MTO context; the design and engineering stage is also not supported. While the job entry and release stages could be planned at an aggregate level based on plant capacity, a key strength of APS is its sophisticated shop floor scheduling functionality; however, if earlier stages are properly supported, the need for this is reduced.

The case study reported by Deep *et al.* (2008) also explained that the case company's 'ERP system selection committee' originally decided to implement a product configurator for repeat orders. However, a significant proportion of the company's work is bespoke and ETO; hence, the product configurator does not provide an effective solution for the full range of manufacturing activities performed by the firm. Other companies are also likely to follow a mix of strategies (ETO, MTO, MTP, MTS, etc); therefore, this presents a significant challenge.

One type of MTO company defined by Amaro *et al.* (1999) is the repeat business customizer. For such companies, developing long-term relationships with customers can be important. Muda & Hendry (2002) state that RBCs usually aim to establish contracts which run long enough for them to take advantage of some of the efficiencies gained by MTS companies. However, RBCs also require flexibility and are constantly negotiating new contracts with new or existing customers. Amaro *et al.* (1999) also define versatile manufacturing companies. CRM applications may help to convert VMCs into RBCs through facilitating stable and long term relationships and to increase the strike rate of MTO companies; however, there is a need to conduct research to improve the utilization of extensions to ERP. This discussion also implies that product life cycles may vary in length. It is unclear whether the PLM software extensions to ERP systems would add value where life cycles are short; research is required which explores this in greater depth

To conclude the above discussion, extensions to ERP systems, such as for SCM and CRM, have received limited attention to date. The fit between the requirements of the MTO sector and the functionality of ERP and these extensions is limited in parts and unclear in others - MTO-specific solutions do not exist in the ERP market. Conducting further research to determine applicability and to embed the requirements of MTO companies within ERP and

its extensions could lead to more suitable systems. Table 4 summarizes the key studies which explore ERP adoption in the MTO sector. The table demonstrates that this is an emerging area but that a greater body of knowledge should be developed. Table 5 provides a summary of the systems considered in this paper and summarises the justification for our assessment of the applicability of these systems to MTO companies with reference back to the research questions raised in Table 3 (i.e., RQ1A-RQ6A).

[Take in Table 4 & Table 5]

In the late 1990s and the early 2000s, the ERP literature focused on describing ERP and issues around its implementation in large organisations. More recent studies have explored the relevance of ERP to SMEs and industry and sector-specific studies have begun to emerge. It is anticipated that this trend will continue and that the MTO sector will be one of the areas in which future ERP research attention is focussed. Table 6 categorizes the literature on ERP, MTO and SMEs discussed in this paper. The following section summarizes the research gaps identified through the process of this literature review.

[Take in Table 6]

6. Gaps in the Literature

From the discussion presented in this paper, a number of areas in need of further research emerge. Eight such areas are briefly described below:

- *Developing AATP and CTP Systems for MTO Companies*: AATP and CTP systems are a growing area of research but available approaches are best suited to a MTS strategy. Furthermore, there is no evidence in the literature of their effectiveness in practice. Hence, there is a need to develop AATP and CTP systems for MTO companies and to conduct empirical studies to explore their impact on performance.
- *MTO-Specific CEM Tool for ERP Embedment*: The value of available AATP and CTP systems for supporting customer enquiry management in the MTO sector has also been questioned. Therefore, a MTO-specific CEM tool, to be embedded within an ERP system, should be developed.
- *Support for the Design and Engineering Stage*: The design and engineering stage, of high importance to producers of bespoke products, has received little attention in the literature. Further research is required to develop design and engineering planning tools. There is also the need for a product design/tailoring solution framework for pure and tailored

customization contexts. PLM add-ons may contain some functionality in this area but no conceptual or empirical evidence in support of its effectiveness has been presented in the literature to date.

