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Information flow in supply chain management: A review across the product lifecycle

Nikolaos Madenas [a,*], Ashutosh Tiwari [a], Christopher J. Turner [a], James Woodward [b]

[a] School of Applied Sciences, Cranfield University, MK43 0AL Bedfordshire, United Kingdom
[b] Axillium Research, Unit 20, Cottesbrooke Park, Heartlands, Daventry, Northamptonshire, NN11 8YL, United Kingdom

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ABSTRACT

The purpose of this review is to provide an analysis and comparison of publications identified in the area of information flow in supply chain management. Although review articles have extensively analysed supply chain management during the manufacturing phase of the product lifecycle, product development and service phases seems to be largely separated. Therefore a total of 132 journal articles were systematically selected and analysed. In order to enable a methodological approach, a framework is proposed to classify the publications based on the product lifecycle phase and the type of the publication. Each phase of the product lifecycle is discussed in detail and research gaps are identified. Finally cross-phase research gaps are identified to provide guidelines for future research.

Introduction

During the last decade, supply chain management (SCM) has changed significantly due to globalisation and the pace of technological innovation. Competitive pressures have forced companies to increase supply chain collaboration throughout the whole product lifecycle. To improve their ability to integrate processes, businesses are also facing the challenge of shorter product lifecycles, globally dispersed design teams, a constant increase in outsourcing and the market demand for mass customisation. This has forced companies to create demand-driven and flexible supply chains that will be able to meet customers' expectations. Key business processes are integrated through the supply chain while strategic knowledge and issues are shared in order to achieve mutual benefits [1]. The integration of SCM systems has recently been under discussion in both information management and SCM literature. One of the main reasons that many researchers have highlighted the importance of information flow in supply chain is the continual increase in its complexity. Operating in this new complex environment, collaboration is no longer a theoretical concept but a key aspect of SCM [2].

SCM has become dependent on information flow as it can be characterised as the enabler of collaboration and improvement [3–5]. Significant improvements can be achieved by integrating the information flow through suppliers. OEMs can concentrate on the core activities of the product while using suppliers' additional resources, capabilities and skills to build lower cost and better quality products [6,7]. Often, suppliers have the capability, the knowledge and the expertise to develop better and more mature products. Bowersox and Calantone [8] state that even though collaboration in supply chain is not new, information advantages have only recently allowed companies to exchange more accurate and low-cost information. Information technology is only one element of the supply chain equation but it can be characterised as the enabler for improvements in global operations.

Whenever OEMs share their information and knowledge with suppliers, they allow their knowledge assets to become public and as a result risk their competitive edge [9]. Therefore, the level of integration into OEMs' processes and the depth of collaboration need to be defined. The level of information sharing is defined by Li et al. [10] as the extent to which critical and proprietary information is communicated to one's supply chain partner. During the last decade several researchers have focused on clustering the different types of relationships between suppliers. A classification of suppliers is key for OEM and Tier 1 companies as it will drive the type of connection required for each cluster of suppliers as well as reduce the number of suppliers required to become directly connected. Multiple types of categorisation have been proposed in the literature and can be used as a starting point for clustering suppliers and as a result reduce the cost in managing multiple types of relationships [7,11–15].

The evolution of technology and the Internet has allowed the development of web-based systems that can lead to improved

* Corresponding author. Tel.: +44 01234 758250.
E-mail addresses: n.madenas@cranfield.ac.uk (N. Madenas), a.tiwari@cranfield.ac.uk (A. Tiwari), c.j.turner@cranfield.ac.uk (C.J. Turner).

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collaboration within the supply chain. Within the manufacturing industry, digital systems are used daily to design, develop, produce, deliver and support products for global markets. However, the wide range of systems used, such as Computer Aided Design (CAD), Product Data Management (PDM), Enterprise Resource Planning (ERP), Product Lifecycle Management (PLM), has created the landscape of ''Isolated Islands of Information'' where information is locked in different repositories making it difficult to share. Although some of these systems allow the data exchange in a dynamic and direct way, organisations still need to work closely with suppliers to improve the decision making process and the entire supply chain performance [16,17].

During the last decade SCM has received significant attention, evidenced by the increasing number of publications in this area. Through these publications a number of definitions have been used to define SCM. Although the definitions provided by Lambert et al. [18] and Mentzer et al. [19] are most commonly referred to; in this review the definition from Swaminathan and Tayur [20] will be used as it is more appropriate for the specific aspect of SCM that this review focuses on. Swaminathan and Tayur [20] define SCM as the efficient management of the end-to-end process, which starts with the design of the product or service and ends when it has been consumed and discarded by the consumer. Information sharing within a supply chain is defined as the integration of information systems, decision systems, and business processes used to conduct information searches, manage business operations, monitor business details and perform other business activities [21].

While this field is widely researched, with several publications during the last decade, knowledge seems to be in silos residing in each phase of the product lifecycle. It is critical at this point to summarise and understand the work that has been completed in this field over the last decade in each stage of the product lifecycle in order to build in the previous work done instead of reinventing the wheel. The review of Power [22] focuses on SCM integration and implementation from a strategic perspective. Although Power follows a holistic approach, most of the examples and the use cases demonstrated focus on the manufacturing phase. Similarly, Pereira [4] reviews the current issues and trends in the IT-enabled SCM strategy using examples from manufacturing and logistics case studies. Burgess et al. [23] provide a systematic and structured review on SCM. Burgess et al. [23] highlight that SCM is relatively a ''young'' field with exponential growth in interest from researchers. Arshinder Kanda and Deshmukh [24] provide a systematic review with an emphasis on SC coordination. A framework is provided to support further research. The work of Marra et al. [25] explores IT enabled SCM from a knowledge management perspective. This review highlights the importance of measuring the impact of knowledge management in supply chain performance by directly relating IT adoption to the firm's growth. Helo and Szekely [26] examine the benefits of SCM that can be achieved through logistics information systems. This review paper demonstrates a software classification which includes applications that improve the information sharing in the manufacturing and service phase. Huang et al. [27] discuss the impact of information sharing in supply chain dynamics. This paper proposes a framework for categorising literature and research publications based on three key elements: supply chain structure, level of decision, and the production information model. Discussing mainly the information flow in the manufacturing phase and how suppliers exchange information such as capacity variances data, order data, lead times etc., this comprehensive review paper is a very good example of literature classification as it clearly shows the different types of information shared among the supply chain members as well as various modelling approaches used by researchers. Buyukozkan and Arsenyan [28] is the only review identified in this study that investigates the area of collaborative product development and provides future direction to support information flow during product development.

