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Reverse Logistics:
Models and applications

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INTRODUCTION

Reverse Logistics consists on the process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in – process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal.

During last years Reverse Logistics has become a relevant topic not only for academics but also for the business world. Companies are giving each day more and more importance to this field, because mainly of two reasons; The first one is the environmental issues and the impact of these issues on the public opinion; the second one is the benefits that the company can obtain by the improvement of their return's processes. To obtain a successful and efficient Reverse Logistics processes there exist the need to collaborate along the supply chain. This thesis focuses on both of these two topics, Collaboration and Reverse Logistics.

The aim of this thesis is twofold; first, we try to understand the returns processes' problems that companies are facing today from the management point of view, from a general perspective and afterwards on the editorial industry. Secondly, we propose some mathematical models and solution methods related to real planning problems faced by the companies when the returns are incorporated.

The thesis is structured as follows: In first chapter we describe and analyze the Reverse Logistics topic in general. We initially assess different definitions of Reverse Logistics found in the literature and, compare them by evaluating the different elements and contributions of each author. From this evaluation, we propose the main areas within Reverse Logistics which are:

- Location theory and logistics network design
- Forecasting
- Inventory control
- Production /Remanufacturing
- Disassembly operations
- Reverse Distribution.

Afterwards, we describe in detail each of the areas and evaluate the different elements between Direct Logistics and Reverse Logistics for each one. Finally, we present a literature review and describe topics of future research focusing on the above proposed areas.

On the second chapter we present a case study of Reverse Logistics for the Spanish editorial sector. The editorial sector is one of the industries where the rate of returns is one of the highest, with returns' rates of more than 40% in average. This is the reason why we became interested in study the returns process for this industry, in particular as far as we know there is not study about this topic in the Spanish editorial industry. Initially, we present a general description of the sector followed by a detailed evaluation of the returns process. This was done with the collaboration of the main editorial companies in Spain. The methodology applied was a case study based on discussion working groups, surveys and company visits. Next, we describe three main research questions and evaluate each of them. The main contribution of this research is a deep knowledge of the returns process in the editorial sector, and the identification of areas of potential improvement.

In Chapter 3, we propose a collaborative production model for strategic and tactical planning, within a remanufacturing environment. In the previous chapters we identified a lack of research in business planning combining a collaborative approach for multiple products and factories with the introduction of the returned parts and assemblies in production process. The current competitive situation of business, requires the use of models where these factors are combined. We propose a mathematical model to solving the production collaborative planning taking into account the following elements:

- A supply chain that consists on several factories, a recovery center and a distribution center.
- Multiple periods, products, production processes and materials
- A Modified Bill of Materials (taking into account the returned parts and assemblies)

The benefits of this model is to help the companies to do the strategic and tactical production planning in the presence of returns and collaborating between themselves. Finally, we present two small examples that represent the potential of this benefits.

In chapter 4, we present three particular cases of the previous collaborative production planning model with returns. The model proposed previously requires a large amount of time to solve. In this chapter we aim to evaluate the impact of several elements on the computing time. So, we present three particular cases that consist on a collaborative multiperiod model without returns, a collaborative production planning model with returns for one factory and, a collaborative production planning model with returns for one period. This models evaluate the impact of the returns, the number of factories and the number of periods respectively on the resolution of the problem.   In chapter 5 where we present the solution techniques for the models, we conclude that the main element affecting the running time is the number of periods, since when we reduce this value to one period, the problem is solved in short running times. Another advantage of these models is that they can be applied to particular supply chain configurations.

In chapter 5 we present the solution techniques for all the models proposed in the previous two chapters. On one hand, we solve the models by branch-and-bound algorithm using the commercial software Lingo. We present the solutions and running times obtained and conclude that most of the models cannot be solved in short running times, some of instances of the general model even took several days without obtaining the optimal solution. This leads to a clear need to define a faster solution technique. Therefore, we propose an heuristic algorithm to solve the models. The heuristic is mainly based in two techniques: A local search method and an optimization subroutine that obtains the optimal solution for a particular case of the general model described in chapter 4. This heuristic obtains very good results in short running times.

In the final chapter we present a summary of the main conclusions and contributions of this work and proposals for future research of each chapter of this thesis.

CHAPTER 1: A Brief Review of Reverse Logistics

1.1 Introduction

Nowadays, companies are constantly working on the improvement of their operations. Globalization, forces the companies to think about many issues that were not considered in the past: competitiveness, productivity, quality, equity and sustainability are now common terms in the companies speech. But more than just talking about that, companies are implementing permanently new strategies to survive in an increasing competitive market.

Reverse Logistics (RL) is one of the issues emerging as a consequence of the increasing pressure made by the competitive forces and specially, by the governments, which are involved in the preservation of the environment. A good example are the EU leaders, which are actively working in several programs to assure the preservation of the natural resources.

Few years ago, RL was practically unknown by the academics and companies, today it is something that is becoming more and more important, as long as the companies are realizing the potential profit derived from RL activities and, the importance of taking care about the contamination derived from their business activities. Given the scope RL is reaching in many companies and countries across the world, it is now a hot topic of research. In few years, RL will be a crucial element in defining the way in which products will be designed, and most companies will take RL into account to perform their business activities.

Rogers and Tibben-Lembke (1998), show us some figures in order to state the real importance of RL today. They found that Logistics costs are estimated to account for approximately 10,7 percent of the U.S. economy. However, the exact amount of RL activity is difficult to determine since most companies do not know how large are the costs of its returns. They concluded that RL costs accounted for approximately four percent of their total logistics costs. Applying this mean percentage to the Gross Domestic Product (GDP), they conclude also that RL costs are estimated to be approximately a 0,5 percent of the total U.S. GDP, amounting to approximately $35 billion in 1997.

The magnitude and impact of RL varies by industry and channel position. It also varies depending on the firm's channel choice. However, it is clear that the overall amount of RL activities in the economy is large and still growing.

The objectives of this chapter are the following: firstly we want to describe what literature says about RL. We will make a comparison between the different existent definitions of RL, and the elements considers in those definitions. Secondly, we want to address some issues that explain why it is necessary to develop new models for RL, instead of using the direct logistics models. We compare both areas and propose some sub-areas of research, and we performed a literature review of the main publications made in the RL area. Thirdly we evaluate the actual state of development of the area and, finally we state some future perspectives RL has both in research and business applications.

1.2 What is Reverse Logistics?

There are several authors proposing a definition for RL. Our purpose in this section is not to develop new concepts or theories about RL, but to provide a brief summary of the principal statements found in the literature.

The actual speed of the business world has forced the companies to develop different strategies to improve their competitive advantage in the market. The continuous search for alternatives of improvement, has made that some areas forgotten in the past, now arise as important sources of efficiency. The re-use of materials, remanufacturing processes, policies like Design for Disassembly (DFD), efficient systems of product's return, between others, belong to this kind of areas that are seen today as a real source of profit for the companies.

There are several definitions of RL in the literature:

Krikke (1998) says (RL…)"*is the collection, transportation, storage and processing of discarded products".*

Fleischmann et al. (1997) define RL as: *“a process which encompasses the logistics activities all the way from used products no longer required by the user to products again usable in a market”.*

Dowlatshahi (2000) says it is *“a process in which a manufacturer systematically accepts previously shipped products or parts from the point for consumption for possible recycling, remanufacturing, or disposal”.*

Guide et al.(2000) define RL as *“the task of recovering discarded products (cores); it may include packaging and shipping materials and backhauling them to a central collection point for either recycling or remanufacturing”.*

Kroon (1995), considers that RL *“are the logistic management skills and activities involved in reducing, managing and disposing of hazardous or non-hazardous waste from packaging and products. It includes reverse distribution, which causes goods and information to flow in the opposite direction from normal logistic activities”.*

Finally Rogers and Tibben-Lembke (1998) say it is “*the process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in – process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal”.*

If we analyze carefully these definitions, there are **six** elements to consider:

- The first one, is the way in which the authors define **what RL is**. Some of them define RL as a task or a set of logistics management skills and activities, but most of them define it as a **process**. The concept of process is more general and incorporates tasks and activities to reach a specific objective. In our opinion RL is not a set of skills, but it uses different skills to perform specific activities. For those reasons RL is better defined as a process since this term is better adapted to the objectives of the RL.
- The second element to consider in the definition are **the inputs** that the RL process uses to perform its activities. Most of the authors agree that they are basically discarded products, used products, products or parts previously shipped, hazardous and non-hazardous waste from packages

and products, information, raw materials, in process inventory and finished goods. These inputs identify the scope of the RL process. Some of them limit the input to only waste or recycled products, but others allow a more wide concept where information, raw materials, inventories and goods are managed through the RL system. We believe this last consideration is more adapted to the RL concept, since it includes the entire “reverse flow” of things through the supply chain, and is not limiting the RL to either the waste management or the used products, which we think is a misleading and narrow vision of the RL concept, but as we can appreciate it is very commonly used.

- A third element to consider, are the **tasks or activities** involved in the RL process, in other words, after the inputs are introduced into the process, what is happening with them? As we shall see, those activities are very similar to the ones performed in the forward logistics processes, but RL also includes some additional tasks. It is also important to remark that RL activities usually introduce more elements of uncertainty in terms of the frequency in which they are performed and the quantity of products they use. Summarizing these activities we essentially found:
    - Planning, implementing and controlling an efficient and cost effective flow of products.
    - Collection, transportation (backhauling), recovering, storage, processing, acceptation, reducing, managing, disposing, and shipping products.

  These are the same activities performed in Forward Logistics, which seems obvious, since they come from the logistics definition. However, as we shall see, the systems incorporated both in Forward and Reverse Logistics are really different. This justify the development of new theories and research in the RL area.

- The fourth element to explore is regarding the **outputs or consequences** of the RL process. The authors claim that the RL objectives are the reusing, recycling, remanufacturing, disposal, reducing, and recapturing value of the “inputs”. None of the authors considers all the activities, but in general, we think all of them must be included in the RL definition.

