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February 2014

CIRRELT-2014-12

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Supply Chain Modelling Frameworks for Forest Products Inventory Industry: A Systematic Literature Review

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Abstract. Considering the economic importance of the forest products industries in Canada, there has been an increasing interest to study the operations and interactions of all the relevant entities involved in its Supply Chain (SC). The forest products industry has a set of specific SC characteristics to meet the needs of its final consumers. While a growing number of mathematical and simulation models are being presented for the SC in this sector, an integrated formal structure is evidently required for guiding the development of and evaluating these models. Therefore, in this research we systematically review and identify existing frameworks for modelling SCs with the interest of highlighting the ones relevant to the forest products SCs. While we find no framework specific to the forest products industry, we identify a number of existing frameworks that could be customized to represent the industry's SC.

Keywords. Modeling framework, agent-based modeling, forest products, supply chain management, systematic literature review.

Acknowledgements. This research was supported by the Natural Sciences and Engineering Research Council of Canada (NSERC) Strategic Network on Value Chain Optimization (VCO).

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Dépôt légal – Bibliothèque et Archives nationales du Québec
Bibliothèque et Archives Canada, 2014

1. Introduction

Forest products industries are an important part of the Canadian economy, contributing $24 billion to the national GDP and $26 billion to total exports in 2012 and providing a major source of employment in many rural communities (FPAC 2013). However, their contribution has been dwindling (Canadian Forest Service 2012) over the past two decades as a result of various factors, including the changing market conditions, increasing competition from other countries, decreasing availability of high quality old-growth timber, and various trade barriers. To improve the performance of the industry, it is necessary to study the operations and interactions of all the relevant entities involved in it, which may be achieved with the aid of Supply Chain Management (SCM) techniques.

SCM has made it possible for organizations across the globe to improve their performance by reviewing and redesigning their network of suppliers, facilities, and customers. This management philosophy involves collective planning of the activities of all nodes along the logistic network of an organization, from the raw material procurement to the final product distribution and sales, while improving customer satisfaction, operations and services efficiency as well as value creation (Stadtler and Kilger 2005). SCM also implies a continuous exchange of information and the alignment of the objectives of all the network members.

Each manufacturing or service industry has a specific supply chain (SC) designed to meet the needs of its final consumers. Forest products SCs in particular are categorized as divergent SCs; i.e. the number of products multiplies along the chain. A typical forest products SC is shown in Figure 1. Harvested trees (logs) from the forest are sent to various primary wood processing facilities directly or after being sorted in a log sort yard (based on their diameter, quality, species, etc.). Next, there are secondary wood processing facilities that use the products or by-products of the primary facilities (e.g. lumber or sawdust) to produce final products (i.e. value-added wood products or bio-energy) that will be distributed to retail units or directly to final consumers.

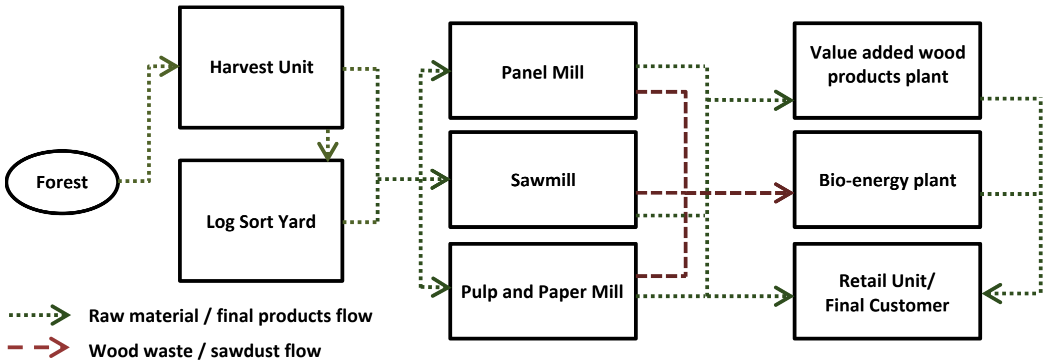

Figure 1. A typical forest products supply chain

It should be noted that the entities in Figure 1 may act independently, or be part of an integrated forest company. Furthermore, considering the public interest and concern in the forest industry, the operations of these SCs are heavily impacted by decisions of external players such as governments or environmental organizations. Consequently, forest products SCs can be viewed as complex networks, consisting of autonomous interacting units. Considering such complexity and the importance of forest industries for Canada, it is not surprising that substantial effort has been dedicated to studying forest products SCs in recent years (Santa-Eulalia et al. 2011b, Jerbi et al. 2012, Shabani and Sowlati 2013) . While an increasing number of mathematical and computer models are being developed to implement various facets of SCM theory and practice in forest products industry, it is becoming evident that a complete and integrated formal structure covering the whole SC is necessary for guiding the development of and evaluating these models. A common representation and understanding of their components would also be useful, as it would facilitate their development, implementation and dissemination to end-users and decision makers. Furthermore, a common framework would create a benchmark to compare various modelling practices.

Therefore, in this research we systematically review and identify existing frameworks for modelling integrated forest products SCs, based on a Systematic Literature Review (SLR). A complete state-of-art review in this area is still lacking in the scientific literature. By investigating the components of these frameworks and evaluating them with regards to their development objectives, we are able to create a reference of existing frameworks in different application areas, identify potential research gaps, and detect examples that can be used in order to develop a framework for forest products SCs.

The methodology for the SLR will be presented in the next section followed by its descriptive and thematic findings. Next, the discussion section addresses the SLR questions, followed by concluding remarks.

2. Systematic Literature Review

A framework is a non-software specific collection of concepts and definitions, along with the relationships among them, which describes the objectives, inputs, outputs, content, assumptions and simplifications of the model (Robinson 2007). In addition to these fundamental elements, the modelling framework that we look for needs to be generic; i.e. it must have the ability to be applicable to a variety of SCs with minimal modifications. It can be constructed based on empirical knowledge, existing theory, and exploratory research. “Concept maps” are a common method for creating frameworks, as they help graphically in showing the relationships among different concepts and entities of the relevant research topic (Maxwell 2005). A successfully developed framework also needs to be credible so the practitioners and modellers can confidently utilize it (Robinson 2007).

