Supply Chain Management:
An opportunity for Metaheuristics

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Abstract

In today's highly competitive and global marketplace the pressure on organizations to find new ways to create and deliver value to customers grows ever stronger. In the last two decades, logistics and supply chain has moved to the center stage. There has been a growing recognition that it is through an effective management of the logistics function and the supply chain that the goal of cost reduction and service enhancement can be achieved. The key to success in Supply Chain Management (SCM) require heavy emphasis on integration of activities, cooperation, coordination and information sharing throughout the entire supply chain, from suppliers to customers. To be able to respond to the challenge of integration there is the need of sophisticated decision support systems based on powerful mathematical models and solution techniques, together with the advances in information and communication technologies. The industry and the academia have become increasingly interested in SCM to be able to respond to the problems and issues posed by the changes in the logistics and supply chain. We present a brief discussion on the important issues in SCM. We then argue that metaheuristics can play an important role in solving complex supply chain related problems derived by the importance of designing and managing the entire supply chain as a single entity. We will focus specially on the Iterated Local Search, Tabu Search and Scatter Search as the ones, but not limited to, with great potential to be used on solving the SCM related problems. We will present briefly some successful applications.

Keywords: Supply Chain Management, Metaheuristics, Iterated Local Search, Tabu Search and Scatter Search

1. Introduction

In today's highly competitive and global marketplace the pressure on organizations to find new ways to create and deliver value to customers grows ever stronger. The increasing need of industry to compete with its products in a global market, across cost, quality and service dimensions, has driven the need to develop logistic systems more efficient than those traditionally employed. Therefore, in the last two decades, logistics and supply chain has moved from an operations function to the corporate function level. There has been a growing recognition that it is through an effective management of the supply chain and logistics function that the goal of cost reduction and service enhancement can be achieved.

The key to success in Supply Chain Management (SCM) require heavy emphasis on integration of activities, cooperation, coordination and information sharing throughout the entire supply chain, from suppliers to customers. To be able to respond to the challenge of integration there is the need of sophisticated decision support systems (DSS) based on powerful mathematical models and solution techniques, together with the advances in information and communication technologies. There is no doubt of the importance of quantitative models and computer based tools for decision making in today's business environment. This is especially true in the rapidly growing area of supply chain management. These computer-based logistics systems can make a significant impact in the decision process on the organizations. That's why the industry and the academia have become increasingly interested in SCM and logistics DSS to be able to respond to the problems and issues posed by the changes in the area.

Many well-known algorithmic advances in optimization have been made, but it turns out that most have not had the expected impact on the decisions for designing and optimizing supply chain related problems. For example, some optimization techniques are of little use because they are not well suited to solve complex real logistics problems in the short time needed to make decisions. Also some techniques are highly problem-dependent and need high expertise. This adds difficulties in the implementations of the decision support systems which contradicts the tendency to fast implementation in a rapid changing world. In fact, some of the most popular commercial packages use heuristic methods or rules of thumb. The area of heuristic techniques has been the object of intensive studies in the last decades with new and powerful technique proposed to solve hard problems, as many metaheuristic methods. Therefore, for one side there is the need for sophisticated logistics DSS to able the organizations to respond quickly to new issues and problems faced on the SCM, and for the other side there are advances in the area of metaheuristics that can provide an effective response to complex problems. This provides a fertile ground for applications of these techniques to SCM and, afterwards, the development of computer-based systems to help logistics decisions.

The objectives of this work is to give an understanding of the role that metaheuristics can play in solving complex supply chain related problems such as optimizing routing distribution, supply chain design, production scheduling and resource allocation.

In the following section we present a brief discussion on the important issues in SCM. Next, we argue that metaheuristics can play an important role in solving complex supply chain related problems derived by the importance of designing and managing the entire supply chain as a single entity. We will focus specially on the Iterated Local Search, Tabu Search and Scatter Search has the ones, but not limited to, with great potential to be used on solving the SCM related problems. In Section 4 we will briefly present some successful applications of metaheuristics in solving real supply chain problems; after, we present some conclusions and directions of future research.

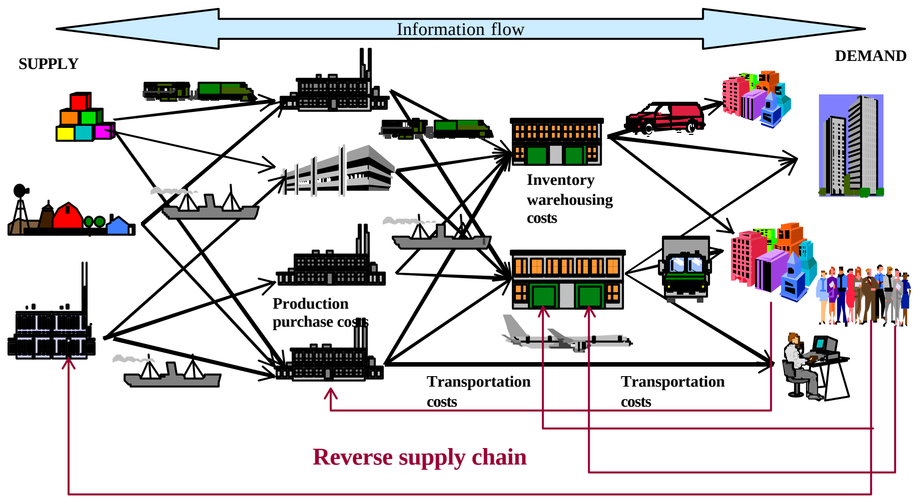

Figure 1: An example of a supply chain.