- The last two topics or elements to be considered, are the starting and ending point of the RL process. All authors agree that the process starts in the point of consumption; although it is important to consider the fact that, when they are referring to the point of consumption, they include the distributors, retailers and consumers. In other words, if the product is, for instance, the return of a non-sold product, it may go from the retailer or distributor to the manufacturer, and it is also considered as part of the RL process. This precision is important in order to clarify which are the Reverse Logistics processes, since the problem increase in complexity because the products can be shipped directly from customers, retailers or distributors to the manufacturer.
- Finally , the destination of the product is described as: the manufacturer, a central collection point or, the point of origin. The key factor to recognize if a process is a RL process or not, is to see if the products have been previously shipped to the one who is now sending them back.

Table 1 shows a brief summary of the elements we considered in the definitions.

A problem we found in the common speech of logisticians is the confusion between Reverse and Green Logistics. The threat that actually exists due to the scarcity and deterioration of natural resources has made companies more conscious about the necessity (obligation, in some countries) of developing green alternatives or ecological ways of doing business.

Certainly, RL and Green Logistics share some activities and, this fact generates a common misleading between both concepts. However, RL is more than reusing containers or recycling packaging materials. Redesigning packaging to use less material, or reducing the energy and pollution from transportation are important activities, but they might be better placed in the realm of “Green” logistics. If no goods or materials are being sent “backward,” the activity probably is not a RL activity. However, many of the green logistics activities are lying within the Reverse Logistics area.

What is?	Inputs	Activities	Output	From	To
• Process • Task • Skills and Activities	• Discarded products. • Used products. • Products or parts previously shipped. • Packages and products from hazardous and non-hazardous waste. • Information • Raw materials • In process inventory • Finished goods • Related Information	• Planning, Implementing, Controlling an efficient and cost effective flow. • Collection • Transportation • Storage • Processing • Acceptation • Recovering • Packaging • Shipping • Reducing • Managing • Disposing • Disassembly • Inventories • Production	• Products again reusable • Recycling • Remanufacturing • Disposal • Reducing • Managing • Recapturing value	• Point of consumption	• Manufacturer • Central Collection Point. • Point of origin.

TABLE 1. COMPARISON BETWEEN REVERSE LOGISTICS DEFINITIONS.

Finally, we think that the definition gave by Rogers and Tibben-Lembke (1998), incorporate the main elements of what, in our opinion, is really known as RL. They explain very well the real meaning of proper disposal and recapturing value as a good extension of the definition. For the scope of this thesis work, this will be the definition considered.

Figure 1 depicts the principal components and activities that should be taken into account in the RL network. It is not as simple as the forward one, mainly because when products are collected from the customers, the route they follow is very different depending on the state of the product. And, considering that not all the parties or product’s components are sufficiently valuable to be transported to a manufacturing plant, we can add more complications to the problem.

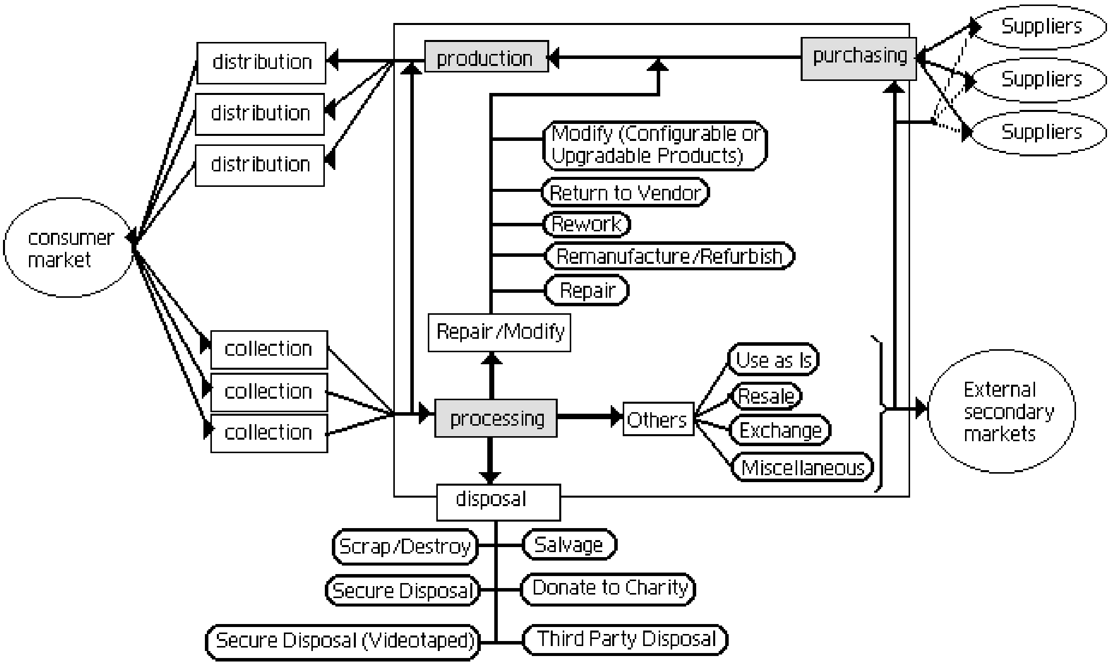

Figure 1. The Reverse Logistics Network

1.2 What's the difference between Forward and Reverse Logistics?

There are many differences between Forward and Reverse Logistics that justify the development of different theories for each area. For the scope of this work, we will concentrate our analysis on the operations management issues of RL, although all the organizational areas may be affected by the introduction of a RL system into a company.

Several authors provide various examples about how RL affects other organizational areas in companies. For instance, the Design for Disassembly (DFD), is a new trend where in the design process of a determined product, it is also considered the disassembly process. In this sense, the product must be easy to demanufacture, probably in modules that should be used in other compatible products, etc. Another issue is the recovery technology, up to now it has not been very well developed, it is necessary to develop technology for both economically and ecologically viable recovery of returns flows. The emergence of secondary markets is a new challenge for the marketing area, it is a new market to develop, but without affecting the original market for the product. For a detailed discussion about the incidence of RL in other organizational areas like technology, finance, marketing, or information management, see Krikke (1998), Thierry et al. (1995) and Van der Laan and Salomon (1997).

To analyze the differences between forward and reverse logistics and, to organize the literature review, we propose the following areas of work:

- Location theory and logistics network design
- Forecasting
- Inventory control
- Production /Remanufacturing
- Disassembly operations
- Reverse Distribution.

Next, we will describe these sub-areas of research, explaining why it is necessary to develop new models for the RL area.

1.2.1 Location theory and logistic network design:

This area of research, comprises all the design of the reverse network. It is concerned with the optimization of the location and capacity of the facilities as well as the flow of goods between them. In traditional location models, the demands and operational costs are considered inputs of the location models. In RL demands are located not only at one side of the chain but in both, since the secondary markets, disposal facilities, etc. also receive the product of the company.

Krikke (1998), considers some elements that differentiate the RL network design from the forward one:

“Forward logistics systems are pull systems, while in RL there is a combination of push and pull, due to the fact that there are clients on both sides of the chain, namely the disposer and the re-user. In forward logistics, only customer markets need to be served and the entire logistic chain, including suppliers (the ‘equivalent’ of disposers), adjusts itself to it. As a result of the extended producer responsibility, the amount of waste supplied to the RL system (the

push) cannot be influenced in the long run and has to be matched with demand (the pull). Disposal can serve as an escape route for unwanted waste, but the amount of disposal is limited by legislation."

"Forward logistics models usually deal with divergent networks, while reverse flows can be strongly divergent and convergent at the same time."

"Return flows follow a predefined processing graph[1] *in which discarded products are transformed into secondary products, components and materials. In forward logistics, this transformation takes place in a production unit, which serves as a source in the network."*

"In RL, transformation processes tend to be incorporated in the distribution network, covering the entire 'production' process from supply (=disposal) to demand (=reuse). In addition since only a fraction of return flows is valuable, it is likely that in an efficient design, operations are spread over a high number of echelons[2]*. Traditional forward logistics models usually focus on one or two echelons."*

Fleischmann et al. (1997) in addition state the following difference:

"A particularity in the reverse distribution networks, is their high degree of uncertainty in supply, both in terms of quantity and quality of used products returned by the consumers. Both are determinants for a suitable network structure since, e.g. high quality products may justify higher transportation costs (and thus a more centralized network structure), whereas extensive transportation of low value products is uneconomical. Moreover, end-markets for recovered products may not be well known, exposing network planning in this context to even more uncertainty."

The uncertainty in the number of products returned, implies that until the moment when the returns are received it is difficult to estimate the number and quality of the products returned. This situation complicates the design of the

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[1] *Processing graph*- a directed graph with one root, reflecting the sequence of processes needed to implement a PRD-strategy of one return product.

[2] *Echelon*- a set of non-interacting processes, used in the construction of a reverse logistic network.

logistics network, since the demands are not known in advance and, although the estimation in quantity should be approximated, it is more difficult to estimate the quality of the products. This influence the decision of location, since the value of the product depends directly of the quality and quantity of the returns.

One of the main decisions a company face in settling the reverse network, is to decide if returns will be made through a centralized facility or different facilities near to the client's stores. On the other hand, another typical issue is to consider if the RL activities will be managed in the same or in different facilities of those in which the direct logistics processes are managed.

1.2.2 Forecasting:

The problem of Forecasting is a difficult task in RL. This activity consist in the estimation of the magnitude, timing, location and quality of the returns received. Most of the times, returns arise from demand forecasting errors. Again, if forecasting is not accurate, some problems should emerge in the RL activities.

On the other hand, the lack of information of some secondary markets, makes it difficult to estimate the number of buyers in those markets.

In some areas like secondary packaging return, forecasting is addressed by considering the system as a closed loop, where the same elements are present in the system and there are some loses at each cycle. This approach help forecasting since the problem is reduced to estimate the number of units lost at each cycle of the product. For secondary packaging is a good way of forecast, since the idea is to recover all the package sent.

