An Exploratory Study of Supply Chain Management IT Solutions

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Abstract
This paper explores the evolution of supply chain management IT solutions and looks at how these relate to each other and the overall performance of supply chain operations. A number of different technologies that help companies master their supply chain are looked at, and major benefits and drawbacks with these are presented. The IT solutions are categorized in three areas: data management, data exchange, and data tracking. In addition, some related process models like vendor managed inventory (VMI) and collaborative planning, forecasting and replenishment (CPFR) are studied.

1. Introduction
Supply chain management (SCM) is highly dependent on information and communication technology (ICT). In today's world, nearly all companies use some form of ICT solution to help them orchestrate logistics and communicate with their partners. This can range from simple solutions in a spreadsheet, printed out and faxed to a supplier, to highly sophisticated enterprise resource planning (ERP) systems combined with automated system-to-system (S2S) solutions. Laudon, cited in [26], defines supply chain IT solutions as "information systems that automate the flow of information between a firm and its suppliers to optimize the planning, sourcing, manufacturing, and delivery of products and services". If we look at SCM as a discipline, many definitions stress the need to integrate business processes across company boundaries to generate value for all parties involved [25,8,30]. As such, two things become important, the need to manage business processes and data as well as the need for integration with supply chain partners.

I have worked in different roles related to supply chain management for over nine years. As a project- and program manager as well as team leader, I have experienced various facets of SCM IT implementation. In a Fortune Global 500 company, I have had the opportunity to engage with numerous suppliers, outsourcing partners, logistics service providers, and SCM/ERP software providers. I have personally participated in, led or overseen the implementation of advanced planning and scheduling (APS) systems, radio-frequency identification (RFID) technology, enhancements to enterprise resource planning (ERP) systems, and VMI implementations with new suppliers (including the automation of data communication between the parties involved). I have been the chief designer of a collaborative planning solution, rolled out to over 150 suppliers, that utilizes all of the above technologies. The combined purchase volume through this solution is more than USD 10 billion annually. With this paper, one key intention is to review relevant academic research against personal experience (my own reflections and personal experience is written in italics) or in essence; to have a “dialogue” between personal experience and academic research in order to see whether these mirror each other or not.

In addition, this paper will provide an overview of the evolution of selected SCM IT solutions in the past fifty years. This is more than a history lesson, as many companies still use technology that was developed a fairly long time ago. In fact, doing a quick assessment of how a company utilizes SCM IT solutions could give us an understanding of the overall maturity of the company's SCM activities. The suggestion here is not that this would be an absolute, unambiguous evaluation of maturity. There are however several elements tying the choice of IT solutions to how advanced operations are. For example, many scholars stress the need for business process re-engineering and management (BPR and BPM) in conjunction with or before an SCM IT implementation [2,17,29]. As such, it would be reasonable to think that if mature business processes are in place (with BPM practices), it is possible to implement mature SCM IT solutions. And business process integration (that requires BPM) is at the core of SCM according to the definition given above. In addition, a number of studies show that advanced SCM IT solutions improve communication, co-operation and visibility in the supply chain [22,40,28]. Thus, if advanced SCM IT solutions are in place (properly implemented also on a business process level) they will have a positive impact on SCM performance. So, while
not fully unambiguous, there is a connection between SCM IT maturity and overall SCM process maturity.

To better formalize the discussion, different SCM IT solutions have been divided to three categories: data management, data exchange, and data tracking. In addition to this, a fourth dimension is introduced: (related) process models. A summary of the different IT solutions and process models (with a timeline of historical evolution) that will be examined in this paper is given in table 1 (the acronyms in table 1 are explained in the corresponding sections below). It should be noted that the underlying principles in some of these solutions (for example material requirements planning, MRP) can be implemented with a spreadsheet and does not as such require stand-alone software.

