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The application of discrete event simulation and system dynamics in the logistics and supply chain context

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ABSTRACT

Discrete event simulation (DES) and system dynamics (SD) are two modelling approaches widely used as decision support tools in logistics and supply chain management (LSCM). A widely held belief exists that SD is mostly used to model problems at a strategic level, whereas DES is used at an operational/tactical level. This paper explores the application of DES and SD as decision support systems (DSS) for LSCM by looking at the nature and level of issues modelled. Peer reviewed journal papers that use these modelling approaches to study supply chains, published between 1996 and 2006 are reviewed. A total of 127 journal articles are analysed to identify the frequency with which the two simulation approaches are used as modelling tools for DSS in LSCM. Our findings suggest that DES has been used more frequently to model supply chains, with the exception of the bullwhip effect, which is mostly modelled using SD. Based on the most commonly used modelling approach, issues in LSCM are categorised into four groups: the DES domain, the SD domain, the common domain and the less common domain. The study furthermore suggests that in terms of the level of decision making involved, strategic or operational/tactical, there is no difference in the use of either DES or SD. The results of this study inform the existing literature about the use of DES and SD as DSS tools in LSCM.

1. Introduction

Discrete-event simulation (DES) and system dynamics (SD) are two widely used modelling tools which underpin decision support systems (DSS) [79,115,149,156]. In the field of logistics and supply chain management (LSCM) simulation-based DSS provide solutions to a wide range of issues at both a strategic, operational and tactical level. Specific examples of the issues that these DSS address are supply chain design and reconfiguration, inventory planning and management, production scheduling and supplier selection [24,26,75,103,132]. Despite the wide use of DES and SD in LSCM, the exact pattern of their use as DSS for specific LSCM issues is not well understood.

This paper aims to explore the application of DES and SD in LSCM with a view to identifying differences and/or similarities in terms of the nature and level of their use. We define the nature of use in terms of the type of LSCM issues modelled using DES and SD. The level of use refers to where on a continuum between strategic and operational/tactical the LSCM issue being addressed lies.

This study explores an important issue in the comparison of modelling methods, that is, the type of problems addressed by different modelling methods. Its contribution is twofold. First, it sheds light on the validity of established views about the differences in the use of DES and SD. Second, it provides a classification of LSCM issues and simulation modelling approach that can serve as supporting evidence in the selection of modelling approach for DSS. Of course, a wider range of criteria need to be considered when choosing between modelling approaches. For instance, Brennan et al. [15] provide a taxonomy of models (including DES and SD) for economic evaluation of health technologies. They list a number of criteria that could affect the choice of modelling, including: decision makers' requirements, system characteristics and system complexity. This paper focuses specifically on one criterion, the type of problems that are being modelled using DES and SD in the LSCM context.

In order to explore the application of DES and SD in LSCM, we undertake a literature review of published papers that use simulation modelling to support decision making in the LSCM context. LSCM is considered a suitable domain for this review due to the fact that both simulation approaches have been extensively used to support decision making activities. Furthermore, decisions made within LSCM involve different levels of the DSS hierarchy: operational, tactical and strategic [83,132]. The literature search undertaken looks into the LSCM issues modelled using each simulation approach in order to identify the issues most modelled with either or both simulation approaches. This in turn, provides evidence about whether there are differences in the nature and level of LSCM issues modelled by each approach. A search using the Web of Knowledge database was performed to identify journal articles, published in the 11-year period from 1996 to 2006, that undertake simulation modelling in the LSCM context.

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The rest of this paper is structured as follows. In the next section, the literature comparing DES and SD and the types of problems modelled is considered. This is then followed by a description of the review approach taken, including the identification of journal articles and the simulation approach adopted, the creation of a schema for classifying the LSCM issues modelled, and the identification of whether these issues lie within the strategic, tactical or operational level of DSS. The results of the literature search are presented in Section 4. Finally, Section 5 concludes the paper, including suggestions for further work.

2. DES and SD: comparison and use

Here we briefly review literature that provides a comparison of DES and SD as well as the opinions found with regards to the type of problems modelled and level of use (strategic, tactical and operational) of the simulation methods.

2.1. Comparing DES and SD

DES and SD developed independently from each other from the late 1950s, with very little communication between the two fields. It is only in recent years that significant interest in comparing the two approaches has emerged. As such, comparison work on the differences and similarities between the two approaches is limited. The existing work largely consists of opinion-based statements which are often influenced by the authors' field of expertise [141]. It has been claimed that DES and SD are quite different modelling approaches, especially in terms of the type of problems modelled [14]. There is a general belief that DES is considered to be more suitable for modelling problems at an operational/tactical level, whereas SD is more suited to modelling problems at a strategic level. However, others claim that the divide between the two modelling approaches might not be so clear-cut. Different aspects of the same problem may be highlighted by each modelling approach [99], but on the other hand, if the problem is similarly represented in both approaches, similar outcomes can be observed from the users' point of view [140].

Simulation models, in both DES and SD, are usually built to understand how systems behave over time and to compare their performance under different conditions [139]. Some technical differences exist between the two modelling approaches related to their underlying principles. For example, DES models systems as a network of queues and activities where state changes occur at discrete points of time, whereas SD models represent a system as a set of stocks and flows where the state changes occur continuously over time [14]. In DES entities (objects, people) are represented individually. Specific attributes are assigned to each entity, which determine what happens to them throughout the simulation. On the other hand, in SD individual entities are not specifically modelled, but instead they are represented as a continuous quantity in a stock. DES models are generally stochastic in nature, where randomness is generated through the use of statistical distributions. SD models are generally deterministic and variables usually represent average values. In DES state changes occur at irregular discrete time steps, while in SD state changes are continuous, approximated by small discrete steps of equal length. For more information about these modelling approaches, interested readers are referred to relevant textbooks [82,114,126] and [136].

The opinions found in the comparison literature refer mainly to the practice of model development, the modelling philosophy and the use of respective models. We next consider in more detail the opinions with regards to the nature and level of problems modelled using each modelling approach.

2.2. Opinions on the nature and level of use of DES and SD

Considering the nature of problems modelled using each simulation technique, the comparison literature states that SD focuses mainly on strategic issues and policy analysis, while DES is generally used to study problems at an operational or tactical level [77,139,143]. Based on the differences between discrete and continuous systems, it is suggested that the choice of one or the other approach depends on the conceptual difference from which one views the problem [125]. The SD approach is considered appropriate when taking a 'distant' perspective (meaning strategic) where events and decisions are seen in the form of patterns of behaviour and system structures [125].

Several papers suggest that DES is not suitable for strategic modelling as it does not normally represent systems at an aggregate level [9,80,108]. To cater for this disadvantage, a number of studies [59,80,116] have suggested the use of hybrid simulation approaches combining DES and SD. For example in a study of an integrated manufacturing enterprise system [116], DES was used to model local production decisions for selected parts of the enterprise, while the SD model captured the long term effects of these decisions on the entire enterprise and the interactions between decisions made at different levels of management. The same study points out the factors that make SD suitable for high level strategic modelling, which one could consider as generally accepted claims found in the existing comparison literature, which have not been empirically validated. These factors consist of the following:

- Takes a holistic approach of systems, integrating many subsystems
- Focuses on policies and system structure
- Use of feedback loops to represent the effects of policy decisions
- Represents a dynamic view of the cause and effect relationships among the system elements
- SD has minimal data requirements to build a model.

