# A SCOR BASED ANALYSIS OF SIMULATION IN SUPPLY CHAIN MANAGEMENT

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**KEYWORDS**

Spreadsheet simulation, System dynamics, Discrete-event simulation, Agent-based simulation, Business games, SCOR

**ABSTRACT**

One of the main goals of simulation in supply chain management is to evaluate the performance and how it can be increased by effectively managing a complex supply chain. Simulation supports managers in decision making at strategic, tactical and operational levels through visualizing, understanding and analyzing the dynamics of the supply chain (SC). This paper provides a detailed analysis of the practice of simulation for different supply chain management (SCM) processes. The supply chain operation reference (SCOR) model is used for the classification of SCM processes. It reports the results of a review and analysis of simulation applications based on literature published within peer-reviewed journals until 2013 in order to provide an up-to-date picture of the role of simulation techniques in SCM. A structured methodology is followed to narrow down the publications (n=569). This research paper mentions different types of simulation in the context to SCM, describes their main characteristics as well as the implementation at different SCM process levels. This leads us to interesting trends and patterns on how different simulation types are applied to different SCM processes in order to answer different managerial questions.

## INTRODUCTION

Popular since 1990, SCM has been increasingly widening its scope from the point of origin to the point of consumption (Svensson 2007; Chang and Makatsoris 2000; Lambert and Cooper 2000). According to Makris et al. (2008), "a company's supply chain comprises geographically dispersed facilities, where raw materials, intermediate products, or finished products are acquired, transformed, stored, or sold and the transportation links that connect facilities along which the products flow".

The development of SCM has been geared traditionally towards minimization of risks and maximization of profit (Persson and Olhager 2002; Fawcett et al. 2008; Ashby and Smith 2012). The increase in global competition has also increased the demand for new decision support tools (Almeder et al. 2009). Effective SCM helps to reduce costs and lead times (Tarokh and Golkar 2006) and it requires a carefully defined approach to investigate and evaluate the performance of a SC (Tarokh and Golkar 2006). Thomas and Thomas (2011) distinguished three ways (Mandal 2012) of carrying out SC performance measurement:

- Analytical methods
- Simulation or emulation
- Physical experimentations

In a SCM context, analytical methods such as queuing theory, markov chains, Petri nets, etc., are generally impracticable because of the limited size of the problem they deal with, and many simplifications from the real world case are made in these approaches in order to solve the given problem (Thierry et al. 2008; Almeder et al. 2009; Thomas and Thomas 2011). Physical experiments, such as lab platforms or industrial pilot implementations, suffer technical and cost-related limitations (Mandal 2012). Simulation, relatively often used in comparison to other quantitative models, seems to be the only better approach to model and analyze performance measurement (Kleijnen 2003; Thierry et al. 2008). It allows the design of best decisions in SCM and their evaluation prior to implementation (Maria 1997; Chang and Makatsoris 2000). It makes simulation an excellent tool to reproduce the behavior of complex systems for decision making and can predict the effect of changes to the system, diagnose problems, optimize internal operations and mitigate risks (Tarokh and Golkar 2006; Mandal 2012). Simulation is used to support decision making (Lee et al. 2002; Huan et al. 2004; Tarokh and Golkar 2006) at:

- *The strategic level*, including (re)designing a supply chain, supplier selection, etc.
- The *operational and/or tactical level*, including setting the values of control policies, scheduling, shop floor management, etc.

There are very few articles that provide a comprehensive review about the application of simulation for SCM. One of the earliest reviews by

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Kleijnen (2005) explained the use of simulation for SCM and distinguished four simulation types for SCM but did not provide the analysis of the application of different simulation approaches for various SCM processes. Tarokh and Golkar (2006) explained how different simulation types can answer different questions in SCM. Jahangirian et al. (2010) have included a broader range of simulation techniques in manufacturing and business sectors. Tako and Robinson (2012) have given a useful discussion by considering only discrete event simulation and system dynamics in the context of Logistics and SC. Othman and Mustaffa (2012) have reviewed different simulation and optimization techniques and analyzed simulation software tools that are being used for SCM, while Mandal (2012) explained the use of simulation for performance measurement in SCM. However, these reviews did not provide a comprehensive conjoint or cross-functional analysis of the application of different simulation approaches for various SCM processes. Therefore, the aim of our literature review is to fill this gap through an extensive coverage of existing academic literature in the field of simulation in SCM and focusing specifically to SCOR-based SCM processes.