- *Workload Control Embedment in an ERP System*: The Workload Control method of production planning and control is considered highly suitable for the MTO sector (Stevenson *et al*., 2005; Hendry *et al*., 2008) and should be (re-)embedded and tested in an ERP system.
- *ERP Applicability to the MTO Sector*: While ERP systems claim to be widely applicable, an empirical study of ERP in the MTO sector, which explores idiosyncratic, sector and industry-specific issues in its adoption, should be conducted. In addition, a similar study should be conducted on the effectiveness of APS for the MTO sector.
- *Managing Customer Relationships in the MTO Sector*: CRM is an emerging area in need of further research, both for MTO companies in general and SMEs in particular. CRM systems that (where appropriate) help MTO companies to turn one-off customers into repeat-purchasers are required.
- *National Perspectives on SME Adoption of ERP*: ERP adoption by SMEs is an increasingly popular area of research at the pre-, actual- and post-implementation phases. Local and national issues affect this process; hence, further research is required which conducts comparative analysis of ERP adoption in different countries. To the best of our knowledge, no studies of ERP adoption by SMEs in the UK, for example, have been conducted.
- *The Administrative Routines of MTO Companies*: The administrative routines of MTO companies may differ from those of MTS companies. These are undocumented in the literature and it is unclear whether they are supported by ERP systems. Fieldwork is required which explores the transactional idiosyncrasies of MTO companies towards supporting the automation of MTO transactions within the design of ERP systems.

7. Conclusion

This paper contributes to the available literature by providing a state-of-the-art review of ERP systems (and extensions to ERP) and an assessment of the applicability of ERP to the MTO sector, building on the assessment of MRP-II by Bertrand & Muntslag (1993) and providing greater depth to the assessment of ERP by Stevenson *et al.* (2005). Though ERP systems are gradually becoming recognized as standard solutions world-wide for certain industries, this does not mean that they suit all members of those industries. Applicability has been explored

by considering: firstly, issues relating to the impact of organization size; secondly, characteristics and requirements of MTO companies (whatever their size); and, thirdly, the relevance of ERP extensions to the characteristics of MTO companies.

The assessment concludes that, in many areas, there is a significant gap between the requirements of MTO companies and the functionality of ERP systems. One such gap is between the customer enquiry management and design & engineering processes of MTO companies and those supported by ERP systems. Eight key areas in need of further research were outlined in Section 6. Addressing these research gaps will increase the applicability of ERP systems to the MTO sector, improving information management in MTO companies, the competitiveness of MTO companies and their ability to align planning and control decisions with those made by firms in the wider supply chain. The current research of the authors focuses on surveying MTO companies in the UK that have either implemented or are currently implementing an ERP system to understand the implementation process and to gauge the effect of ERP on the performance of MTO companies.

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Table 1: Summary of major research contributions of relevance to the MTO sector

MTO Research	Studies											
	Tobin *et al*. (1988)	Hendry & Kingsman (1989)	Bertrand & Muntslag (1993)	Hendry & Kingsman (1993)	Wortmann (1995)	Amaro *et al*. (1999)	Hicks *et al*. (2000)	Rudberg & Wikner (2004)	Sahin & Robinson (2005)	Wikner & Rudberg (2005)	Stevenson *et al*. (2005)	Deep *et al*. (2008)
Customer Enquiry	✔	✔	✔	✔			✔				✔	✔
Design & Engineering			✔		✔		✔	✔				✔
Job Entry & Release		✔	✔								✔	
Shop Floor Dispatching	✔	✔	✔								✔	
Shop Configuration											✔	
Supply Chain							✔		✔		✔	
Customization						✔				✔	✔	
Company Size	✔										✔	✔
Market	✔					✔	✔					✔

Table 2: Example strengths and weaknesses of ERP systems

Strengths	Complete integration within an enterprise with a central database Comprehensive transaction automation at the operational level, across departments Cost reduction and time savings through increased efficiency Vendor supported systems, providing long-term usability Modular, configurable and extendable systems e-business, multi-lingual, multi-currency, and accounting functionality
Weaknesses	Only satisfies internal and individual requirements (mainly transactional) Generic packages, requiring customization, hindering cost and time reductions The most typical ERP-as-a-product offering has high software licensing and implementation costs Creates vendor dependency for improving and using extended solutions Challenging to implement

