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Supply chain network optimization: A review of classification, models, solution techniques and future research

Niki Matinrad[a*], Emad Roghanian[a] and Zarifeh Rasi[b]

[a]*Department of Industrial Engineering, Khaje Nasir University of Technology, Tehran, Iran*
[b]*Department of Industrial Engineering, Alzahra University, Tehran, Iran*

C H R O N I C L E

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A B S T R A C T

With an ongoing progress in industries and technologies, most firms and businesses highly depend on cooperation and collaborations within a supply chain. In today's competitive business environment, customer satisfaction plays an important role for the business survival. These matters can be secured by "supply chain", a chain consists of various companies working together to maintain customers' satisfaction. If various stages of different chains cooperate with each other, "supply chain network" (SCN) will be the outcome. In order to have a supply chain network or just a supply chain-operation in its best possible way, some optimization techniques are needed. In this paper, we present a close look at previous studies in the field of SCN optimization techniques and classify them based on the relative important characteristics.

1. Introduction

1.1. Supply chain management

Nowadays management of supply chain plays an essential role on companies' success and customers' satisfaction (Shukla et al., 2010; Chopra & Meindl, 2001). Supply chain management (SCM) also plays an important role in societies; SCM knowledge and capabilities can be applied to support medical missions, conduct disaster relief operations, and handle other kinds of emergencies. SCM also plays an important role in cultural evolution and helps improve our quality of life. Due to the rapid advancement of technology such as internet networks, connective product marking technologies like RFID and emerging standards for their use defining specific locations based on Global Location Number(s), basic supply chain are rapidly evolving to Supply Chain Network. Supply chains and supply chain networks both have similar characteristics. A system developed to move goods from supplier(s) to customer(s) like a flow, and movement of materials as well as information by linking organizations together to serve the end customer. "Network" depicts a more complex structure, where

* Corresponding author. +98 912 435 6607
E-mail addresses: nmatinrad@gmail.com (N. Matinrad)

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organizations can be cross-linked and there are two-way exchanges between where "chain" explains a simpler, sequential set of links (Harland et al., 2001). In both fields, supply chain (SC) and supply chain network (SCN), optimization is one of main working areas under-study system, which is of high importance. The reason for this importance is because in every chain or network of supply we look for right application of tools and processes to make sure that all operations are executed, properly. In addition, it should be noted that right design of a supply chain (SCD) or supply chain network (SCND) can be considered as an optimization problem, since in this case the right SCD or SCND looks forward to enhancing profitability or shareholders' value.

1.2. Origination

Supply chain network (SCN) is one of the important topics in an ongoing world because of increasing trend on technological change and globalization of trade. It is also because of tending to access external sources and developing economy based on knowledge and technology and the necessity of creating links and networks of strategic and focusing on quality, benefits and customer satisfaction and changeable and competitive world. While surveying different papers in the field of supply chain network optimization (SCNO) and supply chain network design (SCND) in the time spectrum of 2000-2013, importance of SCNO in every industry or business as well as absence of a new and holistic review paper in these fields were the main motivations for writing this paper. In addition, a capable industrial engineer involved in the field of SCNO and SCND should know about their evolutions and different aspects of them to become a reliable engineer and manager in the competitive future world.

1.3. Users and Stakeholders

The comprehensive vision of this paper can assist researchers and scholars who inquire about this subject, and managers to have a glimpse to supply chain network and they can access any information about it and its resources easily and straightly. If a manager wants to know recent progress in SCNO and new modeling and their solution techniques to use them in his/her work, he/she can access this information through this review paper.

1.4. Contribution of paper

Within all papers dedicated to the subject of SCNO or SCND, various issues have been studied. Some of these papers consider only one matter at a time, while some others may try to take different problems into account at once. One point about these papers is the fact that they are not necessarily in a specific industry, which shows that SCNO or SCND have been applied in different industrial contexts. This paper will try to contribute to the SCNO and SCND literature as follow:

- Considering studies within different industrial context,
- Categorizing different issues that have been studied within the area,
- Presenting existing gaps in the available studies in the literature.

As pointed out once before, apart from the above mentioned contributions, main distinguishable aspect of our paper is its holistic view of the field. By this, we mean that this review starts from definition and categorization of SC decision levels to the extent that presents characteristics of studied papers' models.

1.5. Organization of paper

In this study, first we will describe research method and scope of the paper in section 2. Then in section 3, terminology of this study will be illustrated. Section 4 will be devoted to studying supply chain network design and optimization. In this section, we first explicate decision levels of supply chain and then categorize the problems in this area based on those levels, and finally in this section various kinds of models used in the studied papers within the time span will be categorized and explained. Finally, in the section 5, we discuss about current gaps and trends in this area, and through these suggest subjects for future researchers.

2. Research methods and scope

In this section, we attempt to highlight the scope and research method of this review. With respect to the SC matrix originally created by Stadtler and Kilger (2008), we highlight the scope of our paper in Table 1. Since our main focus in this research is on SCNO, every field covered by the papers we have studied from the literature is shadowed in the Table 1. For instance, SCND as will be explained later in section 4, is in the strategic or long-term level of planning and decision making. In order to study literature in a better and more practical manner, we chose a rather long period of time (papers of years 2000 to 2013). We intend to identify gaps and trends in our chosen field and period of time as a conclusion of this research; therefore, a complete data collection will be required.

Table 1
Scope of the paper with respect to SC matrix (Stadtler and Kilger, 2008)

		Process			
		Supply	Production	Distribution	Sales
Planning level	Long-term	Strategic Network Planning			
	Mid-term	Material Requirement Planning	Master Production Scheduling	Distribution Planning	Demand Planning
	Short-term			Transportation Planning	Demand Fulfillment

In order to maintain necessary resources to conduct this survey, we used two main search engines:

- SCOPUS, and
- Google Scholar (Scholar.google.com)

As it is known, SCOPUS is the largest available and reliable database. Although it should be noted that Google Scholar is more up-to-date, and therefore, was used for complementary purposes. We have used different combination of keywords for having a comprehensive search, which has been done on SCOPUS. These combinations are as follow: "Supply chain" and "Network design", "Supply chain" and "optimization", and "supply chain network" and "optimization". In addition, "supply chain network design" and "supply chain network optimization" were used to make sure that every related paper in these fields was found through our search. By using these keywords, a fair number of papers came up, among which at primary screening 231 of those seemed good enough for our review. But due to lack of access to some of journals, and focusing our interest in peer-reviewed research publications, a great deal of papers were omitted (about 156 papers). Through more accurate and detailed study and investigation of the remaining papers, 51 of them were evaluated relevant to our paper's scope and therefore, chosen useful and good for this review. In case some concepts were needed to be explained, some other references were also used.

3. Terminology and definitions

There are a few terms that are important in the studied area from conceptual and understandable point of view, which are:

- Supply chain

- Supply chain management
- Supply chain network
- Optimization and Design
- Supply chain network optimization and design

Before proceeding more with our review, first these main concepts both in the field and our work will be defined.