## REVIEW OF SUPPLY CHAIN SIMULATION METHODS

Computer simulation is the experimentation with a computer model of the system to answer "what-if" questions about the system (Bowden 1998; Seila 2006) and to support decision makers in designing SC operations in order to study their collective and dynamic behaviors (Yancez 2009). In the mid 90's a large number of software packages, used to support SCM operations, have emerged that are called supply chain management systems (Chang and Makatsoris 2000). From scanning of established literature, five simulations (Kleijnen and Smits 2003; Allwood and Lee 2005; Hao and Shen 2008; Yanez et al. 2009; Jain et al. 2013; Kocaoglu et al. 2013) approaches were distinguished that are used in context of SCM:

- Spreadsheet simulation
- System dynamic
- Discrete-event simulation
- Agent-based simulation
- Business game

A simulation model of a SC can be an entire or standalone model reproducing all nodes, or using more integrated models (one for each node) (Terzia and Cavalierib 2004; Thierry et al. 2008).

### Spreadsheet Simulation

"Spreadsheet simulation" refers to the use of a spreadsheet as a platform for representing simulation models and performing simulation experiments (Seila 2006; Othman and Mustafa 2012). It can be used for sampling distribution, test of hypotheses, etc., (Johnson 2011). Spreadsheet simulation is often a simple, economical and relatively straightforward approach. It is possible to develop a simple time slice model but it is difficult to develop a model animation (Kleijnen 2005; Othman and Mustafa 2012; Mishra and Chan 2012). The most prevalent spreadsheet today is Microsoft Excel, which is part of the Microsoft Office package (Greasley 1998; Seila 2006). Any set of calculations in a spreadsheet can be considered as a model. In several studies spreadsheet simulation has not been cited as a formal method of analyzing SCM (Othman and Mustafa 2012) but in a business setting the spreadsheet platform is available to a wide range of decision making (Greasley 1998; Othman and Mustafa 2012) e.g. Koo et al. (1994) used spreadsheet for performance evaluation of a manufacturing system, Sui et al. (2010) used it to determine the replenishment policy in a vendor managed inventory system. Spreadsheet is a tool which can be combined with all other simulation approaches (Thierry et al. 2008).

### System Dynamics

According to Labarthe et al. (2007) supply chain modeling and simulation was originally based on system dynamics. System dynamics (SD) is a simulation in which the state of a system varies continuously (Tako and Robinson 2012; Mandal 2012). In system dynamics, firms are viewed as complex systems with different types of flows (e.g. material, orders, manpower, technology, etc.) and stocks (e.g. WIP at a given point in time) (Kleijnen 2005). System dynamics is based on flow models where it is not possible to differentiate between individual elements (Mandal 2012). The managerial control is realized by changing the rate of variables (Kleijnen 2005) (e.g. production rate, sales rate, etc.), which will change the flow as well as the stocks. A SD model takes the feedback principle (closed loop effect) into account which plays a crucial role i.e. managers will take corrective actions if there is an undesirable variation of a targeted value of a performance indicator (Kleijnen 2003; Thierry et al. 2008; Mandal 2012).

### Discrete-event Simulation

Discrete event simulation (DES), as the name implies, is a simulation where state changes occur at discrete points in time (Mandal 2012) and is widely used for SC planning (Almeder et al. 2009; Tako and Robinson 2012). A DES is more detailed than the previous two simulation types (Kleijnen & Smits 2003). It represents individual events, e.g. arrival of an individual customer order or the departure of a production lot (Kleijnen 2003). DES is an important method in SCM and used to support decision making for different SCM processes, e.g. Finke et al. (2012) used DES to study changes in production lead time if there are disruptions in operations of an individual processing time of a task. According to Tako and Robinson (2012), hybrid

simulation approaches were used to model SCM processes to support strategic decision making as DES does not represent systems at an aggregate level. Lee et al. (2002) proposed a combined modeling architecture for SC simulation, in which they presented a simple example of a supply chain model dealing at strategic level of a supply chain.