A number of frameworks have been developed for representing processes and decisions in generic manufacturing SCs such as SCOR (Supply Chain Council 2008) or the Global Supply Chain Forum Model (Lambert 2008) with great academic and commercial credibility. Growing acceptance and utilization of such frameworks is a result of their success in improving the efficiency of various SCs. For example, an increase in profitability (between two to six times) has been reported within the first year of SCOR implementation (Poluha 2007).

In order to analyze those frameworks and highlight some concepts, methodologies, and guidelines that would be useful by acting as a blueprint for a forest industry-specific framework, a Systematic Literature Review has been conducted. An SLR is “the application of scientific strategies that limit bias to the systematic assembly, critical appraisal, and synthesis of all relevant studies on a specific topic” (Cook et al. 1995). While SLR has emerged from the medical research field (Cook et al. 1995, 1997), it has been utilized in a variety of contexts, including software engineering, and management (Tranfield et al. 2003, Kitchenham et al. 2004, Seuring and Müller 2008). SLR is different from a *narrative* review where researchers use ad-hoc literature selection that could result in a biased review. The goal of SLR is to provide a synthesis of studies that has transparent guidelines and is reproducible.

When conducting literature reviews, one major challenge is that it is impractical to read everything, unless perhaps for emerging fields (Seuring and Müller 2008). To address this challenge, SLR guidelines help in clearly defining the scope of the review, selection criteria, and specific research questions which facilitates the review process.

Three stages can be identified for an SLR (Tranfield et al. 2003), as shown in Figure 2: Planning the review, *conducting* the review, and *reporting and dissemination*. The planning stage requires the review team to identify the need for a review and define the research questions to be addressed. In the conducting stage, a comprehensive search is performed and the studies are selected based on transparent criteria to avoid bias. The selected studies are then assessed based on the research questions defined in the planning stage. The results of the assessment are then synthesized and a conclusion is drawn based on the goal of the SLR. Finally, the conclusions and findings of the SLR are reported to be available to practitioners and researchers. At this stage, aside from the "thematic" findings, a "descriptive" analysis is normally provided as well to indicate information such as journal names, years of publication, geographical areas, etc.

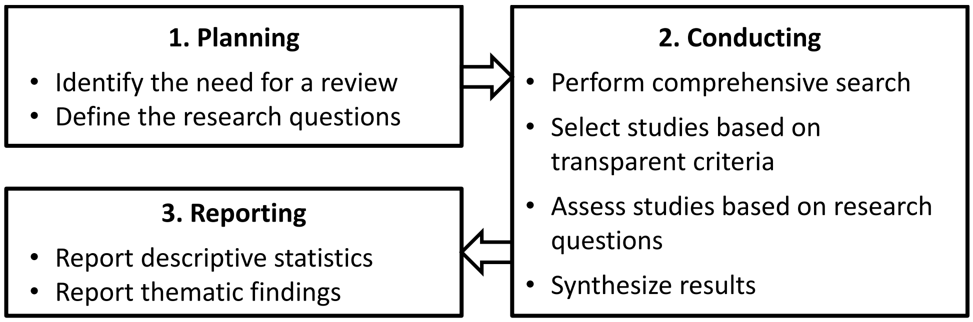

Figure 2. Stages of an SLR

We have used this methodology to conduct our literature review. The details of the three stages adapted for our context are presented here:

2.1 Planning the SLR

There is a need for developing a framework to model forest products SC, as discussed in the previous section. There exist a number of generic frameworks in various application areas that could be useful for developing an industry-specific framework. The goal of this SLR is to identify such modelling frameworks, therefore the research questions to be addressed are:

Q1: How many studies proposed a SC modelling *frameworks* in the context of forest industries during the review time frame?

Q2: How many studies proposed a SC modelling *frameworks* in other fields (not forestry) during the review time frame?

Q3: What were the general Key Performance Indicators (KPI) discussed in the reviewed studies (overall profits, costs, etc.)?

Q3.1: Focusing on forest products industries, by comparison to other countries, which KPIs in Canadian studies have received the most attention and which ones have been neglected?

Q4: What were the methodological approaches in the reviewed studies (traditional optimization, agent-based modelling, discrete-event simulation, etc.)?

Q5: What are the shortcomings in modelling the forest value chains in Canada?

Q6: What would a new framework need to propose to address those shortcomings?

2.2 Conducting the SLR

Search method and selection criteria. We searched the following electronic journal databases whose records are crawled (indexed) by Google Scholar search engine: Elsevier Science direct, JStor, SCOPUS, Emerald, Sage online, Springer link, and Wiley Online. Web of Science database was searched separately using the same keywords. We believe that these databases cover the vast majority of prominent scientific publications and would result in a comprehensive picture of the current state of the literature.

In order to narrow down the review field and select the most relevant studies, we selected the articles that included the following terms in their *title*: "framework" or "conceptual model" or "architecture" and the following terms in either their *title*, *abstract* or designated *keywords*: "supply chain" or "value chain", and "model*"[1]. For example, if an article had only the terms "framework" and "model" in the title, it was not selected. Including the search term "model*" was necessary as there were many instances of conceptual models that did not deal with developing mathematical or computer models, but rather aimed to describe or clarify the concepts of SC management (Chen and Paulraj 2004, Cigolini et al. 2004).

[1] Search term "model*" was used to include all words starting with "model" such as "modelling" or "modeled".

At this stage, articles that met the search term criteria but were clearly unrelated to SC management or modelling literature were excluded[2], as well as articles that primarily focused on aspects such as SC risk analysis or SC performance measurement rather than on the design and modelling stages (Gunasekaran et al. 2004).

Time frame. In choosing a time frame for the SLR, the goal was to decide on one that was long enough to include a large number of published articles that represented the state of the scientific literature, but not too long as to make it impractical to review all the selected articles. Using standardized frameworks for SC modelling has been gaining increasing attention during the past decade, with SCOR model being one of the most prominent frameworks. Huan, Sheoran, and Wang (2004), and Lockamy III and McCormack (2004) were among the first researchers to review the SCOR model and its applications; discussing its advantages and issues. Therefore, year 2004 was selected as the starting point of our review, with 2012 being the final year of the time period.