3.1. Supply chain

Supply chain is a network of four entities: suppliers, distribution networks, manufacturers, and customers; they have different types of connections and influences on each other including transportation, information sharing, and financial flows (Shukla et al., 2010; Chopra & Meindl, 2001; Ding et al., 2009; Beamon, 1998). These connections between different parts of the SC can be a two-sided one depending on the connections' type. In addition, these entities seek a unified goal, which is to maximize the overall generated value of the overall chain and their individual unit. Although achieving this goal may not be an easy task to do if the SC is not integrated and different elements' interests contrast with each other (Mo et al., 2005). Supply chain managers must consider all the interactions and limitations between these elements and also consider operating factors, constraints and the dynamics in the market, such as changes in demand (Perea-Lopez et al., 2003; Ding et al., 2009). In Fig.1 a general supply chain network that includes three various levels of enterprises: retailers, distribution centers and plants can be seen (Chen and Lee, 2004).

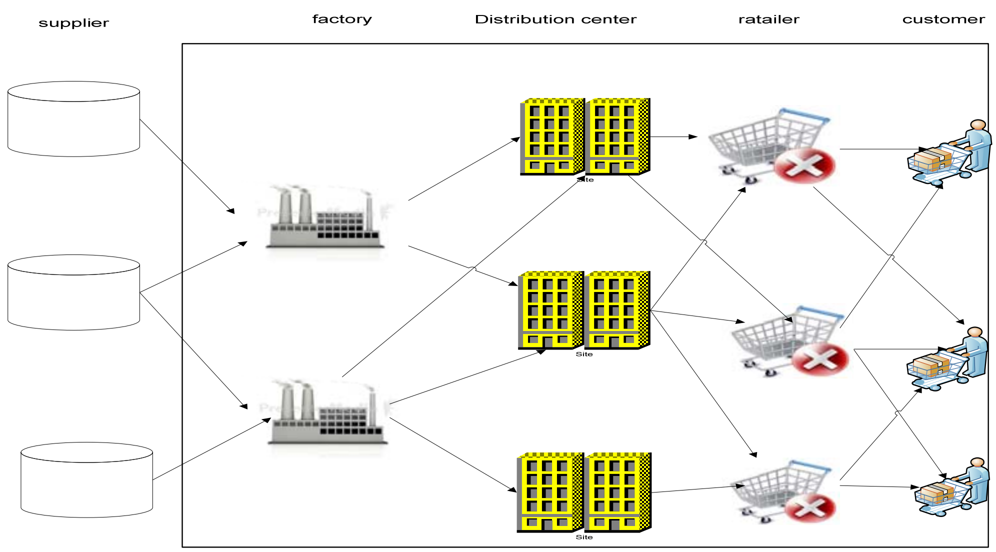

Fig 1. General supply chain network (Chen et al., 2003)

Attention to supply chain integration is increasing as a result of globalization and increasing competition (Wee & Yang, 2004). Competitiveness in a SC can be achieved through high speed of information and material flow with low overhead costs. For success of a SC, managers must consider coordination and collaboration between different activities that exists in it (Shukla et al., 2010) and the entire SC's competitiveness on the market (Ambrosino & Scutellá, 2005).

3.2. Supply chain management

As a result of competitiveness in business environment and progresses in technology, an important task that companies must do to survive in this environment is working with other companies through communication and specialization. These collaborations and co-operations create a chain of companies and business entities with same goals, which will lead to a new concept in the management area, supply chain management concept (Chen & Lee, 2004; Chen et al., 2007; Ding et al., 2009). In addition, with creation of these SCs, the competition in business world will be between SCs (Christopher, 1992). ‘‘Supply chain management’’ was first presented by Houlihan in 1985 (Wang, 2009). Logistics management is one of the crucial factors in supply chain performance (Chan & Chung, 2004b). SCM is the active management of planning, designing, implementing and monitoring and controlling the operations of the supply chain activities with the objective of maximizing total profitability which spans all motion and storage of raw materials, work-in-process inventory, and finished goods from a source to a customer (Melo et al., 2009).

In SCM, optimization of multi criterion problems such as total costs, customer service level, inventory level, manufacturing lead times, and etc. may usually be encountered by decision makers (DM), which may be limited with some constraints, and affect each other in nature (Chan & Chung, 2007). An individual member of organization should not only optimize itself, but also collaborations with other partners for larger optimization planning can improve the individual and global performance (Silva et al., 2009).

3.3. Supply chain network

Supply chain is not just a group of stages involved to satisfy a customer request, but rather a network of interrelated stages involved to do customer requests. We want to manage this network’s flow and also find the best network structure or supply chain design to maximize the beneficially (Geunes & Pardalos, 2003). A large numbers of manufacturing models have been proposed for the design and planning supply chain network (Mo et al., 2005). The selection of partners in the supply chain network management is important because SCN really needs the inter cooperation of the partners at the upstream, midstream and downstream echelons along the supply chain (Wang, 2009).

3.4. Optimization and design

Based on merriam-webster.com optimization is defined as “an act, process, or methodology of making something (as a design, system, or decision) as fully perfect, functional, or effective as possible; *specifically*: the mathematical procedures (as finding the maximum of a function) involved in this”. In management science, mathematical design is the selection of a best element from some set of available alternatives with regard to some criteria. In engineering The American Heritage Dictionary defines design as: “To conceive or fashion in the mind; invent,” and “To formulate a plan”.

3.5. Supply chain network optimization and design

In designing any supply chain, we should be very precise about the decisions concerned with the definition of the number, size, and location of the supply chain nodes (Canel & Khumawala, 2001; Teo & Shu, 2004; Simchi-Levi et al,. 2005; Zhang et al., 2008), the amount and location of production facilities, the capacity at each facility, the assignment of each market region to one or more locations, and supplier selection for sub-assemblies, components and materials (Meixell & Gargeya, 2005; Paksoy et al., 2010). Supply chain network design is an assessment to have great importance for enterprises to gain cost-effectiveness and competitiveness (Ballou, 2005) and to have an important impact in logistics costs (Chopra & Meindl, 2004; Cardona-Valdés et al., 2011).

The questions connected with optimizing a SCN are linked to procurement, production, distribution, transportation, and suppliers’ selection, etc. (Paksoy et al., 2012a). Supplied materials’ quality levels are directly affected the agreements with suppliers and influences the material flow through SCN, indirectly. Optimizations of distribution networks have been studied by many researchers who used linear programming, mixed integer programming, fractional programming, and multi objective linear fractional programming to solve problems, which can generate optimal solutions which are usually time consuming in computation, and complicated in model construction (Abdinnour-Helm S, 1999; Chan & Chung, 2004). In addition, we sometimes use nonlinear programming because of nonlinear situations like the delivery cost changes as a function of delivery quantity which makes the modeling more complex.