**Agent-based Simulation**

Over the last few years, agent-based systems are becoming more and more effective tools for solving SCM problems (Mele et al. 2007). So this simulation approach should be added to the above set of simulation approaches for SCM (Eldabi et al. 2008; Yanez et al. 2009). In agent-based simulation, an agent is a real or virtual entity that encapsulates the behaviors of different entities and acts on itself and its surrounding world (Saberi et al. 2012; Ilie-Zudor and Monostori 2009). The multi-agent system (MAS) collaborates, and considers exchange of information and relationships among other agents in order to obtain improved solutions (Nikolopoulou and Ierapetritou 2012). Supply chain activities such as sourcing, planning, delivery and their interactions are represented by different agents in multi-agent systems (Saberi et al. 2012). Agents are autonomous, reactive, and proactive and have social ability (Julka et al. 2002). Due to these advantages, MAS have become a promising tool for solving SCM problems in the last few years (Puigjaner and Gosalbez 2008).

**Business Games**

Modeling of human behavior is more difficult in comparison to modeling of different SCM processes (Kleijnen 2005). It can be achieved by letting managers operate within a simulated world (consisting of SC and its environment) (Kleijnen and Smits 2003; Mandal 2012). Business games are used for educational and research goals (Kleijnen 2003) and have no relationships to game theory which is applied to SC (Mandal 2012). The beer game is widely used among several proposed games (Mandal 2012). Kleijnen and Smits (2003) distinguished business games in two subtypes:

i. In *Strategic games* several teams of players (representing companies) compete with each other. Players interact with the simulation model for a fixed number of rounds, like beer game which is used to illustrate the bullwhip effect (Kleijnen 2005; Thierry et al. 2008).
ii. In the simulated world of *Operational games,* a single team (one or more players at a time) interacts with a simulation model for several rounds, like games for training of production scheduling (Kleijnen 2003; Thierry et al. 2008).

Furthermore, based on complexity level, Thierry et al. (2008) categorized business games as board games (simple) that are played with tokens on specific boards and sophisticated games (more realistic) that run on computer devices.

The type of simulation applied in SCM depends on the problem that needs to be solved e.g. use of SD demonstrates the bullwhip effect, DES simulation can quantify fill rates, use of business games to educate and train users (Kleijnen 2003).

## CLASSIFICATION OF SUPPLY CHAIN MANAGEMENT PROCESSES BASED ON SCOR MODEL

Every business process has different characteristics. Thus a good understanding of the SCM processes is necessary before developing a simulation model (Chang and Makatsoris 2000). In the past, different metrics were used to measure performance at different SC levels and models for decisions making at strategic level are scarce (Huan et al. 2004). It is not achievable to have a model that perfectly represent SCM but a closely adapted model (Irfan et al. 2008; Mandal 2012) i.e. SCOR. In 1996, the Supply Chain Council (SCC) has developed and released a structured framework model 'SCOR' for SCM systems and practices (Li et al. 2011). SCOR model is the first cross-industry framework for evaluating and improving SC performance and management (Stewart 1997; Huan et al. 2004). The benefit of the 'SCOR' model is that it provides a standard format and a comprehensive methodology to facilitate communication and to improve SC operations (Irfan et al. 2008). It is a flexible framework and common language that can help upper management of a firm to design and reconfigure its SC to achieve the desired performance both internally and externally (Huan et al. 2004). SCOR is widely used in academia and practice. For these reasons we use the SCOR framework as a base of our analysis.

'SCOR' is a business process framework that spans from the supplier's supplier to the customer's customer ('SCOR' 2012). 'SCOR 11.0' describes a SC by four levels of details. *Level 1* is a top level that defines the scope and high level configuration by six core processes, i.e. plan, source, make, deliver, return and enable. *Level 2* is a configuration level and processes at level 2, along with their positioning, determine the SC strategy. *Level 3* is a process element level and describes the steps that need to be performed to execute all of the level 2 processes. *Level 4* is the implementation level and describes industry specific activities which are required to perform level 3 processes.

