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Chapter 15

LOGISTICS MANAGEMENT
An Opportunity for Metaheuristics

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LOGISTICS MANAGEMENT

An Opportunity for Metaheuristics

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Abstract: In today's highly competitive global marketplace, the pressure on organizations to find new ways to create value and deliver it to their customers grows ever stronger. In the last two decades, the logistics function has moved to center stage. There has been a growing recognition that effective logistics management throughout the firm and supply chain can greatly assist in the goal of cost reduction and service enhancement. The keys to success in Logistics Management (LM) require heavy emphasis on integration of activities, cooperation, coordination and information sharing throughout the firm and the entire supply chain, from suppliers to customers. To be able to respond to the challenge of integration, modern businesses need sophisticated decision support systems based on powerful mathematical models and solution techniques, together with advances in information and communication technologies. Both industry and academia alike have become increasingly interested in using LM as a means of responding to the problems and issues posed by changes in the logistics function. This paper presents a brief discussion on the important issues in LM and argues that metaheuristics can play an important role in solving complex logistics problems derived from designing and managing logistics activities within the supply chain as a single entity. Among several possible metaheuristic approaches, we will focus particularly on Iterated Local Search, Tabu Search and Scatter Search as the methods with the greatest potential for solving LM related problems. We also briefly present some successful applications of these methods.

Keywords: Logistics Management, Metaheuristics, Iterated Local Search, Tabu Search and Scatter Search

1. Introduction

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

The key to success in Logistics Management (LM) requires 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, modern businesses need sophisticated decision support systems (DSS) based on powerful mathematical models and solution techniques, together with advances in information and communication technologies. There is no doubt that quantitative models and computer based tools for decision making have a major role to play in today's business environment. This is especially true in the rapidly growing area of logistics management. These computer-based logistics systems can make a significant impact on the decision process in organizations. That is why both industry and academia alike have become increasingly interested in using LM and logistics DSS as a means of responding to the problems and issues posed by 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 decisions for designing and optimizing logistics problems. For example, some optimization techniques are of little help in solving complex real logistics problems in the short time needed to make decisions. Also, some techniques are highly problem-dependent and need high expertise. This leads to difficulties in the implementation of the decision support systems which contradicts the trend towards fast implementation in a rapidly 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 few decades, with new and powerful techniques, including many metaheuristic methods, being proposed to solve difficult problems. There is therefore, on the one hand, the need for sophisticated logistics DSS to enable organizations to respond quickly to new issues and problems faced in LM, and, on the other, there are advances in the area of metaheuristics that can provide an effective response to complex problems. This provides a fertile ground for the application of these techniques in LM and, subsequently, the development of computer-based systems to help logistics decisions.

The objective of this paper is to provide an understanding of the role that metaheuristics can play in solving complex logistics problem in an integrated business processes environment such as optimizing routing distribution, supply chain design, production scheduling and resource allocation.

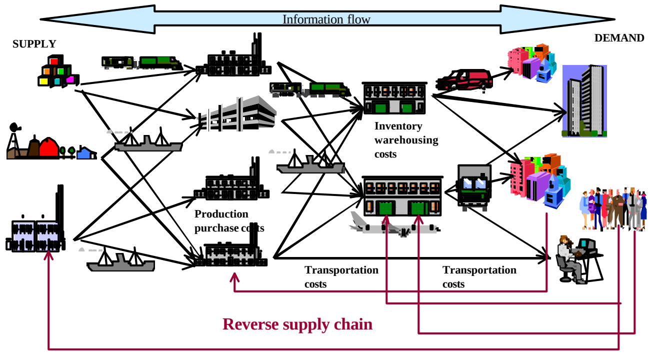

Figure 15.1. An example of a supply chain

In the following section we present a brief discussion on the important issues in LM. Next, we argue that metaheuristics can play an important role in solving complex logistics problems derived from the important need to design and manage the entire supply chain as a single entity. Among several possible metaheuristic approaches, we will focus particularly on Iterated Local Search, Tabu Search and Scatter Search as the methods with the greatest potential for solving LM related problems. In Section 4 we will give a brief presentation of some successful applications of metaheuristics in the solving of real supply chain problems; finally, we present some conclusions and directions for future research.