However, there still in the literature a lack of models in this area.

1.2.3 Inventory Control :

The companies also need to manage efficiently their returns inventories. There are several different characteristics that made more difficult the management of the inventory when returns are incorporated:

- Uncertainty in the quantity of products received (should excess the capacity, or incur easily in stock – out)
- The difficulty of identification of some articles since the bar code is frequently deteriorated.
- In some sectors is frequent to find cases like the following: the products are shipped with promotions, which in fact is considered a new article with a new code but, they are returned alone, without the promotional object. In this cases the product is incorporated to the inventory with the code of the single article. This complications generates problem of inventory balance.

In the literature, we find another reasons to develop new models for the inventory management of the returns:

Krikke (1998) says that Inventory management in product recovery situations is particularly different in those which are closed loop[3]. In the remanufacturing environment, the increased system complexity and uncertainty resulting from interactions between forward and return flows, requires adapted control mechanisms.

Fleischmann et al. (1997) state three differences between reverse and forward logistics inventory control:

- *“In RL, as a consequence of the return flow, the inventory level between new component replenishments is no longer necessarily decreasing but may increase also. This loss of monotonicity significantly complicates the underlying mathematical models. A possible starting point for a closer analysis of this aspect, are the cash balancing models comprising in and outbound flows.”*
- “There are two alternatives for fulfilling the demand[4] that impose an additional set of decisions to be taken. External orders and recovery

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[3] *Closed loop*- In these situations, the reverse chain is directly connected to original forward chain activities or inventories. On the contrary in *Open loop* situations the reverse chain is connected to alternative forward supply chains usually through intermediate markets.

[4] Either the company orders the required raw materials externally and fabricates new products or it overhauls old products and brings them back to ‘as new’ conditions.

have to be coordinated. This can be compared with a two-supply mode inventory system with the special property that supply of one mode cannot fully be controlled.”

- “By distinguishing between products yet to be overhauled and serviceables the situation described above naturally leads to a two-echelon inventory system. Thus, investigations on adequate echelon stock control strategies, such as PUSH versus PULL policies are relevant in this context.”

There are some models proposed to deal with the inventory management of the returns, some of them are reviewed in section 1.3.3.

1.2.4 Remanufacturing:

The recoverable manufacturing system has three distinct subsystems: disassembly, remanufacturing and reassembly. This section examines remanufacturing and reassembly, next section examines disassembly processes.

The problems in this area arise because in Remanufacturing, new products are manufactured using three kinds of components:

- Components that are always retrieved from returned products (the quantity is unknown)
- Components that are always purchased new
- Components that can either be purchased new or retrieved from returned products, depending on availability and costs.

Krikke (1998) shows some reasons for which traditional MRP-systems are not feasible for recovery situations: First problem is the mismatch of supply and demand, due to the simultaneous release of ‘wanted’ and ‘unwanted’ components in the disassembly of returned products. A second major problem he states is regarding the trade-off between reusing return components or outside procurement.

Fleischmann et al.(1997) state the following arguments:

“The repair operations needed to convert a returned product back to an ‘as new’ state depend on the actual condition of the product.” In fact, the company does not know what to do with a product until it arrives and its quality is assessed. Furthermore, in an extreme point this may vary from instance to instance and company can in general only decide the repair operation after a number of testing and disassembly operations. Therefore, in contrast with traditional manufacturing, a no well-determined sequence of production steps exists in remanufacturing. This expose planning in a remanufacturing environment to a much higher uncertainty.

- *“A high level of coordination is required in remanufacturing due to the interdependence between different parts and subassemblies.”* Disassembly of a returned product is not a procurement source for one part but, releases various parts simultaneously. Furthermore capacity problems may arise if several parts require the same repair facility. Analogous problems may be encountered for equipment common to new production and repair.
- *“The dependency between components simultaneously obtainable by disassembly and the choice between multiple supply sources (e.g. different returned products) cannot be handled adequately by a simple level-by-level top down approach as in traditional MRP.”*
- *“Prior to actually processing returned products the specific forms of reuse have to be decided upon.”* In products with complex structures it should be necessary to select the level of disassembly, depending on the expected profit of disassembly one level more, versus the expected probability of obtaining a good material in the next disassembly level.

Guide et al.(2000), determine seven characteristics of the recoverable manufacturing systems that complicate the management, planning, and control of supply chain functions. They are:

- The uncertain timing and quantity of returns
- The need to balance demands with returns
- The need to disassemble the returned products
- The uncertainty in materials recovered from returned items

- The requirement for a RL network
- The complication of material matching restrictions

All the procedures needed to reincorporate the returned product in the fabrication of the new ones, are included in this area. Repair operations can also be considered within this subsystem.

An additional problem arising from a remanufacturing environment is that to manufacture a product the production path is uncertain, since depends of the returned materials and parts.

1.2.5 Disassembly Operations:

Disassembly is a new activity which is not present in Direct Logistics. This activity consist in doing the inverse process of manufacturing. Some authors call it also demanufacturing.

There are several issues to consider in this area, first decision is concerned with disassembly or not disassembly a product, since the quality of the parts is unknown. There is a probability that depends on the cause of return of the product of getting a part (or assembly) of good quality for remanufacturing.

Second common decision in this area is about the level of disassembly. If the company decide to disassembly the product in several assemblies, and some of the assemblies doesn't work, the company decides if disassembly again these assemblies or not. The decision is up to which level of disassembly is profitable for the company to disassembly.

An additional problem arises from the upgrading or downgrading state of the product during its use by the customer. This changes in the product due to repair, upgrading or downgrading, increases the uncertainty of the quality state of the assemblies when the product is disassembled. There is also a damage risk in this disassembly process, since up to now, products have not been designed to support a disassembly process. To deal with this problems companies are working today in Design for Disassembly processes to minimize the impact in the disassembly process at the end of the life (EOL) of the product.

1.2.6 Reverse Distribution:

The design of the reverse distribution network is also a problem that needs specific solutions. The conditions of the returned products are really different from the new ones. For instance, the new products should be easily palletized, allowing companies to plan better the capacity of the vehicles. Returned products should correspond to few or only one unit of a product and, many times they are not very well packaged, therefore the planning and establishment of the reverse distribution networks is more complicated in this case.

Fleischmann et al. (1997) state some differences between forward and reverse distribution:

"A particularity in the reverse distribution networks, is their high degree of uncertainty in supply, both in terms of quantity and quality of used products returned by the consumers. Both are determinants for a suitable network structure since, e.g. high quality products may justify higher transportation costs (and thus a more centralized network structure), whereas extensive transportation of low value products is uneconomical. Moreover, end-markets for recovered products may not be well known, exposing network planning in this context to even more uncertainty."

The uncertainty in number of products returned is complicated with the lead times used, since the service policies implies that companies pick up the returns in a reduced time frame. On the other hand, the products are frequently returned without previous authorization of the manufacturers and, in extreme cases, without at least a communication of the returns sent by the retailer.

As we can observe, there are several reasons to develop new models for the improvement of the RL operations. In the next section we will explain with some detail the principal advances achieved in RL research.

1.3 Actual Areas of Research

In this section we examine the “state of art” of the RL research in each one of the areas proposed in section 1.2. On the other hand, we also want to know the actual areas and opportunities of research in the RL field.

The research done in RL is mostly in practitioner-related rather than academic journals. There are few articles that introduce mathematical or quantitative models.

At the end of this section a special reference to RL and electronic commerce is also considered, since there are three papers considering the elements of e-commerce linked with RL.

1.3.1 Location theory and logistic network design:

There is a huge amount of research in facility location theory in general. However, in the literature we found very few papers on this topic applicable to RL.

Krikke (1998), proposes some models for RL network design. He designs a model for a multi-product and multi-echelon situation. The model allows to add new facilities with the corresponding costs functions when necessary. He proposes the design of a network graph and a transportation graph as basic inputs for his model.

Barros et al. (1998) considers the problem of the recycling of sand (a subproduct of recycling construction waste) in the Netherlands. They propose a two-level location model for the sand problem and consider its optimization using heuristic procedures.

Fleischmann et al. (2000) reviewed nine published case studies on logistics network design for product recovery in different industries and, identify some general characteristics of product recovery networks, comparing them with traditional logistics structures. They classified the product recovery networks in three sub-areas: Re-usable item networks, remanufacturing networks, and recycling network.

Lu and Bostel (2005) present a two-level location problem with three types of facility to be located in a specific reverse logistics system. For this problem, they propose mixed integer programming model, considering simultaneously “forward” and “reverse” flows and their mutual interactions.

Most of the papers in this area are practitioner related, in which a model is designed for a specific problem and/or company. Given the complexity of the RL networks derived from the uncertainty in both quality and quantity of the returns, it is difficult to create models for general purposes.

Another issue that has not been widely considered in the literature, is the outsourcing operations of RL. Krumwiede and Sheu (2002) develop a qualitative model to help companies to affront the decision of outsourcing the RL function. Jeung Ko and Evans (2005) propose a mixed integer nonlinear programming model for the design of a dynamic integrated distribution network to account for the integrated aspect of optimizing the forward and return network simultaneously. There still a need for the development of quantitative models that allow to decide the convenience of the outsourcing decision.

1.3.2 Forecasting:

The problem of forecasting has been addressed by only few authors. Since the uncertainty involved and the lack of information, makes really difficult to develop models in this area.

Kroon and Vrijens (1995) present a forecasting system for returnable containers. They consider a case in the Netherlands where return logistics operation took the form of a depot system with a deposit structure. The system proposed is not only concerned with the forecasting of the containers available, but also in the network design and reverse distribution. The results where very satisfactory, but only applicable for the specific characteristics of the company analyzed.

Marx-Gómez, C. et al. (1995), examine an extended forecasting method to provide prognoses for returns value (amount and time) of scrapped products to recycling. The model is based on relevant influencing factors and product life cycle data and, was applied to a case study of photocopiers. The results obtained suggest that the combination of simulation with a fuzzy system based on the introduction of qualitative criteria from experts of the area, provides good results for the forecasting problem.