Each of the SCOR components is considered as an important intra-organizational function and a critical inter-organization process (Erkan and Bac 2011). SCOR core processes are defined below and shown in figure 1 (SCOR 2012). The process reference model utilized in our research is based on 'SCOR 11.0'. Furthermore, we

concentrated the research scope to Level 1 process types specifically.

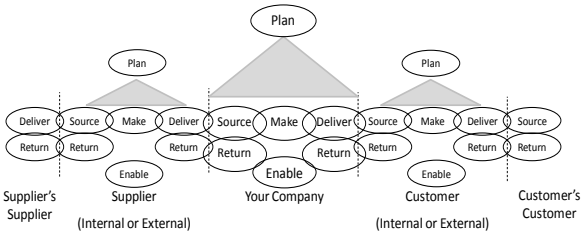


Figure 1: SCOR Model

## RESEARCH METHODOLOGY

The aim of this study is to analyze the use of simulation in SCM; looking specifically into the detail of SCM processes are simulated. In order to accomplish the goal our analysis is based on the frequency with which SCM processes are simulated using spreadsheet simulation, system dynamics, discrete event simulation, agent-based simulation and business games. The study is based on a review of journal articles which describe the application of simulation techniques to different processes in SCM. Following two research questions are addressed here:

- Which simulation approach is used to a great extent across different SCOR-based SCM processes?
- Which SCOR-based SCM process widely employs simulation approach to support decision making?

Our expectations established on initial literature analysis, that all of above considered simulation techniques are used to model various processes of SCM. The systematic literature review undertaken follows two stages:

i. Identification of journal articles and applied simulation approaches

ii. Classification of journal articles by SCOR-based SCM processes

A detailed diagram of steps taken while selecting articles is described in figure 2 (adopted from Eldabi et al. 2008).

### Identification of Journal Articles and Adopted Simulation Approaches

A list of keywords was generated based on an initial literature analysis. Later, these keywords were used to find related scientific articles using Science direct, EBSCO host and Web of Science databases (DB). This provided a multidisciplinary collection of literature, but journal articles that report simulation and are relevant to SCM were selected. Science direct is a leading scientific database offering more than 2,200 journals and almost 26,000 books titles (Elsevier 2014). EBSCO host offers more than 375 full-text and secondary research databases plus subscription management services for 355,000 e-Journals and e-Journal packages (Ebsco*host* 2014). Web of Science provides access to the world's leading citation databases and covers over 12,000 of the highest impact journals worldwide (WEB of Science 2014). All three databases contain articles from top ranked journals in the field of SCM.

Our initial set of keywords consisted of spreadsheet simulation, system dynamics, discrete event simulation, business games and agent-based simulation. Each of these keywords were combined with 'supply chain' as a second keyword by using 'and' as an operator, and searched inside selected scientific databases. Based on the initial results and a review, more keywords were generated and searched with full-text option in each database. Results from each database were compiled in three different Microsoft Excel spreadsheets. It comprised articles published until September, 2013 and included 4 articles that will be published in 2014 but are already available online.