In a study of a manufacturing plant, the successful use of the DES approach to investigate the operational aspects of a production-planning facility is reported [54]. The outcome of the DES study was the recommendation of new production sequencing activities. In addition, it emerged that the disruptions in production planning in the manufacturing plant needed to be further considered. In this case, the SD approach was preferred in order to model the softer aspects related to the problem of disruptions. The SD approach was considered to be more useful for modelling the organisational context of the problem and so moved on to extend the already created DES model using SD.

In another study two models of a supply chain were developed, a discrete event and a hybrid discrete-continuous simulation model [80]. Comparing the results of the two models, the discrete event model overestimated the outputs of the inventory levels compared to those of the combined discrete-continuous model, hence resulting in unnecessary inventory. This was due to the difference between the values for elements such as customer orders, information flows and inventory levels, which were defined as continuous in the combined model. The paper recommends the use of hybrid simulation models for supply chains, which were shown to be neither completely discrete nor continuous systems. With regards to the level of problems modelled, the use of analytical models is suggested for modelling at operational levels, DES for modelling at tactical level, while hybrid simulation models for modelling at strategic levels.

On the other hand, various authors have expressed the view that, even though it has not yet been adequately exploited, SD can be successfully used in modelling operational systems. For example, an operational SD model of an earth-moving system was developed for a study of construction management [58]. The SD model was then compared to an equivalent (already existing) DES model. The study suggests that an SD-based operational model can address the operational aspects of the model as accurately and reliably as a DES-based model. The advantages of using SD at an operational level are discussed. These include modelling of feedback effects, managerial actions and soft variables. Furthermore, the potential of using SD modelling in manufacturing systems modelling is suggested in [108]. Considering the inherent characteristics of the two modelling techniques, SD is recommended as a better choice in the intermediate stages of decision making when less detailed models or results are required. Some of the advantages of SD modelling with respect to the requirements of decision making at intermediate stages of evaluation are: the simplicity of the data required, ease of building a simulation model and reduced execution time. Obviously, these are statements which represent authors' opinions and have not been empirically verified for their accuracy.

In the LSCM context, DES and SD have been used extensively as decision support tools. However, a systematic and conclusive review of simulation modelling of supply chains does not yet exist. Mula et al. [100] recommend the need for empirical work to compare the use of different modelling approaches in practice, even though they base their study only on a sub-set of LSCM issues, that of production planning. Different authors provide some preliminary classifications about the use of different modelling approaches, including DES and SD, for DSS in LSCM. Shah [129], for example, provides some examples selected from the literature rather than a comprehensive list of all existing supply chain papers. He concludes that simulation modelling (DES and SD) is mostly used to model issues for supply chain analysis and policy formulation. DES/stochastic models are mainly used to study the detailed operations of a supply chain under uncertainty and/or to evaluate the expected performance measures to a high level of accuracy, whereas SD modelling tends to concentrate on logistics and inventory planning, and not that much on production aspects.

In summary, based on the literature considered in this section, it is obvious that there is a general belief that SD modelling is more suitable for modelling at a strategic level and DES at an operational/tactical level. Some views have been expressed about the suitability of using SD to model problems at an operational level. Ingalls [67], on the other hand, points out that DES can play a significant role in modelling supply chains at a strategic and tactical level. In their study comparing DES and SD, Morecroft and Robinson contemplate that there is not a straightforward distinction between the two approaches, but that it is rather a result of a careful consideration of various criteria: “Perhaps there is both ‘strategic DES’ and ‘operational SD’ and it's just a matter of which components you chose for your simulated enterprise” [99]. Meanwhile, others consider the use of combined or hybrid approaches, especially for modelling supply chains. With regards to this point, while the existing views in the literature are largely based on personal opinions and authors' personal experience, this paper uses evidence based on published DES and SD simulation studies in the LSCM literature.

3. The research approach

The aim of this study is to explore the use of DES and SD as DSS for LSCM, looking specifically into the nature and level of issues modelled. In order to achieve this we base our analysis on the frequency with which issues in LSCM are modelled using DES and SD. We believe that this is appropriate since both simulation approaches have been used extensively in the LSCM context.

The study is based on a review of journal articles that describe the application of DES and SD to LSCM issues. We address the following two research questions:

- Are DES and SD modelling used to model different LSCM issues?
- Is DES used more for operational/tactical problems and SD more for strategic problems?

Based on the previous literature our expectations are that the two approaches will be used to model different aspects of the supply chain, although there will be some overlaps in the issues addressed. We also expect to confirm the view that DES is more operational/tactical and SD more strategic in focus, at least based on their application as described in the extant literature.

The literature review undertaken follows four stages: identification of journal articles and simulation approach adopted, creation of a schema for classifying papers by LSCM issue, distinguishing between strategic and operational/tactical LSCM issues, and classifying papers by the LSCM issues addressed. In performing this analysis we have made no judgement about whether the most appropriate modelling approach was selected, we simply observe which approach is used for which issue. It is almost certainly the case that for at least some of the papers the choice of modelling approach was not optimal. Instead it is likely to have been based on a range of subjective factors such as the modeller's expertise. Since such information is not consistently reported in the papers studied, it is not possible to make judgements about the optimality of the models employed.

Each of the stages followed to undertake this research is now described.

3.1. Identification of journal articles and simulation approach adopted

Journal papers that report simulation models relevant to DSS for LSCM were selected based on a keyword search using the Web of Knowledge citation database. This provides a multidisciplinary collection of literature including subjects such as sciences and engineering, social sciences and humanities. The keywords used were ‘supply chain’, ‘simulation’, ‘discrete-event simulation’ and ‘system dynamics’. These were combined to include the first keyword (‘supply chain’) and one of the other keywords mentioned, connected by ‘and’. The search included only journal papers published during the 11 year period, between 1996 and 2006. After removing duplicates, the initial list produced resulted in approximately 400 entries.

The search was limited to journal papers only and no books, conference papers or grey literature were included. As such, all articles included in the review are known to have been subject to full peer review. Given that our aim is to compare modelling work in DES and SD, other simulation approaches such as agent-based modelling and Monte Carlo simulation are not included.

A screening process was carried out to make sure that only papers actually using DES or SD modelling in LSCM were included. In some cases this was identified by reading the abstract, while in other cases this was only revealed in the main text of the paper. There were also cases where the type of modelling approach used was not clear, in which case the authors were directly contacted to enquire. Surprisingly, in many papers, analytical models using heuristics and genetic algorithms, were developed, which were claimed to be analytical ‘simulation’ models. A similar observation was also made in [95]. Following this screening process, the list of papers was reduced to 127. For each of these 127 articles the simulation approach adopted was identified as DES, SD or hybrid (i.e. a mixed DES/SD approach). A full list of the 127 articles is provided in Appendix 1.

3.2. Creation of a schema for classifying papers by LSCM issue

The next stage was to devise a schema for classifying the papers into the LSCM issues that each paper addressed. Existing classifications of LSCM issues were initially consulted. Supply chain management is a vast subject, covering a wide variety of topics [104]. A thorough classification of the topics covered in the supply chain literature has not been found. For instance, Chopra and Meindl [24] suggest three high-level categories of topics based on the type of decisions made: design, planning and operation.

A few studies that undertake a literature review of simulation modelling of supply chains have been found, but these are far from systematic. For example, a literature review of the state of the art of supply chain modelling undertaken in OR/MS and engineering is provided by Shah [129]. He categorises LSCM issues into three main areas: network design, analysis and policy formulation, and supply chain planning and scheduling. For each area he provides an overview of the key modelling work undertaken over time. In his review, Shah provides an account of key literature in supply chain modelling work, not necessarily limited to simulation modelling, but does not cover the breadth of papers published.

