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Multiobjective metaheuristics for Integrated Logistics Problems

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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. The keys to success in Integrated Logistics Management (ILM) 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 ILM 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 ILM and argues that multiobjective models and 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. We also briefly present some applications.

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 Integrated Logistics Management (ILM) 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. The 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 ILM and logistics DSS as a means of responding to the problems and issues posed by changes in the area. Turner (1993) said the following "The kind of information technology that is really needed for logistics integration consists of planning and decision support tools that are able to support company's operational planning and decision-making process on an integrated enterprise-wide basis".

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

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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 ILM, and, on the other hand, there are advances in the area of metaheuristics that can provide an effective response to complex problems. The area of multiobjective metaheuristics is also growing significantly in recent years. This provides a fertile ground for the application of these techniques in ILM since most of the integrated logistics problems are multiobjective ones. Note that these problems are as complex as the single-objective problems, with the added difficulty of having more than one objective function. Therefore, clearly the multiobjective metaheuristics can play an important role in solving these problems.

The objective of this paper is to provide an understanding of the role that metaheuristics can play in solving complex multiobjective logistics problem in an integrated business processes environment 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 ILM. 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. In Section 4 we will describe briefly some applications; finally, we present some conclusions and directions for future research.

2. Integrated 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 information from the point of origin to the point of consumption in order to meet customers' requirements" (http://www.clm1.org).

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 and financial 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 material, work-in process inventory, finished goods and information that flows between the different elements. Every firm, whether involved in manufacturing or services, belongs to at least one supply chain. 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. 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. In ILM, the planning, coordinating and controlling of all logistics activities must be done by taking into account the remaining elements of the supply chain. Firms must avoid sub-optimization by managing the logistics activities on the entire supply chain as a single entity. The key success of ILM, 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. This integration aspect increments in a significant way the complexity of any logistics problem. And moreover, as the integrated logistics problems interacts with other areas of the enterprise, or other enterprises, the multiobjective functions are clearly present, where each one may represent an objective function of a particular firm or department within a firm. 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 ILM:

- 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

The above 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. Each of the above issues have aspects that can increase the complexity when optimizing the logistics activities within a firm or the entire supply chain. Interested readers are refereed to Simchi-Levi, Kaminsky and Simchi-Levi (2003), Ballou (2003), Johnson et al. (1999). We also refer to Tayur, Ganeshan and Magazine (1998) where several quantitative models for ILM are presented and a broad taxonomy review research is described.

The dimension of the supply chain and the number of elements in this supply chain has grown. As a consequence of competition, the companies focus their attention to their own goals, which main conflict with the goals of the other partners. But for other side, companies realize that by integrating their process along the supply chain and collaborating between them, it will lead to advantages for every element of the chain. Therefore, models that can represent this situation and decision support systems that can help the decision maker with a global view of the chain have a great potential for the area of ILM, Slats et al. (1995).

Integration in logistics management is a known concept that has been around for many years. The concept is related with the aim of achieving efficient and effective inter-functional coordination and/or inter-enterprises integration along a supply chain to obtain a competitive advantage, Mears-Young and Jackson (1997). One of the main components of integration along the supply chain is the *Information Sharing*. The companies or the department that decide to integrate their process share information through usually an information system. But the next step, and more advanced one, is to integrate also the decision processes, which has a relevant impact and interest at strategic decisions level. We will designate this next step as *Knowledge Sharing*, Giménez and Lourenço (2004). Knowledge is considered, in the Information Systems Management area, the result of applying analysis, interpretation and modeling to information. The access to this knowledge will enable companies not only to share information but also to share planning and decision-making. This collaboration among firms will lead to cost reductions and a better and faster response to the market. Decision technologies that offer the access to this knowledge, or the tools to obtain it, will become an important issue in the future, Swaminathan and Tayur (2003), Sodhi (2001). One example of this knowledge sharing is the collaborative forecasting. The availability of analytical tools (such as forecasting models) to translate sales data into meaningful knowledge and business intelligence can lead to a rapid decision-making to respond to customer demands. We also claim that multiobjective models and metaheuristics combined with information system can help the decision making in integrated logistics.