Evaluation criteria. The evaluation criterion was to what extent the presented frameworks matched the definition of a "modelling framework", as stated in the introduction. The generality of the framework (whether or not it included concepts that could be easily adapted to various application areas) was also a key factor. This was important as many studies claimed they were offering a framework, but presented SC models that were designed for specific industries and situations only.

2.3. Reporting the SLR results

This article presents the results of the SLR by discussing both the "thematic" findings and the "descriptive" information. The descriptive results are presented in the next section, where aggregated information shows how the articles have been distributed in terms of publication

[2] For example a study on ergonomic design of workstations was excluded although it included the search terms.

year, research origin country, and journal categories. The thematic findings are presented in a separate section, where individual articles are briefly discussed and evaluated and the research questions stated above are answered.

3. SLR Descriptive Statistics

From the total of 86 articles in the search results, 58 were considered in the review process after the exclusions mentioned previously, 10 of which could be connected to forest products SC (including one review article), as presented in the following section. Figure 3(a) shows the number of published articles in each year of the review time frame, clearly indicating an increased number during the later years. This can be attributed to growing volume of available SC models and the interest in defining frameworks and protocols for standardizing them. Figure 3(b) shows the articles grouped based on the journals that published them. The grouping is done based on the general area of focus of each journal, even though there may be some overlap. Considering that developing standards and protocols for software architecture development and evaluation is common practice in computer science and information technology areas, it is not surprising that a large number of articles are published in related journals.

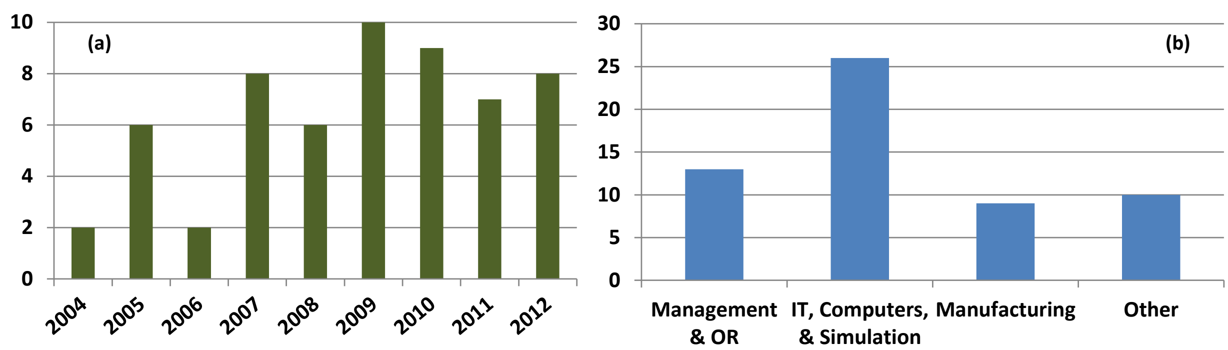

Figure 3. Number of reviewed articles based on: (a) Publication year, (b) Journal topic

Finally, grouping the articles based on country (according to the printed association of the first author) as in Figure 4 shows that the majority of research is performed in the European countries, including the Netherlands, Portugal, and France. The Americas are close, with the majority of articles associated with Canadian researchers. Asian researchers (especially in Taiwan and Japan) are next and overall it seems that the research interest on this topic is shared globally.

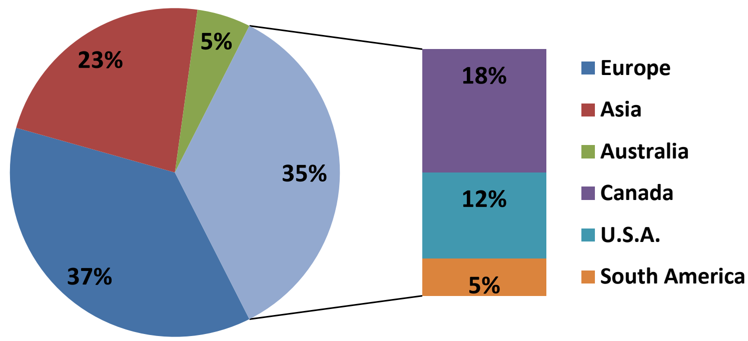

Figure 4. Reviewed articles by associated country of the first author

4. SLR Thematic Findings: Frameworks for SC Modelling

In order to present the key information from the reviewed articles, main aspects of each study are summarized in Tables 1 and 2. A number of reviewed articles offer models that are designed for a distinct type of SC and cannot be extended to other application areas without drastically changing their structure or formulation. While these models are not discussed in detail, they are presented in Table 1 as part of the SLR(Galasso et al. 2009, Costantino et al. 2009, Son et al. 2009, Verderame and Floudas 2009, Acar et al. 2010, Akgul et al. 2012, Wang et al. 2012)(Galasso et al. 2009, Costantino et al. 2009, Son et al. 2009, Verderame and Floudas 2009, Acar et al. 2010, Akgul et al. 2012, Wang et al. 2012)(Galasso et al. 2009, Costantino et al. 2009, Son et al. 2009, Verderame and Floudas 2009, Acar et al. 2010, Akgul et al. 2012, Wang et al. 2012). Classifying such models as "frameworks" may partially be true because of the ambiguity of this term. This issue has previously been raised by Santa-Eulalia (2011a), in an SLR of the frameworks for Advanced Planning and Scheduling (APS) of the agent-based supply chains from 2007 to 2010. Similar to the present work, his results suggested inconsistency in using the terms "framework" or "conceptual model". In fact, his results showed that only 21% of the reviewed studies addressed methodological aspects of the SC modelling that would qualify them as frameworks.

Table 1 also includes two relevant review papers that were among the SLR search results.