2. Supply Chain Management

The supply chain encompasses all activities associated with the flow and transformation of goods from raw material stages through to the end users, as well as the associated information flows. Material and information both flow up and down on the supply chain. A supply chain consists basically on the following elements: suppliers, manufacturing centers, warehouses, distribution centers, transportation systems, retail outlets and customers; raw material, work-in process inventory, finished goods and information that flow between the different elements (see Figure 1). One important aspect in a supply chain is the integration and coordination of all activities in the chain, since decisions in one element affect directly the whole supply chain. Firms must avoid sub-optimization by managing the entire supply chain as a single entity. This obviously increments, in a significant way, the complexity of any supply chain problem. To respond to this challenge there is the need for powerful and robust techniques, as we will discuss in the following section.

There is not a clear consensus on the definition of SCM, however there appears to be some convergence in the literature as to what a supply chain is. In general, supply chain can be summed up as a series of interconnected activities which are concerned with planning, coordinating and controlling materials, parts, and finished goods from supplier to customer. SCM refers to the management of these activities. A firm, be it a manufacturing or service, belongs to at least one supply chain. The key success of SCM, may lay in the system's integration, i.e. requires emphasis on integration of activities, cooperation, coordination, and information sharing throughout the entire supply chain.

Several definitions appear on the literature. Simchi-Levi et al. (2000) presented the following one: "Supply Chain Management is a set of approaches utilized to efficiently integrated suppliers, manufactures, warehouses, and stores, so that merchandise is produced and distributed at the right quantities, to the right locations, and at the right time, in order to minimize systemwide costs while satisfying service level requirements."

The Council of Logistics Management say, "Logistics is part of the supply chain process that plans, implements, and controls the efficient, effective flow and storage of goods, services, and related information from the point of origin to the point of consumption in order to meet customers' requirements" (http://www.clm1.org).

Johnson et al. (1999) say "*Logistics* define the entire process of materials and products moving into, through, and out of a firm. *Inbound logistics* covers the movement of materials received by the suppliers. *Material management* describes the movements of materials and components within a firm. *Physical distribution* refers to the movement of goods outwards from the end of the assembly line to the customer. Finally, *supply-chain management* is a somewhat larger concept than logistics, because it deals with managing both the flow of materials and the relationships among channel intermediaries from the point of origin of raw materials through to the final consumer."

As many authors refer, in actual business practice many times these terms are used interchangeably. The definitions that one can find in actual literature of Business Logistics Management and Supply Chain Management give a special emphasis on the integration of the entire supply chain, including the logistics activities within the organization and the enlace with suppliers and customer. Therefore, we will use both terms without distinction.

The key issues in SCM, which can include, but are not limited to:

- Supply-chain integration.
- Facility location and network design
- Transportation and vehicle routing
- Material handling and order picking
- Customer service

- Product design
- Logistics of production and operations
- Warehouse management and distribution strategies.
- Inventory management.
- Information systems and DSS
- E-commerce and e-logistics
- Reverse and green logistics

For each on the above issues, we present a brief description and discuss aspects that can increase the complexity when optimizing the entire supply chain. The idea is not to discuss the issues in detail, and for the readers interested we refer to the following books in Logistics and SCM, Simchi-Levi et al. (2000), Ballou (1998), Johnson et al. (1999). We also refer to Tayur et al. (1999) where several quantitative models for SCM are presented and a broad taxonomy review of SCM research is described.

2.1 Supply-chain integration and coordination

The supply chain coordination and integration has become a core issue in SCM, not just integration within the organization but integration upstream with suppliers and downstream with distributors and customers. Coordination and integration means many different ideas, but basically all authors agree that it means collaborative working and implies joint planning, joint product development, mutual exchange of information and integrated information systems, cross coordination on several levels in the companies on the network, long term cooperation, fair sharing of risks and benefits, etc., Skoett-Larsen (2000). A enormous advantage of an integrated supply chain is the reduction of the so-called bullwhip-effect, Lee et al. (1997), where a small changes or decision on one level of the network may result in large fluctuations, large amount of stock, and/or increased lead times on other levels of the supply chain. However, as the process becomes more integrated within a supply chain, the complexity of the decisions about the supply chain also increase. As the concept of process integration becomes more embraced by the different industries, the need of sophisticated tools and decision information systems increases, to able the decision makers to evaluate possible alternatives, decisions and their impact in the whole supply chain.

2.2 Facility location and network design

The firm must balance the costs of opening new warehouses with the advantages of being close to the customer. Warehouse location decisions are crucial determinants of whether the supply chain is an efficient channel for the distribution of the products.

In the OR literature, there exist several researches dedicated to location issues, as warehouse location. See, for example, the web page of the European Working Group on Locational Analysis - EWGLA (http://www.vub.ac.be/EWGLA/homepage.htm) and Section on Location Analysis within INFORMS – SOLA (http://www.uscolo.edu/sola/sola.html), and the Miller (1996), Drezner (1995) and Daskin (1995). It seems that some of these models are quite simple when representing real problems in the design of an actual supply chain. For example, they do not take in account the warehouse capacity, the warehouse handling and operational costs (most of then just take in account the warehouse fixed initial cost) or the warehouse service level requirements, which some of these ones are connected to inventory issues. Also, when designing a supply chain that involves several countries, import and export taxes, different transportation options, cultural and legal issues, and several others must be taken into consideration. The incorporation of these aspects in the model can make a significant difference on the analysis of the SC network.