This is a good area of research where there are not so much models developed. As in others areas, the models proposed up to now are specific to particular situations, therefore should not be used as a general tool for the forecasting process.

1.3.3 Inventory Control :

Few papers consider returns and outside procurement in a manufacturing environment. The most relevant papers can be categorized in three groups: cash balance models, periodic and continuous review models. Basically the difference between them is that in continuous review models, lead and repair times can be modeled. In periodic review and cash balance models they are not modeled, but in the last case the value of demands and returns are modeled in money and, some inventory control policies are considered. See Van der Laan et al. (1996) for a detailed review of these aspects.

Richter (1999), considers an EOQ repair and waste disposal model with variable setup numbers for production and repair, within some collection time interval is considered as an integer nonlinear program. The cost analysis is extended to the extreme waste disposal rates and it is shown that the pure strategy for either total repair or total waste disposal is dominant.

De Brito (2004) states that it is important to coordinate storing returns with forward operations such as order picking and internal transport.

Most of the research in RL have been done in this area. However, most of the literature consider simple models used only for specific cases and, there is a lack of models adjusted to the real remanufacturing environment, which is essentially more complex, see Dowlatshahi (2000).

1.3.4 Remanufacturing:

Several factors, including the life-cycle stage of a product and the rate of technological change, influence returns. This characteristic has a marked impact on demand management, and inventory control and management.

Within this classification of production planning and inventory control, we include all the literature related with production, i.e. remanufacturing, planning, inventory control, job scheduling, and all the related areas.

The high level of uncertainty arisen as a result of the different characteristics in terms of quantity and quality of the returned products, makes more complicated the production planning task and increases the complexity of the inventory control process. A good way to understand this uncertainty is to analyze the most common causes of products’ return. Rogers and Tibben-Lembke (1998) describe the principal causes for which the people return the products. Table 2

Repair / Service Codes
· Factory Repair – Return to vendor for repair
· Service / Maintenance
· Agent Order Error – Sales agent ordering error
· Customer Order Error – Ordered wrong material
· Entry Error – System processing error
· Shipping Error – Shipped wrong material
· Incomplete Shipment – Ordered items missing
· Wrong Quantity
· Duplicate Shipment
· Duplicate Customer Order
· Not Ordered
· Missing Part
Damaged / Defective
· Damaged – Cosmetic
· Dead on Arrival – Did not work
· Defective – Not working correctly
Contractual Agreements
· Stock Excess – Too much stock on hand
· Stock Adjustment – Rotation of stock
· Obsolete – Outdated
Other
· Freight Claim – Damaged during shipment
· Miscellaneous

Table 2. Causes of Product’s return.

shows their findings, this list allows us to observe the high variety in product quality and quantity managed through the RL flow, given the possible circumstances that generate the returns.

The process of receiving the returned products imply some different activities of revision and control to determine which is the actual quality state of the product, and only after that process, it is possible to determine what is the best strategy to follow to minimize the costs.

As we mentioned above, in a remanufacturing environment, it is possible to use different parts from different returned products to manufacture a new one and, also it is possible to mix them with new purchased parts. It complicates the production and the planning process.

Factors	Recoverable manufacturing environment	Traditional manufacturing environment
Environmental focus	Seeks to prevent postproduction waste	Environmentally conscious design and manufacturing, focus on Preproduction Pollution prevention and Remediation
Logistics	Forward and reverse flows Uncertainty in timing and quantity of returns Supply-driven flows	Open forward flow No returns Demand-driven flows
Production planning and control	Need to balance demands with Returns Material recovery uncertainty Stochastic routings and processing times Manufacturing system has three major components: disassembly, remanufacturing, and reassembly	No such need Certainty in planned materials Fixed routings and more stable processing times Manufacturing system has two major components: fabrication and assembly
Forecasting	Forecast both core availability and end-product demand Must forecast part requirements because material recovery rates are uncertain	Forecast only end products No parts forecasting needed
Purchasing	Highly uncertain material requirements due to variable recovery rates Cores and parts and components, replacement parts, components	Material requirements Deterministic Raw materials, new parts, and Components
Inventory control and Management	Types: cores, remanufactured parts, new parts, new and remanufactured substitute parts, original equipment manufacturer parts Must track and provide accounting for all part types	Types: raw materials, work-in-process, finished goods Must track and provide accounting for work-in-process and finished goods

Table 3. Comparison between manufacturing and remanufacturing environment. Source Guide et al.(2000)

Table 3 is taken from Guide (2000) and shows a comparison between manufacturing and remanufacturing environment and the impact they have over the functional areas within the organizations.

This is the area where the RL literature has been most widely developed. Most quantitative papers have been made on production scheduling, inventory control and remanufacturing. Some different papers related to this area are:

Van der Laan et al.(1999), studied the production planning and inventory control in systems where manufacturing and remanufacturing operations occur simultaneously. They consider a relatively simple hybrid system related to a single component durable product. They present a methodology to analyze a push control strategy (all returned products are remanufactured as early as possible) and a pull control strategy (where all returned products are remanufactured as late as it is convenient). They derive some managerial insights into the inventory-related effects of remanufacturing.

Klausner and Hendrickson (2000) developed a model that allows to determine the optimal amount to spend on buy-back and the optimal unit cost of RL. They used the latter to select a suitable RL system for end-of-life products. They stated that by buying back end-of-life products, firms could control the flow of returned products. They solve in this way the remanufacturing problem, which requires a continuous flow of returned post-consumer products to be profitable. They applied the model to the remanufacturing take-back concept for power tools, using empirical data on the current take-back program.

Linton and Johnston (2000) develop a decision support system (DSS) for Nortel Networks, an international digital and internet network equipment manufacturer, to improve its planning of its remanufacturing operations for circuit assemblies. The system embodies a RL model that allows decision-makers to better plan the outbound and inbound product flows involved in making design changes. Careful modeling of the decision-making process and its embodiment in appropriate information technology were keys to the successful implementation of the project in Nortel ’s operations.

Inderfurth (1997) addresses a problem of product recovery management where a single product is stocked in order to fulfill a stochastic demand of customers who may return products after usage, generating also stochastic product returns. The material flow can be controlled by procuring new products on the one hand, and by remanufacturing or disposal of returned items on the other. For periodic review control it is shown how the optimal decision rules for procurement, remanufacturing and disposal can be evaluated by a dynamic programming formulation.

Van der Laan et al.(1997), consider a stochastic inventory system with production, remanufacturing, and disposal operations. Customer demands must either be fulfilled from the production of new products or by the remanufacturing of used products. Used products are either remanufactured or disposed of. Other contributions of this paper are to indicate when and why planned disposals are economically beneficial, and to compare the PUSH-disposal strategy to the PULL-disposal strategy.

Daniel and Guide (1997) evaluate some priority dispatching rules in combination with a modified drump-buffer-rope scheduling system under a variety of utilization levels (low, intermediate and high). They simulate those scenarios and evaluate the results obtained

For additional references see Teunter et al.(2000), Teunter and Fortuin (1998) and, Fleischmann et al.(1997).

There are a huge variety of work in progress but also including them, there are a wide range of issues that are actually uncovered by the researchers within the RL area. For instance, most of the papers are concentrated in only one product. Also there are not models that combine remanufacturing with supply chain planning. The actual state of development of the companies, makes necessary to develop this kind of models where integration and collaborative planning are considered together.

1.3.5 Disassembly Operations:

Several authors illustrates the problem of disassembly. Zussman (1995) propose a disassembly system where the end of life value of the product is take in to account to evaluate the strategy to follow in the disassembly process. The process is complemented with a correct identification of the assemblies with adhesive labels, previously attached to the product when it was manufactured.

Krikke et al. (1998) propose a model for the disassembly strategy for a single product. He proposes a two steps optimization model to solve the problem and, complements the problem with the case of a television device.

Gungor and Gupta (1998) proposes a methodology for the Disassembly Sequence Plan (DSP). They propose to first generate a precedence disassembly matrix that represents the physically based precedence relationships between the assemblies of the products. Then an optimum DSP is proposed, and finally third step consists in perform the disassembly process, following the optimal DSP and, adjusting the process when an unexpected situation arises.

Guide, Jr. et al. (1999) examine the impact of the variability of the highly variable lead times on the control of parts release from the disassembly area to the remanufacturing area. They evaluate various disassembly release mechanisms for releasing the parts. Lead time variation is shown to have a significant affect on the choice of disassembly release mechanism. They only consider the lead time as source of uncertainty, it is necessary to evaluate also the impact of others factors as the variation in the number of returns received and the size and location of the inventory buffers.

González and Adenso-Diaz (2004) propose a scatter search (SS) metaheuristic to deal with the optimum disassembly sequence problem for the case of complex products when they should be reused or shredded at the end of its life. They use sequence-dependent disassembly costs, assuming that only one component can be released at each time. They evaluates the heuristic with a set of 48 products where it is compared with the time spend by a feasible sequence consisting in disassembly the components in the reverse order of their assembly sequence.

1.3.6 Reverse Distribution:

Fleischmann et al.(1997) defined reverse distribution as the collection and transportation of used products and packages. Also they add the fact that it can happen through the forward distribution channel, through a separate reverse channel or through combinations of the forward and reverse channel. To understand more the structure of the RL process, let’s look in detail some structures defined for the RL network design: As we state previously, there are more actors involved in the RL network. In the RL network, the supply chain is composed by all the members of the forward logistics network, plus third parties acting as demand points, namely the secondary markets, landfills, Charity organizations, and many more. They have a special characteristic, which is that they do not have a previously established demand, on the contrary, they have limited their capacity by some specific constraints. In the case of landfills for instance, the government regulates the quantity of products that companies can ship to them.

When will a product be returned?, where it must be shipped?, which is the most efficient strategy to choose in order to maximize the firms profits?. These are the most common questions that have occupied the researchers in this area of RL.