Table 1. Summary information for the literature related to search keywords but not qualified as "frameworks" according to the definition employed in this study

References	KPIs	Techniques/Methodology	Application Area
Higgins *et al.* (2004)	Total profits	Combinatorial optimization, simulation	Australian Sugar production
Neiro & Pinto (2004)	Total profit	MIP	Brazilian Petroleum industry
Georgiadis *et al.* (2005)	Fill rate, lead time	System Dynamics, simulation	Greek Food supply chain
Lu *et al.* (2005)	Total cost	Agent-Based Modelling (ABM)	Elevator manufacturing
Melo *et al.* (2006)	Total cost	MIP	Experimental data
Kamath & Roy(2007)	Various (cost, order levels, sales volume, etc.)	System Dynamics	Experimental data
Guillen *et al.* (2007)	Change in equity	MIP	European chemical process industry
Sammons *et al.* (2007)	Profits, environmental metrics	MIP, Mixed Integer Non-Linear Programming (MINLP)	Bio-refinery
Jung *et al.* (2008)	Total cost	Linear programming, ABM	Experimental data
Zheng (2008, 2009)	Total cost	MIP	No case study
Costantino *et al.* (2009)	Total cost	Simulation, auction mechanisms	Italian construction industry
Fathollah *et al.* (2009)	Cost, inventory level, production time, etc.	Conceptual modelling	Iranian automotive industry
Galasso *et al.* (2009)	Total cost	Linear programming combined with simulation	French Aeronautical industry
Son *et al.*(2009)	Total profit	Deterministic and stochastic programming	Various industries (discrete and process manufacturing)

References	KPIs	Techniques/Methodology	Application Area
Verderame & Floudas (2009)	Total cost	MIP	A chemicals production facility
Acar, Kadipasaoglu, & Schipperijn (2010)	Total cost, backorders	MIP, simulation	A global chemical production SC
Diostineau *et al.* (2010)	Cost, distance	ABM, Graph theory	Internet trade
Paxton & Tucker (2010)	General (any KPI)	SCOR	NASA
Azouzi and D'Amours (2011)	No KPIs	Literature Review	No case study
Marchetta, Mayer, & Forradellas (2011)	General (any KPI)	ABM, Business Process Modelling (BPM)	Automotive industry
Santa-Eulalia (2011a)	No KPIs	Literature Review	No case study
Akgul, Shah, & Papageorgiou (2012)	Total daily cost, Greenhouse gas emissions	Multi-objective optimization, MIP	Bioethanol production in the United Kingdom
Kadadevaramath *et al.* (2012)	Total cost	MIP, particle swarm optimization	No case study
Wang, Hsieh, & Hsu (2012)	Total profit, total cost	MIP	Taiwanese consumer electronics industry

Three frameworks have been the research basis for a number of the reviewed articles even though they were not among the SLR search results:

- **SCOR Model**: perhaps the most renowned SC modelling framework, SCOR (Supply Chain Operations Reference Model) was developed by the Supply Chain Council to provide a business process reference model that links business processes, performance metrics, and best practices. It includes five primary management processes of Plan, Source, Make, Deliver, and Return which can be used to model a wide range of supply chains, as well as three hierarchical levels which help to break down the business processes into individual elements (Supply Chain Council 2008). According to the result of our SLR, four of the generic frameworks were based on the structure of SCOR.

- **Gaia methodology**: among the earliest agent-oriented methodologies, Gaia was developed for the analysis and design of agent-based models (ABM), not solely limited to the SC modelling application area (Wooldridge et al. 2000). It is applicable to a wide range of multi-agent systems and deals with both their macro and micro aspects. It views multi-agent systems as computational organisations consisting of various interacting *roles*, which have associated with them responsibilities, permissions, activities, and protocols. By using the metaphors of the human organisation, Gaia provides and approach that a non-technical domain expert can understand, facilitating their interactions with software developers (Henderson-Sellers and Giorgini 2005).
- **ODD methodology**: setting to address the lack of common protocol for describing agent-based models, ODD (Overview, Design concepts, and Details) was developed to facilitate the communication and replications of agent-based simulations (Grimm and Railsback 2005, Grimm et al. 2006). Similar to Gaia, ODD is not specific to supply chain models. The protocol consists of three blocks (i.e. Overview, Design concepts, and Details) which are themselves sub-divided into seven elements: Purpose, State variables and scales, Process overview and scheduling, Design concepts, Initialization, Input, and Sub-models. To present a model according to ODD, all aspects of the model should be described using these seven elements in a pre-defined sequence. Using ODD simplifies the task of understanding a simulation model and replication of the results which would consequently increase the credibility of simulation results.

The reviewed studies qualified as frameworks (33 articles) are presented in three main groups: (1) non-agent-based, (2) agent-based, and (3) forest-products-related (which includes both agent-based and non-agent-based studies), as depicted in Figure 5.

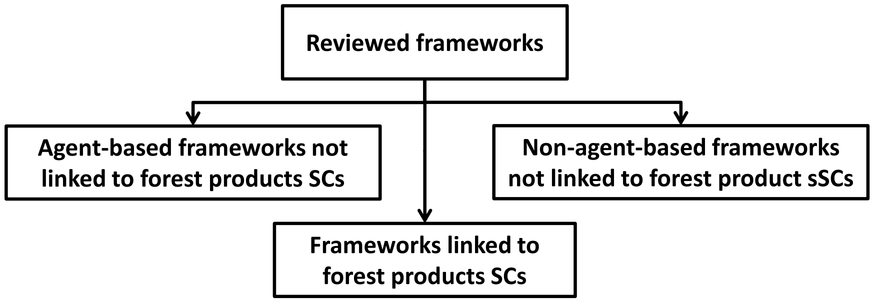

Figure 5. Categories of the reviewed frameworks

The first column in Table 2 shows whether a framework belongs to group (1) or (2), while the frameworks in group (3) are presented separately in

The earliest attempts by Frayret *et al.* (2007) presents a generic agent-based architecture to implement distributed advanced planning and scheduling (APS) systems with both simulation and planning capabilities. The proposed architecture includes two parts: the first part, based on the SCOR model, defines the organizational structure of the SC and how various elements relate to each other. The second part shows how to translate this SC structure into simulation components. While the application of the framework is shown by a case study in lumber manufacturing, this in fact is a generic APS framework with no elements in its organizational structure that are specific to forest products. Nonetheless, the ability of the framework to represent distributed SCs and to accommodate advanced planning is extremely useful in modelling forest products SCs.

Table 3.