2.3 Transportation and vehicle routing

One of the central problems of supply chain management is the coordination of product and material flows between locations. A typical problem involves bringing products located at a central facility to geographically dispersed facilities at minimum cost. For example, a supply of product is located at a plant, warehouse, cross-docking facility or distribution center and must be distributed to customers or retailers. The task is often performed by a fleet of vehicles under direct control or not of the firm. Transportation is an area that absorbs a significant amount of the cost in most firms. Therefore, methods for dealing with the important issues in transportation as mode selection, carrier routing, vehicle scheduling and shipment consolidations are of need in most companies.

One important aspect in transportation management is the coordination with the remaining activities in the firm, especially within warehouse and customer service. In some cases the transport is the last contact with the customer, and therefore, the companies should pay attention to fulfill the customer expectations and use this relationship to improve their sales. The transport coordination of the different elements of a supply chain, that can evolve different companies, can be very important since all of them most likely benefit by having a fast delivery to a specific customer. Therefore, many issues in the integration of transportation with other activities in the network can be a challenge to the academic and industrial communities.

One basic and well-known problem in transportation is the vehicle scheduling and routing. A vehicle scheduling system should output a set of instructions telling drivers what to deliver, when and where. An “efficient” solution is one that enables goods to be delivered when and where required at least cost, subject to legal and political constraints. The legal constraints relate to hours of work, speed limits, vehicle construction and use regulations, restrictions for unloading, and so on. With the growing of sales by Internet, this problem is gaining enormous importance, since the delivery times are usually very short, the customers can be dispersed in a region, every day there is a different set of customers and also with very short time-windows to deliver the product. For a review on the area see Crainic and Laporte (1998).

2.4 Warehouse management and distribution strategies.

Warehousing is an integral part of every logistics system and plays a vital role in providing a desired level of customer service. Warehousing can be defined as the part of a supply chain that stores products (raw materials, parts, work-in-process and finished goods) at and between points of production and points of consumption, and provides information to management on the status and disposition of items being stored. The basic operations on a warehouse are receiving, storage-handling, order picking, consolidation – sorting and shipping. The main objectives are to minimize the product handling and movement and store operations as well as maximize the flexibility of the operations.

But traditional warehouses are suffering enormous transformations by the introduction of direct shipment and cross-docking strategies. These last strategies may be more effective in distributing the products among the retailer or customer. However, to be successful strategies, they require high coordination and information systems integration between all elements on the supply chain, manufactures, distributors, retailers and customers, a certain volume of goods to be transported and a fast and responsive transportation system, just to mention the most important requirements. Deciding which is the best distribution strategy of a particular product of a company can make an enormous impact on the company success or not. Therefore, there is the need to have DSS that helps executive managers to select the best distribution strategies and, at the warehouse level, to exercise decisions to make the movement and storage operations more efficient.

2.5 Inventory management.

The importance of the inventory management and the relationship between inventory and customer service is essential in any company. As for the location issues, inventory management has been well studied in the OR literature; however, the use of inventory systems in helping decision-making process has been less widespread. Most of the models well known in the literature are simple and, for example, do not consider multiproduct inventory management that require the same resources, or in some case do not treat all the complexities involved in inventory management as the demand uncertainty. Recent technological advances have increased the level of uncertainty. Also, so far the most well known inventory models and systems consider a single facility managing its inventories in order to minimize its own costs. As we have mentioned, one important challenge in SCM is the integration and coordination of all activities in the supply chain, in particular an important issue is managing inventory in the whole supply chain minimizing the systemwide cost. This requires models and DSS that are able to help decisions and suggest policies for the inventory management in the whole supply chain. To solve such a complex issue, we will argue that DSS which combine simulation and metaheuristics techniques, can be of great help.

2.6 Product design

Products are a main element in the supply chain, which should be designed and managed to able an efficient flow of these products. This approach is known as “design for supply chain” and is likely to become frequently used in the future. The characteristics of the product, as the weight, volume, parts, value, perishability, etc., influence the decisions on a supply chain, since the need for warehousing, transportation, material handling and order processing depend on these attributes. Products designed for efficient packaging and storage obviously make an impact on the flow in the supply chain and cost less to transport and store. During the design process of a new product, or changes on an existing one, the requirements of the logistics related to the product movements should be taken into consideration. Also, the need for short lead times and the increased request by customer to unique and personalized products put pressure on efficient product design, production and distribution. Postponement is one successful technique that can be applied to delay product differentiation and also lead to an improvement on the logistics of the product, Lee et al. (1993). The use of information systems and simulation technique that help to analyze the impact on the supply chain of a certain design of a specific product can be or great help to the managers.

2.7 Material handling and order picking

Material handling is a broad area that encompasses basically all activities related with the movement of raw material, work in process, or finished goods within a plant or warehouse. Moving a product within a warehouse is a no value-added activity but incurs in a cost. Order processing or picking includes basically the filling of a customer order and making it available to the customer. These activities can be quite important since they have impact on the time that it takes to process customer orders in the distribution channel or to make supplies available to the production function. They are cost absorbing and therefore need attention from the managers. Packaging is valuable both as a form of advertising and marketing, as for protection and storage from a logistical perspective. Packaging can ease movements and storage by being properly designed for the warehouse configuration and material handling equipment.