Other reviews include studies that use only one type of modelling approach. For example, some studies [6,106] consider mainly SD models, whereas others [22] draw their conclusions based on studies using analytical and DES modelling only. Furthermore, the classification categories found in the literature do not cover the breadth of LSCM issues modelled. This is illustrated in Table 1, where the classifications displayed include only a limited range of LSCM issues.

Based on the existing classifications found in the literature, a customised list of issues was developed, which apart from grouping the LSCM issues found in Table 1, also included additional issues that were identified from the 127 papers that form the basis of this study. The final list of issues is shown in Fig. 1. A more full explanation of each of these LSCM issues is provided in Appendix 2.

3.3. Distinguishing between strategic and operational/tactical LSCM issues

Having identified a set of LSCM issues reflecting decisions taken within the supply chain, these were further classified into strategic, tactical and operational issues. Decisions in supply chains can be categorised into the three groups depending on the frequency with which a decision is taken and the time frame during which it makes an impact [24,83]. Strategic decisions normally deal with company-wide problems involving a time span of between 2 and 5 years. These consist mainly of issues such as supply chain configuration and resource allocation. Tactical decisions involve mid-term activities, that is, over a time period of one month to a year, and involve issues related to supply chain planning. Operational decisions normally involve short-term decisions related to day-to-day activities. The goal of these decisions is to handle incoming customer orders in the best possible way, given the already set supply chain design and planning policies. At the operational level the main problems pursued are lot sizes, replenishment orders, and service levels [51].

Attempting to classify a LSCM issue as being strategic, tactical or operational is not straight forward because it is not always possible to be precise about the nature of the decision and in many cases a simulation study might be addressing overlapping decision levels. For the purposes of this review we ranked the list of issues in Fig. 1 between the two extremes of strategic and operational/tactical. The devised ranking is shown on the left side of Fig. 1.

Decision support in LSCM is broadly categorised into strategic, tactical or operational [24,83,132], but a detailed distinction of issues has not been found in the literature. Our ranking is largely based on Shah's ordering of the issues. Where we have added further LSCM issues, these

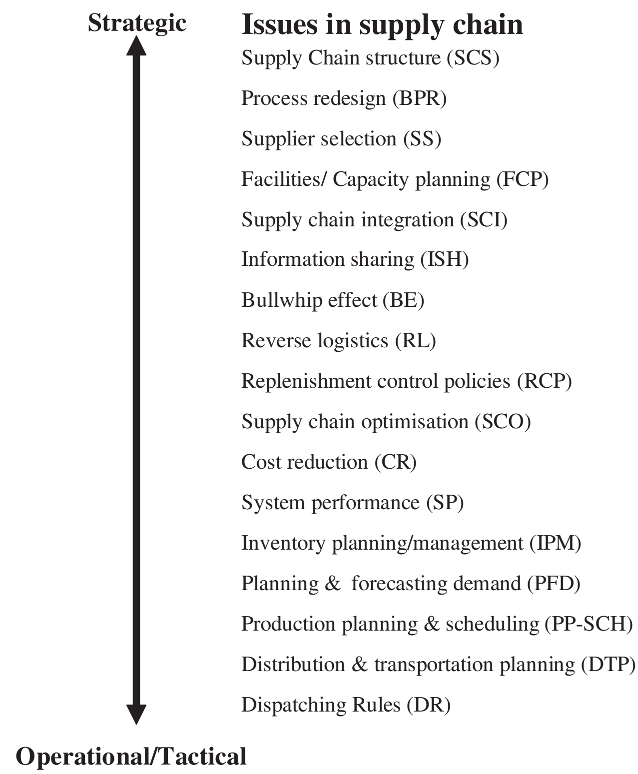

Fig. 1. Ordering of LSCM issues into strategic and operational/tactical.

Table 1
Classification categories of LSCM topics identified.

Angerhofer and Angelides [19]	Otto and Kotzab [20]	Chan and Chan [21]	Shah [15]	Our categories
Supply chain design	Uncoordinated ordering behaviour	Product and process design	Supply chain design	Supply chain structure
Supply chain re-engineering	Distortion of demand pattern	Vendor selection	Supply chain analysis and policy formulation	Process redesign
Demand amplification	Poor inventory visibility	Information sharing/coordination mechanisms	Supply chain planning and scheduling	Supplier selection
Inventory management	Uncoordinated demand planning and forecasting	Inventory management and replenishment process		Facilities/capacity planning
	Uncoordinated manufacturing control	Production distribution/planning and scheduling		Replenishment control policies
				Bullwhip effect
				Information sharing
				Supply chain integration
				Supply chain optimisation
				Cost reduction
				System performance
				Inventory planning/ management
				Planning and forecasting demand
				Production planning and scheduling
				Distribution and transportation planning
				Dispatching rules
				Reverse logistics

have been placed in the ranking based on our interpretation of the issue's strategic or operational/tactical focus in the papers from which the issue was identified. Operational and tactical issues are not specifically separated, since it is difficult to distinguish between the two at the coarse level of an issue descriptor. However, we would expect issues further up the ranking to be more tactical in nature.

Our classification of issues focuses mainly on papers that use simulation, either DES or SD, modelling decisions relevant to DSS in LSCM. Difficulties were encountered in identifying the LSCM issues modelled in the papers reviewed. There is no consistency in the terms used between papers. For example, production planning and management is in some cases referred to as manufacturing policies or production control policies; supply chain instability is often used in place of the bullwhip effect. Hence, the classification of LSCM issues was made based on the authors' judgement and the information provided in the main text of each article. Furthermore, for the classification of LSCM issues into strategic, operational/tactical a readily available classification was not available. Shah's [129] basic guide was used, incorporating the authors' own interpretation, taking into account the time-frame of the decisions involved.

3.4. Classifying papers by the LSCM issues addressed

Finally, the 127 journal papers that were selected were further screened, either by reading the abstract or the full text if it was required, with a view to identifying the LSCM issues modelled. In most cases the models described in the papers addressed more than one LSCM issue, resulting in the classification showing papers being associated with more than one issue. The full classification is provided in Appendix 1. The results from analysing this classification are now presented.

4. Results

The classification of papers was analysed in order to address the questions of whether DES and SD are used to model different LSCM issues, and to determine whether DES is used more for operational/tactical issues while SD is used more for strategic issues. With respect to this, results are presented from three perspectives: the frequency of use of DES and SD in the LSCM context, the frequency with which LSCM issues are addressed by the two simulation approaches, and the focus of DES and SD on the strategic and operational/tactical levels.

4.1. The frequency of use of DES and SD in the LSCM context

Out of the 127 papers, 86 (68%) used the DES approach, 38 (30%) the SD approach, while just 3 (2%) papers used hybrid DES and SD modelling. DES modelling activity is more than double that of SD, suggesting that DES is the most frequently applied simulation approach in the LSCM context. The smaller number of SD papers in supply chain modelling found from this survey could be due to "a period of limited SD modelling activity experienced in the 90s, to resurface back in the late 90s" [145]. After this "slack period", SD applications in LSCM have significantly increased and so has the number of LSCM issues modelled [6].