<table>
<thead>
<tr>
<th>Year</th>
<th>Data Management</th>
<th>Data Exchange</th>
<th>Data Tracking</th>
<th>Process Models</th>
</tr>
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<tbody>
<tr>
<td>1960s</td>
<td>ROP</td>
<td>Mail</td>
<td>Manual Inspection</td>
<td>PO based procurement</td>
</tr>
<tr>
<td>1970s</td>
<td>MRP</td>
<td>Fax</td>
<td>Barcodes</td>
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<tr>
<td>1980s</td>
<td>MRP II</td>
<td>EDI</td>
<td>.</td>
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</tr>
<tr>
<td>1990s</td>
<td>ERP</td>
<td>email, e-Business</td>
<td>.</td>
<td>VMI</td>
</tr>
<tr>
<td>2000</td>
<td>APS</td>
<td>RosettaNet</td>
<td>RFID</td>
<td>CPFR</td>
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</tbody>
</table>

Table 1 Summary of SCM solutions examined in this paper with related historical development

There are also other ways of categorizing SCM IT solutions. A somewhat similar model is by Auramo et al. [2]. They look at the different functional roles of IT in SCM, namely "transaction execution", "collaboration and coordination" and "decision support". Langley et al. [26] categorize the solutions into "business intelligence", "supply chain event management", "supply chain planning", and "supplier chain execution". Dam Jespersen and Skjoett-Larsen [8] categorize supply chain information systems based on maturity into "early stages" and "advanced stages". Their classification follows the outline in table 1 with for example the implementation of ERP, APS, electronic data interchange (EDI) and VMI in the advanced stages. The main difference between the above models and the categorization proposed in this paper is its more encompassing nature; all companies (engaged in some form of supply chain management) use solutions in all four new categories (whereas companies do not necessarily use solutions in the categories proposed by previous authors). This is helpful in gaining a more comprehensive view of the field, one of the key goals with this paper.

All companies should not automatically strive for the latest advances in SCM IT; there are numerous drawbacks with particular solutions. This paper will analyze, in addition to the evolution of SCM IT over the years, the major benefits and drawbacks associated with many technologies. The proposed categorization gives a clear understanding of the main functionality that the selected technologies enable and helps in providing better understanding of the dependencies. The study has been done as an extensive literature review and adds to existing papers by creating a holistic understanding of how the technologies reviewed here interoperate and contribute to SCM process maturity.

In summary, this paper will look at the evolution of SCM IT solutions over the years and examine the dependencies between these with the help of the proposed categorization. This gives us a comprehensive overview of the field, as all companies need the capabilities outlined in the four categories. Since many companies still employ technologies that are fairly old it is also appropriate to look backwards in time. In order to gain a better understanding of the key characteristics of the examined SCM IT solutions, comprehensive studies of academic research as well as personal experience is reflected. With all of the above in mind, what are the pre-requisites and expected gains from a particular SCM IT set-up? This paper is structured so that each category is examined, followed by some limitations to the approach in this article, a further discussion, and conclusions.

2. Data Management

In this paper, data management refers to ways of handling and analyzing data for decision support in supply chain management. Early reorder point (ROP) systems set the basis for the evolution of system capabilities in this area. Originating in the sixties, these systems were designed to automate the calculation of economic order quantities (EOQ) and the economic reorder point [19]. In the late sixties, material requirements planning (MRP) systems started to emerge. This introduced the concept of bill of materials (BOMs) and later the concept of independent and dependent demands. The basic difference is that independent demand refers to end-products whereas dependent demand refers to the material (listed in the BOM) needed for producing the goods. The ROP systems and EOQ calculations were suitable for planning independent demand whereas the MRP systems introduced methods for calculating material requirements, or dependent demands [34]. The so called MRP II or manufacturing resource planning systems further expanded MRP capabilities to reporting, scheduling and overall business planning. The basic notion introduced by MRP and MRP II systems was that instead of looking backwards (where future demand is largely predicted based on past usage), requirements were now planned for the future [22]. These systems are still popular among many
companies, particularly for small and medium sized firms, despite being relatively old technology (ROP systems being a notable exception to this, which is also why it is excluded from table 2 below) [23]. A crucial point in terms of the quality of material requirements from MRP systems (or ERP systems below) is related to product data management [2]. If there are inconsistencies or inaccuracies in the BOM, this will cause significant challenges. Dedicated product data management systems also exist, but the review of these is beyond the scope of this article.

Further development took place during the nineties with the introduction of enterprise resource planning systems (ERP). The origins of ERP systems can directly be traced back to MRP and MRP II systems [14]. Kumar and Van Hillegersberg [24] define ERP systems as "configurable information systems packages that integrate information and information-based processes within and across functional areas in an organization". A few important points emerge: first of all, ERP systems are often implemented as different modules, depending on the particular needs of the company [14] and secondly, ERP systems indeed manage SCM processes but only within the company. One module could for example be an MRP solution. A third crucial characteristic of ERP systems is that of real-time transaction processing [14,19]. So, ERP systems allow for real-time tracking and processing of events in any functional area of the company (where we can note a strong link to the data tracking section in this paper). The improved cross-functional characteristics of ERP systems are in fact what set them apart from MRP II systems [41,19]. A further key goal is also that any piece of information is only entered once [15,33]. From a pure SCM perspective, all of the above is a tempting proposition, in particular combined with data exchange solutions to integrate your partners.