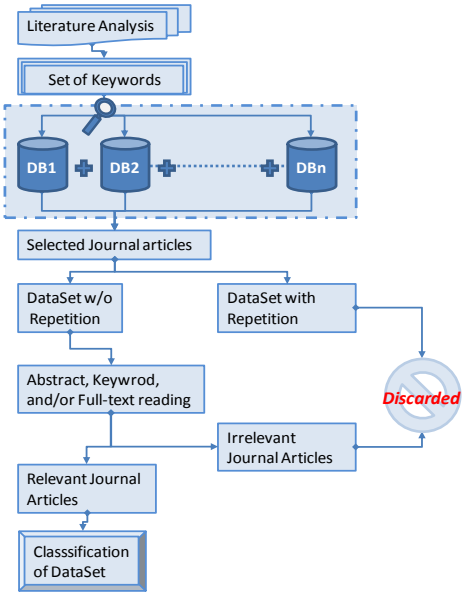


Figure 2: A framework for Literature review

After combining all of the results from three spreadsheet datasets, duplications were noticed. That happened because some of the publications were cited in more than just one database as well as because of the application of different combination of keywords. After removing all duplicates, the initial dataset resulted in 4200 publications. The search was limited to peer-reviewed publications from scientific journals only and no books, conference papers, magazines, etc., were considered. The applied procedure was to read the abstract and/or also full article if the topic was not clear from the title and author keywords. After screening, a reduced list of 569 publications remained. Each of the selected articles has adopted one of the above mentioned simulation (i.e. spreadsheet simulation, system dynamics, discrete-event simulation, agent-based

simulation, business games) approaches or hybrid (i.e. combination of two or more) simulation.

### Classification of Journal articles by SCOR-based SCM Processes

After keeping only unique and relevant publications in the Excel spreadsheet, the next step is to classify each article into SCM processes. Different authors classify SCM differently as it is a vast field, covering a variety of topics (Tako and Robinson 2012). For this purpose, we adopted a classification of SCM processes based on the 'SCOR' model. All 569 selected journal articles from step one have been classified for further analysis. Sometimes authors discussed more than one process or issue in their research work; in that case publications were classified accordingly.

## RESULTS & ANALYSIS

Journal articles classified in our Excel dataset were analyzed to address the research questions mentioned in the research methodology and the results were presented with various perspectives, as given below in detail.

### Distribution by Publication Year, Document type and Language

At first, only English language journal articles were selected for conducting this study. Figure 3 shows the distribution of journal publications by year, and Table 1 shows the percentage and the number of publications per year. One of the interesting findings is the increase in SC simulation between the years 2000 and 2010. Since it is stagnating on a high level and before 2000 there was only small number of publications. Based on the number of publications per year, it can be stated that simulation techniques are becoming ever more important. The percentage of number of publications for one year is calculated as a portion of the publications identified for the purpose of analysis.

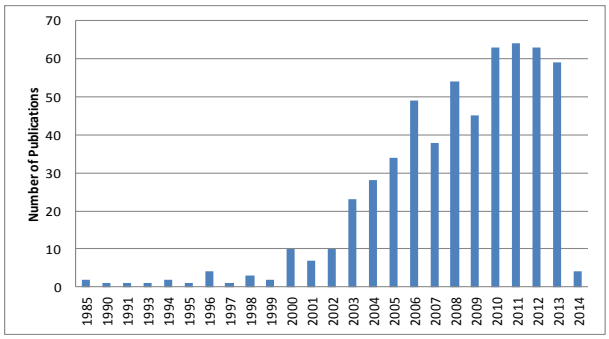


Figure 3: Distribution of Publications per Year

### Distribution of publications by Source Title

Our dataset contains publications from different journals. Table 2 shows a list of most cited journals in our selected dataset. "International Journal of Production Research", "International Journal of Production Economics" and "European Journal of Operational Research" are reported as top three journals with the most publications.

Table 1 : Percentage of Publications per Year

| Pub. Year | # | % | Pub. Year | # | % |
|---|---|---|---|---|---|
| 1985 | 2 | 0,35 | 2003 | 23 | 4,04 |
| 1990 | 1 | 0,18 | 2004 | 28 | 4,92 |
| 1991 | 1 | 0,18 | 2005 | 34 | 5,98 |
| 1993 | 1 | 0,18 | 2006 | 49 | 8,61 |
| 1994 | 2 | 0,35 | 2007 | 38 | 6,68 |
| 1995 | 1 | 0,18 | 2008 | 54 | 9,49 |
| 1996 | 4 | 0,70 | 2009 | 45 | 7,91 |
| 1997 | 1 | 0,18 | 2010 | 63 | 11,07 |
| 1998 | 3 | 0,53 | 2011 | 64 | 11,25 |
| 1999 | 2 | 0,35 | 2012 | 63 | 11,07 |
| 2000 | 10 | 1,76 | 2013 | 59 | 10,37 |
| 2001 | 7 | 1,23 | 2014 | 4 | 0,70 |
| 2002 | 10 | 1,76 | **Total** | **569** | **100,0** |