Table 2. Summary information for the literature qualified as "frameworks", and not related to the forest products SCs

Group	References	KPIs	Techniques/Methodology	Application Area
(1)	Gunasekaran and Ngai (2005)	General (any KPI)	Literature review, conceptual modelling	Build-to-order SCs
(1)	Nagurney and Toyasaki (2005)	Total costs, total profits	Variational inequalities, Game theory	Electronic waste recycling SC
(2)	Van Der Zee & Van Der Vorst (2005)	General (any KPI)	ABM, simulation	Case study in grocery items SC

Group	References	KPIs	Techniques/Methodology	Application Area
(1)	Vieira & Junior (2005)	Lead-time, order level variations, inventory levels	Simulation	No case study
(1)	Burgess & Singh (2006)	General (any KPI)	SCOR	A public utility firm
(1)	Baltacioglu *et al.* (2007)	General (any KPI)	SCOR	Service industry (case study: healthcare)
(2)	Chatfield *et al.* (2007)	General (any KPI)	ABM, simulation	No case study
(2)	Govindu & Chinnam (2007)	General (any KPI)	ABM, Gaia, SCOR	Japanese virtual pet manufacturing
(2)	Labarthe *et al.* (2007)	General (any KPI)	ABM, simulation	Case study in golf club manufacturing
(1)	Bonfill *et al.* (2008)	General (any KPI)	MIP	Chemical process industries
(2)	Puigjaner & Guillén-Gosálbez (2008)	General economic and environmental indexes	ABM, MIP, Genetic Algorithm	Chemical process industries
(2)	Al-Mutawah *et al.* (2009)	Cost, demand fill rate, response time, manufacturing flexibility	ABM, Simulation, utility theory	Electronics
(2)	Lin *et al.* (2009)	General (any KPI)	ABM, DCOR	Design oriented SC
(2)	Xue & Zeng (2009)	General (any KPI)	ABM	Collaborative SC
(2)	Chai *et al.* (2010)	Total tardiness	ABM, Genetic Algorithm, LP	Experimental data
(2)	Ivanov (2010)	General (any KPI)	ABM, Simulation, control theory, MIP, heuristics	Adaptive SCs
(2)	Ivanov, Sokolov, and Kaeschel (2010)	General (any KPI)	ABM, Simulation, control theory, MIP, heuristics	Adaptive SCs
(1)	Salema, Barbosa-Povoa, & Novais (2010)	Total cost	MIP, Graph theory	Portuguese Glass industry
(1)	Umeda & Zhang (2010)	Inventory levels, order lead-time	System Dynamics, simulation	Discrete manufacturing SCs
(1)	Verdouw, Beulens, & Trienekens (2011)	General (any KPI)	SCOR	Dutch flower industry
(1)	Yadav *et al.* (2011)	Total profit, total cost, design complexity	Non-linear optimization, multi criteria optimization	Wiring harness manufacturing
(1)	Hahn & Kuhn (2012)	Economic Value Added (EVA), corporate value, cash flow, free cash flow, market value added	Integrated Business Planning (IBP), Stochastic Programming (SP)	No case study
(1)	Kouwenhoven, Reddy Nalla, & Lossonczy von Losoncz (2012)	General (any KPI)	Conceptual modelling	Food SCs in India and Europe

Group	References	KPIs	Techniques/Methodology	Application Area
(1)	Quaglia *et al.* (2012)	General (any KPI) *Case study KPI*: gross operating margin	MINLP	Soybean processing in a global SC

4.1 Non-agent-based frameworks

These studies present SCM concepts in an organized and graphical manner, mainly with structured modelling guidelines. These guidelines may be tailored to either optimization or simulation modelling of the SC, but they are all software-independent.

Three of these studies, however, provide no such guidelines. Gunasekaran and Ngai (2004) review the literature on Build-to-Order SCs and recommend important factors that need to be noted when developing these SCs. Burgess and Singh (2006) offer a conceptual model for analysing supply chains while including factors such as social climate, infrastructure, and governance of the organization. They suggest that only by understanding all these factors a SC can be comprehensively analysed. Finally, Kouwenhoven, Reddy Nalla, and Lossonczy von Losoncz (2012) divide SC challenges into two categories (challenges in the early stages of SC development, and ongoing challenges related to product or demand characteristics) which can be used by decision makers to analyze the bottlenecks of SCs and eliminate inefficiencies. These frameworks aid the modellers and analysts to study all aspects of a SC before constructing its model, but do not provide a standard or a protocol for its development.

A few articles presented their framework with the objective of aiding the SC **simulation** modelling efforts. Vieira and Junior (2005) present a generic structure for a SC consisting of suppliers, manufacturers, retailers, and customers. Using flowcharts, they conceptually show the decision making processes and information flow among the SC members, so it can be used to develop a simulation model later. Their depiction of SC interactions is simple, yet it covers the basic functions of order processing and product delivery. Baltacioglu *et al.* (2007) introduces a framework for service SCs based on the structure of the SCOR model. They identify key managerial activities that need to be performed to improve the service delivery and describe how the framework could be used in healthcare industry SCs. Umeda and Zhang (2010) combine system dynamics modelling and discrete-event simulation to present a modelling framework that includes the internal business processes of the SC as well as its reactions to external factors such as managerial decisions or the consumers behavior change. Using SCOR model as a basis, Verdouw, Beulens, and Trienekens (2011) aim to develop a business process modelling framework that allows rapid design and configurations of SCs that are demand-driven (as opposed to SCs with *push* system). Their framework is very closely related to SCOR; however, instead of SCOR business process diagrams, a different notation is used to represent the relationships among processes.

Majority of the studies in the non-agent-based frameworks focused on **mathematical modelling**. Yadav *et al.* (2011) develop a non-linear mathematical modelling framework for SC design that includes network design as well as the selection of products and their modularity level. Their framework includes important aspects of SC design from products selection to plant locations and transportation flows, as long as the intended products can be represented by a generic bill of materials. Hahn and Kuhn (2012) present a unified modelling framework for model-driven decision making in Value-Based Management (VBM) - which focuses on maximizing shareholder value. The authors link SCM and financial management and depict the relationships among planning hierarchies (long-term, mid-term, etc.), VBM-relevant business domains (e.g. balance sheet calculation), and performance metrics. They provide a two-stage stochastic optimization framework to combine SC performance and risk management. Since the proposed architecture does not include the planning of production and distribution stages of the SC, it cannot be utilized as a complete SC modelling framework.