Even though these review papers highlight the importance of information sharing in SCM, there seems to be a gap in the literature discussing the product lifecycle from product development to manufacturing and service. Therefore, this review aims to address this gap by examining the area of information flow in SCM holistically including product development and service. The intent of this systematic review is to summarise and analyse the literature both in each phase of the product lifecycle and through cross-phase examinations in order to provide a better understanding of the current research gaps as well as provide directions for further research. This review can also be used as a starting point to guide new researchers entering the field. The following section presents the research methodology and an overview of the classification framework. Section three covers the analysis that was carried out in each phase of the product lifecycle while section four summarises the key findings for each part of the classification framework.

Review methodology

This review examines all publications between 2000 and 2012 that study the subject area of information flow in SCM. It is important to highlight that studies that examine either the information flow internally in organisations or the general literature of SCM are not included in this literature review. In addition, studies that discuss the subject area from high level without referring to a specific phase of the product lifecycle as also considered out of scope. Fig. 1 shows the selection and evaluation process that was taken in order to cover the whole product lifecycle.

Once the scope of the literature was defined, the selection process involved searching in the SCOPUS online database for peer-reviewed journal articles. From the SCOPUS database using two combinations of keywords, ''supply chain'' AND ''information flow'' and ''supply chain'' AND ''information sharing'', 1400 articles were identified. Through a filtering process the authors limited the search by excluding publications before the year 2000. In addition any conference papers, books and notes as well as publications that focus on subject areas outside of the research scope were also excluded from the analysis. As a result the total number was reduced to 676 publications. The abstracts from the first 200 most relevant papers were assessed in order to examine their fit with the scope of the research. As most of the articles identified at this stage

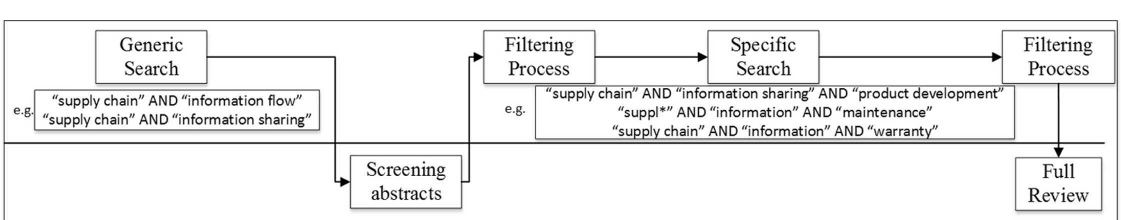

Fig. 1. Selection and evaluation process.

Table 1
Overview of the proposed framework.

	PLM	Product development	Manufacturing	Logistics and maintenance
All the publications included in this table focus on the subject of "Information flow in SCM"	Includes: • Articles that discuss the information flow through the whole product lifecycle or from a PLM system perspective	Includes: • Studies that discuss the information flow in SCM in the PD phase • Studies that refer to the PLM systems but focuses only in the PD phase are also included in this column[a]	Includes: • Studies that discuss the information flow in SCM in the manufacturing phase	Includes: • Studies that discuss the information flow in SCM in the logistics and maintenance phases • Studies that refer to the flow from the customer and the retailers back to the OEMs are also included in the Logistics and Service phase[a]
Review • Publications that base their findings in the literature				
Proof of concept • Publications that through empirical and conceptual research discuss the subject of information flow SCM without using any quantitative analysis				
Modelling and framework • Publications that propose a generic framework to address issues or through modelling techniques simulate or measure the benefits of the information flow in SCM				
System architecture • Publications that propose an architecture or a system that improves the information flow in SCM				

[a] Exceptions.

focused on the manufacturing and logistics phase a combination of keywords and a filtering process was utilised to ensure that the whole research scope was covered. The use of "supply chain" and "information flow" keywords did not reveal any publication that focused solely on the product development phase. Only by including "product development" and "information" or "collaborative product development" as keywords would relevant publications be returned for this phase. Therefore the second part of the selection and evaluation process which was related to specific searches was used to ensure that the selected keywords would cover the research scope. In this way, no meaningful publications have been missed.

From the aforementioned research approach and by excluding papers out of scope the total of 132 publications were analysed. As a number of the articles fit in more than one category, the total number of publications included in the framework is 152. Each article was examined in a greater detail, evaluated and then categorised in the framework. The framework presented in Table 1, is a two-dimensional table which is structured to classify articles based on each phase of the product lifecycle and the type of each publication. Each area of the classification is clearly defined in Table 1. Although it can be argued that the PLM area of the framework does not represent solely a phase of the product lifecycle, the authors decided to separate PLM as an independent part of the framework in order to include either articles that discuss the information flow through the whole product lifecycle or from a PLM system perspective. This selection was based on the premises that PLM systems have received significant attention over the last 5 years and based on the definition provided in Section "PLM" in "Review methodology" they cannot be linked to a specific lifecycle phase as PLM systems can be used to store and maintain data from concept to end of life. Therefore this approach allowed the publications related to PLM systems not to be hidden inside primarily the PD phase where currently the main focus lies.

Once the table possessed a valid range of publications, each part of the framework was analysed in depth in order to identify current research gaps and provide directions for further research. Articles were not only analysed based on each part of the classification framework but were also reviewed holistically to identify the journals, the country of origin and the year of the publication.

Literature classification and analysis

As information sharing occurs in each phase of the product lifecycle from concept definition and Product Development (PD) to manufacturing and service, it is important to understand the benefits that information sharing can bring as well as the modelling techniques and the systems proposed in the literature to support the communication among OEMs and the supply chain. Table 2 shows the classification of the 132 articles identified within literature through the selection and evaluation process.

