From a Literature Review to a Research Direction: Integrative Supply Chain Network Optimization Models

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ABSTRACT

The number of studies addressing supply chain network (SCN) optimization and modeling has grown substantially over the last decade. Here we review the strategic SCN optimization literature and discuss several model features, including decision variables, model objectives, model nature, solution algorithms, SC risk, competition modeling and the multi-objective solution method. Based on this literature review, we propose a novel approach in which SCN optimization modeling and competitive facility location are simultaneously examined.

Keywords: Supply chain, Network optimization, Literature review, Supply chain risk modeling, Multi objective optimization

1 INTRODUCTION

A supply chain (SC) may be defined as an integrated effort where various entities (suppliers, manufacturers, distributors, and retailers) work together in order to: acquire raw materials, convert these materials into specified final products, and deliver these final products to the retailers. Even though researchers have studied the various processes of the SC individually, there has been an increasing attention placed on the performance, design and analysis of the SC as a whole. Specifically, for the last two decades, there has been an increasing number of studies (SCN modeling and optimization studies) to optimize the overall SCN in order to decrease the overall cost or maximize the total revenue.

SCN optimization and modeling is a well-established research area and the number of studies addressing this issue has grown substantially over the last decade. SCN design and optimization problems cover a wide range of studies ranging from single to multi-product models, from two tier networks to more complex networks, from deterministic models to stochastic models, and from mathematical models solvable to exact optimums to heuristic solution models. Here we present a comprehensive literature review of recently developed (from 2009 to 2013) SCN optimization models to identify the different characteristics of the various models and common trends.

Such a review also has led us to identify the need for a new SCN optimization model in which the concept of SCN optimization is simultaneously considered with competitive facility location.

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The remainder of the paper is organized as follows: the next section provides brief information on the review methodology and the scope of the literature review. Section 3 focuses on reviewing SCN optimization models and providing the findings on the different characteristics of the models. Section 4 is devoted to reviewing multi-objective SCN optimization models. The paper ends with final conclusions about the current literature and proposes a new model which aims to close the identified gaps.

2 METHODOLOGY AND SCOPE

In this review, our focus was on identifying studies that included a strategic-level SCN model. Models that considered the reconfiguration or relocation of the SCN nodes and arcs (0-1 decisions) were considered as strategic-level models.

To generate a list of relevant articles published between 2009 and 2013, "SC network modeling" was entered as a search term in the Science Direct database. This generated an initial list of articles, from which 495 that were published only in the most relevant journals were selected.

In previous reviews of SCN optimization models (e.g., Beamon [10]; Meixel & Gargeya [41]; Melo et al. [42]; and Tehseen & Amos [68]), models were typically classified according to different characteristics, such as the nature of the models (deterministic vs. stochastic or mathematical vs. simulation), the performance measures used and the choice of solution algorithm.

In a classical SCN optimization problem there generally is a single commodity and period of analysis. Decision variables are classically defined as the number and the location of SC nodes and the decisions on the network traffic. The model is generally defined as deterministic and the problems are generally solved by either mathematical optimization techniques or generic heuristic approaches. Recently, many extensions to classical problems have been considered and studied to cope with more realistic problems. Therefore we attempt below to provide a classification scheme for the models to fully analyze how SCN optimization models have evolved recently. Our taxonomy characterizes SC models along seven dimensions: 1) number of periods (i.e., one or multi-periods); 2) number of commodities (i.e., single or multiple items); 3) decision variables; 4) model nature (e.g., deterministic, stochastic, simulation or fuzzy-based); 5) number of objective functions (i.e., single or multi-objective); 6) performance measures and objectives (e.g., profit maximization, cost minimization or service level maximization); and 7) solution algorithm (e.g., exact solution, generic heuristic models or problem-specific heuristic models).

3 STRATEGIC SCN OPTIMIZATION MODELS

3.1 Number of commodities and number of periods

In classical SCN optimization models, multiple commodities are aggregated into a single commodity. However, in recent years, the number of multi-commodity models has increased. Similarly, single period models are classically thought to represent long planning periods over which strategic-level decisions are made. Recently, multi-period models have been increasingly used to represent the changes throughout the epochs of the long planning periods. Table 1 presents a summary of the selected articles characterized by the number of commodities and the number of periods considered.