Reflecting on personal experience, ERP systems can indeed provide substantial benefits through real-time tracking of for example material and finished goods movements. A key thing to note is that this requires (at least nearly) all locations to the modeled in the system. While we enjoyed this benefit, this does not seem to be the case in many instances. Partial implementation (with only a few locations actually using the ERP system), or the same system implemented as several instances running independently, can cripple benefits from real-time processing. In addition to frequent errors related to product data in BOMs, life-cycle management is also a key challenge. Frequent component version changes were nearly impossible to model (as a timed change) as they also involved inventory management; old components need to be “flushed out” of the system prior to taking the new version into use.

So why does not everyone take ERP systems into use? A key element is cost, both in terms of implementation and licenses. According to some surveys and case studies, there is a negative return on investment when looking at quantifiable gains from ERP implementations [41,22]. This might be because of a significant delay between the implementation and the benefits being realized, or because the benefits are more intangible in nature (and most probably a combination of both). According to a case study of a SAP implementation (one of the major ERP vendors) done by Kennerley and Neely [22], the main benefits are indeed intangible and qualitative in nature: efficiency and control (eliminating the need for phone, email and faxes), increased leverage on suppliers (the data available forms a robust platform for negotiation with suppliers) and improved planning (related to information availability and transparency). One clearly tangible, quantifiable benefit was observed, namely that of inventory reduction (through improved visibility on inventory quantities, location and type). All in all, this study found that the increased access to information (previously not available or hard to get to) created opportunities for improvements while also creating a complexity in the implementation. This brings us to "hidden" costs related to the vast implementation effort needed in for example training personnel. Also, in order to integrate business processes across functions, there is often a need to transfer and transform data from multiple systems (or even spreadsheets, archives and the like) to the new ERP system [41]. This cost can become very large as this is a tedious, time consuming and rather demanding task (familiarity with old systems, the new ERP and the associated business processes is needed).

Also after a successful implementation, ERP systems are very demanding in terms of maintenance. In our case, one ERP instance was implemented (with all factories, DCs, functional areas etc. modeled). As previously noted, this allows for reaping the greatest benefits from an ERP implementation but it also creates a very high dependency on the system. If crippled, business will grind to a total halt. This in practice resulted in extreme rigor in terms of management, maintenance and development. It was slow, costly and tedious to improve operations through ERP IT enhancements. The highly interlinked nature of ERP systems also caused practical challenges. If some parameter in for example the material management module was incorrectly set, it caused large issues with accuracy in material forecasts.

There are two key features normally missing in
standard ERP solutions: lack of advanced planning functionality [39], and a representation of the supply chain beyond your own company (as previously discussed). This has lead to the development of Advanced Planning and Scheduling (APS) systems (sometimes simply referred to as advanced planning systems or supply chain planning systems). Key features in APS systems are optimization [29,19] and constraint based planning [16]. Optimization can be done against a number of factors, including (but not limited to) capacity, transportation, distribution and product mix. For example using linear programming methods, you can make better decisions what to produce, where to produce it and in which quantities. Network design is another feature, indicating where to best locate production or inventory [20]. If capacity or supply is constrained, APS systems can also help with optimal customer allocation (after all, some customers might be more important that others). Using the notion of constraint based planning, customer orders can be compared to available material supply and production capacity. Any slack can be indicated as so called available-to-promise (ATP) and capable-to-promise (CTP) quantities [39]. A key thing to note is that an APS system does not replace ERP; it is merely an extension of it. APS systems are commonly reliant on information provided by the ERP system [12,20]. APS systems also span over company borders [8], and thus unlike ERP systems, you normally have at least part of your supply chain modeled in the APS. Software vendors often offer tailored solution for collaborative planning with customers and suppliers; and particularly the constraint based planning features of APS rely on this input [39]. We will further discuss this in the data exchange category.

Brown et al. [5] report on an APS that generated significant benefits for the Kellogg Company in the form of reduced costs for production, inventory and distribution. In addition, even bigger savings were generated through longer term capacity balancing. Kellogg was ahead of their time in the sense that they introduced advanced planning algorithms already in the beginning of the nineties. This was an in-house developed system, probably because at the time no software was available for this purpose. Jonsson et al. [20] conclude in their analysis that these types of in-house developed APS systems might have an advantage over standard, commercial offerings due to the inherent complexity and specificity of planning in different companies (both in terms of processes, data and organization).