Descriptive analysis

The analysis of the 132 articles showed that there is no journal that is dominating in the area of information flow in SCM. The articles are almost equally spread over 50 different journals. It was identified that information flow in SCM is covered not only from traditional journals in this area but also from journals that cover a wider variety of topics and disciplines.

The analysis of the articles from a country of origin perspective showed that USA is leading in this area. USA is responsible for 29% of the publications included in the classification framework, the majority of which are in the "proof of concept" and "modelling & frameworks" areas. Similarly, UK publications tend to focus on the "proof of concept" and "modelling–framework" areas with a 10% of the total number. Closer examination showed that publications from Asian countries such as China, South Korea and Hong Kong are responsible for the majority of publications in the "system architecture" area. Fig. 2 shows the number of publications in relation to the country of origin. The other category includes publications from 15 countries that have less than 3% of the total. These articles were published mainly from Europe (e.g. France, Italy, Netherlands) and a few Asian countries (e.g. Singapore, India).

Classification framework analysis

The analysis of the classification framework shows that more that 65% of the publications focus on the manufacturing, logistics and maintenance phase of the product lifecycle (Fig. 3). The majority of these papers examine the benefits that information flow can bring in SCM by validating research or hypotheses models

Table 2
Literature classification.

	PLM	Product development	Manufacturing	Logistics and maintenance
Review		Buyukozkan and Arsenyan [28]	Burgess et al. [23][a]	Burgess et al. [23]
			Power [22]	
			Helo and Szekely [26][a]	Helo and Szekely [26]
			Pereira [4]	
			Marra et al. [25]	
			Swaminathan and Tayur [20][a]	Swaminathan and Tayur [20]
			Huang et al. [27]	
			Arshinder Kanda and Deshmukh [24]	
			Ho et al. [85][a]	Ho et al. [85]
Proof of concept	Waurzyniak [86]	Fliess and Becker [7]	Kim et al. [9]	Ergen et al. [87]
	Kiritsis et al. [34][a]	Schiele [43]	Dunne [63]	Kiritsis et al. [34]
	Rachuri et al. [35]	Liu and Xu [88]	Tarn et al. [89]	Wamba and Boeck [90]
	Luh et al. [33][a]	Luh et al. [33]	Barratt and Barratt [62]	Candell et al. [71]
		Merminod and Rowe [91]	Childerhouse et al. [92]	Baglieri et al. [93]
	Ming et al. [94]	Fagerström and Jackson [95]	Soroor et al. [96]	Puschmann and Alt [97]
	Lee et al. [73][a]	Reed and Walsh [98]	Welker et al. [99]	Lee et al. [73]
	Merminod and Rowe [91][a]		Childerhouse et al. [100]	Boersma et al. [83]
			Rungtusanatham et al. [17]	Barratt and Oke [101]
				Chae et al. [102]
Modelling and frameworks	Jun et al. [103][a]	Huang and Chu [104]	Denkena et al. [105]	Jun et al. [103]
	Sharma [106]	Petersen et al. [44]	Chang [60]	Simchi-Levi and Zhao [107]
	Belkadi et al. [108]	Mishra and Shah [109]	Du et al. [110]	Cachon and Fisher [77]
	Duigou et al. [111]	Parker et al. [112]	Chan et al. [113]	Mishra et al. [114]
	Tang and Qian [14]	Chung and Kim [115]	Yin and Khoo [116]	Nativi and Lee [117]
	Taisch et al. [38]	Ettlie and Pavlou [46]	Kim et al. [9]	Cheng et al. [118]
	Sudarsan et al. [119]	Petersen et al. [13]	Wong et al. [56]	Croom [120]
		Ragatz et al. [42]	Karaesmen et al. [121]	Uusipaavalniemi and Juga [15]
			Yao et al. [122]	Huang and Gangopadhyay [123]
			Li et al. [124]	Raghunathan [125]
			Schmidt [57]	Kulp et al. [76]
			Chan and Chan [126]	Yao and Dresner [127]
			Croson and Donohue [52]	Yu et al. [128]
			Sahin and Robinson [61]	Tai [82]
			Cagliano et al. [64]	Aoyama et al. [129]
			Chengular-Smith et al. [55]	Gavirneni [80]
			Zhou and Benton [54]	Moyaux et al. [79]
			Datta and Christopher [58]	Lee et al. [75]
			Ali et al. [130]	Trapero et al. [78]
			Hall and Saygin [131]	Zhu and Thonemann [132]
			Themistocleous et al. [133]	
			Liu and Kumar [59][a]	
			Lau et al. [134][a]	Lau et al. [134]
			Prajogo and Olhager [135][a]	Prajogo and Olhager [135]
			Yu et al. [53][a]	Yu et al. [53]
			Li et al. [136][a]	Li et al. [136]
			Devaraj et al. [137][a]	Devaraj et al. [137]
			Hsu et al. [21][a]	Hsu et al. [21]
			Sezen [138][a]	Sezen [138]
System architecture	Choi et al. [36]	Trappey and Hsiao [49]	Trappey et al. [67][a]	Trappey et al. [67]
		Yujun et al. [40]	Liu and Young [68]	MacDonnell and Clegg [72]
	Dai et al. [31]	Xu and Liu [48]	Mourtzis [66]	Han and Yang [70]
	Kiritsis [74][a]	Chu et al. [50]	Feng et al. [69]	Kiritsis [74]
	Mahdjoub et al. [32][a]	Mahdjoub et al. [32]	Liu and Kumar [59]	Zhu et al. [139]
	Schilli and Dai [140]	Kim et al. [141]		Chow et al. [142]
	Kim et al. [39]	Huang and Mak [45]		Sun et al. [143]
	Gulledge et al. [144][a]	Zhang et al. [47]		Gulledge et al. [144]
		Kim et al. [30]		Bodendorf and Zimmermann [81]
		Hren and Jezernik [145]		
		Huang and Fan [41]		
		Gunpinar and Han [37]		
		Rodriguez and Al-Ashaab [51]		

[a] Articles that are included in more than one categories.

through survey-based data collection techniques. Similarly, other studies use simulation techniques to demonstrate the effectiveness of information flow. Another important outcome that can be observed through the classification framework is that the majority of the publications in the system architecture area concern the PD phase. It is interesting to note that most of the studies in PD present system architectures to support product data exchange, allowing globally dispersed engineers to work in a collaborative environment. Although it can be argued that the PLM area is relatively empty in this framework, this can be justified as PLM systems became more popular later in the decade.