Table 2: List of Top Cited Journals in dataset

| International Journal | # of Publications |
|---|---|
| International Journal Of Production Research | 83 |
| International Journal Of Production Economics | 63 |
| European Journal Of Operational Research | 25 |
| International Journal Of Computer Integrated Manufacturing | 21 |
| Computers & Industrial Engineering | 16 |
| Decision Support Systems | 15 |
| Expert Systems With Applications | 15 |
| Simulation Modelling Practice And Theory | 13 |
| Computers & Chemical Engineering | 12 |
| Computers In Industry | 12 |

### Distribution by SCOR-based SCM Processes

One of the aims was to determine which objectives of SCM are achieved by simulation and its applicability in supporting decision making at different SCM processes. From figure 4 it can be seen that out of 569 articles, 298 (52%) publications applied simulation for the 'plan' process and similarly for the 'source' process 24 (4%), for the 'make' process 101 (18%), for the 'deliver' process 32 (6%), for the 'return' process 8 (1%), for the 'enable' process 59 (10%) and 47 (8%) publications dealt with more than process at a time.

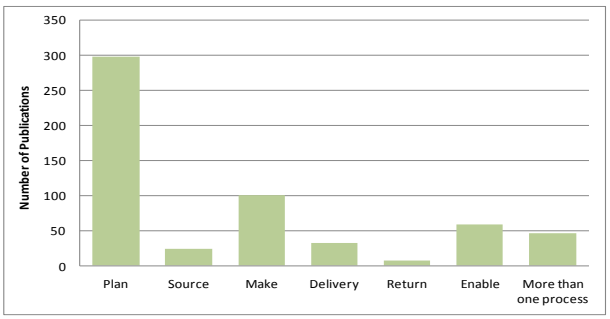


Figure 4: SCOR-based SCM Processes

**Distribution by Application of Simulation Approach**

Another objective of the study was to determine which simulation approach is widely used by researchers to support decision making in SCM. According to figure 5, out of 569 articles, 27% of the publications applied DES approach, 25% of the publications applied agent-based simulation, 19% of the publications applied SD, 15% of the publications applied the spreadsheet simulation, 9% of the publications applied hybrid simulation and the remaining 5% used business games.

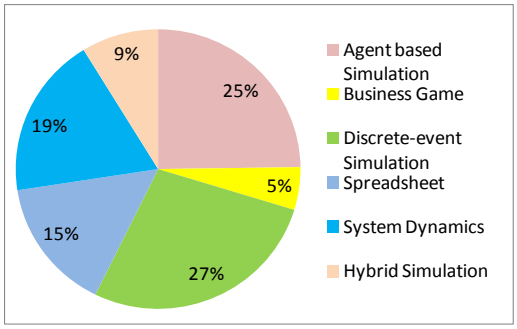


Figure 5: Simulation in SCM

**Distribution based on Simulation Approach and SCM Process**

The use of simulation approaches across the different SCM processes can analyzed from two different perspectives:

- From the SCM process
- From simulation approach

Accordingly the following questions arise:

1. What are the main simulation approaches that support a certain SCOR-based SCM process? (see table 3)

It can be seen that for solving the 'plan' process problems, agent-based simulation is used i.e. 26% out of 298 publications, following are DES and SD i.e. 21% and 20% respectively. For dealing issues within 'source' processes, spreadsheet simulation is widely used i.e. 46% out of 24 publications. For 'make' processes, DES is mostly used i.e. 45% following agent-based simulation i.e. 24%. For 'deliver' processes, again DES is used more frequently i.e. 50% following spreadsheet simulation i.e. 22% of the 32 publications. For SCM 'enable' processes, agent-based simulation and SD are used for 32% and 29% respectively. Similarly, for 'return' processes SD is used most frequently i.e. 65% out of 8 publications.