As we said before, the high level of uncertainty complicates the design of the RL network. This uncertainty comes from the fact that the company never knows in advance when and where the products will be returned, and how many products will also be returned. Depending of the quantity of products returned, it should be necessary to operate with collection points in different facilities than the distribution facilities used in the forward network.

Fleischmann et al.(1997) describe the principal advances in this area. They show how some authors have work in the integration of reverse and forward logistics systems, and they present some models to improve the design of the RL network.

Most of the research in this area has been done in the design of recovery strategies and the optimal choice of them. Krikke (1998), introduces an optimization model for an effective design of multi-echelon networks with recovery of multiple types of durable assembly products. He balances the supply and demand with predetermined recovery strategies, in order to neutralize the push and pull market effects. As a consequence the facility location problem also has transshipment characteristics. He also develops a heuristic algorithm to solve the problem and complement it with an additional practical application to the model in the redesign of a network of copiers.

Dowlatshahi (2000), summarizes the most important advances in the distribution area, he has mentioned in his paper some models from White (1994) on material handling in RL. He states that materials can be transported in bulk, then the packaging and packing occurs at the final point of sale. Andel (1995), discusses the design of cost efficient transportation routes for RL purposes. He shows that the use of a third party logistic firm can be efficient for the managing of the RL flow. Fleischmann et al.(2001) consider logistics network design in a RL context. They present a generic facility location model and discuss differences with traditional logistics settings. In addition, they use their model to analyze the impact of product return flows on logistics networks. They show that the influence of product recovery is very context dependent. While in many cases product recovery may efficiently be integrated in existing logistics structures, other examples require a more comprehensive approach redesigning the company's logistics network in an integral way.

Other Authors have studied some issues about the role of the distributors in the RL network, partial integration of reverse and forward logistics network and special cases of perishable products. They underlie the importance of the warehousing, material handling, routing, distribution, transportation and storage methods in the efficient management of the RL network. For additional references see Fleischmann et al.(2000) , Kroon (1995), Fleischmann et al.(1999) and Mehalik (2000).

The theory developed until today is not very extensive, given the few years that have been dedicated to the study of the RL and, also most of the published papers are trying to organize a more structured framework in this area.

1.3.7 RL and e-commerce:

There is also a special reference to the role of RL in e-commerce. Kokkinaki et al.(1999) consider the role of electronic commerce in RL. They have identified some RL tasks within the e-commerce applications. The following table summarizes their analyses in this aspect.

E-Commerce Applications	**Reverse Logistics Tasks**
Marketing	- Advertisement of available used products, parts or material.
	- Notification of used products, parts or material, currently sought.
Purchasing	- Search for suppliers/customers
	- Making purchasing commitments
	- Receive information of expected delivery
	- Respond to request for sought used products, parts or materials
Sales	- Price setting (i.e. fixed, negotiations, auction)
	- Order processing
	- Tracking and tracing orders
	- Customer invoicing, collection and payment
Post Sales/ Service	- Product tracking
	- Customer support
	- Customer / product monitoring

TABLE 4. REVERSE LOGISTICS AND E-COMMERCE

As we observe, most of the papers are not quantitative and has been made in the area of inventory control and production planning, which seems logical given that this is the area where RL differs more from forward logistics. In the next section we describe the possible areas of research in RL.

1.4 Possible Areas of Research

From this literature review, we should visualize some interesting fields of future research in RL. But, before to have our own conclusions, let's look at Dowlatshahi (2000) who state the following conclusions on RL literature:

— The conceptual, quantitative, and application-case-based articles do not provide an extensive treatment of RL topics.

—The majority of articles are short and lack the depth to demonstrate the level of integration necessary to implement RL across various functional areas.

—Most authors assume prior, comprehensive understanding of the structure of a RL system and ***do not describe the basic structure of a RL system***.

—Most authors do not define the basic concepts and terms. Most of the literature is practitioner-oriented.

There are some issues that still being a good area for future research:

- There are few model treating Forward and Reverse distribution simultaneously; these models consider location of joint facilities for both networks.
- There are no models dealing with reverse routing combined with forward logistics routing.
- There are not empirical evidence about the comparisons between traditional versus specifically adapted inventory control methods in a return flow environment,
- Almost all the models are one-product, one-component models, there are few of them dealing with multiple components but ***none of them with multiple products***.
- Although the authors recognize that traditional MRP systems are not useful to a return flow environment, there are few alternatives developed to solve this problem,

Krikke (1998) also suggest some additional research that is necessary to develop within RL. In particular:

- Forecasting of return flows and secondary markets.

- Extension of the modeling of recovery strategies with flexible disassembly sequences related to classification scheme, economies of scale effects, trade-off between using old or new components and distinguishing geographic differences in parameters.
- Extension of RL network design modeling with logistic performance indicators.
- Efficient algorithms for integral models and the set-up of collection systems
- The effects of sub-aspects of product recovery management (financing or strategic alliances) on the set-up of reverse logistic systems.
- Iterations between recovery strategy and logistics network optimization, given their mutual impact on parameter setting, thus testing the robustness of solutions.
- The operational implementation of recovery strategies

Clearly there are many areas to be investigated in the RL field, both empirically and theoretically. The actual research in this area is still growing and each day there are more companies who decide to introduce a RL system within them. The legislation also helps to increase the importance of this field, given that companies are being forced to be responsible for the packages and the end of life products they had sold. In Europe, Germany has the most advanced legislation in this sense, but is expected in few years that some other countries within the European union start copying the German laws.

Finally, other issue that should be investigated is the RL systems in some particular markets, as the electronics markets, automotive industry, big consumption or editorial industry given the level of returns and the characteristics of those markets which make them more conscious about the RL potential and, on the other hand, it is also interesting to investigate the choice for some policies as zero returns in markets where is not viable to exercise a RL activity.

There is also a lack of appropriate models for the actual manufacturing operations where various products and materials are considered at the same time. Also another elements like collaborative planning are not considered in the remanufacturing environment.

Finally, we want to remark that this thesis will contribute to the RL area basically in two elements:

- We develop a business case considering the actual situation of the editorial sector in Spain and, proposing some ways of improvements.
- We propose four new models for medium term collaborative production planning with remanufacturing with the inclusion of various products, planning periods and materials. We also propose and develop some methodologies to solve the proposed models in a way in which companies can use in an efficient way.

1.5 Chapter References

Andel, T. (1995). "There's power in numbers." Transportation and Distribution **36**(8): 67-68.

Barros, A.I., Dekker ,R. and Scholtenm V. (1998). "A two level Network for recycling sand: A case study." European Journal of Operation Research **110**: 199-214.

Daniel, V. and Guide, R. Jr. (1997). "Scheduling with priority dispatching rules and drum-buffer-rope in a recoverable manufacturing system" International Journal of Production Economics **53**: 101- 116.

De Brito, Marisa P. (2004). "Managing Reverse Logistics of Reversing Logistics Management" PhD Thesis. ERI - Erasmus University Rotterdam. 323

Dowlatshahi, S. (2000). "Developing a theory of Reverse Logistics." Interfaces **30**(3): 143-155.

Fleischmann, M., P. Beullens, J.M. Bloemhof-Ruwaard and L.N. Van Wassenhove. (2001). "The Impact of Product Recovery on Logistics Network Design." INSEAD. Production and Operations Management(Summer 2001).

Fleischmann, M., H.R. Krikke, R. Dekker and S.D.P. Flapper. (2000). "A Characterisation of Logistics Networks for Product Recovery." Omega **28**: 653-666.

Fleischmann, M., H.R. Krikke, R. Dekker, and S.D.P. Flapper. (1999). "Logistics Network (Re-) design for product recovery and re-use." Management report series. Erasmus University of Rotterdam **17**.

Fleischmann, M., Jacqueline, M., Van der Laan, E., Van Nunen, Jo A.E.E. and Van Wassenhove, L.N. (1997). "Quantitative models for Reverse Logistics: A review." European journal of Operational Research **103**: 1-17.

González, B., Adenso-Diaz, B., (2004). " A scatter search approach to the optimum disassembly sequence problem." Elsevier online database. To appear in Computers & Operations Research .

Guide, Jr. VDR, Jayaraman,V. and Srivastava, R. (1999). " The effect of lead time variation on the performance of disassembly release mechanisms." Computers & Industrial Engineering **36**: 759-779.

Guide, Jr. VDR, Vaidyanathan Jayaraman, Rajesh Srivastava, and W.C. Benton . (2000). "Supply-Chain Management for Recoverable Manufacturing Systems." Interfaces **30**: 125- 142.

Gungor, A. and Gupta, S.M (1998). "Disassembly sequence planning for products with defective parts in product recovery." Computers and Industrial Engineering **Vol. 35**(1-2):161- 164.

Inderfurth, K. (1997). "Simple optimal replenishment and disposal for a product recovery system with leadtimes." OR Spectrum **19**: 111-122.

Jeung Ko, H. and Evans, G.W. (2005). " A genetic algorithm-based heuristic for the dynamic integrated forward/reverse logistics network for 3PLs." Elsevier online database.To appear in Computers & Operations Research.

Klausner, M., Hendrickson, Chris T. (2000). "Reverse-logistics Strategy for product take-back." Interfaces **30**(3): 156-165.

Kokkinaki, A. I., Dekker, R., Van Nunen, J. and Pappis. (1999). "An exploratory study on Electronic commerce for Reverse Logistics." Econometric institute report. Erasmus University of Rotterdam. **EI-9950/A**.

Krikke, H. (1998). Recovery strategies and reverse logistic network design. Institute for Business Engineering and Technology Application. PhD Thesis. Enschede, The Netherlands, University of Twente**:** 254.

Kroon, L. and Vrijens, G. (1995). "Returnable containers: an example of Reverse Logistics." Omega 30: 325-333.

Krumwiede, D.W. and Sheu, C. (2002). " A model for reverse logistics entry by third-party providers." International Journal of Physical Distribution & Logistics Management **25**(2): 56-68.