It can be seen from Fig. 3 that the number of papers published in the area of information flow in SCM has fluctuated over the years. The graph shows that this area reached a high in 2005 and 2007

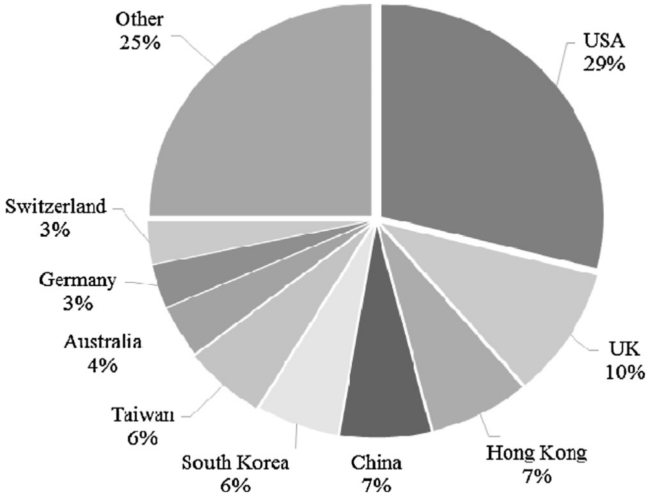

Fig. 2. Country of origin for the selected publications.

and there has been a decrease in the number of publications since then. In 2011 there is a slight increase in the number of publications with the same number following on in 2012. Although on its own Fig. 3 does not represent clearly areas for future directions, what it does demonstrate is that a higher number of articles have focused in the "manufacturing" and "logistics and maintenance" phases while in terms of the type of publication more that 45% focus on "modelling & frameworks" area.

PLM

The literature classification shows that during the last five years the amount of publications in the PLM area has increased significantly. During the last six years, PLM systems received significant attention due to the constantly increasing amount of data sharing between OEMs and suppliers. Moreover, the promise and the potential of PLM systems to reduce the time to market and improve the product quality led to a continuous investment in PLM systems.

CIMdata [29] defines PLM as "a strategic business approach that applies a consistent set of business solutions in support of the collaborative creation, management, dissemination and use of product definition information across the extended enterprise from concept to end of life – integrating people, processes, business systems, and information". Several studies discuss the advantages that PLM systems bring to supplier collaboration and their contribution in sharing knowledge. Another area that is under discussion in the literature is that of system development. Researchers propose various system architectures that aim to link or integrate with PLM systems in order to expand their current functionality and improve supply chain collaboration. Although PLM systems emerged as an application with a potential to integrate systems throughout the product lifecycle, their use and integration still remains at the initial stages of product development [30]. Dai et al. [31] developed a web-based e-commerce system that integrates with PDM/PLM product design environments in order to allow consumers, partners and distributors to take part in product design and share their ideas with suppliers. Mahdjoub et al. [32] developed a collaborative approach using a multi-agent system on a virtual reality platform to allow engineers to re-use knowledge when creating new products. The system is integrated with the PLM system and linked with the virtual reality platform. Luh et al. [33] proposed a customised plan for PLM platform deployment to support the collaborative product development among geographically dispersed sites. This research reveals some of the hardware constrains that companies face while exchanging large quantities of data. Kiritsis et al. [34] presented the concept of closed-loop PLM focusing on the in-service and the end of life phases when in most cases the information flow is interrupted. This study is only one of the few that highlight the advantages that PLM systems can bring during the in-service and the end of life phases of the product lifecycle.

Although in terms of CAD geometry, there are several standards that allow organisations to exchange information among different systems, it was identified in the literature that there is a lack of interoperability among heterogeneous PLM systems. Rachuri et al. [35] provide an overview of IT standards for PLM systems to support the harmonisation of PLM standards. Although there are standards developed to support information exchange, particularly in the area of CAD, data exchange among heterogeneous systems still remains a very indirect and manual process. Researchers have identified gaps in communication among heterogeneous systems and propose solutions to address them. The following publications summarise that: (i) Choi et al. [36] propose a PLM integration system using a standard format to allow communication between heterogeneous PLM systems. (ii) Gunpinar and Han [37] propose a system that allows the integration among different PDM systems using PLM Service standards, which enables data exchange via Internet. This system allows companies to access data from two different PDM systems using web-services. (iii) Taisch et al. [38] present a data model aiming to collect information from various product-lifecycle phases in order to support the development of a new PLM standard. (iv) Similarly Kim et al. [30] propose the Digital Factory Wizard (DFW) as part of a PLM environment which supports the design of manufacturing layouts. DFW is based on PLM adapters which allow interoperability among heterogeneous systems.

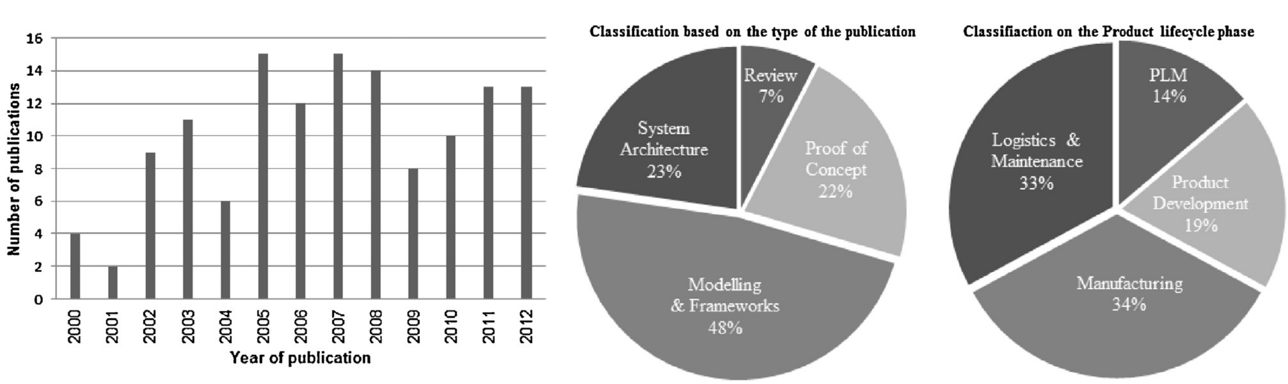

Fig. 3. General view of publications in the whole product life-cycle.

