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# On the research of linear programming solving methods for non-hierarchical spare parts supply chain planning

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Abstract: **The relevance of planning non-hierarchical supply chains has increased due to growing collaboration among industrial and logistic organizations once this planning approach aims to optimize the supply chain while preserving each actor's individuality. Linear programming is the predominant modelling approach to deal with non-hierarchical supply chains according to the state-of-the-art literature. Metaheuristics and exact methods are the classical solving methods for linear programming problems, with different characteristics in terms of solution quality and capability of handling complex problems in feasible computation time. In this context, this paper evaluates methods to solve linear programming problems considering their capability of dealing with most common decision model types associated with spare parts supply chains applying collaborative planning concepts. The gathered references substantiate the conclusion that, for normal sized problems, the simplex method continues to be the most attractive method. For bigger problems, interior point methods can be a better alternative. And for problems that surpass interior point method capacity, metaheuristics are recommended.**



*Keywords: Supply Chain Planning, Spare Parts, Collaborative Planning, Non-hierarchical, Operations Research, Linear Programming, Optimization*

## 1. INTRODUCTION

Specific requirements must be taken into account when dealing with spare parts. At first, higher service level is essential. The value of certain parts used in the industry is usually too high to keep them stored close to the production facilities. Concomitantly, breakdown times in the industry can be very harmful to a company's productivity. One of the most important aspects in a Spare Part Supply Chain (SPSC) is the production facilities as final costumers, which implies a higher cost when not attending the demand, once this cost will be not only the opportunity cost. According to Huiskonen (2001) material and time buffers in production systems are decreasing, causing even more pressure for efficiency on spare parts logistics.

The complexity of spare parts supply chains becomes bigger when dealing with the forecasting task. According to Espíndola et al. (2012), the demand for spare parts is sporadic and urgent. To overcome this, authors have introduced the concept of integrating intelligent maintenance systems and spare parts supply chain, wherein sensors give us a real-time evaluation of elements status in industry as well as failures prediction, turning the forecasting deterministic and simplifying the SPSC planning.

According to Dudek and Stadtler (2005) collaborative planning is the coordination process of autonomous yet inter-connected Master Planning activities. Küppers (2013) classified 26 state-of-the-art collaborative planning concepts. As it can be seen in Fig. **1**, where LP stands for Linear Programs, and Others means other methods of decision support models, LPs are the most usual decision model for non-hierarchical supply chain planning.

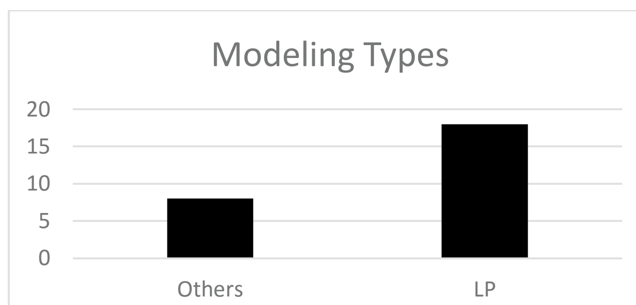


Fig. 1 Occurrence of decision model type (Source:(Küppers 2013), adapted by author)

In this work, methods to solve linear program problems will be evaluated considering their capability of dealing with most common decision model types associated with spare parts supply chains applying collaborative planning concepts. The paper is structured as follows. In the second session, a review on the basic concepts that underlies the present work is provided. In the third session, the main aspects of the principal methods are reviewed. In the fourth session, a discussion on how to fit the solving method with the requirements of collaborative spare parts supply chains is presented.

## 2. LITERATURE REVIEW

### 2.1 Spare Parts Supply Chain

When dealing with spare parts, higher service levels are always required due to the necessity of always having the right part at the right time. However, several aspects can turn this task more complicated than usual, such as: the high volume to be managed, high responsibility required due to


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customer downtime costs, and the risk of obsolete inventory. Among these problems, according to Espíndola et al. (2012), "due to the high costs for spare parts and their sporadic demand, keeping inventories of all parts at all warehouses in the spare parts network are not economical". Also, Supply Chains (SCs) are thus characterized by distinct, yet mutually interdependent decision domains with independent business objectives. In this way, the capability of existing models for supporting an intelligent and flexible synchronization and coordination of the involved process is limited. Given this intertwined and complex aspects, management processes of spare parts supply chain (SPSC) cover different areas of knowledge, which, in turn, use various resources, methods, techniques for solving coordination problems.