Problems with data and how to model the planning set-up are highly relevant (and will be touched upon below). The organizational factor involved in APS implementations is also of great importance. In our case, there were three geographic regions (that at the time were profit centers) with a high degree of independence. Planning process inconsistencies and motivational aspects (between the different regions and towards the global, headquarters led APS implementation) led to significant issues in achieving a reliable and consistent sales plan on a global level. At the same time, many suppliers were operating on a worldwide scale with one order entry point. Needless to say, challenges were persistent also on an individual level. Due to cultural differences, language barriers and competence, it was extremely difficult to harmonize operations in a manner that was required by a global APS implementation.

These issues have also been looked at by Lin et al. [29]. They report on a case where a plan needed to be validated using spreadsheet solutions, and where in the end neither IT specialists nor planners fully understood how the APS system had ended up with the proposal. This of course does not enhance the credibility of the system and it is doubtful whether something like this can truly be taken into use. Problems with data [16], and the fact that even in an optimal situation all complexities associated with planning cannot be modeled in an APS system are frequent challenges. Also, humans are still an integral part of supply chain management and if they do not understand how the APS system works (or if there are problems with data accuracy), they are likely to do everything from start to finish in different solutions. Other shortcomings with APS systems are related to the lack of event based planning (unlike ERP systems, APS often require batch runs to re-calculate plans), handling of uncertainty, and challenges with getting accurate data from your partners (as constraint based planning requires input on for example supply capabilities) [39]. The main differences between APS and ERP (from a SCM perspective) relate to whether you are looking at the supply chain as a whole or your own organization,

<table>
<thead>
<tr>
<th>Maturity</th>
<th>Technology</th>
<th>Main Benefits</th>
<th>Main Drawbacks</th>
<th>Dependency on</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>MRP</td>
<td>Material forecasting, planning based on future demands</td>
<td>More complex, requires links to different corporate functions</td>
<td>ERP, data exchange</td>
</tr>
<tr>
<td></td>
<td>MRP II</td>
<td>Better reporting and scheduling</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ERP</td>
<td>Visibility, control</td>
<td>Cost (direct and indirect)</td>
<td>Data tracking</td>
</tr>
<tr>
<td></td>
<td>APS</td>
<td>Optimization, constraint based planning</td>
<td>Complexity (implementation and maintenance)</td>
<td></td>
</tr>
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</table>

Table 2 Summary of the data management category and its dependencies

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whether you model how constraints affect operations or not, and whether the main focus is on optimization or transaction processing [41,20].

The issue with batch runs can, if combined with data accuracy problems, cause massive challenges. We experienced situations were a weekly planning run was conducted and, after the fact, problems with input data were noticed. In certain instances, the results had already been communicated to suppliers. This caused problems on multiple levels as not only the internal plans had to be re-calculated, but also suppliers (in worst cases over 100 of them) had to re-balance also their production- and shipment plans. The high dependency on and integration with suppliers also demonstrated itself in the difficulties to get reliable supply input from all of them (and sometimes the weakest link in the chain can disable the whole process). The internal efforts to improve supply chain operations suddenly became an effort to improve supply chain competences and systems at a large number of partners. The handling of uncertainty is also a crucial point. For optimal handling of this, we were forced to implement a manual process where uncertainties in plans were discussed with certain key suppliers.

Table 2 summarizes the main aspects related to the data management category. From here we can see that especially for more mature solutions (ERP and APS), there is a need to ensure good capabilities in the data tracking and data exchange categories. Maturity refers to both IT solution maturity and, in accordance with what was outlined in section one, supply chain operations maturity gained with these technologies.

3. Data Exchange

Data exchange in this context refers to how supply chain partners communicate and the SCM IT solutions available for this purpose. Typical documents that are exchanged include invoices, product data, purchase orders (POs), and demand forecasts (the two latter will be examined further in the process model section). This is sometimes referred to as supply chain integration, although this can also refer to intra-company information sharing [32] (which is covered to some degree in the data management section of this paper). Done electronically, information transfer can in certain cases be fully automated but always with the intention of reducing dependency on physical print-outs sent by fax or regular mail. Supply chain integration can be divided into three categories; manual information sharing, semi-automated information sharing and fully automated information sharing [32]. Our focus here is on semi- and fully automated solutions, that is to say methods that require human intervention on only one side of the transfer or no human intervention at all. Automated transfer between two computer systems is often referred to as system-to-system (S2S) communication.