In knowledge sharing, many elements of the supply chain collaborate to obtain better global decisions, and it is frequent that the elements have different objectives that are traduced in different and conflicting objective functions. Example of these objectives can be for example:

- Marketing and Distribution: the distribution department main objective is to reduce distribution costs meanwhile the marketing department is maximizing customer service, this can affect decisions in routing, order picking, stock management, delivery problems.

- Financial, Marketing and Production: the production department objective is to plan the production reducing costs and maximizing lot sizing, meanwhile the other department intent to minimize stocks and rapid inventory turnover.
- Several companies in the same supply chain: collaboration in designing the logistics network and transportation requirements.
- Production and Marketing departments, or Retailing and Manufacturing companies: collaboration in marketing activities as for example promotions, and a better use of the production capacity.
- Internal and external collaboration for product design.

In general, the multiobjective functions are related to minimizing global costs, maximizing customer service, reduce the time-to-market, reduce stockouts and stocks at the same time, reduce uncertainty, etc. The trade-off between these objectives is not always clear and a model and consequently an efficient solution method can help the decision maker to make better decisions by giving him/her a global view of the problem and allowing him/her to evaluate the impact of a particular decision on the global system.

In the following section, we describe briefly the metaheuristics for single and multiobjective models to try to understand how these techniques can easily applied to solve very complex integrated logistics problems.

3. Metaheuristics for Integrated Logistics Management

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, in particular the multiobjective metaheuristics are relevant to the multiobjective logistics problems present in ILM.

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 ILM.

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 ILM 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, Kaminsky and Simchi-Levi (2003). 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 ILM, since many integrated logistic problems are new, subject to rapid changes and, moreover, there is no clear understanding of all of the issues involved.

Multiobjective metaheuristics have been the object of recent studies. We refer the reader to two recent surveys on the state-of-the-art of this topic done by Jones, Mirrazavi and Tamiz (2005) and Ehrgott and Gandibbleux (2004). The metaheuritics for multiobjective problems can be classified in two large group: the local-search based and the population based. The population-based metaheuristics can be easily generalized to solve multiobjective problem since they already consider a set of solution, that can be extend to consider the set of all non-dominated solution. The local search metaheuristics need more adaptations; in particular many of these ones found in the literature consider a weighted function where the search direction or weights are iteratively adapted.

We believe that in the future more applications to integrated logistics problems will appear. 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 integrated logistic problems. The multiobjective metaheuristics have a great potential to solve integrated logistics problem since these problem present complex formulation, the presence of different objectives and require in many situations interaction with the decision-makers.

4. Applications

In this section we present three applications of ILM, with the objective to give examples of potential applications of metaheuristics to integrated logistics problems. The first one is related to the vehicle routing, considering aspects and objectives from the Human Resources, Logistics and Marketing departments. The next one is a production planning problem considering objectives from the Reverse Logistics department. The last one is related to supply chain design, involving different companies in a supply chain.

4.1. Multiobjective VRP

The problems arising in commercial distribution are complex and involve several players and decision levels. One important decision is related with the design of routes to distribute the products, in an efficient and inexpensive way. Ribeiro and Lourenço (2001) proposed an application that deals with a complex vehicle routing problem that can be seen as a new extension of the basic and well-known capacitated vehicle routing problem. The model is a multi-objective combinatorial optimization problem that considers three objectives and multiple periods, which is closer to real distribution problems than previous vehicle routing models described in the literature.

Vehicle routing problems (VRP) have been explored both in the management and operations research literature. The models found in the literature are often away from reality, since they do not consider issues present in real distribution, as for example multi-period planning. To get closer to real world problems and to reflect the multitude of concerns in distribution management we will extend the basic VRP. The final result of this extension is a multi-objective model that takes into consideration three different objectives.