2. Logistics Management

The Council of Logistics Management defines Logistics as follows: "Logistics is part of the supply chain process that plans, implements, and controls the efficient, effective flow and storage of goods, services, and related in formation from the point of origin to the point of consumption in order to meet customers' requirements" (http://www.clm1.org). However, there is no clear consensus in literature on the definition of LM. Many authors refer to Logistics Management as Supply Chain Management (SCM), i.e. they considered that LM is logistics taken across inter-organizational boundaries; and use these terms interchangeably. Simchi-Levi, Kaminski and Simchi-Levi (2000) gave the following definition: "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 system wide costs while satisfying service level requirements.

Johnson et al. (1999) also presented the following definitions. They maintained that "*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 fina l consumer."

Recently, however, there has been some convergence towards accepting SCM as a larger concept than logistics management. Cooper, Lambert and Pagh (1997) clearly described the differences between the two concepts. They claimed that the integration of business processes across the supply chain is what they called Supply Chain Management, therefore, SCM covers more functions than just logistics being integrated across firms. One of the key components of SCM is, of course, Logistics Management, but it also includes Customer Relationship Management and Product Development and Commercialization.

In this paper, following the above definitions, we define LM as the management of all logistics activities throughout a firm and supply chain. We give special emphasis to relationships with other functions of the organization, such as marketing and finance, and to the integration of the logistics activities in the entire supply chain, including those with suppliers and customers. We consider, like Cooper, Lambert and Pagh (1997), that, SCM covers a wider area than LM, but that LM is also of major importance to efficient SCM. In LM, the planning, coordinating and controlling of all logistics activities must be done by taking into account the remaining elements of the supply chain. Every firm, whether involved in manufacturing or services, belongs to at least one supply chain. The key success of LM, may lie in the system's integration, i.e. requiring emphasis on integration of logistics activities, cooperation, coordination, and information sharing throughout the entire supply chain.

The supply chain encompasses all activities associated with the flow and transformation of goods from raw material stages to the end users, as well as the associated information flows. Material and information both flow up and down the supply chain. A supply chain consists, basically, of the following elements: suppliers, manufacturing centers, warehouses, distribution centers, transportation systems, retail outlets and customers; raw mat erial, work-in process inventory, finished goods and information that flows between the different elements (see Figure 15.1). One important aspect in a supply chain is the integration and coordination of all logistics activities in the chain, since decisions in one element directly affect the whole supply chain. Firms must avoid sub-optimization by managing the logistics activities on the entire supply chain as a single entity. This integration aspect obviously significantly increments the complexity of any logistics problem. To respond to this challenge there is the need for powerful and robust techniques, as we will discuss in the following section.

We will consider the following key issues in LM:

- Logistics 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

These areas interact to a large degree with other functions of the firm, and with other elements of the supply chain. They can therefore benefit a great deal from efficient management based on information and optimization systems. For each issue, we offer a brief description and discuss aspects that can increase the complexity when optimizing the logistics activities within a firm or the entire supply chain. The idea is not to discuss the issues in detail, interested readers who are refereed to Simchi-Levi, Kaminsky and Simchi-Levi (2000), Ballou (1998), Johnson et al. (1999). We also refer to Tayur, Ganeshan and Magazine (1998) where several quantitative models for SCM are presented and a broad taxonomy review research is described.

2.1 Logistics Integration and Coordination

Logistics coordination and integration within a supply chain has become a core issue in LM, not just integration within the organization but integration upstream with suppliers and downstream with distributors and customers. Coordination and integration means many different things, but basically all authors agree that it refers to 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). One enormous advantage of an integrated supply chain is the reduction of the so-called bullwhip-effect, Lee, Padmanabhan and Whang (1997), where small changes or decisions, on one level of the network, may result in large fluctuations, large amounts 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 logistics decisions also increases.

There are two main aspects involved in the integration of logistics decisions. The first of these are the information systems. Without integration of information systems between the different players, there can be no translation or sharing of information, which is the basis for any possible integration between departments or firms. With today's technology, the integration of information systems is possible and has been implemented by many firms. The second aspect is the use of optimization systems to achieve an integrated management of the logistics activities. As more and more industries decide to integrate their information systems, the need for sophisticated tools to help the decision makers to evaluate possible alternatives, decisions and their impact in the whole supply chain also increases.