We will start by looking at electronic data interchange (EDI). Although EDI has been around in some form since the late sixties, it was the development of two dominant standards (the so called ANSI X.12 and EDIFACT) in the eighties that triggered its more widespread use [43]. The definition of EDI is not unambiguous; you could argue that EDI is the transfer of any data in electronic format. However, for the purpose of this paper we will rely on Walton and Gupta [43] who define EDI as "the transmission of standard business documents in a standard format from one trading partner's computer application ... to the other trading partner's computer application". This excludes email, faxes (that require manual intervention) and any transfer of data in proprietary formats. It is to be noted, that this definition also holds for the use of other standards like RosettaNet (that will be discussed further below).

According to a study by Ahmad [1], EDI leads to better delivery performance as it positively impacts the timely exchange of information (especially in volatile conditions where a lot of information is exchanged). This is where EDI excels, if a lot of transactional data is exchanged it is obvious that EDI can reduce the need for manual intervention and thus speed up the process (and save costs in terms of manual labor). Yet not everyone is keen on implementing EDI, and in some instances the implementation is driven by mandate rather than need. Some organizations force their subcontractors to implement EDI if they wish to continue doing business with them [1,31]. So why are especially smaller companies reluctant to implement EDI? There is a clear link to the data management category, you need an information system that can process and export the data needed. Some smaller companies do not have for example ERP systems to support this. Secondly, the amount of transactions can be so small that the cost of the infrastructure needed cannot be justified [31].

Previously so called value-added networks (VANs) were the dominant way of exchanging information through EDI. These networks have a cost associated with their use. They are still used today, but as with RosettaNet XML-based exchange, EDI transmissions can also be sent over the Internet. This has lead to a decrease in cost, yet many organizations (even larger ones) are still reluctant to automate the transfer of information. One reason might be the fact that despite the existence of standards, there are still variances in
how the data is processed. In other words, even with an investment in EDI infrastructure, it is unlikely that you can "fire up" automated transfers to all partners without a significant amount of mapping and testing (that have significant costs associated with them). The EDI connections are tailor made for each partner [8]. For example, some companies base their business on the fact that logistics service providers (LSPs) all have slightly different data requirements and EDI mapping requirements. They provide services as mediators between customers and LSPs, so that customers using many different LSPs do not have to build EDI connections to all of them (or pay a penalty for not using electronic transmission) (Kim Friman, lecture on Unifaun Oy's business, 25th of April 2011). Lastly, the use of EDI (or any other S2S method) means that you rely on data in your system to be correct (as in accordance with the definition, no manual intervention is allowed). Even if there are obvious errors in the data these will be sent out to your partners. Walton and Gupta [43] look at this from a slightly different angle. When you automate the transfer of information, you also create a link to the underlying process. Any changes in the process will affect how and what is sent out (and probably requiring changes to your S2S set-up) and it means that your business process management just got a bit more complex. All in all, S2S messaging requires robust data, robust information systems and good process management. Automating chaos is not a good idea.

In order to avoid incorrect data transfers to suppliers, one region in particular made use of a built in possibility to review and make corrections to data in a web-frontend prior to transmission. When the process was enhanced (to be more frequent), this became nearly impossible to do in practice. This had a positive effect, as it triggered a rather massive "clean-up" operation to ensure proper MRP settings and better data quality in the ERP system. In this sense, the implementation of S2S solutions can also be used as a trigger to ensure better data quality.

With the advent of the world-wide web, a lot of hype surrounded e-business. As with EDI, there are a lot of different understandings of what this means. For the purpose of this paper, we will focus on any semi-automated information sharing over the Internet. Usually this means some form of extranet solution. A good example is Kone Corporation in Finland that uses S2S solutions for major suppliers, while smaller ones receive the information through a web-portal (and some, even smaller ones, by fax) [2]. As such, for very large numbers of transactions, these types of semi-automated solutions are not the best option (as they still require human intervention), while for occasional transfer of data they work well. One particular type of e-business solution that received a lot of attention in the Internet hype of the late 90s is the e-marketplace (for example for e-procurement). In the study of several companies' usage of e-business, Auramo et al. [2] found that these were notably absent. It appears the most widespread use of e-business is in semi-automation of information sharing with partners where not too many transactions are needed. Another notable area is in collaborative planning. As discussed in conjunction with the analysis of APS systems, constraint based planning requires understanding of supply capabilities and demands across a number of partners. While again, in a complex setting with a number of products, parts, and suppliers, it makes sense to fully automate this information exchange, web portals can still play a significant role in highlighting demand spikes or supply shortages (or for example ATP or CTP data). This requires rule-based systems that analyze the underlying data for any problems and then highlight these simultaneously for all partners in the chain. These types of applications are often referred to as "dashboards", "cockpits" or "command centers" [21].