4. Supply chain network optimization and design

As discussed earlier, decisions regarding SCN optimization and design are highly concerned with every single part of a chain such as production facilities, distributer centers, suppliers and customers and every type of flow and connection between these nodes of the network. One of important methods for studying existing issues or potential ones in a field is using modeling techniques, and then solving the modeled issue by the appropriate technique. Sometimes existing techniques will not be capable of solving the presented model; therefore, modeler(s) should create a novel approach capable of handling solving phase. In addition, in some cases solving can be done through solver software.

In this section, we intend to cover different angles of issues studied in the literature regarding SCND and SCNO. First, we will discuss decision levels concerned with supply chains. Then, a categorization based on specifications of papers' models will be presented, and later, studied models in the literature from their objective functions and constraints perspective will be studied.

4.1. Supply chain decision levels

In order to ensure success of a supply chain management, right decisions about every aspect of a supply chain or supply chain network should be made (Chopra et al. 2004). These decisions can be categorized into three main classes based on the time horizon it is made for:

- **Strategic**; in this level, decision maker/makers consider long-term decisions and objectives. As it can be concluded, effects of these decisions are also long term. These decisions are considered in high level. Examples of this category include facilities location, supplier selection, partner selection, supply chain design, integration of supply chain, etc.
- **Tactical**; midterm decisions concerning issues such as transportation planning, distribution planning, production planning and etc. are considered in this type of decision making.
- **Operational**; in this category short term decisions (and also low level decisions) which are concern with daily managerial matters are made, among which we can name inventory planning, demand planning and forecasting and etc.

The point that we should pay attention to about these levels of decision making is the fact that lower level decisions are made within the framework and context of the higher level decisions. This means that operational decisions are made within the context made by strategic and tactical decisions. It should be mentioned that some decisions can be considered within two levels, like issue of Vehicle Routing Problem (VRP) which is in a level between tactical and operational decisions. In Table 2 we present a classification of studied papers based on above mentioned decision levels. Some of these papers studied matter considers only one level of decision making, while the others might have several issues in hand or as pointed out issues of between levels.

As it can be noticed from the Table 2 the numbers of times that issues concerned with strategic, tactical and operational decision levels were addressed are almost equal, yet these numbers for strategic decision level issues are slightly higher than others.

Table 2
Classification of studied papers in the literature based on decision levels

Article	Paper's studied Issue	SCM level
Lakhal et al. (2001)	Supply chain network structure	Strategic
Cakravastia et al. (2002)	Supplier selection	Strategic
Perea-López et al. (2003)	Distribution network planning	Tactical
Chan and Chung (2004a)	Order distribution	Operational
Wu and Golbasi (2004)	Facility planning	Strategic
Wee and Yang (2004)	Integration of Supply chain	Strategic
Chen and Lee (2004)	Supply chain scheduling	Operational
Chan et al. (2004)	Supply chain collaboration	Strategic
Chan and Chung (2004b)	Distribution network planning	Tactical
Bredström et al. (2004)	Transportation + Production scheduling + Distribution	Operational
Mo et al. (2005)	Integration of production and distribution systems	Operational
Chan et al. (2006)	Distribution network + Production scheduling	Operational
Venkatadri et al. (2006)	Manufacturing and distribution planning	Tactical
Craven (2007)	Inventory	Operational
Herty and Ringhofer (2007)	Supply chain network optimization	Tactical
Grunow et al. (2007)	Production planning and scheduling + Dispatching	Tactical + Operational
Chen et al. (2007)	Production and distribution planning	Tactical
Kim et al. (2008)	Supply chain design	Strategic
Shirazi et al. (2008)	Facility relocation	Strategic
Al-Othman et al. (2008)	Production and demand forecast	Tactical
Lau et al. (2009)	Vehicle routing	Operational/Tactical
Gumus et al. (2009)	Integrated supply chain design	Strategic
Yang et al. (2009)	Supply chain network optimization	Tactical
Wang (2009)	Partner selection/ Production-distribution planning	Strategic/Tactical
Nagurney (2009)	Supply chain integration	Strategic
Mahnam et al. (2009)	Inventory management	Operational
Wu et al. (2009)	Partner selection	Strategic
Ding et al. (2009)	Design of Production-distribution network	Strategic
Cintron et al. (2010)	Design of distribution network	Strategic
Pishvaee and Torabi (2010)	Closed-loop supply chain network design	Strategic
Guillen-Gosalbez et al. (2010)	Deign of production-distribution network	Strategic
Monteiro et al. (2010)	Supply chain network design	Strategic
Paksoy et al. (2010)	Green supply chain network design	Strategic
Liao et al. (2010)	Location-inventory integration + Performance	Operational + Tactical
Nagurney (2010)	Supply chain network design and redesign	Strategic
Shukla et al. (2010)	Supply chain network optimization	Tactical
Wang et al. (2011)	Green supply chain network design	Strategic
Liao et al. (2011)	Integrated location-inventory distribution network	Strategic/Tactical/Operatio
Georgiadis et al. (2011)	Supply chain network design	Strategic
Cardona-Valdés et al. (2011)	Supply chain design	Strategic
Başligil et al. (2011)	Vehicle routing	Operational/Tactical
Paksoy and Yapici Pehlivan	Facility capacity planning	Strategic
Paksoy et al. (2012a)	Supply chain network design	Strategic
Creazza et al. (2012)	Supply chain design	Strategic
Paksoy et al. (2012b)	Production-distribution network	Operational

*Based on studied issues of paper all three decision levels were taken into account, but among them Operational level was of higher importance

4.2. Classification

Modeling method and their solution techniques are two most important aspects of studying issues presented in the literature. Therefore, in this section we present some of the related works and their solution techniques along with case studies, papers' achievement, strength or weakness points, and the industry which the study was made for -in case there is any- in the Table 3. By having a closer look at Table 3, and more specifically model's specifications column, we realize that main methods for modeling within the context of SCN are mixed integer linear/nonlinear programming.

Works such as Perea-López et al. (2003), Wu and Golbasi (2004), Chen and Lee (2004), Venkatadri et al. (2006), Chen et al. (2007), and Lau et al. (2009) considered multi products for their modeling and studies. Some of these works (Perea-López et al. (2003), Wu and Golbasi (2004), Chen and Lee (2004), and Chen et al. (2007) have also considered multi period for their studies. In some of other works, such as Chun and Chung (2004a), Grunow et al. (2007), Chen et al. (2007), Lau et al. (2009), Wu et al. (2009), Ding et al. (2009), Pishvaee and Torabi (2010), Paksoy et al. (2010), Liao et al. (2010), Wang et al. (2011), Liao et al. (2011), Cardona-Valdés et al. (2011), and Paksoy et al. (2012b) several objectives have been spotted, whereas some others have considered usage of multi criteria for their models among which we can name works of Chan et al. (2004), Chan and Chung (2004b), Chan et al. (2006), and Guillen-Gosalbez et al. (2010). It is worth mentioning that there are also works which developed models for their considered issue with both techniques, for example Mahnam et al. (2009), and Cintron et al. (2010) are of those category.