2. What are the major fields of application (i.e. SCOR SCM processes) for a specific simulation approach? (see table 4)

Agent-based simulation is used 55% (77) for 'plan' processes out of 141 publications, following 'make' processes i.e. 17% (24). DES is also used most frequently to simulate 'plan' processes i.e. 39% out of 157 publications and 29% for 'make' processes. Similarly, SD is used for the 'plan' processes for 58% out of 106 publications. Spreadsheet simulation is used for 46% in 'plan' processes out of 87 publications and business games are used to simulate 'plan' processes for 79% publications out of 28. Hybrid simulation is largely applied for 'plan' processes, i.e. 72% out of 50 publications.

**Implementation of Simulation Approaches with Time**

According to Gartner (2013), there is an increase of 8% in sales of SCM software from 2008 to 2012. From our Excel dataset, as represented in figure 6, it can be interpreted that a sharp increase in use of agent-based simulation is noted in recent years, and a constant trend in use of business games and spreadsheet simulation techniques is noticed. Apart from frequency, simulation in SCM is gaining much more popularity than in the past few years and a continuous increase in all types of simulation approaches is noticed during the analysis.

Table 3: Main Simulation Approaches to Support a certain SCOR-based SCM process

| Simulation Approach | Plan | | Source | | Make | | Deliver | | Return | | Enable | | More than one process | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Publications | %age | Publications | %age | Publications | %age | Publications | %age | Publications | %age | Publications | %age | Publications | %age |
| Spreadsheet | 40 | 13% | 11 | 46% | 12 | 12% | 7 | 22% | 1 | 13% | 6 | 10% | 10 | 21% |
| System Dynamics | 61 | 20% | 1 | 4% | 14 | 14% | 2 | 6% | 5 | 63% | 10 | 17% | 13 | 28% |
| Discrete-event Simulation | 62 | 21% | 4 | 17% | 45 | 45% | 16 | 50% | 0 | 0% | 17 | 29% | 13 | 28% |
| Agent based Simulation | 77 | 26% | 8 | 33% | 24 | 24% | 5 | 16% | 0 | 0% | 19 | 32% | 8 | 17% |
| Business Game | 22 | 7% | 0 | 0% | 0 | 0% | 0 | 0% | 1 | 13% | 4 | 7% | 1 | 2% |
| Hybrid Simulation | 36 | 12% | 0 | 0% | 6 | 6% | 2 | 6% | 1 | 13% | 3 | 5% | 2 | 4% |
| Total | 298 | 100% | 24 | 100% | 101 | 100% | 32 | 100% | 8 | 100% | 59 | 100% | 47 | 100% |

Table 4: Major Fields of Application for a Specific Simulation Approach

| SCM Processes | Spreadsheet | | System Dynamics | | Discrete-event Simulation | | Agent based Simulation | | Business Game | | Hybrid Simulation | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Publications | %age | Publications | %age | Publications | %age | Publications | %age | Publications | %age | Publications | %age |
| Plan | 40 | 46% | 61 | 58% | 62 | 39% | 77 | 55% | 22 | 79% | 36 | 72% |
| Source | 11 | 13% | 1 | 1% | 4 | 3% | 8 | 6% | 0 | 0% | 0 | 0% |
| Make | 12 | 14% | 14 | 13% | 45 | 29% | 24 | 17% | 0 | 0% | 6 | 12% |
| Deliver | 7 | 8% | 2 | 2% | 16 | 10% | 5 | 4% | 0 | 0% | 2 | 4% |
| Return | 1 | 1% | 5 | 5% | 0 | 0% | 0 | 0% | 1 | 4% | 1 | 2% |
| Enable | 6 | 7% | 10 | 9% | 17 | 11% | 19 | 13% | 4 | 14% | 3 | 6% |
| More than One SCM process | 10 | 11% | 13 | 12% | 13 | 8% | 8 | 6% | 1 | 4% | 2 | 4% |
| Total | 87 | 100% | 106 | 100% | 157 | 100% | 141 | 100% | 28 | 100% | 50 | 100% |