The major decisions in this area includes many activities, such as facility configuration, space layout, dock design, material-handling systems selection, stock locator and arrangement, equipment replacement, and order-picking operations. Models and techniques available in our days to help the decision maker see the above decisions processes as independent activities of the remaining ones of the whole system. Therefore DDS that analyze the impact of material handling and order picking activities in the logistics system and able the decision-maker to take the best decision for the whole network are an important and needed tool.

2.8 Logistics of production and operations

The most common definition of production and operations management (POM) is as follows: the management of the set of activities that creates goods and services through the transformation of inputs into outputs, Chase, Aquilano and Jacobs (1998), Stevenson (1999). The interaction between POM and SCM is enormous, since the production needs raw materials and parts to be able to produce a good, and then this good must be distributed, Graves et al. (1993). Therefore, the coordination between both areas is fundamental to the have an efficient supply chain. The techniques required to plan and control the production in an integrated supply chain goes behind the MRP (Material Requirement Planning) so popular in industries. The need to take into consideration the manufacturing or service capacity, labor and time constraints has given importance to the Scheduling area. This field is extremely vast, however, research at a scientific level mainly has focused at the formalization of specific problem types, leading to standard problems like the flow-shop scheduling problem, job-shop scheduling problems, etc. Significant amount of research efforts have been dedicated to the classification of the problem hardness by deriving complexity results for a large variety of problem variants and the development of efficient solution techniques for standard scheduling problems, Pinedo (1995). The latter research efforts have shown that for many problems the use of heuristic algorithms, which cannot guarantee to find optimal solutions but in a large number of experiments were shown to be able to find extremely high quality solutions in short time, are currently the most promising solution techniques for hard scheduling problems. Despite the research efforts in academic scheduling research, there still exists a considerable gap in the application in practical problems of the techniques developed on the academic side. Scheduling problems are already quite hard problems per se, if there exists the need to extend them to consider aspects of the whole supply chain the complexity will increase significantly. Moreover, in many supply chains, the bottleneck activity is the production, therefore planning and managing efficiently the production and scheduling activities is of great importance to be able to have an efficient supply chain.

2.9 Information systems and DSS

Computer and information technology has been utilized to support logistics for many years. Information technology is seen as the key factor that will affect the growth and development of logistics, Tilanus (1997). It is the most important factor in an integrated supply chain, also playing an important role in the executive decision-making process. More sophisticated applications of information technology such as decision support systems (DSS) based on expert systems, simulation and metaheuristics systems will be applied directly to support decision making on SCM. A DSS incorporates information from the organization's database into an analytical framework with the objective of easing and improving the decision making. A critical element on a DSS for logistics decision is the quality of the data used as input of the systems. Therefore, in any implementation, efforts should me made to have accurate data. Afterwards, the modeling and techniques applied to obtain a scenario or analysis of a logistics situation should be adapted to the environment of the company and support the managers and executives in their decision processes.

We believe that metaheuristics, when incorporated to a DSS for SCM, can contribute significantly to the decision process, especially taking into consideration the increased complexity of the logistics problems previously presented. DSS based on metaheuristics are not currently widespread, but it appears to be growing as a potential technique to solve hard problems as the one related with SCM.

2.10 e-commerce and e-logistics

In just a few short years, the Internet has transformed the way in which the world conducts business and business partners interact between themselves. e-business and electronic commerce are some of the hottest topics of our days. In e-commerce, business partners and customers connect together through Internet or other electronic communication system to participate in commercial trading or interaction. Here, we will not discuss the e-commerce in detail, but certainly e-commerce makes new and hard demands on the company's logistics systems, calling in same cases to completely new distribution concepts and a new design of the supply chain. Companies are requiring DSS that help them to make the best decisions in an uncertain and rapid changing world as the one related with e-commerce and e-business. Many of the problems can be seen as extensions of the ones described before, as for example, the transportation management, while others are completely news with some added complexities as the uncertainties associated with the evolution of the commerce on the web. An example of new problems that can appear are related with the home distribution, generated by the business-to-consumer (B2C), during no-labor hours and searching for solution that can permit an efficient distribution. As for example, the inclusion of 24 hours dropping-points, where the transportation companies can leave a package that will be collected later by the customer, avoiding in this way to have to distribute during nights and Saturday and Sunday. Questions as: where to locate and the size of these dropping-points, frequency of visits, partnership with stores, etc. are issues yet not treat in the metaheuristics and logistics literature.

2.11 Reverse and green logistics

The concerns about environment have never been as important as in our days. Also, the strict regulation regarding removal, recycling and reusing is on increase, especially in Europe. This will bring Reverse Logistics and Green Logistics into the main focus in the near future. Reverse logistic is related to the process of recycling, reusing and reducing the material, i.e. goods or materials that are sent "backwards" in the supply chain. The issues faced in reverse logistics are not just the "reverse" issues of a traditional supply chain, they can be more complex, as for example, aspects related to the transportation and disposal of dangerous materials. By green logistics, it usually understands the activities related with choosing the best possible means of transportation, load carriers and routes and reducing the environmental impact of the complete supply chain. Some of the areas clearly affected are packaging of products, transportation means and product development, as many others. Logistics is also involved in removal and disposal of waste material left over from the production, distribution or packaging process, as the recycling and reusable products.

All the above make clear the relevance of the area of reverse and green logistics, since many companies have to re-organize their supply chains and even extend them to able the return, reuse or disposal of their product and materials. These pose many new and challenging questions to the area of SCM.