Linton, J. D., Johnston, David A. (2000). "A decision support system for planning remanufacturing at Nortel Networks." Interfaces **30**(6): 17-31.

Lu, Z. and Bostel N. (2005). "A facility location model for logistics systems including reverse flows: The case of remanufacturing activities". Computer & Operations Research. Elsevier online:To appear in printed version.

Marx-Gómez, C., Rautenstrauch, C., Nürnberger, A., Kruse, R. (2002). "Neuro-fuzzy approach to forecast returns of scrapped products to recycling and remanufacturing." knowledge-based systems **15**: 119-128.

Mehalik., M. M. (2000). "Sustainable Network Design: A commercial Fabric case study." Interfaces **30**(3): 180-190.

Richter, Knut and Dobos, Imre (1999). "Analysis of the EOQ repair and waste disposal problem with integer setup numbers". International Journal of Production Economics 59 (1999) 463-467

Rogers, D. S. and Tibben-Lembke, Ronald S. (1998). Going Backwards: Reverse Logistics Practices and trends. Reno, Nevada, Reverse Logistics Executive Council.

Teunter, R., Van der Laan, Erwin. and Inderfurth, Karl (2000). "How to set the holding cost rates in average cost inventory models with Reverse Logistics." OMEGA the International Journal of Management Science **28**: 409 - 415.

Teunter, R. H. Fortuin, L. (1998). "End-of-life Service: a case study." European Journal of Operations Research **107**(1): 19-34.

Thierry, M. M. S., J. Van Nunen and L. Van Wassenhove. (1995). "Strategic issues in product recovery management." California Management Review, **37**(2): 114-135.

Van der Laan, E., Dekker R., Salomon, Marc. , Ridder, Ad. (1996). " An (s, Q) inventory model with remanufacturing and disposal." International Journal of Production Economics **46-47**: 339-350.

Van der Laan, E., Salomon, Marc. (1997). "Production planning and inventory control with remanufacturing and disposal." International Journal of Operational Research **102**: 264-278.

Van der Laan, E., Salomon, Marc. , Dekker Rommert, Van Wassenhove Luk. (1999). "Inventory Control in Hybrid systems with remanufacturing." Management Science **45**(5).

White, J. A. (1994). "Reverse Logistics moves forward." Modern Materials Handling, **49**(1): 29.

Zussman, Eyal. (1995). "Planning of disassembly systems." Assembly Automation, **Vol. 15**(4): 20-23.

CHAPTER 2: Reverse Logistics In The Editorial Sector: An Exploratory Study

2.1 Introduction

In the previous chapter, we concluded that there still some interesting areas of research within the RL field. One of this areas was the research of the RL performance in some particular markets where returns levels are really important. Based on that, we decided to engage an exploratory study to know also the state of development of the RL in the real business.

Examining the different sectors, we decided to propose an study with the Spanish Editorial sector, because is one of the sectors where returns are becoming a big handicap. In fact, the Spanish editorial sector, is one of the leaders in the world with nearly 2500 millions of Euros of sales annually. They have an average return rate of 41,17%[5] of the sales. For this reason, RL is a topic of importance among professionals in the editorial sector. However, it has not been considered as an outstanding topic in the RL literature. None of the existing studies considers this industry. The objectives of this chapter are: to describe and analyze the RL process within this industry and to propose some ways to improve it.

We believe that this chapter will be both informative and insightful to managers and researches in the SCM field. Managers are provided with some guidelines to improve the RL process. And, researchers are given some lines of further research.

The chapter is structured as follows: section two briefly examines the specific literature related with the work performed in this chapter; section three describes the characteristics of the Spanish editorial sector. Section four shows the research methodology; section five presents the results, and, finally, section six provides some conclusions and lines of future research.

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[5] Federación Nacional de Gremios de Editores, Spain, 2001.

2.2 Literature Review

Some authors have performed exploratory studies to determine the “state of the art” of RL in other countries and other industries Kroon (1995), Barros et al. (1998), Fraser (1998), RLEC (1999a), RLEC (1999), Kokkinaki et al.(1999), Krikke et al.(1999) and, Goodman (2000), but there is not any evidence of this kind of work in the editorial sector in Spain.

Kroon (1995) considered a practical application of RL in the reuse of secondary packaging material. They present a number of methods that may be used to create a return logistic system for returnable containers. They presented a quantitative model and a case study. Barros et al.(1998) conducted a case study in the construction industry. They analyzed a two-level network responsible for recycling sand. The paper described the RL process but it also proposed a mathematical model to decide the most efficient location of the recycling containers. Fraser (1998) explored the role of purchasing and other functional areas in the RL systems of 12 North American manufacturing plants. The Reverse Logistics Executive Council (RLEC) sponsored several studies to assess the state of the art of the RL process in the apparel, electronics and small appliances industries RLEC (1999). Kokkinaki et al.(1999) conducted an exploratory study to analyze the RL services provided by companies selling in the e-commerce channel. They classified the internet sites object of study and described their RL processes. Krikke (1999) described the case of Roteb, the municipal waste company of Rotterdam, which implemented some recovery strategies for PC-monitors. And, finally, Goodman (2000) described how sustainable operations in Scandic hotels were performed and the savings achieved.

Our study shares with Kroon (1995), Fraser (1998), Barros (1998), Krikke (1999), Kokkinaki (1999) and Goodman (2000) the use of the case study methodology. Researchers are claiming the use of more case study based papers (see, for example, Voss et al. (2002)). But our study differs from the existing ones in the industry object of study. De Brito (2004) presents a complete study of sixty study cases in RL and, non of them is based on the editorial sector.

Our study focus on the editorial industry, which is characterized by a high return rate. Editorial companies have, in average, nearly 1 book returned for each 2 books sent to the market. Our objectives are to describe and analyze the RL process and to identify how this process can be improved.

In the next section we describe the main characteristics of the Spanish editorial sector.

2.3 The Spanish Editorial Sector

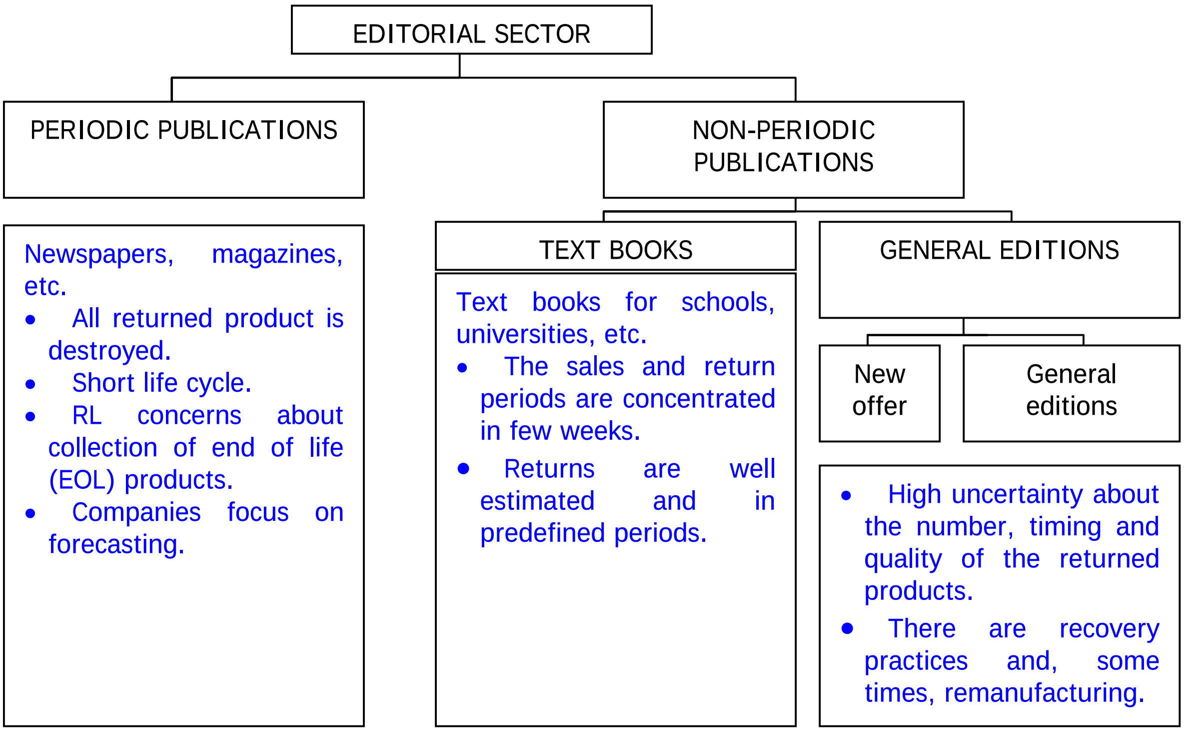
The Spanish editorial industry is the fifth on the world ranking according to the sales figure (2.450 millions of Euros). It represents 0,6% of the Spanish GDP. The business network is composed by 2000 editorial producers, with approximately 13.000 direct employees. 80,5% of the production corresponds to private editorial companies, 12,5% to public companies and the remaining part (7%) is distributed between ONG's and individual editors.

One important characteristic of this sector, is the high rate of product introduction. Every day 175 new titles are introduced in the market. Also, it is important to remark that the number of books and the volume of the average production by title is decreasing every year. This implies that editors have to make a great effort to sell their products.

Book sales are mainly done through bookstores; however, sales through hypermarkets have been increasing during the last years. This is leading to a higher competitive environment, as hypermarkets are pressing editorial companies for reducing prices.

Regarding the distribution system it has to be pointed out that there is not a unique distribution system. Some editors have their own distribution network. Others combine their own network with the network provided by a Third Party Logistics (TPL) company. And, other companies use the postal service to send some urgent deliveries. The trend is to increase the use of TPL to distribute the goods. Some of these TPL companies provide this service exclusively to a specific editorial company, while others work simultaneously for different editors.