In order to investigate these claims, we next consider the trend of DES and SD modelling activity to support decision making in the LSCM context throughout the review period. Fig. 2 presents a frequency-of-use timeline for the 124 DES and SD only LSCM papers published in the period between 1996 and 2006. The 3 papers using hybrid modelling are omitted from Fig. 2 due to its low frequency of use. The graph shows that there was limited supply chain modelling activity using DES in the first five years of the review period, after which there has been a steady growth in the number of DES papers (2001–2006). However, a similar level of growth is not observed for the SD papers. Albeit, an increase in SD applications in the LSCM context in the late 90s has been claimed [6,145], fewer SD applications

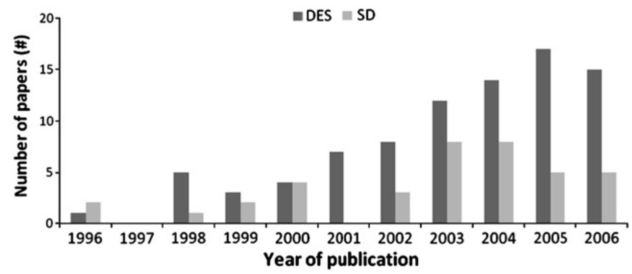

Fig. 2. Historical emergence of DES and SD applications in the LSCM context in the period 1996–2006.

have been found compared to DES applications for the same time period. From 2001 onwards DES applications outnumber SD applications. Fig. 2 also shows a greater level of growth in the use of DES applications over SD applications for supply chain modelling.

4.2. DES and SD modelling by LSCM issue studied: percentage and frequency of use

Table 2 shows the extent to which each LSCM issue presented in Fig. 1 is addressed by each modelling approach in the papers that form this review. The column for each modelling approach (DES, SD and hybrid-DES/SD) presents the number of papers (#) that address each LSCM issue. The percentage use by modelling approach (%) is calculated as the proportion of the number of papers on that specific LSCM issue over the total number of papers identified for that modelling approach (the last row in Table 2). It should be noted that the totals in the last row are higher than the total number of papers reviewed for each approach due to the fact that most papers describe the modelling of more than one LSCM issue.

4.2.1. Percentage use by LSCM issue

Based on the percentages displayed in Table 2 we can identify the issues in LSCM that have been most frequently modelled with each simulation approach. An issue is considered to be frequently modelled if the percentage use for a simulation approach is 10% or more (shaded cells in Table 2). The issues most often modelled using DES are *system performance*, *inventory planning/management*, *production planning and scheduling* and *system performance*. The SD approach is most often used to model issues regarding *information sharing*, *bullwhip effect* and *inventory planning/management*. Hence, *inventory planning/management* is modelled to a high extent within both simulation approaches, albeit that DES is used much more frequently than SD for this issue based on the count of papers addressing this issue (48 compared to 18 respectively). Hybrid DES/SD is used predominantly for modelling of *production planning and scheduling* issues. However, the number of papers found using hybrid modelling is so limited that we cannot make any definitive observations.

Further analysis allows us to identify which percentage use values are significantly different between DES and SD modelling. This shows us which issues DES and SD modellers focus on proportionately more in their modelling work. Table 3 shows the results from z-tests for comparing proportions. For each LSCM issue 95% confidence intervals are calculated in order to test for differences in the percentage use between DES and SD.

Significant differences in the proportion of use are found for 6 out of the 17 LSCM issues in Table 3. There is however the probability of conducting a type I error, that is, that any of the 6 issues identified as different from the z-tests may not be different in reality. This is a result of undertaking 17 independent tests, which compare the difference in proportions using multiple confidence intervals. However,

Table 2
The extent to which LSCM issues are addressed by each modelling approach; number of papers (#) and percentage use by modelling approach (%).

	LSCM issues ranked	DES		SD		HYB	
		#	%	#	%	#	%
Strategic	Supply Chain structure (SCS)	16	6%	2	2%	1	10%
	Process redesign (BPR)	5	2%	3	3%	1	10%
	Supplier selection (SS)	3	1%	2	2%	0	0%
	Facilities/ Capacity planning (FCP)	5	2%	3	3%	1	10%
	Supply chain integration (SCI)	21	8%	8	8%	1	10%
	Information sharing (ISH)	14	5%	10	10%	0	0%
	Bullwhip effect (BE)	5	2%	18	18%	0	0%
	Reverse logistics (RL)	4	2%	3	3%	0	0%
	Replenishment control policies (RCP)	22	8%	2	2%	1	10%
	Supply chain optimisation (SCO)	21	8%	3	3%	0	0%
	Cost reduction (CR)	10	4%	2	2%	0	0%
	System performance (SP)	28	11%	8	8%	1	10%
Operat/tact	Inventory planning/management (IPM)	47	18%	18	18%	1	10%
	Planning and forecasting demand (PFD)	19	7%	8	8%	0	0%
	Production planning & scheduling (PP-SCH)	27	10%	9	9%	3	30%
	Distribution and transportation planning(DTP)	14	5%	1	1%	0	0%
	Dispatching Rules (DR)	4	2%	0	0%	0	0%
	Total	265	100%	100	100%	10	100%

due to the high number of categories, relevant tests that can control the type I error (such as Bonferroni) were not considered appropriate because it results in a very small p-value for each independent test.

Based on the differences identified in Table 3, the SD approach has a significantly higher percentage use on the *bullwhip effect* compared to the DES approach. The DES approach has significantly higher percentage uses for the following LSCM issues: *supply chain structure*, *replenishment control policies*, *supply chain optimisation*, *distribution and transportation planning* and *dispatching rules*. A 1-sided test of the comparison of proportions, which investigates the sign of the differences identified, confirms all 6 differences identified as significant at a 95% level.

4.2.2. Relative frequency of use by LSCM issue

The frequency with which DES and SD are used for each LSCM issue is shown in the columns labelled # in Table 2. This shows the number of papers that address each issue. Fig. 3 provides a 100% stacked column chart for these data, normalised as a proportion of the total papers addressing each LSCM issue. The absolute number of times DES and SD is used for each LSCM issue is also displayed on the relevant part of each bar.

A similar z-test is undertaken to compare the relative difference in the proportion of DES and SD applications for each LSCM issue. Table 4 shows the results from z-tests for comparing proportions. For each LSCM issue 95% confidence intervals are calculated in order to test for the relative differences in the percentage use between DES and SD. Significant differences in the proportion of use are found for 12 out of the 17 LSCM issues in Table 4. It is found that DES has a relatively higher frequency of use for a number of LSCM issues: *supply chain structure*, *supply chain integration*, *replenishment control policies*, *supply chain optimisation*, *cost reduction*, *system performance*, *inventory planning/management*, *planning and forecasting demand*, *production planning and scheduling*, *distribution and transportation planning*, and *dispatching rules*. The issue of *dispatching rules* is exclusively modelled using DES modelling, whereas no issues have been modelled using exclusively the SD approach. The *bullwhip effect* has been modelled relatively more using the SD approach. It is interesting to notice that this test reveals that *inventory planning and management*, which seems to be a highly modelled topic in both DES and SD modelling approaches, is modelled relatively more using the DES approach.

For the LSCM issues *process redesign*, *supplier selection*, *facilities/capacity planning*, *information sharing* and *reverse logistics* insignificant differences have been found from the z-tests of proportions. This implies that these LSCM issues have been modelled to a fairly similar extent using either the DES or the SD approach.

Table 3
Confidence intervals of the differences in the percentage use of DES and SD for each LSCM issue (issues with significant differences are highlighted).