Under the third column of this Table, used solution techniques in the studied papers have been summarized, techniques such as heuristics and meta-heuristics (like GA), goal programming, fuzzy approaches, novel approaches, hybrid methods and etc. can be seen. Among used techniques, a number of times, solving by solver software can be found. This part is one of most important part of any modeling. Sometimes this phase of study is even used as evaluator of presented model, and sometimes researchers use case studies to make the evaluation.

Most of these studies, present a case study or numerical example. For those papers, presented details in the studies can be observed under the column "Case Study or Numerical Example/Analysis". Some of papers we had an overview on were conducted in a specific industry, which will be found under the last column of Table 3 "Studied Industry".

Two other remaining columns of Table 3, "Paper's Achievement" and "Strength and Weakness Points of Paper", as can be concluded from their names, attempts were put to demonstrate "By studying the issue, what the study has accomplished", or "What other things could or should have been added into study in order to make the work completer" and also "In what aspects the work can be considered more comprehensive".

4.3. Modeling

One of methods for studying an issue is modeling. Modeling different aspects can be investigated without any limit, which means that no change is needed to be made on the real world system. Among different types of modeling, mathematical modeling is the main one in studying various aspects in this under review field. Any mathematical modeling consists of four important parts, parameters, variables, objective function(s), and constraints. By objective function(s) and constraints model developer demonstrates goals of developing a model and also boundaries it faces.

Table 3
Models' specifications, solution techniques, achievements, and case studies

Article	Model's specifications	Solution Technique	Paper's Achievement	Case Study or Numerical Example/Analysis	Strength or weakness points of Paper	Studied Industry
Cakravastia et al. (2002)	Mixed integer programming, two level, three basic manufacturing strategies MTO, MFS, and MTS, three possible manufacturing strategies, the make-to-order (MTO), make-from-stock (MFS), and make-to-stock (MTS) strategies	Producing general characteristics of the mixed-integer programming technique	The operational model and chain level model has been able to generate the most efficient strategy and allocation	180 generated data sets	Validating the model by comparing its behaviors with the results of previous research	-
Perea-López et al. (2003)	Mixed integer linear programming, Multi product, Multi period, Multi echelon distribution network, Single stage batch plants, Multiple customers, centralized global approach,	Dynamic model, an MPC strategy	-	Three plants, each with three different products, three plant warehouses, four distribution centers, ten retailers, twenty customers	-	-
Chan and Chung (2004a)	Multi objective mixed integer programming-multi-criterion genetic optimization	Genetic Algorithm and AHP	-	Hypothetical two-layer demand driven supply chain with three different, ten customers and each customer will release one demand with a total of ten orders	-	-
Wu and Golbasi (2004)	Mixed integer programming, Multi product, Multi facility, Multi stage, Multi item, Multi period	Lagrangian Decomposition scheme; sub-gradient search algorithm using AMPL with the CPLEX solver	Shows that the shortest path algorithm serves as an effective heuristic for the product-level sub-problem (a mixed integer program), achieving high quality solutions with only a very short amount of the computer time (roughly 2%)	-	-	High-tech industries that have capital-intensive equipment and a short technology life cycle
Wee and Yang (2004)	Revised Goyal's model, single product, two distributer, four retailer	Optimal solution procedure; Heuristic solution procedure	-	Single-producer, two-distributor and four-retailer system	-	-
Chen and Lee (2004)	Mixed integer nonlinear programming, Multi product, Multi stage, Multi period, Uncertain market demand and price	Two stage fuzzy approach	-	A small-scaled but typical supply chain with one plant, two distributer centers, two retailer, and two products	-	-
Chan et al. (2004)	Multi criteria genetic optimization, Central coordination system, AHP	Genetic Algorithm and AHP	-	Hypothetical three-tier supply chain consisting of four manufacturing facility, four warehouses, and ten customers that each release one order demand	-	-

Table 3 (Continued)
Models' specifications, solution techniques, achievements, and case studies

Article	Model's specifications	Solution Technique	Paper's Achievement	Case Study or Numerical Example/Analysis	Strength or weakness points of Paper	Studied Industry
Chan and Chung (2004b)	Linear programming, Multi criteria decision making	Genetic Algorithm and AHP	-	Typical distribution network with four manufacturing plants, four warehouses, ten customers and each will release one demand with a total of ten orders	-	-
Bredström et al. (2004)	Model A: Column generation, one binary variable for each production plan; Model B: based on explicit mixed integer formulation	Column generation-constraint branching heuristic (The algorithms were implemented using ILOG AMPL 10.6.16 with ILOG CPLEX 7.0 as solver)	Finding new strategic policies in order to reduce the company's supply chain's costs	pulp producer with five pulp mills located in Scandinavia	Developing 2 new models	Pulp industry
Mo et al. (2005)	Minimum cost flow problem, several sub-networks dealing with raw material and production separately	Linear programming problem with bounded variables-developing a simplex primal algorithm	-	Numerical experiments	Testing the efficiency of the method by numerical experiments	-
Chan et al. (2006)	Multi-criterion genetic integrative optimization, Multi echelon distribution network, Uncertainty in production lead time and transportation lead time and due dates of orders	Proposed integrative optimization methodology adopts GA for optimization & AHP to calculate the fitness values, and probabilistic representation to capture uncertainties	-	Three experiments	Discussing the inter-relationship between total system cost, total lead time, utilization, fulfillment reliability (in mean value), and fulfillment reliability (in probability)	-
Venkatadri et al. (2006)	Linear programming, Multi product	Standard LP solvers (modified)	Building an optimization-based decision support system (DSS)	One supplier, an assembly plant, two warehouses, and two customers	-	Firms involved in ecommerce/it has not modeled customer orders explicitly
Grunow et al. (2007)	2Phase: Cultivation planning, Mixed integer linear programming, MiniMax reformulation of model; Harvest scheduling, Mixed integer linear programming, Multi objective	ILOG's OPL Studio 3.6.1 as the modeling environment and CPLEX 8.1 as the solver	-	Data retrieved from the 2004–2005 zafra (harvest season) of CEPSA, a large Venezuelan sugar producer	-	Raw sugar industry

Table 3 (Continued)
Models' specifications, solution techniques, achievements, and case studies