Product development

As part of SCM strategies, product development has also moved away from traditional centralised methods where all the activities were carried out by the OEM. It has now progressed towards a more collaborative approach where the OEM concentrates on the core activities while working collaboratively with suppliers to support and control subsidiary activities [39,40]. The purpose of collaborative product development is to integrate knowledge, processes, technologies and resources among the different members of the product creation lifecycle [41]. The level of involvement of each supplier varies from a simple consultation relationship to a fully integrated co-development partner in the product development process [13,42]. The type of relationship that an OEM has with each supplier will define the level of interaction and the amount of data that will be exchanged. Moreover, different relationships can be established in different phases of the product development lifecycle. Research studies have shown that early supplier involvement can improve the product development and innovation process [43] and increase the likelihood of achieving product development goals [44].

Significant efforts have been made in research to improve the communication and the information flow between OEMs and suppliers. By examining the results it was concluded that although there are several publications that present modelling and framework techniques, the majority of the articles focus on developing systems to support the exchange of product-related data. The research studies identified on improvement of information flow in SCM can be divided into two categories based on the product development lifecycle: those that focus on facilitating the early supplier involvement in the concept definition phase and those that facilitate the product development after the concept definition phase.

Over the last decade, several studies have proved that significant benefits can be achieved by involving the suppliers as early as possible in the product development process [14,45]. Therefore OEMs are now facing the challenge of sourcing suppliers as early as possible to support the co-development process in the concept definition phase. Huang and Mak [45] highlighted that suppliers can provide input during the concept definition phase by using their expertise to identify the latest technology, assisting on "make or buy" decisions, and by providing solutions on part designs. In order to support their opinion and prove the concept, Huang and Mak [45] developed a fully functional web-based prototype system, named WEBid, to facilitate both customers' and suppliers' new product development processes. The first part of the system is a BOM-oriented model and the second one captures customers' requirements and suppliers' capabilities. Huang and Fan [41] proposed an engineering portal for supporting the sourcing and the collaboration process between OEM and suppliers. Schiele [43] discussed the subject area from a purchasing perspective and includes the tools and the roadmaps used by several companies in order to link a firm's strategy with the innovation and the sourcing strategy during early supplier involvement.

Moving forward from the concept definition phase to the design and the engineering phase, the level of information between the OEMs and suppliers has seen a significant increase. Nowadays, PDM and PLM systems allow designers and engineers to share product-related data while working in a collaborative environment with teams that are globally dispersed. The use of web-enabled technologies allowed companies not only to integrate their IT systems but also their processes from a business perspective. As suppliers are characterised as an important knowledge source as customers [43], they need to invest in building the IT-infrastructure to work in a collaborative environment with OEMs. Suppliers have claimed that they are willing to reduce their offering prices in addition to higher involvement in the development process [43]. However suppliers have also stated that OEMs use their know-how and then give it away to their competitors when bids are let [46]. Building trust and a culture of collaboration is the key on achieving benefits in collaborative product development.

Several studies propose system architectures that utilise ISO standards in order to improve collaboration and share of knowledge among OEMs and suppliers. The following studies propose systems to facilitate the exchange of product data, using STEP (Standard for the Exchange of Product model data) and other neutral formats between heterogeneous computer-aided technologies (CAx). (i) Zhang et al. [47] proposed a web-based system for exchanging STEP data. (ii) Xu and Liu [48] developed a web-enabled PDM system that allows OEMs and suppliers to integrate multiple CAD systems by using STEP as a CAD standard in conjunction with CORBA language. (iii) Kim et al. [39] proposed a framework for exchanging CAD data using Web-Services. The system's architecture is based on an Extensible Markup Language XML and neutral format CAD model with a web interface for retrieving CAD data. (iv) Trappey and Hsiao [49] developed an information hub to improve the visibility of information and support collaborative product design. This research focuses mainly on supporting the SMEs to participate in the current global landscape. (v) Chu et al. [50] showed three software prototypes to demonstrate the importance of web-based collaborative visualisation. The three prototypes proposed allow different users of the system to access 3D models through a web-based platform without the need of CAD or any sophisticated software. (vi) Rodriguez and Al-Ashaab [51] developed a web-based system for facilitating the information and knowledge sharing in collaborative product development. (vii) Yujun et al. [40] propose the Internet-based collaborative product development chain (ICPDC) framework and a proof-of-concept system as an example of a collaborative product development environment based on web-services technology to allow users to disseminate, share and manipulate product related data.

Manufacturing

Similarly to product development, SCM in the manufacturing phase has seen significant changes over the last two decades. Modern supply chains not only need to be cost-effective but also flexible and adaptable to new unsettled environments where demand is constantly changing. Nowadays OEMs have a strong dependency on their suppliers and partners to deliver the right parts in the right quality at the right time and under the pressure of cost reductions. One of the key enablers, widely recognised in the literature for improving the efficiency of the supply chain, is information sharing within supply chain. Researchers have highlighted the importance of sharing different types of information such as forecasting data, inventory levels and capacity planning data, demand and order data. Some of these studies prove that inter-organisational information sharing can reduce the bullwhip effect. Croson and Donohue [52] proved, based on results from two experiments, that integrated information systems have the potential to reduce the bullwhip effect. Yu et al. [53] suggested, based on different information-sharing scenarios, that exchanging information on demand with suppliers and dealers is the key enabler for reducing the bullwhip effect.