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 OR literature, there are several research projects dedicated to location issues, such 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 the one for the Section on Location Analysis within INFORMS–SOLA (http://www. uscolo. edu/ sola/ sola.html), as well as the following references 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, most of them do not take into account warehouse capacity, warehouse handling and operational costs (most of them just take into account the initial fixed cost of the warehouse) or warehouse service level requirements, which can be 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. Another important aspect is the relationship between network design and demand management. Aspects such as the seasonal nature of demand has never been taken into account, as far as we know. However, it could be an interesting research area since many firms are interested in designing their supply networks in partnership with other firms that have products with completely different seasonal behavior, e.g. air conditioning and heating equipment. The incorporation of all the aspects mentioned above into a location or network design model can make a significant difference to the analysis of the logistics on a supply chain and the decisions with respect to location and supply chain design.

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, the product supply 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 the 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, such as mode selection, carrier routing, vehicle scheduling and shipment consolidations are needed in most companies.

One important aspect in transportation management is coordination with the remaining activities in the firm, especially within warehouse and customer service. In some cases transport is the last contact with the customer and companies should therefore take care to meet the customer expectations and use this relationship to improve their sales. The transport coordination within the different elements of a supply chain, involving different companies, can be of great strategic importance, since all of them most likely benefit by offering 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 academic and industrial communities.

One basic and well-known problem in transportation is 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 the lowest possible cost, subject to legal and political constraints. The legal constraints relate to working hours, speed limits, regulations governing vehicle construction and use, restrictions for unloading and so on. With the growth in Internet sales, this problem is gaining momentum, since delivery times are usually very short, customers can be dispersed in a region, every day there is a different set of customers and with very short product delivery time-windows. 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 also provides information to management on the status and disposition of items being stored. The basic operations at a warehouse are receiving, storage-handling, order picking, consolidation – sorting and shipping. The main objectives are to minimize product handling and movement and store operations as well as maximize the flexibility of operations. Given the actual importance of the activities related to order picking we dedicate a subsection to it.

Traditional warehouses are undergoing enormous transformations due to the introduction of direct shipment and cross-docking strategies. The latter may be more effective in distributing the products among retailers or customers. However, in order to be successful, these strategies require a high level of coordination and information systems integration between all elements in the supply chain: manufacturers, distributors, retailers and customers, a definite volume of goods to be transported and a fast and responsive transportation system, to give just the most important requirements. Deciding which is the best distribution strategy for a particular product of a company can make an enormous impact on the success of that company. Therefore, there is the need for a 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 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 OR literature; however, the use of inventory systems in helping decision-making processes has been less widespread. Most of the well known models in literature are simple and do not, for example, consider multi-product inventory management that requires the same resources, or, in some cases, do not treat all the complexities involved in inventory management such as demand uncertainty, returns and incidents. So far, the better known inventory models and systems consider a single facility managing its inventories in such a way as to minimize its own costs. As we have mentioned, one major challenge in LM is the integration and coordination of all logistics activities in the supply chain, a particularly important issue being inventory management within the whole supply chain in order to minimize systemwide costs. This requires models and DSS that are able to aid decisions and suggest policies for 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 in such a way as to enable 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, such as weight, volume, parts, value, perishability, etc., influence the decisions made in relation to 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 to an existing one, the requirements of the logistics relating to product movements should be taken into consideration. Also, the need for short lead times and the increased demand from customers for 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 in the logistics of the product, Lee, Billington and Carter (1993). The use of information systems and simulation techniques that help to analyze the impact on the supply chain of a certain design of a specific product can be of great help to managers.

2.7 Material Handling and Order Picking

Material handling is a broad area that basically encompasses all activities relating to 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 it incurs a cost. Order processing or picking basically includes the filling of a customer order and making it available to the customer. These activities can be quite important since they have an 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 well 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 include many activities, such as facility configuration, space layout, dock design, material-handling systems selection, stock locator and arrangement, equipment replacement, and order-picking operations. Most of the models and techniques available these days consider the above decision processes as activities independent of the remaining ones in the whole system. Therefore, DDS that analyze the impact of material handling and order picking activities on the logistics system and enable the decision-maker to make the best decision for the whole network, are an important and essential tool.