Article	Model's specifications	Solution Technique	Paper's Achievement	Case Study or Numerical Example/Analysis	Strength or weakness points of Paper	Studied Industry
Chen et al. (2007)	Multi-objective mixed integer linear programming, Multi echelon, Multi period, Multi product, Uncertain market demand	Two-phase fuzzy decision-making method	Providing a compensatory solution for the multiple conflict objectives	Numerical example, an uncertain multi-echelon supply chain network	-	-
Kim et al. (2008)	Mixed integer linear programming, Stochastic optimization, two-stage programming approach, Uncertain demands	Implemented in GAMS, and solved using the MILP solver of CPLEX 7.0	Creating a robust model for various activities of a hydrogen economy-Incorporating forecasting uncertainty	Evaluating the future hydrogen supply chain of Korea.		Hydrogen supply chain
Shirazi et al. (2008)	One product, Deterministic demand, Mathematical modeling	Genetic Algorithm	-	-	Considering more factors simultaneously	-
Al-Othman et al. (2008)	Two-stage stochastic linear program with fixed resource, Uncertainty in market demands and prices, Multi period	Using GAMS (2001), and CPLEX 7.5 as solver	Shows that the impact of economic uncertainties may be tolerated by an appropriate balance between crude exports and processing capacities	12 cases-a petroleum organization owned by an oil producing country	It consists of all activities related to crude oil production, processing and distribution	Petroleum industry
Lau et al. (2009)	Multi-Objective vehicle routing optimization, Multiple products, Multiple depots, Multiple customers	Fuzzy logic guided non-dominated sorting genetic algorithm 2 (FL-NSGA2)	Minimizing both the total traveling distance and the total traveling time	Three scenarios of VRP, (i) 5 depots and 50 customers, (ii) 15 depots and 150 customers, (iii) 25 depots and 250 customers-In each scenario, considering 10 various data	Comparing it with the following: non-dominated sorting genetic algorithms 2 (NSGA2) (without the guide of fuzzy logic), strength Pareto evolutionary algorithm 2 (SPEA2) (with and without the guide of fuzzy logic), and micro-genetic algorithm (MICROGA) (with and without the guide of fuzzy logic)	-
Gumus et al. (2009)	Neuro-fuzzy and Mixed integer linear programming, Three echelon network, Demand uncertainty	Matlab 7.0 is used for neuro-fuzzy demand forecasting, and the MILP model is solved using Lingo 10.0	A comparative study to show the applicability and efficiency of ANN simulation, considering only a part of the reference company's supply chain system	A reputable multinational company in alcohol free beverage sector-a three echelon SC network is considered	-	Drink production Industry

Table 3 (Continued)
Models' specifications, solution techniques, achievements, and case studies

Article	Model's specifications	Solution Technique	Paper's Achievement	Case Study or Numerical Example/Analysis	Strength or weakness points of Paper	Studied Industry
Yang et al. (2009)	Closed-loop supply network modeling, Multiple tiers of decision makers	The theory of variational inequalities	-	Using two raw material suppliers, two manufacturers, two retailers, two demand markets and two recovery centers.	-	-
Wang (2009)	Germane mathematical programming model, Multi echelon defective supply chain network, Three module/defective supply chain (DSC) system	The novel solving approach TAC based on ant colony algorithm	-	Comparative numerical experiment is performed by using the proposed approach and the common single-phase ant colony algorithm (SAC)	Due to ant colony algorithm it cannot ensure that the result is the best one, but it can help to get a near-optimal solution or an acceptable germane result in a very short time	-
Nagurney (2009)	System-Optimization problem, Non-linear programming	Modified projection method, implementing the algorithm in FORTAN	-	Five numerical examples	A model with capacities on the links to represent the capacities associated with manufacturing plants, shipment/distribution routes, and storage facilities	-
Mahnam et al. (2009)	Bi-criteria optimization model, Fuzzy model, Multi echelon, Multiple supplier, one product, Uncertain environment, Multi-objective decision making	Hybridization of multi-objective particle swarm optimization and simulation optimization-fuzzy model (MOPSO algorithm, simulation and fuzzy expert system), using MATLAB 7	-	(Example taken from Wang & Shu, 2005) one distribution center, six production centers, and eight external suppliers for an electronic product	Determining the order-up-to level for each SKU in the SC according to partial coordination approach	-
Wu et al. (2009)	Analytic network processes-Mixed integer multi objective programming, Two-stage, Agile supply chain	ANP methodology and MIMOP method, solved by LINGO	Presented model enables decision-makers to make trade-offs between several tangible and intangible factors with different priorities	-	-	-

Table 3 (Continued)
Models' specifications, solution techniques, achievements, and case studies

Article	Model's specifications	Solution Technique	Paper's Achievement	Case Study or Numerical Example/Analysis	Strength or weakness points of Paper	Studied Industry
Ding et al. (2009)	Combination of Multi objective genetic algorithm and simulation based optimization	NSGAII-based evolutionary algorithm; A hybrid evolutionary algorithm for MOGA	-	Case study: the network is composed of three plants, five distribution centers and six customer zones-case study from automotive industry	A flexible simulation framework	Automotive industry
Cintron et al. (2010)	Multiple criteria mixed-integer linear programming, Multi objective	Goal programming	-	A case study with real data from a specific region of a consumer goods company that included 66 retailers, five independent distributors, and four manufacturing plants.	-	-
Pishvaee and Torabi (2010)	Bi-objective possibilistic mixed integer programming, Uncertainty and risk	An interactive fuzzy solution approach is developed by combining a number of efficient solution approaches from the recent literature	-	Numerical experiments	Integrating the network design decisions in both forward & reverse supply chain networks	-
Guillen-Gosalbez et al. (2010)	Bi-criteria mixed-integer linear programming	Pareto solutions of the problem are computed via the e-constraint method; All the problems were implemented in GAMS39 and solved in the full-space using the CPLEX 9.0 solver	-	Example taken from Almansoori and Shah (2006)	-	-
Monteiro et al. (2010)	Mixed integer nonlinear programming, One period, Stochastic demand, ABC classification of finished goods	Outer Approximation OA algorithm proposed by Duran and Grossmann, solved by applying MINOS 5.5	-	Three randomly generated instances of a certain supply chain network design. Some of the data originated from an earlier work of Monteiro	Including inventory levels in warehouses based on the stochastic demand of customers	-
Paksoy et al. (2010)	Multi objective linear programming, Closed loop supply chain	Solved by LINDO 6.1	-	In the numerical example, a CLSC network was designed which considers the environmental impacts.-based on a hypothetical data	-	Gas Emission
Liao et al. (2010)	Multi objective Mixed-integer non-linear programming, Vendor managed inventory, Performance measurement system	NSGAII-based evolutionary algorithm; A hybrid evolutionary algorithm for MOLIP	-	A base-line problem was developed by taking the size of a Gamma company's supply chain network with 15 DCs and 50 buyers as reference	Integrated model to incorporate inventory control decisions	-

Table 3 (Continued)
Models' specifications, solution techniques, achievements, and case studies