The objective functions are:

1. Cost objective;
2. Human resource management objective;
3. Marketing objective.

The idea is to do a cross-functional planning in the supply-chain management by including in the model decisions that belong to different areas of the firm. The first objective is the common cost minimization, the second is related with balancing work levels and the third is about assigning the same driver to the same client. This last objective is important for the Marketing area since it can lead to an improvement on the relationship between the company and the customer, and consequently an increase on the demand. The results of the model show the complexity of solving multi-objective combinatorial optimization problems and the contradiction between the several distribution management objectives. In the work, it is also proposed and Iterated Local Search method to solve this multiobjective problem. For more details see Ribeiro and Lourenço (2001)

4.2. Recoverable production planning

In last years, a constant concern has arisen regarding to the ecological impact of the business activities. In special, the European Community has developed an extensive legislation regulating the business activities in order to protect the environment. Within this legislation the responsibilities for the end of life products and recyclable materials have been assigned in most of the cases to the manufacturers. On the other hand, the extensive competitiveness between companies to sell their products has obliged the companies to develop new policies to improve the service level. Today, policies such as accepting devolution without questions within 60 days since the reception of the product are more common along the business world. Also the development of e-commerce has made this kind of policies an obligation for any company that wants to sell its products through Internet.

The increasing competitiveness and the globalization trend has made the companies more conscious with respect to the advantages of the integration within the supply chain. Companies have realized that the product must be developed and improved in all the stages of the supply chain; the quality and costs of the products are the summation of the work of all the entities that participate in its elaboration and distribution.

These new trends have imposed to the companies new challenges to adapt their processes and policies. Managing these returned materials and products is becoming a key factor for the ILM area. It imposes a lot of variations in the way that companies are used to do their logistics activities. Remanufacturing processes, stochastic supply, multi-echelon network design, disassembly strategies are some of the new terms this new policies have created in the logistics activity. All these concepts have been grouping under the concept of Reverse Logistics, which is the study of the product flow from the customer to the manufacturer, i.e. the logistics in the reverse way.

Soto and Lourenço (2003) proposed some production planning models that incorporate the possibility of using recycled products and parts into the manufacturing plan. In forward logistics systems (the traditional ones), production planning is concerned to programming the production in the most efficient way. The models consider a pull system, where the demand is estimated and the subsequent material's requirement are calculated from this estimation. When remanufacturing is incorporated to the production process, all the materials supply becomes stochastic given the uncertainty behind the quality and quantity of the returned products and components. These issues lead to a production-planning model that can deal with these new elements.

The proposed model tries to optimize the production and product flow through the supply chain, taking into account the parts and components that are obtained from the reverse logistics activities. It is especially useful in companies with various factories or companies that outsource part or the total production process. For more details see Soto and Lourenço (2003).

4.3. Supply Chain Design

Sabri and Beamon (2000) propose an integrated multiobjective supply chain design model that considers simultaneously strategic and operational supply chain planning issues. The main problem is to decide the supply chain configuration and material flow. The model incorporates production, delivery and demand uncertainty issues that arise from different department of an enterprise or from different companies on the same supply chain. The multiobjective considered are related with minimizing total cost, maximizing customer service levels (fill rates) and maximize flexibility. Flexibility can be defined as the ability to respond to customer requirements, in terms of volume and delivery. For more information see Sabri and Beamon (2000).

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, and how multiobjective model are adequate to solve the problems of this area.

Many other issues and questions surrounding ILM 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, in particular multiobjective metaheurisitics, will put them on the front page as an excellent tool to solve ILM problems within an integrated management approach. 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 ILM. 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 ILM problems. Metaheuristics can make an important contribution to coping with the challenges posed by ILM, especially with the new economy and electronic business and the issues posed by the necessity to integrate processes along a supply chain. Applications of metaheuristics-based DSS for ILM 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 ILM problems will be developed.

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