Table 1. Multi Commodity and Multi Period Models

Type of the Model	# of Articles
Single Commodity - Single Period Models	25
Single Commodity - Multi Period Models	5
Multi Commodity - Single Period Models	15
Multi Commodity - Multi Period Models	26
Total	71

3.2 Decision variables

Classical SCN optimization models determine the optimum location of SC nodes and the optimal product flow(s) between them. However, 23 different decision variables have been used in the reviewed articles (Table 2). Given that facility location selection and optimal product flow decisions are the classical decision variables for SCN optimization models, it is not surprising that the majority of the models (69 % and 97% of the models respectively) explicitly include these decision variables.

The reviewed SCN optimization models were often combined with tactical level decisions, such as inventory optimization decisions (15 articles), production scheduling (13 articles) and distribution scheduling decisions (6 articles).

Table 2. Decision Variables in Reviewed Articles

Decision Variable	# of Articles	%
Optimal Product Flow	69	97,18
SC Facility Location Selection	49	69,01
Capacity / Capacity Expansion Decision	19	26,76
Inventory Level Decisions	15	21,13
Production Level (rate) Decision Production Scheduling	13	18,31
Supplier Selection	12	16,90
Price (at final market or at each echelon)	10	14,08
Demand Satisfaction Level	8	11,27
Distribution Scheduling	6	8,45
Transportation Mode Selection	5	7,04
Other Decision Variables	22	31,88

The prices of the work in process (WIP) products or finished products were utilized as decision variables in some models. The majority of such models were variational inequality-based models (e.g., Cruz & Zuzang [24], Nagurney [47], Nagurney & Nagurney [50], Nagurney [48], Yamada et al. [75]). Within these models, competition among SC partners was also modeled as variational inequality, with prices at each echelon used to reach balance among SC partners.

Another basic assumption in classical SCN optimization models is that demand is completely satisfied. However, recent models (e.g., Kabak & Ulengin [31], Schütz et al. [65], Li et al. [37]) have included demand satisfaction level as a decision variable. The objective here being profit maximization, with the models also attempting to identify the sales level or order fill rate that maximizes profit.

3.3 Model nature

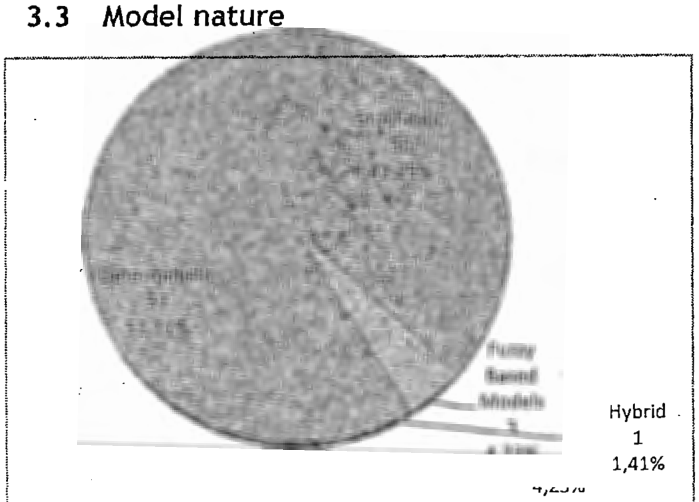

Figure 1. Classification of SCN Optimization Models

Models are most often classified according to their deterministic (i.e., variables are known with certainty) or stochastic (i.e., variables represent probability distributions of values) nature (Figure 1).

Other than deterministic and stochastic models, three of the reviewed articles (Kabak & Ulengin [31], Xu et al. [74], Nepal et al. [52]) employed fuzzy-based models, in which a probabilistic logic is utilized to handle uncertainties. Probabilistic logic deals with reasoning that is approximate rather than fixed and exact. Unlike traditional binary sets, fuzzy logic variables may have a truth value that ranges in degree between 0 and 1.

One of the reviewed articles utilized a specific hybrid approach (Pinto-Varela et al. [58]), where the model variables were defined as deterministic but fuzzy logic sets were utilized to solve multi-objectivity.