Table 3: Summary of MTO characteristics and issues for ERP systems to support

Characteristics		
1. Planning & Control Stages	Summary of MTO Issues	The full range of planning and control stages are important for MTO production (customer enquiry, design and engineering, job entry, job release, and shop floor dispatching).
	ERP System Provision	Through combining ERP with extensions, support for quoting, design and engineering, job entry, job release, and dispatching stages is possible (ATP & CEM, product configurator & PLM, MPS and shop floor scheduling functions).
	Emerging Research Question(s)	RQ1A: Can ERP software provide sufficient support at the customer enquiry stage to help quote accurate delivery dates? RQ1B: Can ERP software provide a suitably flexible platform to plan and control complex design and engineering activities? RQ1C: Can ERP software provide sufficient support for the job entry and release stages of MTO companies?
2. Shop Floor Configuration	Summary of MTO Issues	Job shop configuration is typical in MTO companies but can lead to planning and control complexity.
	ERP System Provision	MRP-driven replenishment support provided but may be unsuitable for a job shop environment.
	Emerging Research Question(s)	RQ2A: Can ERP systems provide a suitably flexible solution for dynamic job shop production environments?
3. The Supply Chain	Summary of MTO Issues	Many MTO companies are positioned upstream in the supply chain; rush orders are prominent.
	ERP System Provision	Internet-enabled supply chain information sharing and co-ordination functionality offered by ERP extensions.
	Emerging Research Question(s)	RQ3A: Can the functionality of ERP software, and its extensions, provide sufficient planning and control support for handling rush orders effectively?
4. Product Customization	Summary of MTO Issues	Highly customized production typical, including repeat but also unpredictable one-off manufacturing.
	ERP System Provision	Product life cycle and product configuration software available; customer relation management software is available.
	Emerging Research Question(s)	RQ4A: Is the product configuration and life cycle management software effective for highly customized, including one-of-a-kind, products? RQ4B: Can ERP systems help MTO company to develop customer relations (and turn one-off customers into repeat purchasers)?
5. Company Size	Summary of MTO Issues	A significant proportion of MTO companies are SMEs with relatively simple organisational structures; ERP adoption factors may also differ and IT budgets are smaller than in large organisations.
	ERP System Provision	Many ERP systems claim to be for all business sizes; a variety of pricing structures and user licences are available.
	Emerging Research Question(s)	RQ5A: Are SMEs in need of, or sufficiently complex to require, large-scale integrating mechanisms such as an ERP system?
6. Market Characteristics	Summary of MTO Issues	Uncertain market features, high levels of competition, and a low strike rate are typical.
	ERP System Provision	It has been claimed that ERP systems can provide a source of competitive advantage, although in some contexts they are now the ‘industry standard’.
	Emerging Research Question(s)	RQ6A: Can ERP systems help MTO companies, including MTO SMEs, to increase their competitiveness in the market?