The first attempt at an extranet solution for sharing demand forecasts with suppliers and gathering supply data from suppliers did not succeed very well. This was (among other things) due to the fact that the amount of transactions was high and the solution was mainly reliant on manual processing. Some refused to accommodate for the increase in manual labor. Later developments built automated S2S transfers for the data itself while the extranet solution provided administrative functions and highlighted problems that would require further attention (for example low inventory or demand/supply mismatches).

A cornerstone in the RosettaNet standard that was born in 1998 is the so called Partner Interface Process (PIP). The RosettaNet standard itself is based on the extended mark-up language (XML). The PIPs specify...
not only the formatting for business documents to be exchanged but also the associated business processes [4]. In this sense, RosettaNet goes beyond what EDI standards define, but otherwise a lot of similarities exist. These days both commonly use the Internet as the data exchange platform and automating chaos with RosettaNet as opposed to EDI is no better. Nurmiilakso [32] concludes that the comparison between EDI and XML is not a comparison between the Internet and VANs but a comparison of different frameworks for standardization. So the main difference relates to the standard itself, and RosettaNet is to a certain extent a more comprehensive and a more in-depth specification. For example Sridharan et al. [38] note that effective SCM requires a good understanding of how business processes work together, and RosettaNet can to a certain extent help in this (due to the process dimension in the specification). In a comparison between RosettaNet and "traditional" EDI over VANs it also clear that RosettaNet has a cost advantage [6].

Table 3 contains a summary of the discussion on the data exchange category. Again, all companies need some form of data exchange but the move to either EDI or XML-based solutions needs to matched with proper capabilities in back-end systems (reviewed in the data management category). Since we are talking about data exchange between partners in the supply chain, it is of essence to also ensure necessary capabilities at interfacing customers or in the supplier base.

4. Data Tracking

Data tracking in this paper refers to means of following the movement of goods while ensuring timely and accurate information on these movements. Barcodes have been around for some time already, this technology is however not examined in detail. Sufficient to say it is a well established method of tracking for example incoming shipments or outgoing products. Radio-frequency identification (RFID) is likewise a technology that has been around in some form already quite a while but it is only in recent years that it has gained a foothold as a new way of tracking material. RFID is defined as the usage of radio frequency to identify and track items that have a coded chip. This enables remote, real-time reading of the material [37]. Compared to barcodes, RFID provides reading without line of sight (also in harsh conditions where barcodes would not be used), smaller tags and longer lifespan of the tags [27]. RFID tags also enable writing to the tag, which is impossible with barcodes. The big downside with RFID is the cost. There are investments needed in infrastructure to read the tags but the biggest part of the cost stems from the tags themselves. In 2006, prices ranged anywhere from 25 cents (USD) to 10 dollars for specialized tags with for example longer range [11]. Concerns about privacy have also been raised [23]. Consider the following example: a product is sold with RFID tags in the most expensive modules or components (enabling for example better warranty processes, through information on where it has been sold and manufactured, by whom, and who has manufactured any possibly faulty components). A good case for an OEM, but in theory anyone can read this information while for example tracking its movements.

According to Sarac et al. [35] there is a strong link between various IT applications (in our case in the data management category) and RFID as traceability and particularly the visibility in the supply chain is increased. As previously noted, data accuracy is a key challenge in for example ERP applications, and RFID is one method of improving this. Other benefits include increases in speed of processes and better decision support as real-time information is available. As with S2S communication, RFID technology needs a back-end system capable of handling the data.

RFID was put in place for fast moving goods where multiple deliveries were received daily. Cost was in this particular case not that big of an issue as one pallet (as opposed to one item) was tagged. With the implementation, we saw an increase in speed as operators did not have to spend time looking for the tag that sometimes was "hidden away" or simply torn (and made unusable). More importantly, data accuracy was improved as previously mentioned issues with barcodes no longer existed (an unreadable barcode mandated error prone manual processing). In addition, discussions were also held on how to possible improve warranty follow-up with RFID technology.