The cost per unit in RL is very high due to the high manipulation required and the lack of economies of scale. Companies can not benefit from economies of scale in RL because the batches are usually lower than in the direct logistics. In some cases, they become unitary batches. For example, editors have to assess quality book by book. This, added to the high returns rate existing in the editorial sector, makes the RL costs be considerably higher than the direct logistics costs.



Newspapers, magazines, etc.

- All returned product is destroyed.
- Short life cycle.
- RL concerns about collection of end of life (EOL) products.
- Companies focus on forecasting.

Text books for schools, universities, etc.

- The sales and return periods are concentrated in few weeks.
- Returns are well estimated and in predefined periods.

- High uncertainty about the number, timing and quality of the returned products.
- There are recovery practices and, some times, remanufacturing.

FIGURE 2.EDITORIAL PRODUCTS AND THEIR CHARACTERISTICS

The returns volume is different for each type of publication (periodic and non-periodic publications). Figure 2 shows the different types of publications and their main characteristics.

In periodic publications, the return volume is usually higher than in the non-periodic publications. Companies usually receive all the non-sold products and they have to destroy them. These are usually goods with short life cycle, and they cannot be on sale once the period of commercialization expires. The RL process of this group of publications is only concerned with the collection of the final products once the commercialization period has expired. Due to the short life cycle and the need to have the right number of publications to avoid lost sales and minimize returns, the objective of the editorial companies for this group of publications is to obtain “good” forecasts. In the market, there are many software companies, which offer good forecasting solutions for the periodic publications group.

Within the non-periodic publications we have two different subgroups: textbooks and general editions. Textbooks include all the books sold to schools and universities. They are used in training programs and law specifies their content. These books are sold through the traditional channels (such as bookstores, hypermarkets, etc) and directly to the schools and universities. The seasonality of this type of books is easily identified and is concentrated in few weeks. The returns period is also small and clearly defined. Returns in textbooks are lower than in the general editions. Forecasting for textbooks is easier than in the general editions case, given that the number of students passing from one course to another can be more easily determined.

General editions include the rest of books, which are sold during all the year. In this group there is also some seasonality during special events or dates but, in general, there is a constant flow of goods forward and backward. There is not any knowledge about how much, when, where and how the goods are sold and returned. This makes this group of products the most problematic one. Our work will be mainly focused in the analysis of this group of publications.

For further details about the Spanish editorial sector see FANDE (2003).

2.4. Research Methodology

The research methodology used was based on Malhotra (2004). He defines two different types of research design: conclusive research design and exploratory research design (see figure 3). The objective of the conclusive research design is to test specific hypothesis and examine relationships. In this kind of studies, the information needed is clearly defined, the research process is formal and structured, samples are large and representative and the data analysis is usually quantitative. On the other hand, the objective of the exploratory research design is to discover ideas or to provide insights and understanding about something. A flexible and versatile research process characterizes this kind of studies. The samples are usually small and the analysis is basically qualitative. The methods recommended for this kind of research are: expert surveys, pilot surveys, secondary data and qualitative research, among others.

In order to obtain a deep knowledge of the actual state of the RL process in the editorial sector in Spain, we have conducted an exploratory multiple case study using the methodologies recommended by Malhotra (workgroups, visits and interviews).

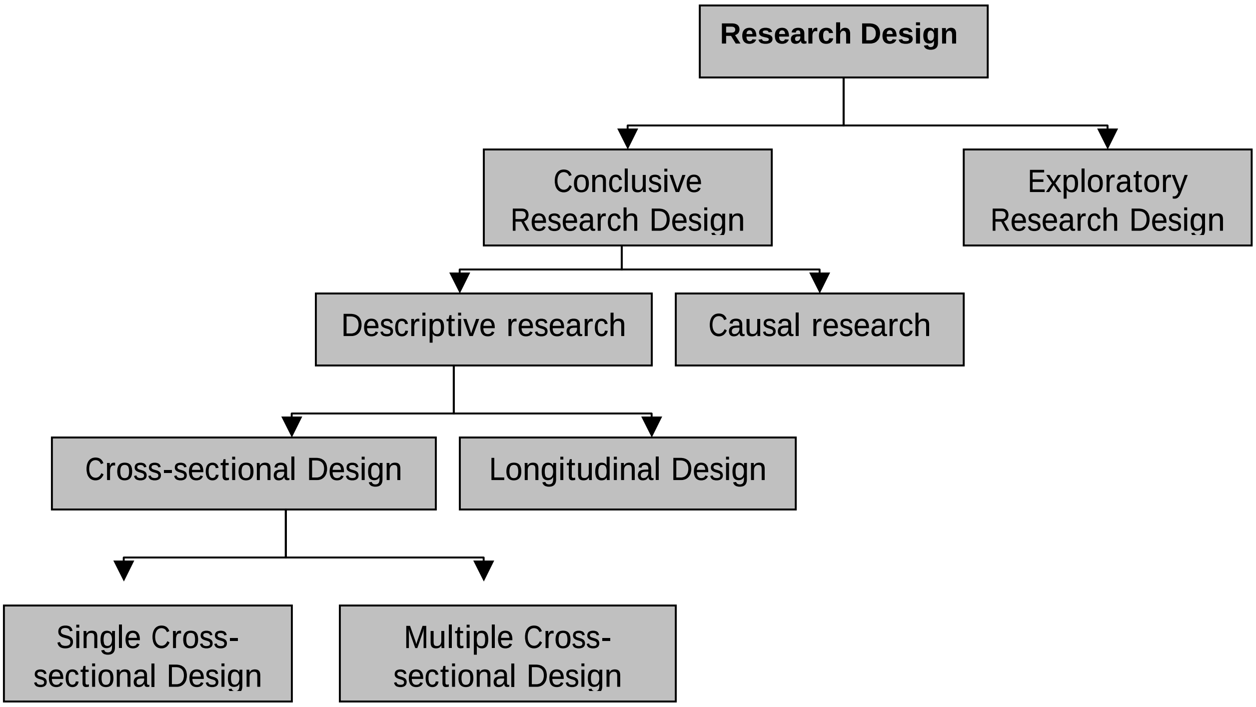


FIGURE 3. A CLASSIFICATION OF RESEARCH DESIGNS. MALHOTRA (2004)

The case study methodology followed was adopted from Yin (2003). Figure 4 summarizes the main steps.

First, the research questions were established:

How is the RL process in the editorial sector?

How are Spanish editorial firms in each one of the three areas of work within the RL process?

How can the RL process be improved?

The next step consisted on defining the units of analysis and selecting the sample. The units of analysis chosen were Spanish editorial companies. Initially, the Logistics Managers of sixteen editorial firms were contacted and invited to participate in a work group on RL conducted by the Centro Español de Logística (CEL) and the Research Group in Business Logistics (GREL) of

Universitat Pompeu Fabra. Eleven companies accepted the invitation. Table 1 summarizes the characteristics of these companies.

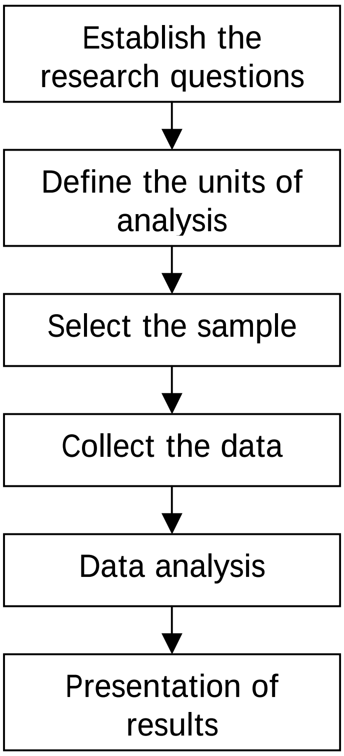


FIGURE 4. CASE STUDY METHODOLOGY. ADAPTED FROM YIN (2003)

As stated in section 2.3, due to the complexity of the returns management of the general editions group our work was focused on this category of products.

To gather the data we decided to use different techniques: surveys, meetings and company visits. Table 5 presents the three research questions related to our objectives, the aspects needed to be analyzed to answer each research question and the technique used to collect the data.

To collect the data, the work group was created in December 2001. In the first meeting, the research project with its three main research questions was presented. We met every 2 or 3 months, depending on the workload of the participants. After each session a summary was written for our case study database. The process we followed was: Firstly, we defined the RL process. Then, we conducted the exploratory survey. With the results of the survey, the group continued working on the discussion of how to improve the Returns Management. The project ended in September 2003.The questionnaire used to conduct the survey can be observed in appendix I.

COMPANY	% RETURNS	SALES IN EUROS
Company 1	21%-25%	55.000.000
Company 2	17%-12%	2.003.980
Company 3	0%-35%	80.500.000
Company 4	15%-30%	162.000.000
Company 5	17%-12%	21.317.133
Company 6	37%-35%	22.847.916
Company 7	0%-35%	901.518.000
Company 8	37%-35%	484.558.000
Company 9	NA	1.905.000.000
Company 10	25%	N/A
Company 11	NA	66.000.000

Table 5. Companies participating in the study

In the next section we present the case study results.

	QUESTION	METHODOLOGY
RQ1. How is the RL process in the editorial sector?		
1.1	Which is the RL process the editorial companies are following?	• Teamwork • Companies' presentations • Visits.
RQ2. How are the Spanish editorial firms in each one of the three areas of work within the RL process?		
2.1	How are they in terms of knowledge about their returns and their causes?	• Survey: **Q1:** In which percentages the following causes of return are present in your company? **Q2:** What are the returns' rates of your company in each one of the following items? • Companies' presentations • Visits.
2.2	Which is the performance of the returns process?	• Survey: **Q6:** What are the principal causes of discussion with your clients in terms of returns' management? **Q8:** Do you know what is the average cost of returning a book to your company? **Q9:** In case of yes, How do you calculate it? i.e. what are the elements included in this calculation?