Table 4: Summary of key ERP studies of relevance to a MTO context

Study	Topic	Firm Size	Manufacturing strategy of the firm(s)	Research Methodology			Summary
				Method	Data	Size	
Bertrand & Muntslag (1993)	PPC	N/A	ETO	Conceptual	N/A	N/A	Assessment of MRP-II suitability to ETO firms and a proposed framework.
Wortmann (1995)	IS	N/A	ETO	Conceptual	N/A	N/A	IS comparison for ETO and MTS production, and an ETO data-structure proposition.
Akkermans *et al*. (2003)	ERP, SCM	Large	Multi-national SC buyers	Delphi	I	23	Delphi study results for future impact of ERP on SCM.
Jonsson & Mattsson (2003)	PPC	Various	Various	Survey	Q	84	Assessment of PPC applicability to different production environments.
Mabert *et al*. (2003)	ERP	Various	Various	Case Study, Survey	I, Q	12, 18	Investigation of the impact of organization size on ERP adoption.
Stevenson *et al*. (2005)	PPC	N/A	MTO	Review	N/A	N/A	Review and assessment of PPC applicability to MTO production.
Buonanno *et al*. (2005)	ERP	SME	Various	Survey	Q	366	Investigation of factors influencing ERP adoption in SMEs compared to large companies.
McKay & Black (2007)	PPC, ERP	Unknown	Unknown	Action Research	I	1	Description of the evolution from a simple PPC tool to an embedded ERP system.
Koh & Simpson (2007)	PPC, ERP	Various	Various	Survey	Q	108	Diagnosis of uncertainties in SMEs using ERP systems.
Olsen & Sætre (2007a)	ERP	SME	ETO	Conceptual, Case Study	I	1	Proposition of an alternative in-house company-wide software framework for SMEs.
Olsen & Sætre (2007b)	ERP	SME	ETO/MTO	Case Study, Action Res.	I, M	2, 2	Proposition of proprietary company-wide software based on four case studies for niche companies
Deep *et al*. (2008)	ERP	SME	MTO	Case Study, Action Res.	I, M	1	Investigation of factors influencing ERP selection by a MTO SMEs.

Topic: ERP – Enterprise Resource Planning; SCM – Supply Chain Management; PPC – Production Planning & Control; IS – Information System.
Firm Size: SME – Small and Medium sized Enterprises; Various – SMEs to large organisations.
Compt. Strategy: SC – Supply chain; Various – from MTS to ETO
Data Collection: I – Interview; Q – Questionnaire; M – Meeting.

Table 5: An assessment of the applicability of ERP systems to MTO companies

Software	Features Applicable to MTO Companies	Gap between Software and MTO Companies
Enterprise Resource Planning	Wide availability; Transaction automation; Departmental integration (RQ5A); E-business capabilities (RQ5A, (RQ6A).	A lack of sufficient support for the customer enquiry stage (RQ1A); A lack of sufficient support for the design and engineering stage (RQ1B); Job entry and release stage support no longer available (RQ1C); MRP-driven replenishment strategy unsuitable for job shop production (RQ2A). The need for departmental integration in a SME is limited (RQ5A).
Supply Chain Management	Internet-enabled supply chain information sharing and coordination may improve ability to cope with rush orders (RQ3A).	Implementing ERP systems, and extensions such as for SCM, can be an expensive and high-risk strategy for MTO SMEs (RQ5A).
Advanced Planning and Scheduling	Supply chain planning and scheduling solutions (RQ3A).	Inability of ATP to support price determinations (RQ1A); The effectiveness of APS systems for planning and scheduling in a MTO context remains unclear (RQ1A-C); Implementing ERP systems, and extensions such as for APS, can be an expensive and high-risk strategy for MTO SMEs (RQ5A).
Customer Relationship Management	CRM software can help to build stable and long term relationships with the right customers; this may also increase the strike rate of MTO companies (RQ4B, RQ6A).	Implementing ERP systems, and extensions such as for CRM, can be an expensive and high-risk strategy for MTO SMEs (RQ5A).
Collaborative Planning, Forecasting and Replenishment	None (see Gap between Software and MTO Companies)	Not suitable for the MTO sector, but widely applicable to the fast-moving consumer goods market.
Customer Enquiry Management	Transaction automation functionality at the customer enquiry stage (RQ1A).	Functionality provides automation rather than decision support (RQ1A).
Product Configurator	Software may be relevant to companies with a mix of production strategies and to MTO companies employing strategy close to ATO production (RQ4A).	Functionality allows buyers to customize products over only a limit range; hence, has limited relevance, especially for products where design and engineering is bespoke, e.g., ETO firms (RQ1B).
Product Lifecycle Management	Cost estimation and product data management functionality for the customer enquiry and design and engineering stages (RQ1A, RQ4A).	The effectiveness of PLM systems in a MTO context, where product life cycles may vary greatly, remains unclear (RQ4A); Implementing ERP systems, and extensions such as for PLM, can be an expensive and high-risk strategy for MTO SMEs (RQ5A).