	LSCM issues ranked (strategic to operational/tactical)	Difference (DES-SD)	Lower limit	Upper limit	Percentage use (2-sided z-test)
Strategic	Supply chain structure (SCS)	4%	0.1%	8%	DES is higher
	Process redesign (BPR)	-1%	-4.8%	3%	Similar
	Supplier selection (SS)	-1%	-3.9%	2%	Similar
	Facilities/ capacity planning (FCP)	-1%	-4.8%	3%	Similar
	Supply chain integration (SCI)	0%	-6.3%	6%	Similar
	Information sharing (ISH)	-5%	-11.2%	2%	Similar
	Bullwhip effect (BE)	-16%	-23.8%	-8%	SD is higher
	Reverse logistics (RL)	-1%	-5.1%	2%	Similar
	Replenishment control policies (RCP)	6%	2.0%	11%	DES is higher
	Supply chain optimisation (SCO)	5%	0.3%	10%	DES is higher
	Cost reduction (CR)	2%	-1.8%	5%	Similar
	System performance (SP)	3%	-3.9%	9%	Similar
Operat/tact	Inventory planning/management (IPM)	0%	-9.1%	9%	Similar
	Planning and forecasting demand (PFD)	-1%	-7.0%	5%	Similar
	Production planning and scheduling (PP-SCH)	1%	-5.5%	8%	Similar
	Distribution and transportation planning(DTP)	4%	1.0%	8%	DES is higher
	Dispatching Rules (DR)	2%	0.04%	3%	DES is higher

4.3. The focus of DES and SD on the strategic and operational/tactical levels

In order to identify whether DES is used more for operational/tactical issues while SD is used more for strategic issues we compare the cumulative percentage use of DES and SD along the ranked list of LSCM issues presented in Fig. 1. The cumulative percentage lines are shown in Fig. 4. Our expectation is that the SD line would rise quickly and then level off, signifying greater use on strategic issues, while the DES line would show the opposite pattern. A close fit would signify little or no difference in terms of use on strategic and operational/tactical issues.

Fig. 4 shows that the two lines seem to fit quite closely for the issues at the strategic end of the spectrum (left-hand end of the graph). The lines then separate around the middle of the graph as the spectrum moves towards operational/tactical issues. There is a step change in the SD line at the "bullwhip effect", after which the lines gradually narrow. This is not surprising given the level of interest in the *bullwhip effect* in the SD literature, particularly based around the beer distribution game [136].

A chi-square test shows that these distributions are significantly different at a 95% level ($\chi = 50.71$, $p = 0.00001$). Since the SD line runs just above the DES line, this suggests that SD models have a slightly more strategic focus, albeit that the lines largely overlap for the issues at the very left of the graph. The main difference occurs at the *bullwhip effect*. If the *bullwhip effect* is removed from the data, a similar chi-square test shows that the distributions are not significantly different at 95% level ($\chi = 19.7$, $p = 0.233$). This suggests that with the exception of the *bullwhip effect* there is no significant difference in the use of DES and SD on a strategic or operational/tactical level.

From the cumulative percentages displayed in Fig. 4 a relatively low use of DES and SD for modelling strategic LSCM issues can be observed. Depending on where the spectrum moves from strategic to operational/tactical issues, the use of DES and SD for strategic issues might be as low as around 20% to 30% of modelling applications (cut-off at "information sharing").

Table 4
Confidence intervals of the differences in the percentage relative use of DES and SD for each LSCM issue (issues with significant differences are highlighted).

	LSCM issues ranked (strategic to tactical/operational)	Relative Difference (DES-SD)	Lower limit	Upper limit	Relative Percentage use (2-sided z-test)
Strategic	Supply chain structure (SCS)	78%	31.6%	124%	DES is higher
	Process redesign(BPR)	25%	-44.3%	94%	Similar
	Supplier selection(SS)	20%	-67.7%	108%	Similar
	Facilities/ capacity planning(FCP)	25%	-44.3%	94%	Similar
	Supply chain integration (SCI)	45%	8.4%	81%	DES is higher
	Information sharing (ISH)	17%	-23.3%	57%	Similar
	Bullwhip effect (BE)	-57%	-97.4%	-16%	SD is higher
	Reverse logistics (RL)	14%	-59.8%	88%	Similar
	Replenishment control policies (RCP)	83%	43.3%	123%	DES is Higher
	Supply chain optimisation (SCO)	75%	35.0%	115%	DES is higher
	Cost reduction (CR)	67%	10.1%	123%	DES is higher
	System performance (SP)	56%	22.9%	88%	DES is higher
	Inventory planning/management (IPM)	45%	20.3%	69%	DES is higher
	Planning and forecasting demand (PFD)	41%	3.0%	78%	DES is higher
	Production planning and scheduling (PP-SCH)	50%	17.3%	83%	DES is higher
	Distribution and transportation planning (DTP)	87%	36.1%	137%	DES is higher
Operat/tact	Dispatching Rules (DR)	100%	n/a	n/a	DES is higher

5. Summary of findings

DES and SD have both been used to model DSS for a wide range of LSCM issues. Based on the journal papers identified in the review period (1996–2006), DES is used more frequently than SD for supply chain modelling. The use of DES in the LSCM context is also growing at a faster rate.

For most LSCM issues DES is used more frequently with the exception of the *bullwhip effect*. Compared to SD modelling, DES is used relatively more frequently to address LSCM issues such as *supply chain structure*, *supply chain integration*, *replenishment control policies*, *supply chain optimisation*, *cost reduction*, *system performance*, *inventory planning and management*, *planning and forecasting demand*, *production planning and scheduling*, *distribution and transportation planning* and *dispatching rules*.

Within each modelling approach, the percentage use identifies which issues each modelling approach focus on most. For DES there is a significantly greater focus on: *supply chain structure*, *replenishment control policies*, *supply chain optimisation*, *distribution and transport planning*, and *dispatching rules*. For SD the only significantly greater focus is on the *bullwhip effect*. For all other LSCM issues the percentage use of DES and SD is similar (there is no significant difference).

The findings on the use of DES and SD are summarised in Table 5. The LSCM issues are grouped into 4 categories: common (DES, SD) domain, DES domain, SD domain, less common (DES, SD) domain. The issues are categorised using primarily the percentage of modelling activity undertaken in each modelling approach by LSCM issue. The bottom left and top right quadrants, DES/SD domain include LSCM issues for which the analysis has identified a significantly higher modelling activity for the DES or SD approach respectively. The remaining two categories, common or less common domain include LSCM issues for which the analysis revealed a similar (no significant difference) modelling activity undertaken between the two modelling approaches. The distinction between the two categories is based on the total number of papers identified for both approaches. For LSCM issues where a relatively large modelling frequency is identified (for example *supply chain integration* has 29 overall applications), they are categorised as being in the common domain, whereas for others that have a relatively small number of total applications up to 12 in total (for example *business process engineering* with a total of 8 applications), these are included in the less common domain category. The latter category also includes issues that have not been tackled by either approach (in brackets). These issues have been identified in non-simulation papers that undertake analytic modelling of LSCM.

In terms of application of DES and SD to support decisions at a strategic or operational/tactical level, there is little evidence of any difference within the LSCM context. It may be that SD, when it is used, is marginally used proportionately more often for strategic issues. Overall, DES and SD are used more frequently to model operational/tactical issues in the LSCM context. Indeed, in light of the categorisation of issues in Table 5, the common domain category includes only two strategic issues (*supply chain integration* and *information sharing*) with the rest being mainly operational/tactical. The DES domain again includes mostly operational tactical issues, with the exception of *supply chain structure*, whereas the SD domain again includes the *bullwhip effect* which can be considered more at a strategic level. The majority of the strategic LSCM issues are categorised as part of the less common domain, suggesting that the use of simulation for strategic issues in the LSCM context is generally low.