In the area of process industries, two mathematical optimization frameworks are presented. One is at the operational level for simultaneous production and transportation planning in chemical industry SCs (Bonfill et al. 2008). The second framework is to simultaneously address strategic and tactical decisions in process industries. This Mixed Integer Non-Linear Programming (MINLP) framework can be used to address a range of processing industry SC problems such as resource allocation, scheduling, or retrofit design (Quaglia et al. 2012).

With the growing interest in “closed-loop” or “reverse” logistics (which take into account the SC processes required for a product’s after-sales life such as waste management, recycling, and product recovery), a number of mathematical frameworks focus on this modelling application. Looking at a SC for electronic waste recycling, Nagurney and Toyasaki (2005) present a multi-tiered optimization model of SC members and find the SC network equilibrium values for material flow and prices through solving these problems simultaneously. Wikner and Tang (2008) provide various examples and diagrams to argue that the concept of decoupling point which is extensively used in forward SCs (traditional SCs), can also be exploited to explain the structure of closed-loop SCs. Finally, Salema, Barbosa-Povoa, and Novais (2010) provide an optimization framework for a closed-loop SC, aiming to combine strategic and tactical decision-making levels.

4.2 Agent-based frameworks

The studies in this group view the SC as a collection of individual, autonomous or semi-autonomous agents that behave according to a set of goals and attitudes. In comparison to traditional models of SC, Agent-Based Models (ABMs) offer a more natural way of representing distributed SCs and are less-complex in terms of implementation (Moyaux et al. 2006).

We discovered a number of generic ABM frameworks with easy to follow guidelines and clearly defined decision rules, such as the work of Van Der Zee and Van Der Vorst (2005) and Labarthe *et al.* (2007). The latter develop a framework for mass customization of products and present a case study of their framework in Unified Modelling Language (UML) before implementing it in a simulation software tool.

Some of the reviewed ABM studies are based upon existing standards and frameworks. Suggesting that currents frameworks and standards such as SCOR are either too high level or too specific, Govindu and Chinnam (2007) propose an integration of SCOR standards and the Gaia methodology in a framework called MASCF. Incorporating more detailed levels and decisions with SCOR allows modellers to follow certain steps and develop an ABM of any organization's SC. Lin *et al.* (2009) integrate the DCOR (Design Chain Operations Reference) reference model (which is similar to SCOR model, but tailored to design-oriented SCs) with ABM to create a generic framework that is easy to follow. However, their framework does not include traditional processes of a manufacturing/distribution SC.

A number of the reviewed works combine **ABM concepts with traditional simulation or optimization methods** to generate hybrid frameworks. For example, Chatfield *et al.* (2007) argue that while ABM has many advantages over traditional SC simulation, it cannot address the order-driven nature of many SCs since the life cycle of an order (i.e., a product) may include more than one agent. They propose a new framework that mixes the two simulation worldviews, and they show its applicability by developing a software platform and simulating a hypothetical SC. Puigjaner and Guillén-Gosálbez (2008) combine ABM simulation, optimization, and heuristics to facilitate holistic modelling of chemical process industries, incorporating a variety of economic and environmental KPIs.

Collaborations and negotiations among agents are another area of focus in the reviewed articles. Al-Mutawah *et al.* (2009) present an agent-based framework to model the sharing of cultural beliefs (a.k.a "tacit knowledge") among SC members. Agents are allowed to interact and change their beliefs if it improves their utility. While this framework is useful at a high level management view, it is not directly relevant to SC operations planning. Xue and Zeng (2009) also provide a conceptual framework for modelling and implementing the infrastructure for collaboration in SCs. In a related context, Chai *et al.* (2010) propose a multi-agent model of the SC for concurrent negotiations at the operational level among customers and the manufacturers, as well as among manufacturers and the suppliers. The goal is to modify the production plan with respect to inventory levels, customer orders, and the supplier bids, to improve the profitability of the SC.

Finally, the issue of **adaptive planning of SCs -** where there is a feedback between the operations and plans of SC - is discussed by Ivanov (2010) and Ivanov, Sokolov, and Kaeschel (2010). The authors present a framework that links supply chain strategies, design, tactics, and operations through a feedback module. There are multiple building blocks to this framework that combine optimization and simulation with control theory and ABM. The resulting framework is translated into a software platform; however its concepts and elements are software independent and can be used to develop a variety of adaptive SC models.

4.3 Forest-industry-related frameworks

While SC modelling and simulation for the forest products industries have been presented in literature for well over a decade, we found surprisingly few studies claiming to present frameworks for such a purpose. While there have been studies that claimed they presented a framework, they were either too general to be considered forest-industry-specific, or too narrowly focused on one application. An industry specific framework can benefit the modellers by defining all existing elements of a forest products SC and their links. It would result in standardized modelling building blocks that could be adapted more easily in future research projects. It could also facilitate the transition of academic research to industry, as it would allow industry problems to be identified and translated into a formal approach that would streamline the development, modifications, and evaluations of forest value chain models.

The earliest attempts by Frayret *et al.* (2007) presents a generic agent-based architecture to implement distributed advanced planning and scheduling (APS) systems with both simulation and planning capabilities. The proposed architecture includes two parts: the first part, based on the SCOR model, defines the organizational structure of the SC and how various elements relate to each other. The second part shows how to translate this SC structure into simulation components. While the application of the framework is shown by a case study in lumber manufacturing, this in fact is a generic APS framework with no elements in its organizational structure that are specific to forest products. Nonetheless, the ability of the framework to represent distributed SCs and to accommodate advanced planning is extremely useful in modelling forest products SCs.

Table 3 presents the KPIs and the methodologies used in the reviewed articles. Interestingly, the majority of these studies are geared towards the Canadian industries. It should be noted that from the 10 articles that were relevant to the forest industry, one was a literature survey articles.

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represent distributed SCs and to accommodate advanced planning is extremely useful in modelling forest products SCs.