3.4 Solution methodology

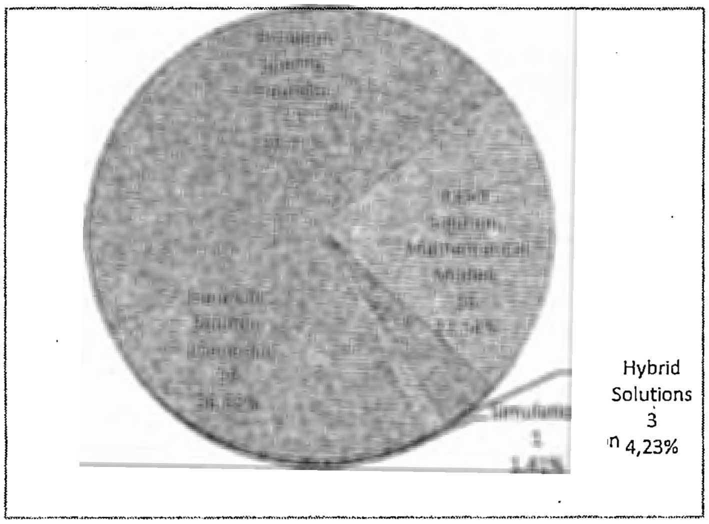

Figure 2: Solution approaches for SCN opt. problems

Figure 2 presents an overview of the solution methodologies that have been utilized for solving models. Five categories were used to classify the solution algorithms as follows: 1) exact solution, where mathematical models find exact solutions; 2) problem-specific heuristic solutions that include the use of a heuristic solution algorithm specifically developed to solve the model; 3) generic heuristic solutions that employ general solution algorithms (e.g., branch-bound, genetic algorithms, ant colony optimization and bender's decomposition technique); 4) simulation algorithms; and 5) hybrid solutions that combine two or more algorithms within a model.

3.5 SC performance measures / objective functions

The performance objectives may be categorized into two broad groups: 1) objectives that are based directly on cost or profit (e.g., cost minimization, sales maximization, profit maximization); and 2) objectives that are based on some measure of customer responsiveness (e.g., fill rate maximization, customer response time minimization, lead time minimization).

Models can also be categorized according to the number of the objective functions utilized. Therefore, we categorized the reviewed models as either single (cost minimization), single (profit maximization) or multiple objective models (Figure 3).

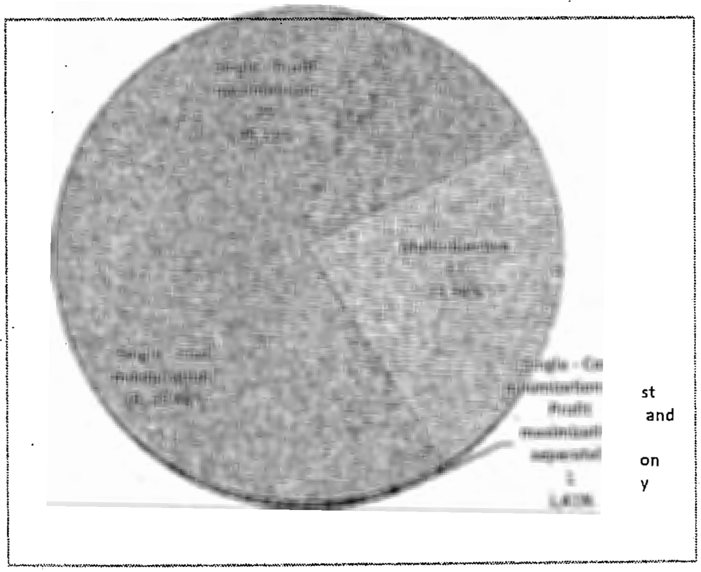

Figure 3: SCN opt. models - objective classifications

Although the majority of the articles reviewed here feature single purpose cost minimization or profit maximization objectives, when compared to the findings of the review by Melo et al. [42], there appears to have been a major shift from cost minimization to profit maximization objectives; 16% of the models reviewed by Melo et al. [42] included profit maximization objectives, while 75% of the models included cost minimization objectives. As seen in Figure 3, around 24% of the studies reviewed here feature multi-objective functions, compared to 9% of the articles reviewed by Melo et al. [42].