We would note that there is very little evidence for the use of hybrid-DES/SD modelling for supply chains. This may be an area of future development.

Based on the findings summarised above, we can now turn our attention to assess the appropriateness of using DES and SD as DSS tools in LSCM. Evidently, DES and SD are capable of modelling the complexity and uncertainty inherent in the LSCM environment. They are powerful techniques that can be integrated in DSS of LSCM to undertake

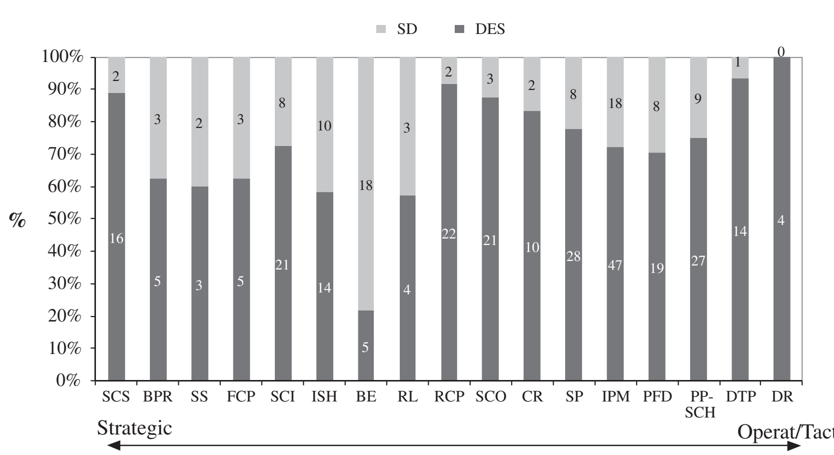

Fig. 3. Number of papers that address each LSCM issue using DES or SD.

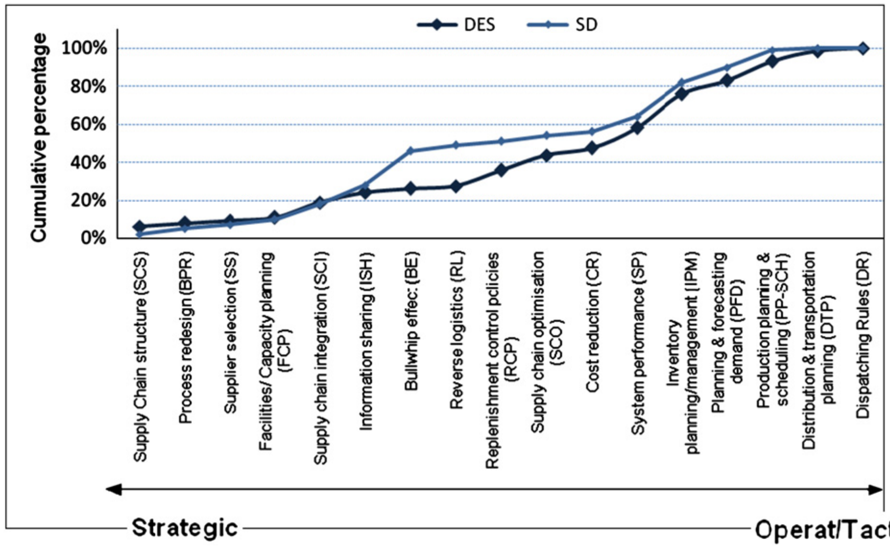

Fig. 4. Cumulative percentage use of DES and SD by LSCM issue.

"what if" analysis with a wide range of scenarios. The analysis undertaken in this paper shows that DES and SD can be used interchangeably in DSS to address a number of problems at the operational/tactical level, including: *information sharing*, *system performance*, *inventory planning/management*, *planning and forecasting demand* and *production planning and scheduling*. DES, however, appears to be most suited to *replenishment control policies*, *supply chain optimisation* and *distribution and transportation planning*.

At the strategic level the issue of *supply chain integration* can be modelled using both approaches. Meanwhile, there are a number of strategic issues such as *process redesign*, *supplier selection* and *facilities/capacity planning* where we found only limited use of DES and SD. These issues can be addressed, at least to a degree, by methods other than simulation, for instance, optimisation methods can be used in model based DSS for process redesign, and location and capacity planning [24]. Some strategic LSCM issues appear to be more amenable to only one of the simulation approaches, for instance, the *bullwhip effect* (SD) and *supply chain structure* (DES).

What emerges is a limited polarisation in the use of DES and SD for LCSM. This lack of a clear pattern could be in line with the findings from a recent empirical study on users' perceptions of a DES and SD model of the same problem [140]. This study found that the two models were not perceived as significantly different, implying that from the user's point of view the type of simulation approach makes little, if any, difference as long as it is suitable for addressing the problem situation at hand. Based on these considerations, it can be concluded that the majority of LSCM issues (at the strategic and tactical/operational level) can be modelled by both simulation approaches, and that there are only a few issues which might remain the sole preserve of just DES or SD. There are, however, differing degrees of use across the LSCM issues, which suggests some preference for one approach over another. Of course, in selecting a simulation approach for a model based DSS in LSCM, consideration also needs to be given to a wider set of criteria than just the issue to be modelled [15].

6. Conclusion

The findings of this study bring useful insights about different simulation approaches used as decision support systems in the field of logistics and supply chain modelling. It is a novel study that provides evidence about the extent and use of DES and SD modelling in the LSCM context, contributing to the limited litera-

Table 5
Classification of LSCM issues into domain areas based on the frequency modelled by each modelling approach.

	SD high frequency of use	SD low frequency of use
DES high frequency of use	Common (DES and SD) domain Supply chain integration (SCI) Information sharing (ISH) System performance (SP) Inventory planning/management (IPM) Planning and forecasting demand (PFD) Production planning and scheduling (PP-SCH)	DES domain Supply chain structure (SCS) Replenishment control policies (RCP) Supply chain optimisation (SCO) Distribution and transportation planning (DTP)
DES low frequency of use	SD domain Bullwhip effect (BE)	Less common (to DES and SD) domain Process redesign (BPR) Supplier selection (SS) Facilities/capacity planning (FCP) Reverse logistics (RL) Cost reduction (CR) Dispatching rules (DR) (Pricing policies) (Return policies) (Global supply chain)

ture that compares DES and SD. This paper explores the use of DES and SD as modelling tools used to support decision making in the LSCM context. This is done with respect to the nature and level of problems considered. Journal articles published between 1996 and 2006 that describe the application of DES and SD in LSCM issues were reviewed. The analysis undertaken sheds light on the two questions initially posed.

The first question asked whether DES and SD are used to model different LSCM issues. The findings show that both simulation approaches have been used to model the majority of LSCM issues identified, albeit to differing extents. It was established that the DES approach has been used more frequently compared to SD. The LSCM issues were then classified into four categories based on a comparison of the percentage of modelling activity in each modelling approach. The result is presented in Table 5 in which the LSCM issues are categorised as belonging to either the DES domain, SD domain, the common domain (frequently modelled using both approaches) or the less common domain (modelled using both approaches, but infrequently). This suggests that while there are a number of issues in LSCM that may lend themselves to one specific modelling approach, other modelling issues lie in a range between the two extremes and can be modelled using either approach.