2.8 Logistics of Production and Scheduling

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 (2004), Stevenson (1999). The interaction between POM and LM is enormous, since production needs raw materials and parts to be able to produce a commodity, and then this commodity must be distributed, Graves, Rinnoy Kan and Zipkin (1993). Therefore, coordination between both areas is fundamental to an efficient supply chain. The techniques required to plan and control the production in an integrated supply chain go beyond the MRP (Material Requirement Planning) so popular in industries. The need to take into consideration manufacturing or service capacity, labor and time constraints has given importance to the Scheduling area. This field is extremely wide; however research at a scientific level has focused mainly on the formalization of specific problem types, leading to standard problems like the flow-shop scheduling problem, job-shop scheduling problems, etc. A significant amount of research has been dedicated to the classification of problem difficulty by deriving complexity results for a large variety of problem variants and the development of efficient solution techniques for standard scheduling problems, Pinedo (1995). Research efforts in the latter area have shown that in the case of many problems, the use of heuristic algorithms, which cannot guarantee optimal solutions, but were able, in a large number of experiments, to find extremely high quality solutions in a short time, are currently the most promising techniques for solving difficult scheduling problems. Despite efforts in academic scheduling research, there is still a considerable gap in the application to practical problems of the techniques developed on the academic side. Scheduling problems are already quite hard to solve per se, and their extension to include aspects of the whole supply chain significantly increases their complexity. Moreover, in many supply chains, the bottleneck activity is production, therefore efficient planning and managing of production and scheduling activities within the coordination of the supply chain is of great importance to an efficient supply chain. The development of production and scheduling models and solving techniques that consider the logistics activities related are a challenge for both academia and industry. Some ERP providers have already incorporated metaheuristics for solving complex scheduling problems, such as SAP (www.sap.com) with its product APS (Advanced Planning and Scheduling). We do believe that in the future many more Information Technology companies will make use of metaheuristic techniques to solve those very difficult problems, such as those relating to integrated logistics and production scheduling.

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 within modern businesses and particularly in LM. 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 in a DSS for logistics decisions is the quality of the data used as input for the system. Therefore, in any implementation, efforts should me made to ensure the data is accurate. Consequently, modeling and techniques can be applied to obtain scenarios and analysis of the logistics situations within the environment of the company and, can be used to support the managers and executives in their decision processes.

We believe that metaheuristics, when incorporated into a DSS for LM, can contribute significantly to the decision process, particularly when taking into consideration the increased complexity of the logistics problems previously presented. DSS based on metaheuristics are not currently widespread, but the technique appears to be growing as a potential method of solving difficult problems such as the one relating to LM.

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, Deitel, Deitel and Steinbuhleral (2001), Chaffey (2001). In e-commerce, business partners and customers connect together through Internet or other electronic communication systems to participate in commercial trading or interaction. We will not discuss e-commerce in detail at this stage, but it certainly makes new and high demands on the company's logistics systems, calling in, in same cases, completely new distribution concepts and a new supply chain design. Companies are looking for DSS, such as the one relating to e-commerce and e-business that help them to make the best decisions in an uncertain and rapidly changing world. Many of the problems can be seen as extensions of the ones described above, such as, for example, transportation management, while others are completely new with some added complexities such as the uncertainties associated with the evolution of commerce on the web. An example of new problems that can appear relate to home distribution, generated by business-to-consumer (B2C), during non-labor hours and the search for a solution which will allow an efficient distribution. An example of this is the inclusion of 24-hour dropping-points, where transportation companies can leave a package that will be collected later by the customer, thus avoiding the need for distribution during nighttime or on Saturdays and Sundays. Questions as to the location and size, for example, of these dropping-points, frequency of visits, partnership with stores, etc. are issues that have not yet been dealt with in metaheuristics and logistics literature.

2.11 Reverse and Green Logistics

Concern over the environment has never been as strong as today. Also, strict regulations regarding removal, recycling and reuse are on the increase, especially in Europe. This will bring Reverse Logistics and Green Logistics into the main focus in the near future, Rogers and Tibben-Lembke (1998). Reverse logistics are related to the process of recycling, reusing and reducing 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, such as, for example, aspects relating to the transportation and disposal of dangerous materials. Manufacturers in Europe will soon be held responsible for the total cost of recycling or disposal of all materials used in their product. This legislation will put an enormous emphasis on efficient reverse logistics decisions that will need to be optimized. Green logistics is generally understood as being activities relating to 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 product packaging, transportation means and product development, as well as many others. Logistics is also involved in the removal and disposal of waste material left over from the production, distribution or packaging process, as well as the recycling and reusable products.