Article	Model's specifications	Solution Technique	Paper's Achievement	Case Study or Numerical Example/Analysis	Strength or weakness points of Paper	Studied Industry
Nagurney (2010)	Novel System-Optimization problem for supply chain design and redesign modeling	The modified projection method	-	8 examples consisted of a firm faced with three possible manufacturing plants, two distribution centers, and had to supply the three retail outlets	Formulating the design & redesign problems as variational inequalities	-
Shukla et al. (2010)	Simulation modeling using ARENA, Optimizing operating condition, Mathematical modeling using regression analysis	Proposing a hybrid approach incorporating simulation, Taguchi method, robust multiple non-linear regression analysis and the Psychoclonal algorithm. The programming of the Psychoclonal algorithm and AIS has been done in C++ language	-	-	Six factors have been considered, two factors are qualitative and rests are quantitative	-
Wang et al. (2011)	Multi-objective mixed-integer programming,	Normalized normal constraint method implemented by Microsoft Visual C++ 6.0, and each sub-problem is solved by ILOG CPLEX 9.0 solver subroutine.	-	Two examples: a six-node problem, and a mid-size network	Considering environmental factors	-
Liao et al. (2011)	Mixed-integer non-linear programming, Capacitated multi-objective location-inventory problem, Vendor managed inventory	A NSGAII-based evolutionary algorithm (hybrid)	-	A base-line problem was developed by taking the size of a Gamma company's supply chain network with 15 DCs and 50 buyers as reference	Dual experiments	-
Georgiadis et al. (2011)	Mixed-integer linear programming, Demand uncertainty, Four-stage network, Multi product	Standard branch-and-bound techniques	-	An European wide production and distribution network comprising of three manufacturing plants producing 14 different types of products located in three different European countries: UK, Spain, and Italy	SCN comprising multi product production facilities with shared production resources, warehouses, distribution centers and customer zones	-
Cardona-Valdés et al. (2011)	Multi-objective stochastic programming, Demand uncertainty, Two echelon	**L-shaped algorithm** within an optimality framework	-	Numerical example	Satisfying the economical and service quality objectives of the decision maker within two levels supply network setting	-

Table 3 (Continued)
Models' specifications, solution techniques, achievements, and case studies

Article	Model's specifications	Solution Technique	Paper's Achievement	Case Study or Numerical Example/Analysis	Strength or weakness points of Paper	Studied Industry
Başligil et al. (2011)	Two-stage, Mixed-integer programming, genetic algorithm, Third party logistics service provider (3PL)	1st stage: mixed integer programming by using GAMS 21.6/CPLEX; 2nd stage: developing a genetic algorithm by using C#	-	A numerical example	-	-
Paksoy and Yapici Pehlivan (2012)	Fuzzy linear programming, triangular and trapezoidal membership functions, Multi echelon	Solved by LINDO-Multi-stage supply chain model	-	Required data taken from an edible vegetable oils manufacturer	Conducting sensitivity analysis to show the correlation between the objective function value and the structure of the membership function forms/ fuzzy facility capacities	Edible vegetable oils industry
Paksoy et al. (2012a)	Novel mixed integer linear programming, Four echelon, Multi suppliers, Multi manufacturers, Multi retailers, Multi distribution centers, Multi quality raw material options	Branch and bound technique as a LINDO 11.0 solver(original problem including 499 constraints and 106 variables related with 5 suppliers, 3 manufacturers, 3 DCs and 4 retailers requires only 0.01 s)	-	Five suppliers in different places, three manufacturers, three distribution centers and four retailers for selling; 4senarios and 7 different test problems	Discusses the relationship between product quality and supply chain design. Also several managerial insights is discussed	-
Creazza et al. (2012)	Mixed integer linear programming	Solved by LINDO	-	The Pirelli Tyre European logistics network	-	-
Paksoy et al. (2012b)	Fuzzy multi objective linear programming, triangular fuzzy numbers, Edible vegetable oil manufacturer	Solved via LINDO	-	Case study on ABC Oil Company (a crude oil supplier which is located in Izmir, the factory located in Konya, private label warehouses located in Istanbul, Adana, Kayseri, Izmir and ABC Oil Company warehouses located in Ankara, Antalya, Diyarbakır and Çorum in Turkey)	Model can be solved by using a commercial optimizer and computational times are reasonable for real sized problem	Oil industry

In Table 3, general characteristics of studied papers in the literature were presented. Here in Table 4, we will try to summarize objective functions and constraints of some of models.

Table 4
Some of models' objective function(s) and constraints

Article	Model's Characteristics		
	Objective function		Constraint
Cakravastia et al. (2002)	*Operational-level model*	*Minimization of the value of the level of dissatisfaction*	✓ *Production activity* ✓ *Allowed production quantity* ✓ *Resource* ✓ *Dependency of manufacturing and logistics activity* ✓ *Constraints on performance*
	Chain-level model	*Minimization of estimated total level of dissatisfaction (money)*	✓ *Physical flow constraints* ✓ *Order quantity constraints* ✓ *Performance estimation constraints*
Perea-López et al. (2003)	*Maximization of profit*		✓ *Balance flow constraints* ✓ *Process unit restriction* ✓ *Processing constraints* ✓ *Updating constraint at time period t*
Chan and Chung (2004a)	*Minimization of total costs, total delivery lead time, and equity of utilization ratios*		✓ *Demand allocation constraints*
Wu and Golbasi (2004)	*Minimization of costs*		✓ *General multi-commodity constraint* ✓ *Production specific constraints*
Chen and Lee (2004)	*Maximization of participates expected profit, average safe inventory levels, average customer service levels, and robustness of selected objectives to demand uncertainty*		✓ *Manufacturing constraints* ✓ *Transportation constraints* ✓ *Inventory constraints*
Chan and Chung (2004b)	*Minimization of total costs*		✓ *Manufacturing plant constraints* ✓ *Maximum production capacity* ✓ *Warehouse constraints* ✓ *Maximum inventory handling capacity* ✓ *Demand allocation constraints*
Bredström et al. (2004)	*Model A*	*Minimization of total costs*	✓ *Flow conservation of assortments at pulp mills* ✓ *Flow conservation of products at pulp mills* ✓ *convexity constraints that require each pulp mill to use exactly one production plan* ✓ *binary restrictions*
	Model B	*Minimization of total costs*	✓ *Relation between recipe variables and recipe-change variables* ✓ *Constraint specifying that only one recipe per time period can be in use at each pulp mill*
Mo et al. (2005)	*Minimization of total cost of raw material, production and distribution*		✓ *Capacity constraint* ✓ *Mass balance constraint* ✓ *Plant production constraint*
Chan et al. (2006)	*Minimization of total costs, total lead time, utilization, fulfillment reliability in mean value, fulfillment reliability in probability*		✓ *Production capacity* ✓ *Warehouse handling capacity* ✓ *Demand allocation* ✓ *Transportation mode*
Venkatadri et al. (2006)	*Minimization of product related costs*		✓ *Flow balance constraint* ✓ *Outflow limitation* ✓ *Throughput capacities at resources* ✓ *Production capacities at the aggregate level*