The second question asked whether DES is used more at an operational/tactical level and SD more at strategic level. No evidence was found to support the belief that DES is used more for operational/tactical issues, whereas SD for strategic problems. On the contrary no difference was found in the extent of DES/SD modelling on a strategic or operational/tactical level.

The findings of this study are defined by the sample of journals chosen, but also the approach and the setting in which the study has been undertaken. For example, the literature review is based on peer reviewed journals only. Journal articles, which by nature are more academic than practice based, might not reflect the full range and frequency of use of DES and SD in the LSCM context. Meanwhile, the LSCM context may by nature be more operational than strategic, and this would affect the picture presented by this study. Furthermore, the study has not considered the success of the models in addressing the LSCM issues, i.e. *did the SD models address an issue better than the DES models, or vice versa?* This would be difficult to establish because detailed information about the models and their impact is not always made readily available in the papers.

As well as providing some interesting results, this study provides the basis for further comparison studies. Future work could expand on this study as well as address the limitations discussed above. Grey literature and conference papers could be used to undertake a similar review of supply chain simulation models and to provide a more practice based focus. This paper takes a literature-based approach to identifying the LSCM issues modelled using DES and SD, and it does not consider the other criteria used in choosing the simulation approach. This type of information is not provided by published papers. The research presented here could be extended to consider the criteria that affect the choice of modelling approach for specific modelling projects by interviewing modellers to gain access to more detailed information on their choice of approach. This might also make a review of the success of the models possible. Future work could also undertake a similar analysis in other areas of application, such as health care, insurance and education; and compare the findings.

Appendix 1. List of selected papers categorised by LSCM issues and simulation approach

No	Article	BE	PFD	ISH	IPM	PP-SCH	DTP	BPR	CP	DR	SP	RCP	SCI	SCS	SS	CR	SCO	RL
1	Alfieri and Brandimarte 1997 [1]				DES								DES	DES				
2	Ali et al. 1999 [2]					DES												
3	Anderson et al. 2005 [4]	SD																
4	Anderson and Morrice 2000 [3]			SD														
5	Andeson et al. 2000 [5]	SD																
6	Angulo et al. 2004 [7]		DES	DES	DES	DES						DES						
7	Ashayeri and Lemmes 2006 [8]		SD															
8	Beamon and Chen 2001 [10]		DES		DES		DES				DES							
9	Berry and Naim 1996 [11]	SD		SD	SD	SD		SD					SD					
10	Bhaskaran 1998 [12]	DES											DES	DES				
11	Biswas and Narahari 2004 [13]				DES				DES								DES	
12	Ceroni and Nof 2005 [19]		DES	DES				DES					DES					
13	Ceroni and Nof 2002 [20]		DES	DES	DES	DES												
14	Caputo et al.2003 [18]						DES		DES									
15	Chan and Chan 2005 [21]															DES	DES	
16	Byrne and Heavey 2006a [17]												DES				DES	
17	Byrne and Heavey 2006b [16]										DES			DES				
18	Cheng and Duran 2004 [23]				DES		DES										DES	
19	Cigolini et al. 1999 [25]					DES				DES								
20	D'Alessandro and Baveja 2000 [28]	SD		SD														
21	Dejonckheere et al.2002 [29]					DES		DES										
22	Croson and Donohue 2003 [27]	SD	SD															
23	Ding et al.2006 [31]					DES									DES		DES	
24	Ding et al. 2005 [30]					DES	DES		DES					DES	DES		DES	
25	Disney et al. 2004 [32]			SD										SD				
26	Disney et al. 2003 [35]				SD		SD						SD			SD		
27	Disney and Towill 2002 [34]		SD		SD								SD					
28	Disney and Towill 2003a [37]	SD			SD								SD					
29	Disney and Towill 2003b [36]	SD											SD					
30	Disney and Towill 2003c [33]	SD			SD							SD						
31	Dong and Chen 2005a [38]													DES				
32	Dong and Chen 2005b [39]				DES									DES			DES	
33	Fiala 2005 [40]			SD									SD					
34	Fleisch and Tellkamp 2005 [41]			DES	DES								DES					
35	Fleischmann et al. 2003 [42]				DES							DES		DES		DES		DES
36	Fowler 1998 [43]							SD										

Appendix 1 (*continued*)

No	Article	BE	PFD	ISH	IPM	PP-SCH	DTP	BPR	CP	DR	SP	RCP	SCI	SCS	SS	CR	SCO	RL
37	Ganeshan et al. 2001 [44]		DES	DES	DES						DES							
38	Garavelli 2003 [45]					DES	DES						DES				DES	
39	Georgiadis and Vlachos 2004 [46]		SD			SD					SD							SD
40	Georgiadis et al. 2005 [48]				SD				SD									
41	Georgiadis et al.2006 [47]		SD						SD		SD							SD
42	Giannoccaro and Pontrandolfo 2002 [49]				DES								DES					
43	Giannoccaro et al.2003 [50]				DES								DES					
44	Gnoni et al. 2003 [51]					DES					DES						DES	
45	Gobel and Hocke 2001 [52]												DES					
46	Goel et al. 2002 [53]					DES												
47	Guerrin 2004 [55]				SD							SD			SD		SD	
48	Gupta et al. 2002 [56]				DES	DES					DES							
49	Hafeez et al.1996 [57]				SD	SD		SD			SD							
50	Helo 2000 [60]	SD			SD				SD									
51	Hieber and Hartel 2003 [61]	DES			DES													
52	Higuchi and Troutt 2004 [62]	SD	SD															
53	Holweg and Bicheno 2002 [63]		SD		SD	SD								SD				
54	Holweg et al. 2005 [64]	SD			SD													
55	Hung et al. 2004 [65]		DES		DES							DES						
56	Hwarng et al. 2005 [66]		DES		DES									DES				
57	Ingalls et al. 2005 [68]	DES																
58	Jain and Ervin 2005 [69]		DES		DES						DES	DES			DES			
59	Jansen et al. 2001 [70]				DES		DES				DES						DES	
60	Jeong et al. 2006 [71]				DES						DES			DES			DES	
61	Jung et al. 2005 [72]			DES		DES			DES				DES					
62	Karabakal et al. 2000 [73]				DES		DES	DES						DES		DES	DES	
63	Koh and Gunasekaran 2006 [74]		DES		DES	DES					DES							
64	Kutanoglu and Sabuncuoglu 2001 [76]					DES				DES								
65	Larsen et al. 1999 [78]	SD			SD													
66	Lee et al. 2002 [80]				HYB	HYB			HYB			HYB						
67	Lee and Kim 2002 [81]					DES	DES									DES	DES	
68	Liberopoulos and Koukoumialos 2005 [84]				DES	DES								DES				
69	Lim et al. 2006a [85]				DES	DES					DES	DES					DES	
70	Lim et al. 2006b [86]						DES										DES	
71	Lin et al. 2000 [87]				DES	DES					DES	DES					DES	
72	Lo Nigro et al. 2003 [88]					DES							DES					
73	Lu et al. 2005 [89]			DES							DES					DES		
74	Machuca and Barajas 2004 [92]	SD		SD							SD					SD		
75	Marquez et al.2004 [90]			SD							SD		SD					
76	Marquez and Blanchar 2004 [94]														SD		SD	
77	Mason-Jones and Towill 1999 [91]			SD														
78	Mason et al. 2003 [93]				DES					DES		DES	DES					
79	Mertins et al. 2005 [95]												DES					
80	Metz et al. 2004 [96]				DES												DES	
81	Minegishi and Thiel 2000 [97]	SD			SD	SD												
82	Moon and Kim 2005 [98]	SD																
83	Myers and Richards 2003 [101]				DES						DES					DES		
84	Naim 2006 [102]	SD			SD	SD					SD							
85	Olhager and Persson 2006 [105]				DES	DES												
86	Ovalle and Marquez 2003 [107]				SD	SD							SD					
87	Ozbayrak et al. 2006 [109]					DES												
88	Persson and Olhager 2002 [110]				DES	DES					DES			DES				
89	Petrovic 2001 [111]		DES		DES													
90	Petrovic et al. 1999 [112]		DES		DES						DES	DES						
91	Petrovic et al. 1998 [113]		DES		DES						DES							
92	Rafaeli and Ravid 2003 [117]			SD	SD													
93	Rao et al. 2003 [118]				DES								DES					
94	Rathore et al. 2005 [119]												DES					
95	Ravulapati et al.2004 [120]				DES								DES					
96	Reiner 2005 [121]					HYB		HYB			HYB		HYB					
97	Reiner and Trcka 2004 [122]	DES	DES	DES							DES	DES		DES				
98	Rios and Stuart 2004 [124]					DES						DES						DES
99	Rios et al. 2003 [123]													DES				DES
100	Saad and Kadirkamanathan 2006 [127]				DES						DES	DES						
101	Schwaninger and Vrhovec 2006 [128]				SD						SD							
102	Shang et al. 2004 [130]			DES	DES				DES			DES	DES				DES	
103	Shin and Benton 2004 [131]				DES							DES	DES					
104	Sirias and Mehra 2005 [133]										DES	DES	DES					
105	Sokhansanj et al. 2006 [134]					DES	DES											
106	Spengler and Schroter 2003 [135]		SD								SD						SD	SD
107	Suwanruji and Enns 2006 [137]										DES	DES						
108	Swaminathan et al. 1998 [138]		DES		DES						DES						DES	
109	Tang and Naim 2004 [142]	SD		SD		SD												
110	Tommelein 1998 [144]					DES							DES					
111	Umeda and Zhang 2006 [146]				DES	DES						DES						
112	Vamanan et al. 2004 [147]				DES		DES										DES	