Our review showed that multi-objective models typically include a cost minimization or profit maximization function, together with customer service, environmental effect or risk mitigation related objectives (e.g., Shankar et al. [66], Akgul et al. [1], Prakash et al. [59]).

The results also support the idea that optimizing a single objective is inadequate for effectively optimizing a SC, which is a dynamic network consisting of multiple transaction points with complex transportations, information transactions and financial transactions between entities. SC modeling is inherently multi-objective in nature and involves several conflicting objectives.

3.6 Competition within the market / Demand functions

The existence of competition within the market (both among firms and via other SC's providing the same or substitutable goods) is an important factor that must be considered when designing a SCN. If rivals offering the same goods are already present, any new chain will have to compete for the market and the realized demand will be determined by the factors of that competition.

Only 5 of the reviewed papers explicitly model the competition within the market (Nagurney [47], Yu & Nagurney [78], Nagurney & Yu [51], Masoumi et al. [40], Zamarripa et al. [79]). Among these, the demand is simultaneously modeled as a function of both the retailer's and the competitor's price (oligopolistic competition). In the other 6 models (Cruz & Zuzang [24], Yamada et al. [75], Yang et al. [76], Cruz [23], Amaro & Barbosa-Povoa [3], Meng et al. [44]), the demand is modeled as a function of only the retailer's price. Only 1 study (Carle et al. [15]) modeled demand as a function of selected marketing policy.

We identified 2 studies that incorporated the effects of the SCN optimization models with customer demand models (Rezapour & Farahani [60], Rezapour et al. [61]). Those papers also modeled oligopolistic competition that was solved by variational inequality formulation. Authors developed an equilibrium model to design a centralized SCN operating in markets under deterministic price-depended demands and with a rival SC present. The two chains provide products, either identical or highly substitutable, that compete for some participating retailer markets. By this approach the authors were able to model the joint optimizing behavior of these two chains, derive the equilibrium conditions and establish and solve the finite-dimensional variational inequality formulation.

It may be concluded that the vast majority of the models assume that the customer demand, either deterministic or stochastic, is not substantially influenced by the SCN configuration itself. However, the physical network structure of a SC clearly influences its performance, and is an important factor that impacts a chain's competitiveness, especially for retail markets.

3.7 SC risk modeling

SC risk management is an important part of SCN configuration and optimization and involves designing a robust SCN structure and managing the product flow throughout the configured network in a manner that enables the SC to predict and cope with disruptions (Baghalian et al. [6]). The uncertainties associated with disruptive events such as heavy rain, excessive wind, accidents, strikes and fires may dramatically interrupt normal operations in SCs. In this review, we categorized how the reviewed SCN models quantify SC risks and are affected by network disruptions.

Only 9 of the reviewed models (Cruz & Zuzang [24], Baghalian et al. [6], Lundin [39], Yu & Nagurney [78], Cruz [23], Masoumi et al. [40], Bassett & Gardner [8], Pan & Nagi [56], Kumar and Tiwari [35]) explicitly included SC risk modeling (defined as SC robustness or SC risk models). An additional 9 articles (Wang [71], Hsu & Li [29], Kim et al. [33], Li et al. [37], El-sayed et al. [25], Kostin et al. [34], Huang et al. [30], Andersen et al. [4], Bogataj et al. [12]) included some sort of sensitivity analyses in their models (e.g., sensitivity to the changes in price, demand, yield rate or costs).

4 MULTI OBJECTIVE OPTIMIZATION MODELS IN THE LITERATURE

We next specifically focused on identifying the methodologies employed in multi-objective models. Several distinct approaches have been utilized to handle the multi-objectivity of SCN optimization models. Eighteen studies were identified to evaluate and summarize the various approaches utilized to handle multi-objectivity in SCN optimization models.