Table 3. Summary information for the literature on forest products SC modelling frameworks

References	KPIs	Techniques/Methodology	Application Area
Frayret *et al.* (2007)	General (any KPI) *Case study KPI*: total cost, resource utilization rate, backorders, total production value	ABM, MIP, constraint programming	Canadian lumber industry
Santa-Eulalia, Frayret, & D'Amours (2008b)	General (any KPI)	ABM	Canadian lumber industry
Santa-Eulalia, D'Amours, & Frayret (2008a, 2010, 2012)	General (any KPI) *Case study KPI*: average inventory, backorders	ABM, MIP, constraint programming, heuristics	Canadian lumber industry
Weigel, D'Amours, & Martel (2009)	Total profits	MIP	Canadian pulp and paper industry
Laflamme-Mayer, Janssen, & Stuart (2011)	Functional unit cost (e.g., product or process)	Activity-Based Cost (ABC) modelling	Canadian pulp and paper industry
Marques *et al.* (2011)	General (any KPI)	Business process modelling, Enterprise Architecture	Portuguese pulp and paper industry
Jerbi *et al.* (2012)	Revenue minus variable costs	LP, simulation	Canadian lumber industry

In a series of publications, Santa-Eulalia, Frayret, and D'Amours (2008b) and Santa-Eulalia, D'Amours, and Frayret (2008a, 2010, 2012) present FAMASS, a framework for analysis and identifying simulation requirement of distributed agent-based supply chain models. FAMASS creates a top-bottom approach to analyse and understand the simulation steps (from a large-scale system view to individual agents). Consequently, any supply chain can be decomposed into various interacting agents and the necessary requirements to create an agent-based model can be expressed in details. The authors validate the usefulness and ease-of-use of their framework through a case study in the Canadian lumber manufacturing industry. Similar to the work of Frayret *et al.* (2007), FAMASS is also a generic framework that is not customized for forest products industry, but certainly has the potential to be adjusted or modified to reflect the specifics of forest industry's SCs.

Weigel, D'Amours, and Martel (2009) present a mathematical modelling framework for including the properties of wood fiber in determining the optimal allocation of fibre and production plans in the pulp and paper industry. They present a Mixed Integer Programming (MIP) model and validate it using data from the Canadian pulp and paper industry. While their generic model is shown to be adaptable to various academic and industrial scenarios, it is narrowly focused on pulp and paper industries, and is not easily adjustable for application in other forest products industries.

Laflamme-Mayer, Janssen, and Stuart (2011) present an operations-driven cost model to improve the cost calculations of continuous processes such as that of the pulp and paper industry. While their proposed model can be useful for SC design through comparing the costs of different design alternatives, it is not a modelling framework for developing a simulation or optimization model of the SC.

Marques et *al.* (2011) utilize and extend an Enterprise Architecture (EA) framework to incorporates the forest practitioners and stakeholders in forest management decision support system (DSS) development. The authors hold workshops for stakeholders of a pulp and paper company and capture their knowledge and expertise through business process modelling and information representation. Consequently, the technological requirements for developing a wood supply management DSS emerge. This framework focuses on the first step in developing any SC model: identifying the model elements and the requirements, with an emphasis on the importance of including the human dimension. Their methodology can be adopted to include other forest industries, as long as enough time and resources are spent on gathering information from the stakeholders and decision makers.

Jerbi *et al.* (2012) develop a framework that combines optimization and simulation to link mid-term and short-term decisions. They use an optimization model (LogiLab) to generate optimal mid-term production and transportation plans, and then combine these plans with the stochastic details of the SC in a discrete-event simulation model (implemented in Simio software). The current model is specific to softwood lumber SCs with a *push* system, where operational decisions are impacted by mid-term plans, not the customer demand. Additionally, the platform is software-dependent. Therefore, it is not suitable to adopt as a generic modelling framework.

In addition to the studies mentioned above, a review article by Azouzi and D'Amours (2011) addresses the issue of standardization of modelling efforts for collaborative forest products SCs. Authors draw attention to the importance of a framework that allows different and multidisciplinary SC models to cooperate and have Information and Knowledge Sharing (IKS) throughout. Some generic and industry-specific standards for IKS are reviewed. They focus prominently on communication standards, especially those used for electronic data exchange which can facilitate the real time IKS in SCs. Additionally, they provide a number of agent-based platforms that have been developed for forest products SCs, which have been implemented using ABM specific software. The authors propose that a first step towards collaborative SC modelling is a common ontology and a unified modelling framework for which they suggest ODD framework (Grimm et al. 2006) as a starting point.

The general lessons and insights from the SLR results are discussed in the next section.

5. Discussions

We can now revisit the SLR research questions and draw some conclusions based on the responses, summarized in Table 5.

Q1 and **Q2** can be answered by looking at Tables 2 and 3. There have been 24 studies proposing frameworks in areas other than the forest products industries and 9 studies with frameworks which are either focused on forest industries or have a case study that involves forest products. The small number of articles focused on forest products SC modelling frameworks clearly shows a research gap. Although the reviewed articles have started to address this gap, there is still need for considerably more academic and industry research to reach a credible unified framework that can be adopted for forest products industries.

Q3 involves the KPIs that have been considered in each work. Table 4 shows the ratio of articles using each KPI (note that the total is more than 100% since some articles use multiple KPIs). It is seen that the majority of the general application frameworks (54%) allow the use of any chosen KPI (e.g. costs, profits, service levels, etc.). This is a positive feature, considering that a general framework should accommodate a variety of performance measures based on the requirements of each specific model. Among frameworks with pre-defined KPIs, there is a focus on customer-related KPIs such as order lead-times or demand fill-rate. Other traditional KPIs such as cost or profit are not featured prominently. Studies related to the forest products industry also include a majority that allows generic KPIs (56%), with case study examples including financial measures as well as customer-related measures such as back-order volumes. However frameworks that did not allow for generic KPIs mainly focused on costs and profits and have no mention of customer-related KPIs which shows a lack of market focus in this domain compared to other application areas. Other more SC-related KPIs, such as supply chain alignment, integration, agility etc., or even KPIs related to recent concerns about supply chain sustainability (including environmental and social aspects) are not presented in the reviewed works.