Table 6: Summary of literature reviewed in this paper

Categories	References
ERP Research	
Review & Classification	(Davenport, 1998; Gupta, 2000; Klaus *et al.*, 2000; Rao, 2000; Esteves & Pastor, 2001; Mabert *et al.*, 2001; Rashid *et al.*, 2002; Shehab *et al.*, 2004; Botta-Genoulaz *et al.*, 2005; Jacobs & Weston, 2007; Moon, 2007)
Future Concepts	(Davenport, 2000; Markus *et al.*, 2000; Chen, 2001; Rashid *et al.*, 2002; Al-Mashari, 2003; Jacobs & Bendoly, 2003; Davenport & Harris, 2007; Jacobs & Weston, 2007)
Extended ERP (SCM, APS, CRM and others)	(Davenport, 2000; Stratman, 2001; Tempelmeier, 2001; Bose, 2002; Rigby *et al.*, 2002; Stadtler & Kilger, 2002; Tarn *et al.*, 2002; Wiers, 2002; Akkermans *et al.*, 2003; Fleischmann & Meyr, 2003; Kovács & Paganelli, 2003; Ptak & Schragenheim, 2003; Addison, 2004; Davenport & Brooks, 2004; Rigby & Ledingham, 2004; de Búrca *et al.*, 2005; Møller, 2005; Stadtler, 2005; Hendricks *et al.*, 2007)
MTO Research	
Customer Enquiry	(Tobin *et al.*, 1988; Hendry & Kingsman, 1989; Hendry & Kingsman, 1991; Hill, 1991; Hendry & Kingsman, 1993; Kingsman *et al.*, 1993; Kingsman *et al.*, 1996; Easton & Moodie, 1999; Moodie, 1999; Cakravastia & Nakamura, 2002; Olhager, 2003; Hendry, 2005; Stevenson *et al.*, 2005; Stevenson & Hendry, 2006; Hendry *et al.*, 2008; Stevenson & Silva, 2008)
Design & Engineering	(Bertrand & Muntslag, 1993; Wortmann, 1995; Lampel & Mintzberg, 1996; Amaro *et al.*, 1999; Spring & Dalrymple, 2000; Bertrand & Sridharan, 2001; Rudberg & Wikner, 2004)
Job Entry, Job Release & Dispatching	(Hendry & Kingsman, 1989; Kingsman, 2000; Kingsman & Hendry, 2002; Stevenson *et al.*, 2005; Hendry *et al.*, 2008; Stevenson & Silva, 2008)
Non-PPC	(Muda & Hendry, 2002; Wikner & Rudberg, 2005; Dekkers, 2006; Olhager, 2007)
ERP & MTO Research	
Review & Assessment	(Wortmann, 1995; Stevenson *et al.*, 2005; McKay & Black, 2007; Olsen & Sætre, 2007a, b)
Specific Sector/Industry Application	(Wiers, 2002; David et al., 2005, 2006)
ERP & SME research	
National Perspectives	(Adam & O'Doherty, 2000; Mabert *et al.*, 2003; Baki & Cakar, 2005; Koh & Simpson, 2005; Morabito *et al.*, 2005; Lee *et al.*, 2006; Argyropoulou *et al.*, 2007; Chien *et al.*, 2007; Laukkanen *et al.*, 2007)
SME ERP Adoption	(Van Everdingen *et al.*, 2000; Muscatello *et al.*, 2003; Buonanno *et al.*, 2005; de Búrca *et al.*, 2005; Koh & Simpson, 2007; Olsen & Sætre, 2007a, b; Raymond & Uwizeyemungu, 2007)