Although the benefits of improving the information flow in the supply chain are clear the following studies have evidenced those benefits and highlighted areas where potential failure factors may exist. More than half of these articles were published after 2007. (i) Zhou and Benton [54] proved among others that effective information sharing will result in an effective supply chain practice. (ii) Chengular-Smith et al. [55] provide empirical evidence that both information sharing and business leveraging will provide business benefits. (iii) Similarly, Wong et al. [56] performed an empirical study which resulted in findings that proved the beneficial effect of information sharing in cost and customer-oriented operational performance of SCM in uncertain environments. (iv) The simulation study of Schmidt [57] showed performance improvements through the exchange of order data, as this study showed improvements in the calculations of inventories stock without affecting the service levels. (v) Datta and Christopher [58] highlight that information sharing alone is insufficient to handle the supply chain uncertainty and by using an agent-based simulation approach they examined different coordination and information sharing mechanisms to identify the best combination for managing SCM performance under uncertainty. (vi) Liu and Kumar [59] focus on supply chain configurability in leveraging supply chain information exchange. Therefore in this paper they present the results from a simulation study that proves that the correct configurations can improve the supply chain performance. (vii) Chang [60], based on data collected and analysed from Taiwanese and UK companies, confirms that improved manufacturing performance can be achieved by integrated systems such as ERP, CIM and SCM. Most of these studies prove that efficient information flow is critical in order to achieve high supply chain performance. However, there are few studies that provide quantitative results on the level of improvement that can be achieved. (viii) Sahin and Robinson [61] results from a mathematical model and a simulation-based framework showed that fully integrated supply chains can lead on a 47% cost reduction compared to traditional systems. Although information sharing is a key enabler for cost reductions it was highlighted in this study that coordinated decision-making processes are the driver for the main economic benefits.

Some researchers refer to this subject area from a visibility perspective. Kim et al. [9] define inter-organisational information systems visibility as "the extent to which partners firms' information/knowledge related to supply chain cooperation is visible to the focal firm through inter-organisational information systems". Through their study they put forward the opinion that by making information systems visible within the supply chain, benefits in supply chain performance will be achieved. Barratt and Barratt [62] refer to the importance of visibility in both the external and the internal linkages. Based on their empirical study they provide suggestions on how to evaluate the type of relationship with a supplier and therefore extend visibility and reduce uncertainty.

One of the main differences highlighted between the product development and the manufacturing phase is that during manufacturing both the intra-organisational and the inter-organisational links are critical for successful communication. Developing mechanisms for internal collaboration is critical in order to achieve substantial benefits from inter-organisational information flow. Several studies presented the importance of improving both intra and inter-organisational communication to reduce uncertainty in supply chains [63]. Currently ERP systems handle most of the information sharing internally. However it was highlighted in the literature that ERP's external links still remain weak [64]. Similarly with the PD phase, it was mentioned that interoperability issues also exist in the manufacturing phase as it is necessary to build links among the different ERP systems used in supply chain [4,65]. Similarly with the PD phase, the level of involvement for each supplier will vary. Dunne [63] states that a non-collaborative relationship does not necessarily lead to an ineffective relationship. In the case study Dunne [63] showed that building a relationship with a supplier is difficult and resource-intensive as it requires time, resources and managerial skills.

Several works have discussed the subject area through empirical and conceptual studies and even more studies have simulated the information flow in SCM to prove the benefits that can be achieved. Compared to PD, there seems to be fewer studies that propose systems or architectures of systems that will improve the information flow in SCM. Mourtzis [66] proposes a web-based system that allows customers and suppliers to maintain visual access and consistency in their delivery schedules, order variations and derive an accurate view of the inventory stock levels. This XML-data exchange software framework utilises information sharing and supports collaborative and flexible production planning. Trappey et al. [67] propose a centralised cross-functional platform. This system is an XML-data exchange, integrated business and logistics hub (IBLH) which integrates information and material flows to ensure the transparency of the flow in order to reduce inventory costs and provide efficient product distribution. Suppliers, clients and other manufacturing members have electronic access to order, shipment and inventory stock data. Liu and Young [68] propose the GMC (Global Manufacturing Co-ordination) experimental system based on an object-oriented database management system to allow decision-makers to communicate order information, manufacturing process information and logistics information with the extended enterprise. Feng et al. [69] propose a software agent-enabled process integration framework and through a prototype system proves that agents can assist on the automation of tasks in order to reduce human effort during information exchange.

Logistics and maintenance

While PD and manufacturing phases still face many challenges in terms of information flow, it is widely recognised that during these two phases several software applications have been developed to support the flow, such as CAD/CAM, PDM, PLM, and ERP systems. Moving to the logistics and maintenance phase this link seems to be more fragmented. The amount of information and knowledge that returns back to designers and engineers is less complete [34]. Publications in the modelling section focus more on discussing information sharing in the area of Demand/Forecasting/Capacity data from a retailer's perspective. Although the sample is relatively small to obtain clear results for just one section of the table, the rate of publications in the area of logistics seems steady over the years. The area dealing with system architectures covers systems proposed from researchers to improve both Maintenance and Repair Overhaul (MRO) processes and information sharing from a retailer's point of view.

Maintenance data. During the last decade an extensive body of literature has been formed to improve maintenance and support efficiency. The use of technology and especially web-based applications has allowed the movement from traditional models of maintenance to e-maintenance [70]. E-maintenance is becoming an area that receives significant attention mainly due to the latest movement to the Product-Service System (PSS) models, especially in the aerospace sector. To address the upcoming challenges, researchers are focusing on developing methodologies and tools to enable full utilisation of the product data and information in processes [71]. Although web-based technologies have significantly improved communication among supply chain members, there are still many challenges to be addressed. One of the main challenges that companies are currently facing is the lack of a central repository to manage and maintain maintenance data. Until recently organisations had developed multiple internal systems to manage different types of information and as a result they now face the need to develop transaction standards and integrate those systems [72]. Lee et al. [73] observe that PLM systems are used 10 times less frequently in the service phase and highlight that the potential of PLM systems in aviation MRO has not been realised.