All the above points make the relevance of the reverse and green logistics area clear, since many companies have to re-organize their supply chains and even extend them in order to be able to return, reuse or dispose of their product and materials. This poses many new and challenging questions to the area of LM.

2.12 Customer Service

Customers have never before been taken so seriously. The successful fulfillment of customer expectations is a task pertaining to LM, 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 ranging 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 in the supply chain interact and a decision on one element affects all the others, any logistic decision within the supply chain can affect the customer service. Therefore, systemwide DSS that help the decision maker at a strategic, tactical and operation level, to evaluate, simulate and analyze different options and scenarios, and the interaction between the players in a supply chain are being requested more and more by many companies.

We have briefly reviewed some actual issues and aspects of the logistics 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 analyses in a short time, allowing him 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 LM.

3. Metaheuristics for LM

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 the logistics activities of their supply chain as an entire and unique system in order to be able to improve their business. However, in most cases, the task of designing, analyzing and managing the supply chain has been carried out based on experience and intuition; very few analytical models and design tools have been used in the process. This means that finding the best logistics strategies for a particular firm, group of firms or industry poses significant challenges to the industry and academia. We argue that metaheuristics can be an important aid to managers and consultants in the decision process.

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 of the two (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 others 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 on heuristics see Corne, Dorigo and Glover (1999), Aarts and Lenstra (1997) and Glover and Kochenberger (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 for LM related problems.

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

The next important aspect is the amount of data involved in any optimization model for an integrated logistic problem, which can be overwhelming. The complexity of the models for LM and the inability to solve the problems in real time using traditional techniques, necessitate the use of the obvious technique for reducing this complex issue: data aggregation, Simchi-Levi and Kaminsky (2000). However, this approach can hide important aspects that have an impact on decisions. For example, consider the aggregation of customers by distance, customers located near to another can be aggregated, but suppose they require a totally different level of service? Therefore, instead of aggregating data so as to be able to obtain a simple and solvable model, but one which is not a good reflection of 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, such as transportation and inventory costs. Why spend time on an optimal solution to a model when the data in hand consists solely of estimations? Maybe we should use the time 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 the best characteristics of human decision-making and a computarized model and algorithmic based systems into interactive and graphical design frameworks have proven to be very effective in LM, since many integrated logistic 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 solving LM problems and take advantage 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.

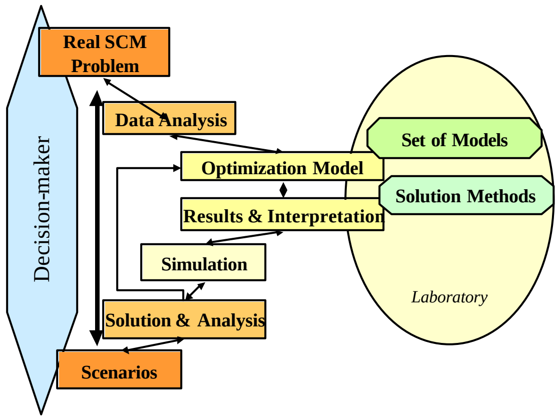

Figure 15.2. A DSS scheme for Logistics Management

In Figure 15.2, we present a 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 the exact method or other heuristics techniques. We use the laboratory to study the application of metaheuristics to well-known models, with the objective of providing guidelines for real applications. Moreover, upgrades of the DSS can be easily developed and also implementing for a specific firm with specific logistic problems.