(*continued on next page*)

Appendix 1 (*continued*)

No	Article	BE	PFD	ISH	IPM	PP-SCH	DTP	BPR	CP	DR	SP	RCP	SCI	SCS	SS	CR	SCO	RL
113	van der Vorst et al. 2000 [148]				DES		DES	DES			DES	DES		DES				
114	van der Zee and van der Vorst 2005 [150]							DES		DES				DES				
115	Venkateswaran and Son 2004 [151]		DES	DES	DES						DES	DES						
116	Venkateswaran and Son 2005 [152]					HYB								HYB				
117	Villegas and Smith 2006 [153]	SD			SD	SD												
118	Walsh et al. 2004 [154]		DES		DES													
119	Watson and Polito 2003 [155]				DES		DES				DES	DES				DES		
120	Yee 2005 [158]			DES							DES							
121	Ying and De Souza 1998 [159]					DES											DES	
122	Xu and Hancock 2004 [157]			DES			DES						DES					
123	Zhang et al. 2006 [161]			DES	DES													
124	Zanoni et al. 2006 [160]	DES			DES							DES				DES		DES
125	Zhao and Xie 2002 [163]		DES	DES	DES						DES					DES		
126	Zhao et al.2001 [162]		DES								DES	DES						
127	Zhao et al. 2002 [164]		DES								DES	DES				DES		

Appendix 2. The LSCM issues explained

LSCM issues	Brief explanation
Supply chain structure	Designing the supply chain structure refers to the configuration of the chain, the sequential links between different activities or processes. Typical decisions made are related to the flow of materials between stages, involvement or not of intermediaries, pull versus push configurations, etc.
Process redesign	Supply chain redesign or re-engineering involves changes in its structure (facilities, production processes, transportation) and processes. An emerging stream of work in this category explores the streamlining of physical transformation processes to simplify the decision-making and control to eradicate waste, such as: Total Quality Management, Just-in-Time, Kaizen etc. Supply chain redesign is associated with strategic management as it requires an overall understanding of business processes.
Supplier selection	Related to procurement that is the process of purchasing raw materials needed to make finished goods or to support the operations of a firm. The selection of intermediaries or suppliers is made based on the evaluation of procurement bids for multiple products or suppliers.
Facilities/capacity planning	Typical decisions are the determination of the facility role and processes to be performed, facility location and capacity allocation, etc. These decisions are usually linked with the objectives and long term vision of the firms or partners in the chain and hence considered a strategic issue.
System performance	The performance of the supply chain is evaluated using a number of criteria, such as transportation cost, resources utilisation, inventory level, order cycle time, delivery performance, etc.
Bullwhip effect	The phenomenon of upstream order magnification in the supply chain. Due to the fluctuations, supply chain partners do not receive a reliable picture of inventory levels which results into a poor alignment between demand and production patterns across echelons.
Supply chain integration	Supply chain integration enables the cooperation of two or more systems in pursuit of complementary objectives. This category includes a number of coordination mechanisms such as: vendor managed inventory, quantity discounts, quantity flexibility, allocation rules, quick response, strategic partnerships, etc.
Information sharing	Information sharing strategies are introduced as a sub-set of supply chain integration mechanisms, which aim to reduce the bullwhip effect and to improve the supply chain performance. Some of the hurdles encountered in operationalising these strategies are the reluctance of firms to share information on sales, demand, production and delivery, inventory levels, etc. This is considered as a separate category, due to the large number of papers on information sharing.
Supply chain optimisation	Supply chain optimisation is mainly concerned with the identification of optimal policies that optimise key performance indicators, such as profits, costs, product flows, etc.
Cost reduction	Cost reduction is often the incentive of various policies undertaken such as electronic data interchange, inventory management, etc.
Replenishment control policies	These policies deal with the control of stock levels in the echelons of the supply chain and the ordering policy. The aim is to have the right product quantity at the right location and at the right time. The choice of inventory replenishment policies aims to achieve low inventory while maintaining high delivery performance.
Inventory planning/management	Deals with the management and movement of goods throughout the supply chain. Studies on inventory planning and management focus on optimisation of service levels or process time by varying the location or quantity of inventory. In each echelon, a decision is made to manage the inventory based on inventory levels, holding and backlog costs and replenishment control policies.
Planning and forecasting demand	It can be the primary or secondary focus of simulation studies, where the objective is to anticipate or to mitigate the risks involved. These models generate forecasts of the expected future demand and investigate the impact of major demand changes on supply chain echelons.
Production planning and scheduling	Production planning and scheduling deals with the management of manufacturing processes and the policies that determine the configuration of the production sequence and resource allocation, material handling, scheduling of machines and work centres. Simulation models are often concerned with the effect of different production planning rules on supply chain performance.
Distribution and transportation planning	Deals with the physical movement of inventory (products, materials) from one stage of the supply chain to another. Some decisions made are: the design of the transportation network, choice of transportation models, the management of vehicle fleet (routing and scheduling), etc.
Dispatching rules	Dispatching rules deal with decisions made regarding the fulfilment of specific customer orders, considering on one-hand delivery dates and on the other hand utilisation of the manufactures' shop floor.
Reverse logistics	Reverse logistics is concerned with the recovery of products as spare parts or recycled products at the end of their life cycle. Product recovery is driven by economical and environmental incentives, which at the same time affects companies' manufacturing and collection activities.

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