Table 4. Ratio of SC frameworks using various KPIs

KPI	General (any KPI)	Cost	Profit	Customer related	Other
General application frameworks	54%	8%	4%	17%	25%
Forest-industry-related	56%	11%	22%	0%	0%

To answer **Q4** we look at Figure 6 which shows the percentage of each group of techniques used to develop the frameworks. The simulation category includes both traditional and ABM simulations. There are also hybrid frameworks that combine optimization and simulation. It is seen that no individual method is dominant in the general applications. However, the articles related to the forest industry have a majority of hybrid methods. Interestingly, if we only compare ABM frameworks (11 articles) with the remaining ones (12 articles) by looking at Table 2, we see that nearly half of the frameworks accommodate agent representations of SC. This observation holds true for articles with forest industry relevance; over half of them are ABM focused. This indicates a positive trend towards formalizing the modelling efforts in ABMs, considering the growing number of studies that utilize ABM to represent forest industry SCs (a recent review of such studies has been presented by Frayret (2011)). A standard modelling framework would facilitate their development and implementation which in turn can increase their popularity with the SC modelling community.

Looking at

The earliest attempts by Frayret *et al.* (2007) presents a generic agent-based architecture to implement distributed advanced planning and scheduling (APS) systems with both simulation and planning capabilities. The proposed architecture includes two parts: the first part, based on the SCOR model, defines the organizational structure of the SC and how various elements relate to each other. The second part shows how to translate this SC structure into simulation components. While the application of the framework is shown by a case study in lumber manufacturing, this in fact is a generic APS framework with no elements in its organizational structure that are specific to forest products. Nonetheless, the ability of the framework to represent distributed SCs and to accommodate advanced planning is extremely useful in modelling forest products SCs.

Table 3 to answer **Q5** and **Q6**, we see that all but one of the articles are focused on Canadian forest products industry. Considering the challenges facing the forest products industry in Canada and the increasing efforts in SC modelling research, this observation is a positive indication. We may not be able to compare the Canadian forest industry SC modelling frameworks with ones from other countries, but there exist many general application frameworks that can be viewed as good targets to strive for. A framework that is supported by industry collaboration, similar to SCOR, will be more easily accepted and implemented. The existing frameworks such as FAMASS or the work of Frayret *et al.* (2007) have proved to be applicable to forest products SCs.

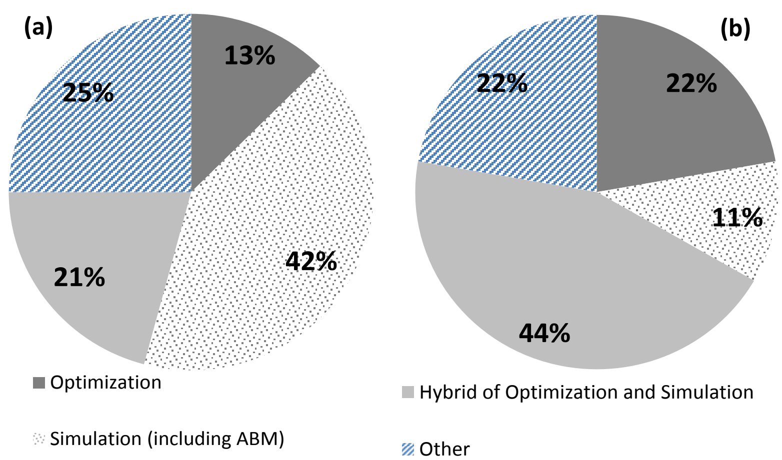

Figure 6. Methodology used in SC modelling frameworks; a) general applications, b) forest-industry-related

While developing more frameworks to address the specific issues of the industry is valuable, the next step could be to involve stakeholders from the forest products industry to further customize the existing general frameworks to the decisions and processes of the industry. It is possible to classify processes and decisions within the forest products SC according to the concepts and entities of existing frameworks, and identify the links and feedbacks among them. If some processes seem to not fit within the limits of a framework, modifications could be made to include them as well. This approach minimizes the development effort while meeting the specific requirements of forest products SCs. Nevertheless, if the developed framework is to be used by industry practitioners, it is important to include their knowledge and experience when developing a new framework or modifying an existing one. Another direction could be to expose the academic researchers to existing frameworks through special meetings or conferences and encourage them to follow an established standard when developing their SC models.

Table 5. Answers to the SLR research questions

Research Question	Answers
Q1. Number of studies proposing frameworks related to forest products SCs	9
Q2. Number of studies proposing frameworks related to other SCs	24
Q3. Types of KPIs used	The majority allowed for any KPI; for the remaining frameworks, customer related KPIs were represented the most
Q3-1. Types of KPIs used in forest product SC frameworks	The majority allowed for any KPI; while the remaining focused on costs and profits, there is a lack of focus on customer or sustainability-related KPIs
Q4. Techniques used in the reviewed frameworks	A variety of techniques are used with a strong trend towards using ABM for representing SCs as well as combining optimization and simulation techniques
Q5. Areas neglected in Canadian studies on forest products SC modelling frameworks	Cannot be compared to other countries as all forest products studies were focused on Canada, indicating the interest and research potential in the country
Q6. Recommendations for a new framework	Including industry stakeholders to increase the industrial credibility and utilization of the framework

6. Conclusions

In this article we conducted an SLR of the research literature on SC modelling frameworks and standards between 2004 and 2012. The SLR objective was to identify the potential existing frameworks that could aid research on modelling the forest products SC. 57 articles were reviewed and 32 frameworks were identified, 9 of which were relevant to the forest products industries. The results suggest that there exist frameworks and standards which are potentially applicable to the case of the forest products SCs, mainly within the Canadian research community. Development of mathematical and simulation SC models of the forest products industry can benefit from such frameworks as they will facilitate the process and lend more credibility to the results.

In the interest of practicality, the results of this SLR were limited by the selection of search terms, as there may have been relevant articles which did not fit the search criteria. Additional literature surveys can be performed with a wider range of search terms to expand the current work. Furthermore, the next step in developing a modelling framework for the forest product

SCs can begin by utilizing one of the identified existing frameworks, such as SCOR or FAMASS, and tailoring it to the industry, making modifications as necessary.

7. Acknowledgments

This research was supported by the NSERC Strategic Network on Value Chain Optimization (VCO).

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