For the maintenance phase several systems are proposed by researchers. Kiritsis [74] proposes an architecture of a closed-loop PLM system that supports the middle-of-lifecycle such as use and maintenance and the end-of-lifecycle such as recycling. The PROMISE project focuses on improving the information flow by linking software platforms and intelligent products. The main components used are Portable Product Embedded Information Devices (PEID), Product Data Knowledge Management (PDKM), and applications for decision support. Candell et al. [71] emphasise the fact that ICT can be the enabler to support the maintenance process. Han and Yang [70] developed a web-based e-maintenance system that allows the integration of the required advanced techniques while information is shared through a communication platform. MacDonnell and Clegg [72] propose a proof-of-concept MRO supply chain system in order to minimise the maintenance holding costs among different members of the supply chain. This research is based on three levels: firstly, from a process point of view, secondly from an information flow perspective and finally from a computerised information management level. The system proposed was tested with a small number of parts and demonstrated inventory reductions up to 40% without affecting the service levels.

Demand/forecasting data. Although most of these studies were thoroughly examined during the manufacturing phase some publications are presented in this section as they examine the same topic from a retailer's perspective. Information integration between suppliers and retailers is perceived in the literature as an effective approach to improve supply chain performance.

Exchanging demand and forecasting data can reduce the demand variability amplification and as a result the bullwhip effect. Some studies demonstrate that the benefits that can be achieved from information sharing are not as significant as those presented in the manufacturing phase. Lee et al. [75] model showed that although manufactures can obtain inventory and cost reductions, retailers have no direct benefits from information sharing. Kulp et al. [76] study shows that the majority of the benefits can be achieved through collaboration and not through information sharing. Based on this study it seems that only information sharing related to the stock inventory levels can be linked with profits while warehouse inventory levels and customers' needs are not associated with supply chain performance. Cachon and Fisher [77] found more valuable the use IT to accelerate the flow of physical goods rather than expand the information flow. Other studies argue and provide evidence in order to prove that information sharing could result in benefits. Trapero et al. [78] provide significant evidence proving that information sharing between suppliers and retailers can increase forecasting accuracy resulting in a 6–8% reduction in forecasting errors. Moyaux et al. [79] simulated the value of two principles that show how to use information sharing in order to reduce the amplification of order variability caused by lead times. The computational study of Gavirneni [80] indicates a cost reduction as high as 33% with an average of 10% by making better use of the information flow in SCM. During the research undertaken in this paper, only one system was identified to support the information flow from a retailer's perspective. Bodendorf and Zimmermann [81] highlight the importance of reacting to unpredictable disruptive events and propose a Supply Chain Event Management (SCEM) system for a logistics service provider.

Market data. These studies focus on the information flow from the customer back to the OEMs. While information flow is used extensively to support SCM in every phase of the product lifecycle, it has been proved that information sharing can also support marketing activities [82]. Boersma et al. [83] proposed a business model to capture high-quality market information in order to support future market needs and as a result improve the product development process.

Research trends and future directions

PLM

The continuous investment into PLM systems from various industries, not only aerospace and automotive, and the promise and the potential that PLM systems bring in reducing time-to-market, have caught researchers' attention who since 2005 publish heavily in that space. Although the amount of publications in the PLM area has significantly increased it is widely acknowledged that more research is required to clearly define the functionality of PLM systems. Still PLM systems focus mainly on the product development phase with the majority of studies either proposing system architectures that allow data exchange among heterogeneous PLM systems or systems that expand the functionality of PLM systems beyond the traditional PDM systems. Kiritsis et al. [34] highlight that information flow during the manufacturing and service phases still seems to be broken. Although there are a few PLM vendors that provide solutions on integrating maintenance and service information within the PLM system there are little or no studies that aim to calculate the benefits are that can be achieved by integrating maintenance information within the PLM system. In addition, there are fewer studies that demonstrate how design improvements could be achieved using maintenance and warranty information integrated within PLM systems.

Over the last few years a number of authors proposed frameworks to support information sharing in collaborative design and enhance supply chain integration. In addition there are a number of studies that propose frameworks to integrate PLM systems with various systems such as CRM, ERP and SCM across different phases of the product lifecycle. However there are still little or no studies that quantify the benefits that can be achieved by managing information in a central location. While enterprise applications such as ERP and PLM are evolving in order to support each phase of the product lifecycle this may result in a situation where applications are overlapping, with the same information being held in disparate silos.

Another area that is under discussion in the research is that of interoperability issues and the lack of standardisation that PLM systems are currently facing. As PLM systems require considerable investment of time and effort, suppliers are now facing the challenge of being able to integrate their systems and share information with various OEMs. Similarly Small and Medium Enterprises (SME) are required to invest in such systems in order to have the capability to exchange information with their extended enterprise. What this study also showed is the importance of developing standards that not only cope with the existing CAD formats but also support the standardisation of PLM, PDM and ERP systems. The standardisation of systems will allow suppliers to reduce the cost of implementation and maintenance of multiple systems and as a result work in a more collaborative way with customers and suppliers without the need to invest in implementing and maintaining multiple systems.

Product development

The literature review conducted has highlighted that significant benefits can be achieved by involving suppliers as early as possible in the PD process. It is clear that during recent years the amount of publications in this area is relatively constant. This is due to the constant requirement from companies to reduce the time-to-market and improve efficiencies. The advent of the Internet technology has also played a key role for this stability. However the link between product development and SCM is not as strong as in the other phases of the product lifecycle. Although research has focused on integrating SCM systems with ERP and CRM, product development seems to be largely separated [84]. The analysis of review papers enhances Porter [84] observation as it demonstrated that publications which discuss the IT-enabled SCM strategy holistically do not include product development within their scope.