We found that simple approaches (e.g., ε-constraint, weighted sum, and goal programming) were most commonly utilized. In half of the considered papers (Sabri & Beamon [62]; Guillen et al. [26], Akgul et al. [1], Olivares-Benitez et al. [54], Zhang et al. [81], Bojarski et al. [13], Pinto-Varela et al. [58], Nepal et al. [52], Osman & Demirli [55]), simple approaches were utilized to convert multi-objective models into single objective models.

In 3 of the considered papers (Cruz & Zuzang [24], Nagurney & Yu [51], Pan & Nagi [56]), one of the objectives is directly added to the cost factor as a penalty fee, thereby converting these models to single objective models.

Alternatively, in 3 of the studies (Chaabane & Paquet [16], Zamarripa et al. [79], Costantino et al. [22]) the models were run with all possible alternatives, thereby presenting all results to the decision maker and showing how each of the multiple objectives simultaneously change with alternatives. In these models, the number of alternatives are limited, therefore, all possible solutions could be provided to the decision makers.

Finally, another 3 studies (Shankar et al. [66], Martinez&Zhang [45], Prakash et al. [59]) employed evolutionary algorithms to successively determine the Pareto Optimal Set (POS) of solutions, which contains all non-dominated solutions to a problem. These solutions represent trade-off solutions that facilitate decision makers to develop management policies under the changing weights of the objectives. Determination of the selected solution from the POS is totally dependent on subjective comparisons among model objectives. Therefore, all Pareto optimal frontiers that depend on the relative importance of the weights are explored and presented to the decision makers.

5 SUMMARY OF FINDINGS AND PROPOSED DEVELOPMENT OF FUTURE STRATEGIC SC MODELS

A major finding that can be drawn from our analysis of the literature is that many relevant tactical/operational level decisions in SC Management (e.g., procurement planning, production scheduling, distribution scheduling, the choice of transportation modes, inventory optimization decisions, and competition decisions) are being increasingly integrated into SCN optimization decisions in order to provide a better representation of the interdependent nature of decisions in SCN optimization problems. In addition, although most models remain deterministic, the proportion of non-deterministic models is increasing.

Our analysis found that the reviewed models mostly differ in their solution methodology. Around one third of the reviewed models were solved by specifically developed heuristic- based algorithms and more than one third of the models used generic heuristic algorithms to identify approximately optimal solutions. About 22% of the models used mathematical formulations that may be solved to find exact, optimal solutions. Another major finding of our review is that only around 24% of the models are multi-objective, even if all SCNs are multi-objective in their nature. Our analysis also showed that only a small portion of SCN Optimization models analysis how the robustness of SCNs are influenced by network decisions. As SC risk management is an important part of SCN configuration and optimization, SC risks also need to be defined within the models.

Perhaps most importantly, we found that almost all of the literature on SCN modeling assumes that customer demands (either deterministic or stochastic) are not substantially influenced by the configuration of SCN itself. However, the physical network structure of a SC clearly influences its performance, and is one of the most important factors impacting a SC's competitiveness, especially for SCs serving retail markets. This disconnect between models and reality represents a gap in the literature and an opportunity for future research. To address this, we propose that future SCN model research should focus on the explicit incorporation of how competitive facility location factors (e.g., changing demands dependent on not only price but also customer service related functions), can affect strategic-level SCN configuration decisions.

All SCNs are multi-objective in their nature. Therefore, future SC research should be multi-objective. Such multiple objectives might include profit maximization, demand maximization and SC risk minimization. Cost minimization or profit maximization are traditional objectives in SCN optimization problems. Demand maximization might be also utilized within the modeling framework as companies aim to increase (or at least maintain) their sales by reconfiguration of their SCN and possibly by adding new SCN point(s). The third objective proposed in the multi-objective framework is a risk minimization function. Since SC risks have enormous effects on long- and short-term SC operational and financial performance of the SC, strategic-level SCN decisions should be modeled with a risk metric to help understand how network decisions influence SC risks.

The principal contribution of the proposed direction for future SCN optimization model research is the improved modeling of demands, which are affected by the price and service characteristics of SCs, both of which are themselves substantially influenced by strategic-level SCN model decisions. A second contribution of the proposed framework is the explicit inclusion of SC risk in modeling strategic-level SC decisions. Among the many published multi-objective SCN optimization models, only a few include SC risks as an objectives.

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