Some features of SPSC can be highlighted in the literature. First, the demand for spare parts usually has an intermittent and/or erratic behaviour, making more difficult to forecast by classical statistical methods and inventory control (Boylan & Syntetos 2010). The second aspect relates to high levels of required services. Components for maintenance need to be available as soon as a fault occurs, otherwise the productive systems may be unavailable, causing high costs for their companies (Huiskonen 2001). Another feature derives from the two previous characteristics, as there is a wide variation in demand and a network of well-lined stocks, distribution costs are high. In periods of low demand, inventories are still needed for high periods, endearing distribution processes (Frazzon et al. 2014).

Having seen these concepts, detailed planning of the spare parts supply chain is necessary in order to meet service levels while minimizing costs. Furthermore, not only the planning but also the coordination between the different domains can be seen as a relevant topic, considering the autonomy of the different actors involved in the supply chain coordination. The collaboration can be reached through exchanging relevant data from multiple individual planning domains (e.g. demand planning, master planning, production planning, etc.), aiming to design a collaborative planning concept (CP). But the applicability of existing CP approaches for coordinating the different autonomous actors in non-hierarchical SPSCs has not yet been investigated (Espíndola et al. 2012). The portability of CP approaches to other scenarios is still an open research issue, especially to a SPSC scenario.

## 2.2 Collaborative Planning

The integration of processes and activities related to supply logistics, support to production and distribution logistics, is an important requirements for cost management and services, usually with aiming to enhance competitiveness. Also, good part of a company's performance can be attributed on production and logistic activities. Kopczak & Johnson (2004) explored important aspects of integrated management of logistics processes and their effects on business competitiveness and the creation of value. According to the authors, ongoing changes are forcing companies to re-examine their business vision and redefine in which processes they focus their resources and skills. In addition to this, the resulting inter-organizational network consists of several autonomous companies, which cannot necessarily be forced to go along with decisions, strategies or plans of a leader unit. Thus, "the effective and efficient management and hence coordination of such SCs cannot be achieved in the same way as in hierarchical organizations which can be controlled by one dominant actor" (Hellingrath & Küppers 2011). The main problem is to equate the material and information flows that run throughout the supply chain. In other words, as many known and monitored are those flows, the necessity for safety stocks to attend demand and production requirements will be lower (Ferrozi et al. 1993; Christopher 1997). This means that the less information the company has, or poorer the information flows are, the need of safety elements will be more necessary to meet the fluctuations in demand, which brings direct impact on the organization's profit margins. The lack of decisional and organizational integration leads to inefficiencies related to poor coordination of production and distribution decisions result in missed opportunities, delays, inefficient inventory decisions, poor capacity allocation, and misuse of resources, all leading to the increase of cost (Chen & Lee 2004).

Collaborative planning (CP) concepts address these necessities by avoiding centralized planning or decision making components and relying on coordination based on mutual agreement, without the expose of private information and loss of local decision autonomy in the companies (Hellingrath & Küppers 2011). This way, CP can be defined as a "joint decision making process for aligning plans of individual SC members with the aim of achieving coordination" (Stadtler 2009). Thus, "two or more chain members working together to create a competitive advantage through sharing information, making joint decisions, and share benefits, can result in a greater profitability of satisfying end customer needs, when compared to act alone" (Simatupang & Sridharan 2002).

Different approaches to decentralized coordination by CP have been developed (Dudek 2009; Hegmanns 2010; Stadtler 2009). Basically, these approaches share several characteristics, as the fact that this inter-organizational planning process depends on the object of coordination (e.g. collaborative production planning) and the SC structure which is intended to be supported (e.g. multi-tier, build-to-order production and logistics networks). On the organization and management level, for example, the CP approach helps to the flexibility and robustness of a company's structure and to the transport system's efficiency.

In summary, this approach has the goal of achieving more sophisticated SC coordination mechanisms regarding their better applicability in today's complex production systems and respecting the autonomy of the SC actors. Also, according to Espíndola et al. (2012) this kind of coordination intends to overcome the restrictions of traditional hierarchical planning concepts regarding the practical applicability in today's supply chains, while simultaneously improving supply chain cost and/or performance.

## 2.3 Linear Programming