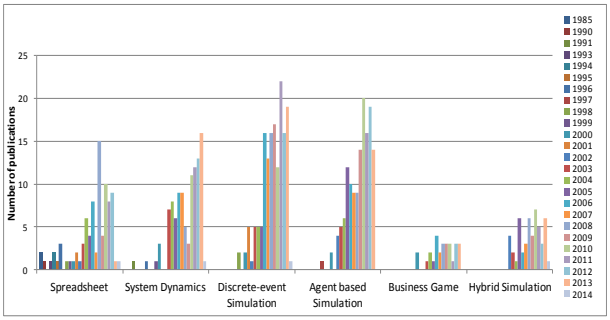


Figure 6: Implementation of Simulation Approaches with Time

## CONCLUSION AND FURTHER RESEARCH

Data from three scientific databases were collected. It was experienced through database search that an inclusion of new scientific databases will not distort the result and will lead only to a few new entries in our dataset. An increasing number of repetitions were noticed while searching the second database after EBSCO host and after that more repetitions were noticed while searching for the third database i.e. Web of Science (see figure 7). So, it was decided to limit database search to a maximum of three scientific databases.

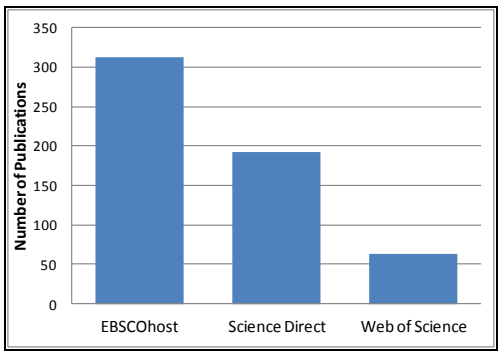


Figure 7: Distribution of Publications in Dataset

All simulation approaches are used for solving problems and support the decision making at almost all SCOR-based SCM processes. There are however, different degrees of use across SCM, which suggests some preference for one approach over the others.

The analysis of journal articles reflects that DES is more frequently used in comparison to other simulation types and at the same time application of agent-based simulation in SCM is growing at a faster rate than other simulation approaches. English language journal articles until 2013 were reviewed in order to elucidate the two questions initially placed.

The first question, frequency of use of simulation approaches for SCM processes? Use of a particular type of simulation depends on the type of the SCM question to be answered. DES approach has been applied most frequently in comparison to other simulation approaches. It can be seen from the analysis that all simulation approaches are getting popularity in academia.

The second question, which SCOR-based SCM process largely employs simulation as a decision support tool? The research shows that the 'plan' process employs simulation most frequently in comparison to other processes in SCM.

From the percentage use of simulation for SCM processes, it is revealed that for 'plan' process of SCOR model, agent-based simulation was mostly used and the use of all other simulation approaches is relatively small. For the 'source' process the spreadsheet simulation is widely used. For 'make' and 'deliver' processes, DES approach is mostly used and the 'return' process employs the SD approach as a decision support tool in SCM. There are only 9% of the publications that uses more than just one simulation approach at a time. So, it can be expected that a hybrid simulation approach could be an area of a future research and development.

This study makes a contribution to limited knowledge about the use of different simulation approaches in the context of SCM. Future work could expand the focus specifically on phenomena in SCM such as SC risk management, SC complexity, SC sustainability, etc.

Further research could also focus and analyze more details of the 'SCOR' model e.g. going deeper to SCOR's Level 2 and Level 3 processes. This will help to find out how far the different types of simulation are applied in certain SCM processes and contexts.

The findings of this study are based only on journal publications. These publications show more the academic interest than the practice use of simulation (Tako and Robinson 2012). This may affect the analysis results which are presented in our study as it might not reflect the full range and frequency of use of simulation approaches in the SCM practice: Thus future work could extend on this study by considering more practice-oriented journals and also other literature resources e.g. conference papers and/or book chapters, etc, to conduct a similar review about the application of simulation in SCM with a more practiced based focus.

This paper does not provide information about the selection and the success of a specific simulation approach for a particular SC process. Such study can also lead to further comparison studies.

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