Table 4 (Continued)
Some of models' objective function(s) and constraints

	Objective function		Constraint
Grunow et al. (2007)	Cultivation	Maximization of milling requirement coverage	✓ Readiness of all haciendas for harvesting only once during zafra ✓ Controlling the spatial distribution of haciendas that are simultaneously ready for harvest ✓ Ensuring that no situation may occur in which haciendas preponderate in any given week which must be harvested manually
	Harvesting	Minimization of costs related to harvesting and transfer of reaped sugar cane	✓ Harvesting time and its way, manually or mechanically ✓ Reaping ✓ Stock balance ✓ Limitation of harvesting due to manpower ✓ Transportation ✓ Mill crane capacities
Chen et al. (2007)	Objective 1: Minimization of total costs Objective 2: Maximization of the robustness to various scenarios Objective 3: Maximization of local incentives Objective 4: Minimization of total transport time		✓ Network structure ✓ Transport ✓ Material balance ✓ Production resource ✓ Capacity
Kim et al. (2008)	Minimization of total daily costs (which consists of capital and operating costs)		✓ Mass balance constraint ✓ Capacity constraint
Shirazi et al. (2008)	Maximization of profit		✓ Transferred capacity constraint ✓ Production capacity in new factories ✓ Production capacity in existing factories ✓ Balance between input and output for existing and new facilities ✓ Supplying all customers' demands ✓ Allocation of customers to facilities ✓ Operational cost guarantee
Al-Othman et al. (2008)	Minimization of total production and logistics costs, lost demands and backlog penalties, and maximization of sales income		✓ Material balance ✓ Demand balance ✓ Crude oil production bounds ✓ Production yields ✓ Refinery throughput ✓ Storage capacities
Lau et al. (2009)	Minimization of total of all vehicles' travel times and distances		✓ Flow constraint ✓ Sub-tour constraint ✓ Way of serving customers (vehicle related) ✓ Supply of the product from depot should be at least more than demand ✓ Total volume of different products demanded should be at most less than vehicle's maximum capacity
Gumus et al. (2009)	Minimization of costs related to transportation between warehouses and factories, and fixed costs of facilities		✓ Factory capacity ✓ Warehouse capacity ✓ Number of warehouses ✓ Balance constraint for first echelon ✓ Balance constraint for second echelon (demand constraint) ✓ Binary constraint
Wang (2009)	Module 1	Minimization of number of partners	✓ Whole manufacturing system flow should satisfy all demands ✓ Gross yield rate at each echelon should be higher than average yield rate
	Module 2	Maximization of gross yield rate	✓ whole supply chain should satisfy all demands ✓ Number of partners in Module 2 should be equal to the one of Module 1
	Module 3	Minimization of T-score	✓ Capacity of partners ✓ Whole supply chain should satisfy all demands

Table 4 (Continued)
Some of models' objective function(s) and constraints

	Objective function	Constraint
Mahnam et al. (2009)	Minimization of costs satisfying an appropriate fill rate.	✓ Customer demand ✓ Lead time ✓ Each production unit can have multiple suppliers; ✓ Final product demand is completely fulfilled ✓ Conformance of quality level with ✓ specifications and standards ✓ Reliability of supplier transportation system. ✓ Company experience in supply chain environment. ✓ Financial stability. ✓ Guarantee, insurance, and support. ✓ Production efficiency. ✓ Production time. ✓ Vacant capacity percentage. ✓ Access level to resources.
Wu et al. (2009)	<u>Objective 1:</u> Minimization of raw materials' cost <u>Objective 2:</u> Minimization of production cost <u>Objective 3:</u> Minimization of transportation complexity <u>Objective 4:</u> Minimization of total distribution costs <u>Objective 5:</u> Minimization of establishment flexibility cost <u>Objective 6:</u> Minimization of defective rate for every product <u>Objective 7:</u> Maximization of total service level	✓ Material balance ✓ Supplier's capacity limit ✓ Production capacity limit ✓ Distribution center throughput limit ✓ Total supply and demand limit ✓ Defective rate constraint ✓ Distribution center constraint ✓ Service level
Cintron et al. (2010)	<u>Objective 1:</u> Maximization of profit <u>Objective 2:</u> Minimization of lead time <u>Objective 3:</u> Maximization of power <u>Objective 4:</u> Maximization of credit performance <u>Objective 5:</u> Maximization of distributers' reputation	✓ Option selection per customer per plant ✓ Customers' service getting ✓ Independent distributers' supplying options ✓ Customers' demand related constraint
Pishvaee and Torabi (2010)	<u>Objective 1:</u> Minimization of total costs (fixed opening, variable transportation and processing costs) <u>Objective 2:</u> Minimization of total tardiness	✓ Demand satisfaction ✓ Collection of all of returned products from all customers ✓ Flow balance ✓ Capacity constraint
Guillen-Gosalbez et al. (2010)	Minimization of total costs and caused damage	✓ Mass balance constraints ✓ Capacity constraints
Monteiro et al. (2010)	Minimization of costs related to decisions about facilities location, production, transportation and inventory	✓ Equality of shipped raw material to facilities and produced goods ✓ Demand constraints ✓ Capacity constraints ✓ Limitation of purchased raw material and finished products
Paksoy et al. (2010)	<u>Objective 1:</u> Minimization of forward logistics' total cost <u>Objective 2:</u> Minimization of reverse logistics' total cost <u>Objective 3:</u> Minimization of penalty costs due to environmental emissions <u>Objective 4:</u> Maximization of usage of recyclable products	✓ Facility capacity in forward/reverse logistics ✓ Truck capacity in forward logistics ✓ Equilibrium constraint in forward/reverse logistics
Liao et al. (2010)	<u>Objective 1:</u> Minimization of total cost <u>Objective 2:</u> Maximization of customer service level by specifying volume fill rate <u>Objective 3:</u> Maximization of customer service level by specifying responsive level	✓ Maximum capacity restriction of opened distribution centers ✓ Buyers serving conditions
Nagurney (2010)	Minimization of total cost (total cost of operating and total cost of capacity investment)	✓ Satisfying demand for products ✓ Equality of total amount of a product on a link and its utilization
Wang et al. (2011)	<u>Objective 1:</u> Minimization total cost <u>Objective 2:</u> Minimization of CO_2 emission	✓ Flow conservation ✓ Satisfaction of demand ✓ Facility's processing capacity ✓ Supply capacity

Table 4 (Continued)
Some of models' objective function(s) and constraints

Article	Model's Characteristics Objective function	Constraint
Georgiadis et al. (2011)	Minimization of costs (fixed infrastructure, production, material handling at warehouses and distribution centers, inventory holding, transportation)	✓ Network structure constraints ✓ Transportation flow constraints ✓ Material balance constraints ✓ Production resources constraints ✓ Warehouses and distribution centers' capacity constraints ✓ Safety stock constraints
Cardona-Valdés et al. (2011)	Objective 1: Minimization of cost related to opening distribution center, and expected value of transportation cost Objective 2: Minimization of sum of maximum of lead time	✓ Satisfying customers' demands ✓ Plants capacity limit ✓ Flow balance ✓ Distribution center's source constraint
Başligil et al. (2011)	Minimization of trip's cost	✓ Satisfying all demands ✓ Maximum and minimum number of vehicles used for trips
Paksoy and Yapici Pehlivan (2012)	Minimization of total cost	✓ Suppliers' capacity restriction ✓ Production capacity restriction ✓ Distribution centers' capacity restriction ✓ Shipped materials' limitation ✓ Chain's distribution capacity limitation ✓ Balance constraint
Paksoy et al. (2012a)	Maximization of distribution network's profit	✓ Raw material supply limitation ✓ Production capacity limitation ✓ Distributor capacity constraint ✓ Flow balance
Creazza et al. (2012)	Minimization of total logistics cost annually	✓ Single sourcing policy ✓ Service-level requirement
Paksoy et al. (2012b)	Objective 1 & 2: Minimization of transportation costs between different nodes of chain	✓ Fuzzy capacity restrictions ✓ Transportation flow balance

As it can be seen from Table 4, the main objective of these studies has been "Minimization of costs". Either they focused specifically on one or several type of cost, or their attention was put on system's total cost. In addition, some of other researches maximized profit instead of minimizing cost. Some of other noticeable objective functions are "Minimization of travel and transportation time", "Minimization of total tardiness", "Minimization of lead time", "Maximization of service level", and "Maximization of distributers' reputation". Only nine papers of all studies have considered multi objectives, and Cakravastia et al. (2002) and Grunow et al. (2007) are only multi stage models. Bredström et al. (2004) presented two models and Wang (2009) considered three. Among constraints, "Inventory", "Flow balance", "Transportation", "Manufacturing and production", and "Demand related" constraints have higher population.