Table 4 illustrates the main discussion points related to the data tracking category. As with S2S solutions, more advanced tracking requires back-end system support. Modern ERP systems can certainly

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<th>Main Drawbacks</th>
<th>Dependency On</th>
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<tr>
<td></td>
<td>Barcodes</td>
<td>Accurate tracking</td>
<td>Reading requires line of sight</td>
<td>Data management</td>
</tr>
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<td></td>
<td>RFID</td>
<td>Fast and accurate tracking w.o. line of sight, small tags</td>
<td>Cost of tags, privacy issues</td>
<td>Data management</td>
</tr>
</tbody>
</table>
support this, but if for example material planning is done in spreadsheets, it is likely that manual intervention is needed for data entry (thereby reducing the benefits of more automated scanning solutions like RFID).

5. Process Models

The final category to be looked at is that of process models, summarized in table 5. For our purpose, this refers to ways of collaboration between customers and suppliers in the supply chain. The capabilities in focus here are vendor managed inventory (VMI) and collaborative planning, forecasting and replenishment (CPFR). As we will see, these methods for sharing forecasts and collaborating in the supply chain require strong IT support, and this is why these process models cannot be implemented without capabilities outlined in the data management and data exchange categories (and why these process models have been included in this analysis).

VMI originates from the late eighties when Wal-Mart and Procter & Gamble started piloting these processes [36]. Chopra and Meindl [7] define VMI as a process where the supplier is responsible for all decisions regarding inventory at the customer. In a traditional model, the customer is using an MRP or ERP system to calculate purchase orders (POs), taking into account the master production schedule or sales plan, current inventory, lead times, packaging sizes etc. The supplier effectively gets a plan with the “net” demand of what is needed at a particular time (and it should be noted that the supplier in this case has no or little visibility to actual, “gross” demands). In a VMI model, the supplier gains visibility to the above (sales plan or master product schedule, available inventory) and makes all decisions on how much to ship and when. Continuing with Chopra and Meindl [7], they also discuss push and pull strategies in the supply chain. A PO model is a typical pull model where the OEM or retailer "pulls" the material (and is thus alone steering the supply chain) whereas VMI is a push model where decision making responsibility is shared in the supply chain as suppliers "push" the material further downstream. In a VMI model, timely, accurate and comprehensive information sharing is a key. Poorly implemented, a VMI model is merely outsourcing of MRP calculations to suppliers (adding to their burden and easing the load on the customer) [40], but with proper data management and data exchange support it is a powerful tool to increase visibility and responsiveness in the supply chain. This can be used to counter for example the bull-whip effect [36]. VMI is more suitable for fast moving goods. With only occasional demands, the investments in IT infra and process management might not be justified and a simple purchase order might be better.

VMI was largely put in place to reduce demand fluctuations resulting from poor supplier visibility to gross demands. It was perceived as successful (although no measures were put in place to compare it to customer managed inventory), and expanded to cover nearly the entire supplier base and later also “enhanced” with consignment inventory.

Wal-Mart was again a pioneer when they in 1995 introduced collaborative planning, forecasting and replenishment (CPFR). Later in 1998 this process was formalized by the Voluntary Inter-industry Commerce Standards (VICS) committee who define it as "a collection of new business practices that leverage the Internet and electronic data interchange in order to radically reduce inventories and costs while improving customer service". Essentially CPFR is an extension of the VMI model in that collaboration extends not only to the replenishment activities, but also to joint forecasting and planning [8]. An important factor of CPFR is that it goes beyond information exchange and communication to synchronization of plans and management of exceptions in the supply chain [9]. This is where we see a link to the APS and data management features discussed earlier. Danese [9] has looked at several case examples of CPFR implementations and two main reasons for implementation emerge: reduced costs (investments in stocks) and increased responsiveness (better availability). Several success stories related to the previous have also been reported by Aviv [3]. It should be noted that compared to VMI, CPFR requires a more substantial implementation and maintenance effort (and thus higher costs). Mutual trust of the parties engaged is also required. At the same time, CPFR has been shown to produce lower total cost and better customer service compared to VMI [36].