The majority of the articles analysed propose systems that allow OEMs to share product data with suppliers using ISO standard formats through web-based applications. In addition, there are several studies that discuss the exchange of light-weight CAD data to support non-engineers in decision-making. However there seems to be a lack of studies that deal with data exchange other than CAD and its attributes, such as documentation associated with a part, the BOM and all the other metadata which surround a CAD model and are usually held within PDM systems. This review enhances Buyukozkan and Arsenyan [28] observation that each one of the systems proposed are addressing a specific issue which leads to a lack of a guidance roadmap within literature that will drive the development of the right applications. In addition, most of the systems proposed, lack of practical implementation and testing which could demonstrate the practical benefits that could be achieved.

Although it is widely acknowledged that IT has improved supply chain integration, there seems to be little attention given to studies that quantitatively measure the impact of IT-enabled product development to SCM performance, especially from suppliers point of view. These studies could support researchers and practitioners to justify the development of tools that support supply chain collaboration. Finally, it was identified in the literature that there are a number of studies that focused on clustering the different types of relationships between suppliers. As building the IT-infrastructure for exchanging data during PD is resource-intensive, that requirement needs to be taken into consideration and needs to be fully defined within each cluster of suppliers.

Manufacturing

The literature review conducted has shown that during the manufacturing phase, information flow in SCM is critical and results in achieving significant improvements in terms of cost and efficiency. Over the last decade the number of peer reviewed articles in the area of review, proof-of-concept and modelling has remained high. Most of these studies proved, through empirical and conceptual studies, that significant benefits can be achieved. Modelling techniques are used extensively to demonstrate positive effects among various factors and information flow while simulation techniques are used to quantify the benefits that could be potentially obtained. However, the level of detail and the amount of information that needs to be exchanged with each supplier is not widely discussed within the literature [27]. Similarly with the other phases of the product lifecycle, there needs to be an association between the amount and the type of information exchange against the different clusters of suppliers, as not all suppliers will require the same level of data exchange. A prioritisation of information types might be useful as it will define what is critical to meet the expected benefits for each cluster of suppliers. As a result, practitioners and researchers can target short term "quick wins" while planning for long term benefits.

One of the main differences highlighted between the manufacturing phase and the other phases is that during manufacturing both the intra-organisational and the inter-organisational links are critical to achieve successful communication. Developing mechanisms for internal collaboration is critical in order to achieve substantial benefits from inter-organisational information flow. Compared to PD, there seems to be fewer studies that propose systems or system architectures that aim to improve the information flow in the supply chain. Currently, ERP systems handle most of the data transactions but their external links remain weak. Therefore, although the benefits that can be achieved are very well recognised it still remains unclear how IT systems can support supply chain collaboration during the manufacturing phase. Researchers need to define a roadmap with the most suitable technologies for implementation. In the opinion of the author, ERP systems are expanding to support more manufacturing processes while at the same time, PLM systems are expanding to integrate more systems and as a result create a centralised database. There needs to be a clear distinction between PLM and ERP systems moving forward, as there might be a point where these two enterprise systems will start to overlap and as a result cause operational issues.

Logistics and maintenance

Based on the research presented in this paper, it was identified that most of the publications in the area of modelling approaches focus on measuring the benefits that can be achieved by improving the information flow between OEMs and retailers. Similarly with the manufacturing phase these studies highlight how information sharing can reduce the bullwhip effect, although there might be a need for prioritisation among the different factors and benefits that can potentially be achieved. That will allow companies to use this knowledge for both quick wins and benefits but also plan longer term results. In terms of system proposed there needs to be an investigation on architectures that utilise Internet resources compare to the traditional channels.

In the area of service and maintenance most of the peer reviewed articles identified propose an actual system or the architecture of a system to improve the information sharing between OEMs and suppliers in order to reduce maintenance costs. System development has attracted low attention from researchers and still remains more related to the aerospace sector. Other sectors with high data transaction and significant maintenance and warranty costs such as automotive, marine and transportation can be benefited from research conducted in the aerospace sector. This article supports Lee et al. [73] findings that the potential of PLM systems and in MRO are not yet realised. Further research is required to establish and define the integration of PLM systems in the service and maintenance phase of the product lifecycle. This will allow utilisation of knowledge and data across the product lifecycle that will support not only the external supply chain but also internal decision makers. Although during recent years there are several studies that focus on the maintenance area, it seems that this area will gain more attention in the near future.

Conclusions

This review analyses and compares publications identified in the area of information flow in the supply chain and provides a comprehensive review of representable articles for each phase of the product lifecycle in order to offer an overall view of the subject area and reveal research gaps. The articles were not only analysed based on the classification framework but also reviewed to identify the journals, the country of origin and the year of the publication.

Although useful conclusions have been identified in the literature by examining each phase of the product lifecycle, a few interesting conclusions can be extracted through cross-phase examinations. SCM is perceived narrowly during the manufacturing and logistics phases rather than the whole product lifecycle. The types and amount of information that needs to be shared during the manufacturing phase are comprehensively examined in the literature. While during the manufacturing and logistics phases the majority of publications focus on modelling and simulating the information flow in order to measure the benefits that can be achieved, there are little insights on which enterprise applications can support the information flow. During PD, systems such as CAD, PDM and PLM are well defined with several system architecture studies proposed to enhance the information sharing both internally and externally. However the majority of these studies still focus on exchanging engineering data with no indication on which type of information is more critical and beneficial during the PD phase. While enterprise applications such as ERP and PLM are evolving in order to support each phase of the product lifecycle this may result in a situation where applications are overlapping, with the same information being held in disparate silos. In the opinion of the author there is a need to identify the systems utilised in each phase of the product lifecycle and identify the integration points in order to create a continuous information flow from PD through manufacturing, service and back. Although individually most of the systems are very well established, further research is required to integrate systems and processes across multiple phases of the lifecycle. To achieve that, standardisation of data is becoming more essential. Finally it is important to highlight that overall the literature identified potential benefits of information sharing in SCM but there is only limited evidence of this coming from industrial case studies. The use of service oriented approaches (SOAP) and Extensible Markup Language (XML) seems a common theme across all the systems proposed in each phase of the product lifecycle.

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