5. Future research

With consideration of SCNO/SCND in today's business and industrial importance, in this paper, as a review paper of investigations in the field between the years of 2000 and 2013, we tried to present a full categorization of these fields. For this purpose several classification tables were prepared and required information were extracted from previous studies in the literature.

By focusing on the studies in the area, we will be able to guess what direction future researches will take and what issues were left vacant. Therefore, it will be possible to present some suggestion for future research. Before presenting trends and gaps we found in the studied literature, we will mention some of suggestions presented by our reference papers from latest years which are as follow:

- Paksoy et al. (2012b) with respect to their study suggest:
  - ✓ Studying robust fuzzy programming with consideration of both vagueness and ambiguity simultaneously,
  - ✓ Applying other fuzzy mathematical programming-based approaches,
  - ✓ Designing an expert system that works according to a decision maker's aspirations, experiences and business,
  - ✓ Applying a simulation model as an interesting option to integrate the best capacities of the facilities for supply chain planning problems, and
  - ✓ Applying fuzzy multi- objective linear programming models due to the multi-objective nature of the problem.
- Paksoy et al. (2012a) suggest:
  - ✓ To get better solutions with trade-offs, more mathematical statements [inverse problems (Aster et al. 2004); regressions models (Weber et al. 2009) etc.] can be added the model formulation, and
  - ✓ Usage of robust optimization techniques (El Ghaoui 2003; Werner 2007) in order to increase the models' robustness.
- Liao et al. (2010) suggestions for further research are:
  - ✓ Adapting the proposed hybrid evolutionary algorithm to other integrated location, inventory and distribution systems that have different characteristics or network structures, and
  - ✓ Exploring more competitive MOEAs or other existing optimization technologies, such as Lagrangian relaxation, particle swarm optimization, ant colony optimization, or other soft intelligent computing techniques,
- Suggestions of Shukla et al. (2010) are:
  - ✓ Including strategic costs relating to design changes of the supply chain.
- Cintron et al. (2010) have the following suggestions:
  - ✓ Using the results of tactical model as input to several operational models (e.g., optimal routing for locally supplied customers),
  - ✓ Making additions to the model to make it more specific to other situations such as performance of cross docking at the distribution center,
  - ✓ Introducing quantity discounts in the model or to make decisions of offering discounts (when and how much) when the inventory in the distributor center is too high,
  - ✓ Performing sensitivity analysis to obtain the optimal amount of inventory that should be stored at the distributor center, and
  - ✓ Method of convincing the customer to receive direct shipments from the plants.
- Pishvaee and Torabi (2010) suggest:
  - ✓ Addressing multi-product closed-loop supply chain network design under different kind of uncertainties and risks,
- Suggestions of Paksoy et al. (2010) regarding their study is:
  - ✓ Handling uncertainty embedded in demand, capacity and recovery rates to facilitate practical applications,
  - ✓ Associating the reverse part of their model with plants or other facilities in other supply chains, and
  - ✓ The model's environmental and greenness factors can be enlarged via adding noise pollution, accident risk and time assessment factors etc.

In next parts we will present some of gaps and trends that we found in the literature.

5.1. Gaps

Based on our review and categorized tables presented in different sections of this paper, we will summarize some vacancies found in the existing literature:

- The following fields compared to other ones were less paid attention to in the time horizon of this study:
  - ✓ Partner selection,
  - ✓ Supplier selection,
  - ✓ Vehicle routing problems (VRP),
  - ✓ Demand forecasting,
  - ✓ Facility planning,
  - ✓ Supply chain collaboration, and
  - ✓ Issues related to inventory.

These can be found by a close look at Table 2 in section 4.1. As mentioned before they have less population among overall issues. All of above mentioned fields are very important issues in a SC or SCN. For instance, a right choice of partner in any SC or SCN is a very important factor for having a successful SC or SCN with the right structure; this also applies for supplier selection and supply chain collaboration. Demand forecasting, facility planning, inventory related issues and VRP are also very important issues of SCs and SCNs because if decision reagargin them are not made correctly huge amount of costs can be the outcome.

Another gaps in this field by focusing on Table 3 and Table 4, are:

- Multi objective modeling,
- Multi criteria decision making, and
- Uncertainty and more specifically robustness.

In years between 2000 and 2013, among all the studies dedicated to modeling one or more specific issue(s) of SNC in order to optimize the existing situation, a few number of those considered several objectives at a time for their problem, or used multi criteria decision making. Also, in this time span few of these papers have considered the factor of uncertainty in their parameters and models, which is actually a very important factor since in real world uncertainty is a matter that exists and cannot be simply disregarded due to the fact that sometimes these uncertainties can completely change all the answers.

5.2. Trends

In the same manner, by investigating studies of the SCNO and SCND literature, we will be able to find out what direction they have taken, and possibly what issues will be having more attention and interest into. What we have found out about trends of studies are:

- **Strategic level issues of SC**; by focusing on Table 2, we can see that number of issues of all three levels of SC decision making are in general equal to each other, but focus on strategic issues has got more by moving from 2000 to 2013.

Regardless of decision level of a SC issue, the following issues have attracted more attention in recent years and it can be assumed that they will most likely face even more attention, and more proportion of studies be dedicated to them in the near future:

- Distribution, and distribution network,
- Transportation and its network system,

- Production, and
- SC and SCN optimization and design.

All of these issues are of relatively high importance for optimization of SCNs. Therefore, it can be said that it will be logical to consider studying them more accurately and better than it was done before.

Through investigating categorizes of Tables 3 and 4, the following have been found out:

- **Uncertainty**; in recent years uncertainty has been considered more in recent years. Although, it has been mostly in the form of fuzziness and less as robustness of a model. Having said that, we believe that considering uncertainty in the future studies will keep rising and more efforts will be put into taking it into account.
- **Multi-period**; consideration of this factor in modeling and studies has lowered during our under-study time span, although we cannot say it for sure that it will keep lowering in the upcoming years.
- **Multi echelon/stage**; paid attention to this element has risen while moving from the year 2000 to year 2013.

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