Supply confirmations were requested from a large part of the supplier base but true collaborative planning was only done with key suppliers. This

<table>
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<th>Table 5 Summary of the process model category and its dependencies</th>
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<td>Maturity</td>
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<td>High</td>
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<td>VMI</td>
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involved quarterly meetings that focused on supply chain planning (where for example uncertainties and flexibility were high on the agenda). Later, also weekly meetings were put in place on an operational level to manage exceptions. A key complexity with this was the modeling of this information in planning systems; a large part of the intelligence was still in the hands of key persons who “orchestrated” the decisions related to planning.

6. Limitations and Further Discussion

An analysis of benefits and drawbacks alone is of course not sufficient when making a decision on SCM IT capabilities. Correct understanding of needed business processes for a particular set-up is crucial. The few process models analyzed here do not however cover business process re-engineering and management in conjunction with SCM IT implementation. In the implementation of new ways of working and new information systems, the human factor is also a considerable challenge. Socio-technical challenges are examined only on a general level (the implementation of an APS system is more complex than the implementation of bar-code scanners from a purely change management perspective). Also, it can be difficult to distinguish between direct IT system benefits and benefits stemming from improved business processes [2]. In addition, there can be differences of opinion about when a system really is implemented (and thus where you are in the matrix in table 1); criteria for this are however not established in this article. Lastly, as the primary focus has been on SCM IT systems used by manufacturing companies, the characteristics of service supply chains are not dealt with directly.

Coming back to the discussion on SCM IT and process maturity, the obvious consequence of the thinking outlined here is that not all companies need be world-class performers in terms of supply chain management. Sometimes less is more, and slightly less mature IT and SCM process solutions can be sufficient and the most cost-effective solution. If however your company operates on a world-wide scale with highly volatile demand and with expensive products; while recognizing that your IT solutions (in accordance with what has been outlined here) are not particularly mature, there is cause for concern. Your SCM capabilities are not up to par with your required state and this can have severe implications in terms of competitiveness.

In the introduction, we looked at Langley et al.’s [26] categorization of SCM IT solutions. One of these was "business intelligence”. This paper has approached the categorization differently from Langley, yet it is clear that as we approach 2012 we are on the brink of the era of analytics and business intelligence. Davenport and Harris [10] write a compelling story on how analytics is becoming more and more essential to compete, and they look at supply chain analytics from many different perspectives (for example planning, location analysis, routing and simulation). Although many of these features are covered by APS systems, further development and refinement of these capabilities can be expected. Iyer [18] presents an analysis of IT analytic capability (referred to as "IT applications that provide managers with information and ability to plan and execute decisions"), specifically in conjunction with collaboration practices, and concludes that these do have a positive impact on performance in the supply chain. Trkman et al. [42] report on similar findings. All in all, in addition to managing, exchanging and tracking of data, decision support and business intelligence is becoming more and more important in a supply chain context.

7. Conclusion

As we have seen during the course of this paper, the different categories we set out to investigate are highly interlinked. Best in class companies like the Kellogg Company, Kone Corporation or Wal-Mart have an IT infrastructure and engage in practices that are relatively new but provide big benefits (from an SCM perspective). At the same time, this does not mean everyone needs to do the same; it is highly dependent on what type of supply chain the company operates in. An understanding of the potential downsides of these solutions is essential, while it is also of essence to understand the dependencies between them. For example, automated data transfer is dependent on a back-end system capable of processing the data. When for example an OEM requires the supplier base to implement automated data transfers, they should also ensure that necessary capabilities exist in terms of data management (which might not always be the case). Otherwise potential cost savings only result in an increase of cost elsewhere in the supply chain (as from the supplier’s perspective, the cost of implementation is realized while the benefits are not). Another example relates to the use of APS systems and constraint based planning. To realize its full potential, this technology requires input from customers and suppliers. If they on the other hand do not have necessary capabilities in place, the benefit from such an implementation is watered down. These are merely a few examples; when companies make decisions on how to develop their SCM IT, they need not only to understand how these solutions relate to each other and operations in their company, but also whether they are
suitable for the supply chain as a whole. This means that the capabilities and requirements of key partners is also a factor when making decisions on the IT strategy.

The reviewed literature for this article forms a solid base of understanding that correlates very well with my personal experience. I made a conscious decision to include articles and books that corroborate my earlier work as a practitioner. Needless to say, there is a lot of research I could not relate to (or completely disagree with), but reviewing this is not possible within the context of a relatively short paper like this. A key thing to note is that many papers typically have a lot of subject depth compared to the approach in this article, where a broad approach to the analysis of SCM IT is presented. Both approaches are needed.

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8. References