2.12 Customer service

Customers have not been taken so seriously as in our days. Being able to fulfill the customer expectations is a task of the SCM, and deciding the level of customer service to offer customers is essential to meeting a firm's profit objective. Customer service is a broad term that may include many elements raging from product availability to after-sales maintenance. In brief, customer service can be seen as the output of all logistics activities, that also interact with other functions in the firm especially with marketing. Since all the elements of the supply chain interact and a decision on one element affects the other ones, then any supply chain decision can affect the customer service. Therefore, systemwide DSS that help the decision maker at strategic, tactic and operation level, to evaluate, simulate and analyze different options and scenarios, and the interaction between the players in a supply chain are of increased request by the many companies.

We have briefly reviewed some actual issues and aspects of the management of an integrated supply chain. The problems in general are complex and the decision maker will benefit from having a DSS that can generate several scenarios and what-if analysis in short time to able them to analyze the impact of one decision on the whole system. In the next chapter we will argue that metaheuristics can be an excellent tool to be included in such a DSS for SCM.

3. Metaheuristics for the SCM

As we have seen in previous sections, the supply chain is a complex network of facilities and organizations with interconnected activities but different and conflicting objectives. Many companies are interested in analyzing their supply chain as an entire and unique system to be able to improve their business. However, in most cases the task of designing, analyzing and managing the supply chain has been done based on experience and intuition; very few analytical models and design tools have been used in the process. This implies that finding the best supply chain strategies for a particular firm, group of firms or sector poses significant challenges to the industry and academia. We argue that metaheuristics can be an important tool of helping managers and consultants in the decision process.

The optimization literature focuses on algorithms for computing solutions to constrained optimization problems. An exact or optimal algorithm in the optimization context refers to a method that computes an optimal solution. A heuristic algorithm (often shortened to heuristic) is a solution method that does not guarantee an optimal solution, but in general has a good level of performance in terms of solution quality or convergence. Heuristics may be constructive (producing a single solution) or local search (starting from one or given random solutions and moving iteratively to other nearby solutions) or a combination (constructing one or more solutions and using them to start a local search). A metaheuristic is a framework for producing heuristics, such as simulated annealing and tabu search. To develop an heuristic for a particular problem some problem-specific characteristics must be defined, but some other can be general for all problems. The problem-specific may include the definition of a feasible solution, the neighborhood of a solution, rules for changing solutions, and rules for setting certain parameters during the course of execution. For a general discussion in heuristics see Corne, Dorigo and Glover (1999), Aarts and Lenstra (1997) and Glover F. and G. Gkochenberger (2001).

Well-designed heuristics packages can maintain their advantage over optimization packages in terms of computer resources required, a consideration unlikely to diminish in importance so long as the size and complexity of the models arising in practice continue to increase. This is true for many areas in the firm, but especially to SCM related problems.

Metaheuristics have many desirable features to be an excellent method to solve very complex SCM problems: in general they are simple, easy to implement, robust and have been proven highly effective to solve hard problems. Even in their most simpler and basic implementation, the metaheuristics have been able to effectively solve very hard and complex problems. Several other aspects are worth to mention. The first one is the metaheuristics modular nature that leads to short development times and updates, given a clear advantage over other techniques for industrial applications. This modular aspect is especially important given the current times of implementing a DSS in a firm and the rapid changes that occurs in the area of SCM.

The next important aspect is the amount of data involved in any optimization model for an integrated supply chain problem, which can be overwhelming. The complexity of the models for the SCM and the incapacity of solving in real time some of them by the traditional techniques, force the use of the obvious technique to reduce this complex issue by data aggregation, Simchi-Levi et al. (2000). However this approach can hide important aspects that impact the decisions. For example, think about customer aggregation by distance, customer close can be aggregate, but suppose they require a total different level of service. Therefore, instead of aggregate data to be able to obtain a simple and solvable model, but which not represent well the reality, maybe we should consider the complex model but using an approximation algorithm.

The last aspect that we would like to mention in favor of using metaheuristics is the estimation of costs, like transportation and inventory costs. Why solve to the optimal a model, where the data are estimations? Maybe we should use the time to be able to produce several scenarios for the same problem. For example, various possible scenarios representing a variety of possible future demand patterns or transportation costs can be generated. These scenarios can then be directly incorporated into the model to determine the best distribution strategy or the best network design. The scenario-based approaches can incorporate a metaheuristic to obtain the best possible decision within a scenario.The combination of best characteristics of human decision-making and computarized model and algorithmic based systems into interactive and graphical design frameworks have proven to be very effective in SCM, since many supply chain problems are new, subject to rapid changes and moreover, there is no clear understanding of all of the issues involved.

Hax and Candea (1984) proposed a two-stage approach to solve SCM and take advantages of the system dynamics:

1. Use an optimization model to generate a number of least-cost solutions at the macro level, taking into account the most important cost components.
2. Use simulation models to evaluate the solutions generated in the first phase.

In Figure 2, we present scheme for a DSS combining simulation and optimization techniques. We argue that the user can analyze more and better scenarios within the same time framework if metaheuristics techniques are used as the solution method instead of exact method or other heuristics techniques. Moreover, the upgrades of the DSS can be easily developed and implementing for a specific firm with specific problems.