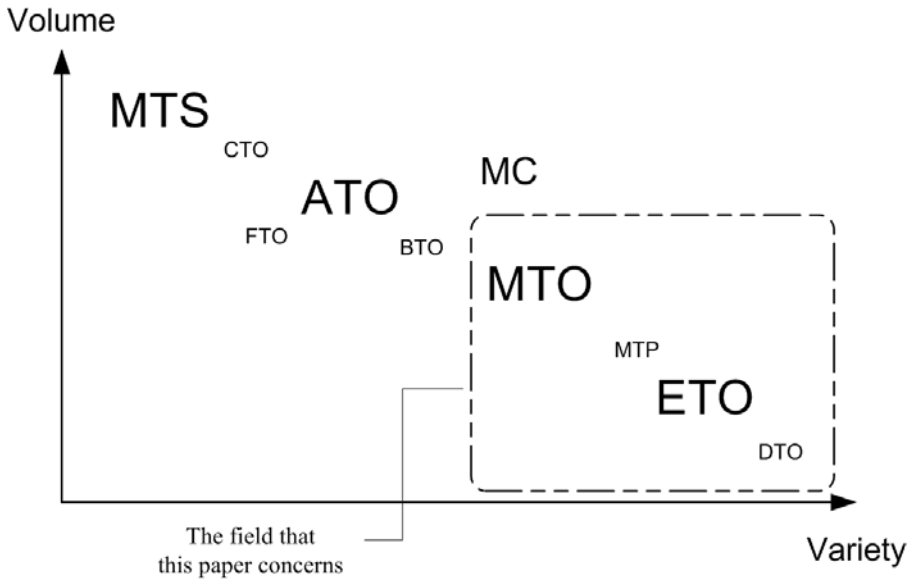

Figure 1: Field of interest based on volume vs. variety scale

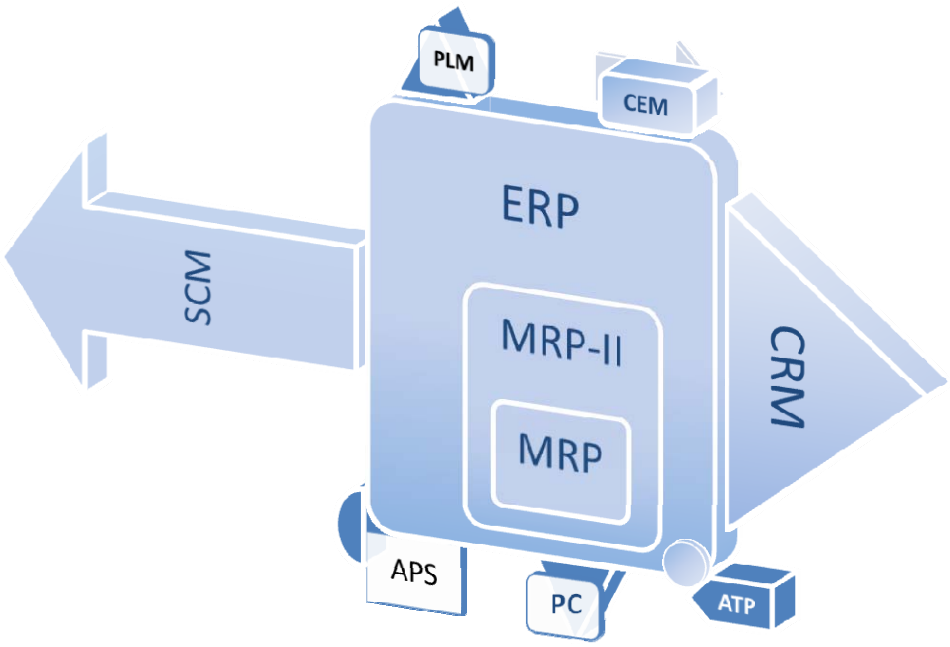

Figure 2: The scope of ERP systems, major extensions and add-ons