Metaheuristics will help users to take system decisions within certain parameters and environments and then simulation techniques can be applied to analyze the system behavior in the presence of uncertainties. Simulation-based tools take into 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 pre-specified 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 a very interesting approach to the solving of complex logistic 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, 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 the presence of uncertainties. Recent developments are changing this, 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 the presence of uncertainties. These advances have been made possible by the developments in heuristic research, particularly in metaheuristics. The OptQuest computer software, by Glover, Kelly and Laguna, of OptTeck Systems, Inc. (http://www.opttek.com/) already offers this innovation, Laguna (1997, 1998), Glover, Kelly and Laguna (2000). OptQuest replaces the inaccuracy of trial-and-error usual in simulation systems 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, the OptQuest has been integrated with several 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 solutions 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 others have similar features and are also potential methods that could be applied to LM problems. We discuss these ones because, in their simple form, they present quite good results and are somehow representative of the latest developments in modern heuristic research. At the end of the chapter we will comment on common aspects of these metaheuristics that can be relevant in solving LM problems, Lourenço, Martin and Stützle (2001).

Iterated Local Search (ILS) is a simple, yet powerful metaheuristic to improve the performance of local search algorithms. Its 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 one of 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 called *Perturbation* that perturbs the current solution s (usually a local optimum) giving rise to an 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 on ILS see Lourenço, Martin and Stützle (2001). An algorithmic outline for the ILS is given in Figure 15.3.

***Iterated Local Search* Procedure:**

$s_0 = GenerateInitialSolution$;

$s^* = LocalSearch(s_0)$;

Repeat

$s' = Perturbations\ (s^*, history)$;

$s'' = LocalSearch\ (s')$;

$s^* = AcceptanceCriterion\ (s^*,\ s'', history)$;

Until ***termination criterion met***

end **return** s^*.

Figure 15.3. Iterated local search

Tabu Search is an adaptive procedure originally proposed by Glover (1986). Recently, this metaheuristic has been gaining ground as a very good search strategy method for solving combinatorial optimization methods. For a survey, see Glover and Laguna (1997). We sketch a simplified version of the approach, as follows.

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 in the illustrated simplified formulation 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, as a result, 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 to the current solution that is neither tabu nor 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 value 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 given in Figure 15.4.

***Tabu Search* Procedure**

$x = GenerateInitialSolution$;

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.**

Figure 154. Short term tabu search procedure

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, Laguna and Martí 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 high quality solutions that are also diverse. The overall proposed procedure, based on the scatter-search elements listed above, is as follows:

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 main feature of the scatter-search is a population-based search, we believe it will be an adequate technique for solving difficult and large-scale multi-objective problems by finding an approximation of the set of Pareto-optimal solutions. Therefore, the inclusion of scatter search methods on scenario-based DSS software can have an important impact, since several good scenarios can be obtained in just one run. Several applications have already been completed, Martí, Lourenço and Assigning (2000) and Corberán et al.(2000), and we believe more will appear in literature in the near future.

All the above metaheuristics have this in common: even the simpler implementations are able to solve difficult problems in a short amount of running time. Moreover, the inclusion of new features, constraints, objective functions can be relatively simple, which is quite important in the rapidly changing world of LM.

Given a description of the problem and the 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 for complex problems, regardless of the specific mathematical characteristics of the problem, as linear or non-linear functions, and for the specific characteristics of the logistic problem within a firm. The integration aspects of a logistic problem can be implemented by adapting the objective function, or the multi-objective functions, and by taking this into account in the neighborhood definition. For example, if a metaheuristic has been developed to solve the logistic problem of a firm, and the consulting company needs to solve a similar problem, but with different aspects, for another firm, the adaptation can be relatively simple since many modules can be the same. This gives metaheuristics a great advantage. Moreover, since the methods share modules, it would be easy to implement several metaheuristics for the same problem in hand. As mentioned, the logistics decision-makers are experiencing enormous changes every day and challenges that need a quick response. The consideration of these changes can be quickly incorporated into a metaheuristics-based DSS without the need for modification of the complete software, which is an enormous advantage for software and consulting companies.

Problems in the LM area can also benefit from the vast amount of successful applications of metaheuristics in combinatorial optimizations and other well-known difficult problems. From this list, the DSS developer can learn what can be the best approach to a specific LM problem by studying the combinatorial optimization problem that has the most aspects in common with the specific real problem, such as, for example, the best metaheuristics, the best neighborhood, etc. Research on metaheuristics should give insights and guidelines for future implementations of metaheuristics into other similar problems, so commercial producers of software and consulting companies could develop the most adequate solution method to a specific problem. The excellent results, modularity and flexibility of metaheuristics are the major advantages of this technique for solving LM problems. As we have discussed, there is enormous potential in LM for applications of metaheuristics. Research academia and industry should both benefit from these applications.