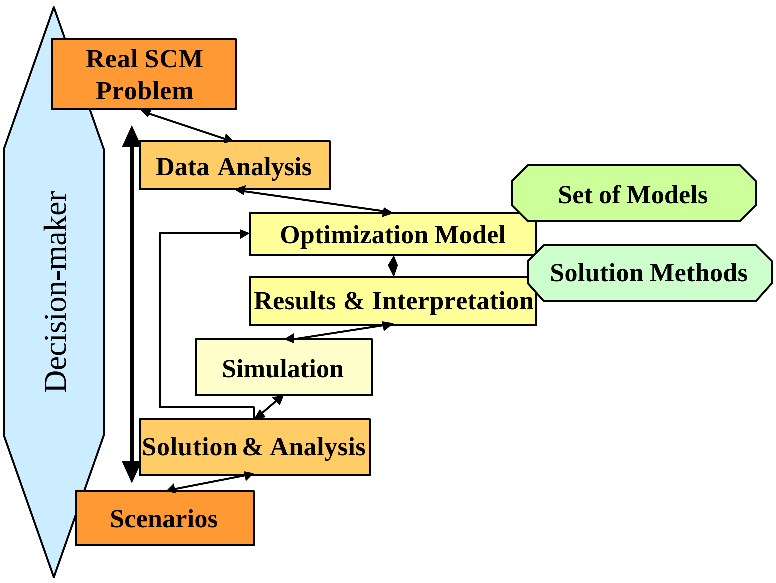

Figure 2: A DSS scheme for the SCM.

Metaheuristics will help to take system decisions within a certain parameters and environment and then, simulation techniques can be applied to analyze the system behavior in presence of uncertainties. Simulation-based tools take in account the dynamics of the system and are capable of characterizing system performance for a given design (or decisions). The limitations of the simulation models are that they only represent a prespecified system, i.e. given a particular configuration, a simulation model can be used to help estimate the costs associated with operating the configuration (simulation is not an optimization tool). Therefore the combination metaheuristics-simulation can provide very interesting ideas about the SC problems. The use of simulation has produced widespread benefits in the decision process within firms, however, simulation-based tools have not been good in proposing the optimal or near optimal solution of several possible solutions. On the other hand, the mathematical programming models and techniques are able to find the best solutions, but not able to simulate the behavior and effects of a particular decision in presence of uncertainties. Recent developments are changing this picture, and the decision making process can benefit enormously by having a system that is able to identify and evaluate the optimal or near optimal solution in a present of uncertainties. These advances are possible by the development made in heuristic research, particularly in metaheuristics. The OptQuest computer software, by F. Glover, J.P. Kelly and Manuel Laguna, of OptTeck Systems, Inc. (http://www.opttek.com/) present already this innovation, Laguna (1998), Laguna (1997), Glover, Kelly and Laguna (2000). OptQuest replaces the inaccuracy of trial-and-error usual in simulation system by using a potent search engine that can find the best decisions that fall within a domain that the simulation or other evaluation model encompasses. Actually, there are several versions of the OptQuest integrated with commercial simulation packages.

We believe that in the future more combinations of simulation and optimization techniques will be developed. Metaheuristics techniques play a very important role in this direction since they can obtain very good solution within a small time framework, which can be easily adapted and developed to solve very complex logistic problems.

Next, we focus on three metaheuristics: iterated local search, tabu search and scatter search. Many other have similar features and are also potential methods to apply to SCM problem. We discuss these ones because, in their simple form, they present quite good results and can be in certain way representative of the last developments in modern heuristic research. At the end of the chapter we will comment on common aspect of these metaheuristics that can be relevant in solving SCM problems.

Iterated Local Search (ILS) is a simple, yet powerful metaheuristic to improve the performance of local search algorithms. The simplicity stems from the underlying principle and the fact that only a few lines of code have to be added to an already existing local search algorithm to implement an ILS algorithm. ILS is currently among the best performing approximation methods for many combinatorial optimization problems.

To apply an ILS algorithm to a given problem, three "ingredients" have to be defined. One is a procedure designated by *Perturbation* that perturbs the current solution s

(usually a local optimum) leading to some intermediate solution s'. Next, a *Local Search* is applied taking s' to a local minimum s''. Finally, one has to decide which solution should be chosen for the next modification step. This decision is made according to an *Acceptance Criterion* that takes into account the previous solution s, the new candidate solution s'' and possibly the search history. For an extended reference in ILS see Lourenço et.al. (2001). An algorithmic outline for the ILS is given in Figure 3.

```
Procedure Iterated Local Search
        s_0 = GenerateInitialSolution;
        s* = LocalSearch(s_0);
        repeat
                s' = Perturbation(s*, history);
                s'' = LocalSearch(s');
                s* = AcceptanceCriterion(s*, s'', history);
        until termination crietrion met
end return s*.
```