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

4. Applications

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

Weigel and Cao (1999) presented a vehicle-routing DDS to help the decision process relating to the home-delivery and home-service business for 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 to be successfully applied to other types of business. This generic capability derives from using the OptQuest Engine (www.opttek.com) to adaptively tune the parameter settings for different regions. The system has improved the Sears technician-dispatching and home-delivery business resulting in an annual saving of over $42 million. 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, within the decision process, to gain understanding of the problem, use their resources more efficiently, give a better customer service and finally, but of no less importance, to reduce costs.

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

Other applications of logistics relating to vehicle routing can be found in literature, such as the inventory routing problem for vending machines, Kubo (2001).

Ichoua, Gendreau and Potvin (2000) present a new strategy for the dynamic assignment of new requests in dynamic vehicle routing problems which include diversion. These dynamic vehicle routing problems are common in organizations such as 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 yet served. A tabu search heuristic was used to make an empirical evaluation of the new strategy. The results demonstrate the potential savings in 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 metaheuristics, not only as a direct aid in operational decisions, but, more relevantly, as an aid in the identification of the best strategies for handling highly dynamic problems such as real-time vehicle dispatching.

Bosë et al. (2000) describe the main processes at a container terminal and the methods, based on evolutionary algorithms, currently used to optimize these processes. They focus on the process of container transport, by gantry cranes and straddle carriers, between the container vessel and the container yard. The reduction in the time spent by the vessel in port, the time required for loading and unloading the vessel and the increase in the productivity of the equipment are main objectives for the management of a container yard. The global increment in container transportation, the competition between ports and the increase in multi-modal parks give rise to the need for improved techniques to help the decision process of the senior management of a container terminal. 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 for the container terminal. As future research, they expect to develop a hybrid system using simulation and evolutionary methods which will allow uncertainties to be taken into account. This report is a good example of the direction LM is following in order to be able to solve the complex problems in the area.

Fanni et al. (2000) describes the application of a tabu search to design, plan and maintain a water distribution system. Since water is a sparse resource, especially in some countries, and the design and maintenance of pipe networks for water supply distribution involve high costs, achieving the highest level of performance of existing networks at minimum cost is mandatory. The complexity of a 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 the continuous 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 personnel scheduling. Many authors have applied metaheuristics to crew scheduling in airline industries, Campbell, Durfee and Hines (1997), and bus and train companies, Cavique, Rego and Themido (1998), Kwan et al. (1997), to mention just a few.

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

For an extensive list of applications, many in the area of LM, 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, our intention in writing this report, was not to carry out a complete survey on the issue (something that we would like to do in the near future), but to bring the reader's attention to potential of metaheuristics in the field of LM, especially when logistics integration has to be taken in account.

5. Conclusions

Logistics 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 for companies, decision-makers, consultants and academics. The process of implementing and managing integrated logistics has been shown to be very difficult. We have discussed several important logistics activities within a supply chain and their interrelationships.

Many other issues and questions surrounding LM are not treated in the paper, since this is a rapidly changing world with new challenges appearing every day. We strongly believe that the recent developments in the area of metaheuristics techniques will put them on the front page as regards solving existing LM problems and new complex ones that arise due to the lack of any integrated management. Their modularity, easy implementation, easy updating and adaptation to new situations combined with simulation systems and DSS can make a strong positive impact on the decision process in LM. We have focused on Iterated Local Search, Tabu Search and Scatter Search as being some metaheuristics that present characteristics for potential successful application to LM. Developers can learn from the extensive applications of these metaheuristics to well-known optimization problems, and consequently, these methods have short development and implementation times.

With this paper, we hope to contribute to a better understanding of the issues involved in integrated logistics and to encourage further research on the applications of metaheuristics for solving complex LM problems.

Metaheuristics can make an important contribution to coping with the challenges posed by LM, especially with the new economy and electronic business. Applications of metaheuristics-based DSS for LM are work-in-process. In many companies, ambitious projects to implement DSS to evaluate and help the decision process of the integrated logistics within a supply chain have yet to be completed, and many others have not yet begun serious initiatives in this direction. We believe that this work should be updated sometime in the near future, as a large amount of successful applications of metaheuristics-based DSS in LM problems will be developed.

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