Figure 3: Iterated Local Search

Tabu Search is an adaptive procedure originally proposed by Glover (1986). Recently, this metaheuristic has been gaining importance as a very good search strategy method to solve combinatorial optimization methods. For a survey, see Glover and Laguna (1997).

```
Procedure Tabu Search
        x = GenerateInitialSolution;
        repeat
                Let x'= neighbor(x), not tabu
                    or satisfying an aspiration criteria, with
                    minimal value of the objective function;
                Set x = x' and update the tabu list
                    and aspiration criteria;
        until termination criterion met
end return the best solution found.
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Figure 4: Tabu Search

The basic idea of tabu search is to escape from a local optimum by means of memory structures. Each neighbor solution is characterized by a move and short term memory is used to memorize the attributes of the most recently applied moves, incorporated via one or more tabu list. Therefore, some moves are classified as tabu and consecutively some neighbor solutions are not considered. To avoid not visiting a good solution, an aspiration criterion can be considered. At each iteration, we choose the best neighbor of the current solution that it is not tabu or verifies an aspiration criterion. The aspiration criterion used here was the most common one; the tabu status is overruled if the neighbor solution has an objective function value smaller than the best found up to that iteration. The algorithm stops when a certain stopping-criterion is verified. The best solution found during the search is then the output of the method. The main steps of the tabu search algorithm are presented at Figure 4.

Scatter search, from the standpoint of metaheuristic classification, may be viewed as an evolutionary (also called population-based) algorithm that constructs solutions by combining others. It derives its foundations from strategies originally proposed for combining decision rules and constraints (in the context of integer programming). The goal of this methodology is to enable the implementation of solution procedures that can derive new solutions from combined elements in order to yield better solutions than those procedures that base their combinations only on a set of original elements. As described in tutorial articles (Glover 1998 and Laguna 1999) and other implementations based on this framework (Campos et al. 1998), the methodology includes the following basic elements:

- Generate a population *P*.
- Extract a reference set *R*.
- Combine elements of *R* and maintain and update *R*.

Scatter search finds improved solutions by combining solutions in *R*. This set, known as the reference set, consists of solutions of high quality that are also diverse. The overall proposed procedure, based on the scatter-search elements listed above, follows as:

Generate a population P: Apply the diversification generator to generate diverse solutions.

Construct the reference set R: Add to *R* the best r_1 solutions in *P*. Add also r_2 diverse solutions from *P* to construct *R* with $|R| = r_1 + r_2$ solutions.

Maintain and update the reference ret R: Apply the subset generation method (Glover 1998) to combine solutions from *R*. Update R, adding solutions that improve the quality of the worst in the set.

Since the scatter-search main feature is a population-based search, we believe it will be an adequate solution technique to solve hard and large-scale multiobjective problems by finding an approximation of the set of Pareto-optimal solutions. Therefore, the inclusion of scatter search methods on a scenario-based DSS software can have an important impact, since in one run several good scenarios can be obtained. Several application have already be completed, Martí et al. (2000) and Corberán et al.(2000), and we believe in a near future more will appear in the literature.

All the above metaheuristics have in common even the simpler implementations that are able to solve hard problems in a short amount of running time. Moreover, the inclusion of new features, constraints, objective function can be relatively simple which is quite important in a rapid changing world of the supply chain management.

Given a description of the problem and necessary data, the above metaheuristics have the following modules in common:

- Generate an initial solution or a population of solutions;
- Obtain the objective value of a solution;
- Obtain the neighborhood of a solution;
- Perform a perturbation on a solution or obtain a subset of combined solutions;
- Perform an acceptance test;
- Stopping criteria.

All of the above modules can be developed to complex problems, independently of the specific mathematical characteristics of the problems, as linear or non-linear functions. This gives a great advantage to the metaheuristics. Moreover, since the methods share modules, it would be easy to implement several metaheuristics for the same problem on hand. As mentioned, the supply chain decision-makers are suffering enormous changes every day and challenges that need a quick response. The consideration of these changes can be quickly incorporated on a metaheuristics-based DSS without the need to modify the complete software. Also, the problems in the SCM area can benefit from the enormous amount of successful applications of metaheuristics to combinatorial optimizations and other hard problems. From this list, the DSS developer can learn what can be the best approach to a specific problem on the SCM by studying the combinatorial optimization problem that has more aspects in common with the real problem, as for example the best metaheuristics, the best neighborhood, etc.

Next, we will present some applications in the area of SCM that exemplified the advantages of using a metaheuristic in a decision process of SCM and their role in the management of an integrated supply chain.

4. Applications

We can already find several applications of metaheuristics to SCM problems and incorporation of metaheuristics in DSS to SCM, however, they are not yet widespread as we could expected the potential of the technique. We will review next some successful logistics applications, ranging from vehicle routing to container operations problems. The objective is not to make a survey on the applications of metaheuristics to SCM, but to give a few examples of the possibilities of the metaheuristics to SCM.

Weigel and Cao (1999) presented a vehicle-routing DDS to help the decision process related with home-delivery and home-service business for the Sears, Roebuck and Company (www.sears.com). The system was developed together with a software company ESRI (www.esri.com) and is based on a combination of geographical information systems (GIS) and operations research. More specifically, the main techniques used in the development of the algorithms behind the DSS are local search and tabu search methods. The algorithms and their technical implementations have proven to be generic enough that can be successfully apply to other business. The system has improved the Sears technician-dispatching and home-delivery business resulting in saving over $42 million in annual saving. This is a clear example of how metaheuristics integrated in a DSS for SCM can make a strong impact on a company by helping them in the decision process, gain understanding of the problem, use in a more efficient way their resources, give a better customer service and finally, but not less important, to reduce costs.

Ribeiro and Lourenço (2001) presented a complex vehicle routing model to the distribution in the food and beverages industries. The main idea is design routes taking in consideration issues of the responsibility of different departments in a firm. This cross-function planning is the basis to obtain an integrated supply chain. The authors propose a multiobjective multiperiod vehicle routing model, where there are three objective functions that respond to three different areas; the usual cost function which is responsibility of the distribution department; an human resources management objective which related to a fair work load, and in case of variable salary also relates with a fair equilibrium of possible percentages of sales; and finally a marketing objective with ties to assign always the same driver to the same customer so the customer service can improve.
To be able to solve such a complex model in a short amount of time, or integrate a solution method within a DSS to help distribution logistics, the solution method must be give a proposed solution in very short time and allow simple updated and changes during the installation process and future use. This of course advocates for the metaheuristics techniques. In their work, Rita and Lourenço (2001) proved the importance of taking the several function and the difficulty of solving the model even for very small instances of the problem.

Ichoua, Gendreau and Potvin (2000) present a new strategy for the dynamic assignment of new requests in dynamic vehicle routing problem which includes diversion. These dynamic vehicle routing problems are common on organizations like courier services, police services, dial-and-ride companies and many others. In the dynamic context, each new request is inserted in real time in the current set of planned routes, where a planned route is the sequence of requests that have been assigned to a vehicle but not served yet. A tabu search heuristic was used to make an empirical evaluation of the new strategy. The results demonstrate the potential savings on total distance, total lateness and number of unserved customers when compared to a simple heuristic where the current destination of each vehicle is fixed. This application shows a potential use of the metaheuristics, which is not only to help directly on operational decisions, but more relevant to help on identifying the best strategies to highly dynamic problems as the real-time vehicle dispatching.

Bosë et al. (2000) describe the main processes in a container terminal and present methods, based on evolutionary algorithms, to optimize these processes. They focus on the process of container transport by gantry cranes and straddle carriers between the container vessel and container yard. The reduction on the time in port for the vessel, time for load and unload the vessel and the increment of the productivity of the equipment are main objectives for the management of a container yard. The global increment of container transportation, the competition between ports and the increment of multimodal parks leads to the need of a better techniques to help the decision process of the responsible of a container terminal management. Bosë et al.(2000) proved that with a simple genetic algorithm, combined with a reorganization of the process, the amount of time in port for container vessels can be reduced, leading to a competitive advantage of the container terminal. As future research they expect to develop a hybrid system using simulation and evolutionary methods to be able to take in consideration uncertainties. This work exemplifies well the direction that SCM is following to be able to solve the complex problems on the area.

Fanni et al. (2000) describes the application of a tabu search to design, plan and maintain a water distribution system. Being that water is a sparse resource, especially in some countries, the design and maintenance of pipe networks for water supply distribution require high costs, achieving the highest level of performance of existing networks at minimum cost is mandatory. The complexity of real water distribution network grows with the necessity to consider non-smooth non-convex large-size problems and discrete variables. This is a clear application in continuos flow industry that can be seen as an application in the area of green logistics.

In service industries, the logistics to produce a service are highly dependent on the human resources. Therefore, in this firm the most important problem can be the crew or personal scheduling. Many authors have applied metaheuristics to crew scheduling in airline industries, Campbell et al. (1997), bus companies, and train, Cavique et al. (1998), Kwan et al. (1997), just to mention some.

Scheduling is another area where you can find an enormous amount of applications of the metaheuristics, see as example Voss et al. (1998) and Osman and Kelly (1996). However, most of the application focus on a specific scheduling problem and little attention has been given to the integration in a supply chain. The main application are for job-shop scheduling problem or similar problems, however these models take little attention to the integration of production scheduling with the rest of elements on the supply chain. However, efficient production scheduling is enormously relevant to the rest of the chain as discussed in the previous chapter. So, aspects as customer service and delivery times must be integrated in the scheduling decisions, turning in many cases in a non-linear multiobjective problems.

For a large list of applications, many in the area of SCM, we refer the author to Glover and Laguna (1997). We believe that we have missed many references on the applications of metaheuristics to supply chain problems. However, the intention of this work was not to do a complete survey in the issue (something that we would like to do in the near future), but to call the attention the potential of metaheuristics for the field of SCM, especially when integration has to be taken in account.

5. Conclusions

The integrated management in a supply chain offers significant benefits to the elements across the chain, reducing waste, reducing cost and improving customer satisfaction. However, this strategy is a challenging and significant task to the companies, decision-makers, consultants and academics. The process of implementing and managing an integrated supply chain has been shown to be very difficult. We have discussed several important activities within a supply chain and their interrelationships.

Many other issues and question in SCM are not treated in the work, as this is a rapidly changing world with new challenges appearring every day. We strongly believe that the recent developments in the area of metaheuristics techniques will put them on the front page to solve SCM existing and new complex problems that arise by the need of an integrated management. Their modularity, easy implementation, easy updating and adaptation to new situation combined with simulation systems and DSS can make a strong impact to help the decision process in SCM. We have focus on Iterated Local Search, Tabu Search and Scatter Search as some metaheuristics that present the characteristics for a potential successful application on SCM. The developers can learn from the extensive applications of these metaheuristics to well-known optimization problems, and in this way have short development and implementations times.

With this work we hope to contribute to a better understanding of the issues in supply chain and to encourage further research on the applications of metaheuristics to solve complex problems in SCM. Metaheuristics can make an important contribution to carrying out the challenges posed on an integrated supply chain, especially with the new economy and electronic business. Applications of metaheuristics-based DSS for integrated supply chain management are work-in-process. In many companies, ambitious project to implement DSS to evaluate and help the decision process of the integrated supply chain have yet to be completed, and many other have not yet seriously begun initiatives in this direction. We believe that this work should be rewritten sometime in the nearfuture, as a large amount of successful applications of metaheuristics-based DSS to the SCM problems will be developped.

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- The Educational Society for Resource Management - APICS: http://www.apics.org
- Institute for Operations Research and the Management Sciences - INFORMS: http://www.informs.org
- Production and Operations Management Society - POMS: http://www.poms.org
- Council of Logistics Management: http://www.clm1.org
- Logistics Web: http://www.logisticsweb.co.uk
- Centro Español de Logística: http://www.cel-logistica.org
- The Institute of Logistics and Transport: http://www.iolt.org.uk/index2.htm
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And I am sure there exists many more…