		Q10: What percentage of the return costs corresponds to…? • Companies' presentations • Visits.
2.3	Are they creating value from the returns?	• Survey: **Q4:** What is the percentage in which you perform each one of the following practices with the returned products in your company? • Companies' presentations • Visits.
RQ3. How can the Returns Management be improved?		
3.1	Can the returns be reduced?	• Discussion • Teamwork
3.2	How can the RL process be improved?	• Survey: **Q3:** what kind of useful information your clients or distributors can provide in order to improve the RL processes? **Q5**: If you should work together with clients and distributors in RL, what do you believe that are the priorities of the work? **Q7:** What kind of information you think is useful to know in returns management? • Discussion • Teamwork
3.3	How can more value be created from returns?	• Discussion • Teamwork

TABLE 6. RESEARCH QUESTIONS AND METHODOLOGY USED

2.5 Results

The results are presented in terms of the Research Questions.

2.5.1 RQ1: How is the RL process in the editorial sector?

The first question is related with the actual RL process in the editorial sector. To better understand how they are performing this process, we used two different methodologies. Firstly, we asked the companies to make a presentation explaining how they were performing this process, and then, we visited the distribution plants of some of the companies in order to extend the knowledge acquired with the presentations.

From the presentations, the visits and some additional documents the companies provided, we evaluated the differences and common issues between the companies regarding the RL process. In this paper, we consider that the RL process starts when the company receives the information about the return of a product, and finalizes when the product is disposed or eliminated.

For simplicity we evaluate the transportation process independently from the rest of the RL process. The following two sections describe these processes.

2.5.1.1 The transportation process:

The process starts when a client decides to return a good. Practices vary not only between companies, but also within the companies. There are two different ways of doing the transportation process:

a. *The Product is retrieved by the editor from the client's stores:* In this case, returns are made when orders are delivered to the client. The normal practice is that the editor gives an authorization that determines the products that can be retrieved. However, some editors follow the policy of receiving everything from the clients without any explicit authorization. The editor is responsible for all the costs. The common practice is to transport the products to an intermediate warehouse, from where, once the books are consolidated, they are returned to the central warehouse.

b. *The product is send by the client to the Editor:* In this case, the client is usually responsible for the transportation costs.

c. *The product is send by the client to the editor with authorization:* In this case the editor pays the transportation costs, but he specifies the transportation company. The products can be sent to a central warehouse or to an intermediate warehouse.

The most common practice is that the editor picks up the books from the client with its transportation resources (own or outsourced) (option a). If the client decides to send back the books without the editor's authorization, then it has to pay for the transportation fees and it assumes the risk of not having the books accepted by the editor (option b). As it can be appreciated in table 3, these two options are the common practice in all the companies analyzed.

When the client has some books to return and the editor can not pickup the books, the editor authorizes the client to send the books through an agreed TPL (option c). As it can be appreciated in table 7, only six of the eleven companies have this practice.

2.5.1.2 The rest of the RL processes

These processes are usually known as the internal processes. They start when the return arrives to the company. The basic activities we identified in the internal return process are:

1. Product reception
2. Refunding
3. Quality assessment
4. Legal certification for destroying the books
5. Other classifications
6. Recovery
7. Disposition practices

We identified some differences between the order in which the different processes are performed in different companies. However, the basic activities are almost the same for all of them. Now, we will describe and analyze some aspects of each one.

COMPANY	TRANSPORTATION PROCESS USED
Company 1	a, b, c
Company 2	a, b
Company 3	a, b
Company 4	a, b, c
Company 5	a, b, c
Company 6	a, b, c
Company 7	a, b
Company 8	a, b
Company 9	a, b, c
Company 10	a, b, c
Company 11	a, b

TABLE 7. TRANSPORTATION PROCESS FOR THE COMPANIES

1. Product reception: In this stage of the process, the product is received. This means that the product is physically located in the editor's warehouse. The client is still the owner of the product. The ownership of the product is only transferred to the editor when the refunding has been done. Products are retained in this stage until they pass to the next stage of the process. The duration of this process can vary, depending on the company, between a couple of hours and 30 days.

2. Refunding: This process consists on transferring the ownership of the product from the client to the editor, and refunding the money to the client. To refund the money, companies follow different strategies. The most extended practice is to reduce this quantity from the next customer's invoice. Other practice is to make a payment order with the same lead time applied to the client in its orders.

Most of the companies perform this process before the quality assessment process, but some do it after. The position of this activity in the total process has several logistical implications. Doing the process later implies that the owner of the products is still the client, and therefore, in the warehouse, its products have to be together. This means that these products cannot be reorganized with other logistical criteria. As a result, the logistics costs increase (due to manipulation problems) and customer service decreases (due to the fact that the accumulated stock levels in the reception area delay the whole RL process).

3. Quality assessment: The quality assessment process is very costly in terms of time and personnel because each book must be evaluated individually. The quality assessment is made following some empirical rules previously established. Is in this process when the disposition practice for each individual book is decided. There are basically three quality states: excellent quality, recoverable and non-recoverable. If the quality is excellent, the products are usually reincorporated to the inventory and sold like the new ones. If in the quality assessment of the product, it is considered "recoverable", then it is sent to the recovery process described below. And finally, if the quality statement is non- recoverable, then the product is either sent to the landfill or returned to the client. The general rule is to do not accept the product if the quality state is non-recoverable, but not all companies follow this rule.

In some companies, there is a previous quality assessment classification, where the editor decides if the product should be accepted or rejected. If it is accepted the product continues to a more detailed quality assessment; if it is rejected, then the book is returned to the client.

4. Legal certification for destroying the books: When books are selected to be destroyed a legal certification must be obtained.

5. Other classifications: In some cases additional classifications are performed. For example, if a third party Logistics Company is performing the RL process for different editors, it has to classify the books by editors. Also, many editors decide to classify the books by title, reference, etc. These additional classifications are made in order to develop economies of scale in manipulation and storage.

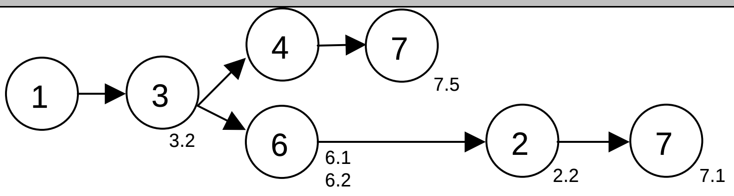
6. Recovery: If the quality assessment for the product is “recoverable”, then the product needs to pass through a recovery process. The objective of this recovery process is to do some activities on the book in order to have it in a like-new state. This recovery process can vary depending on the problem of the book. The most common problem is that books are returned with the price ticket; in this case the recovery process becomes to take out the ticket. Another problem can be that the cover is not clean. In this case the practices are: to clean the cover or to change it. All these processes are manual and, therefore, with a high cost for the organization. One of the eleven companies decided to outsource this recovery process to a third party company in order to reduce costs.

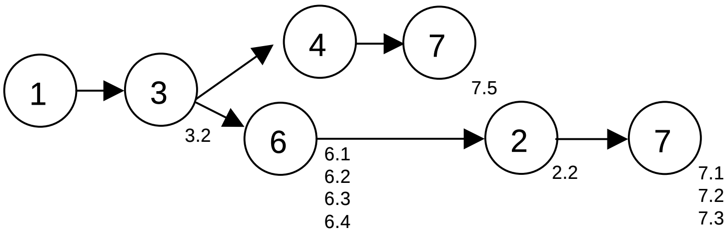
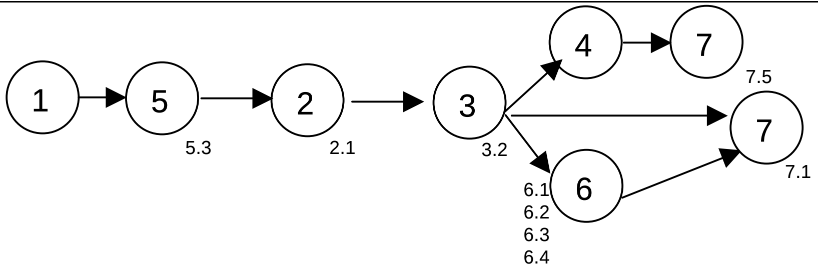
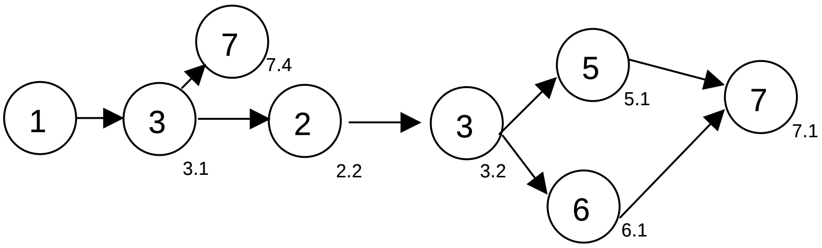
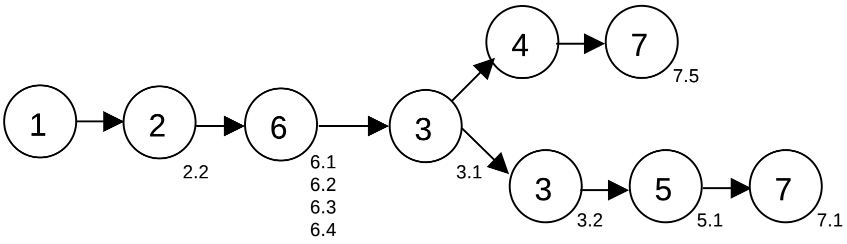
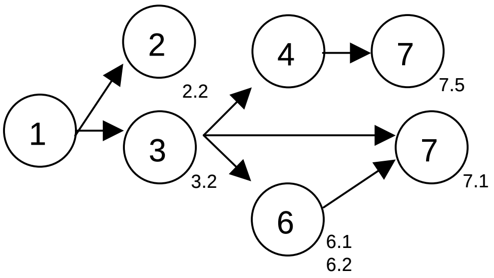
7. Disposition practices: There are different disposition practices within the companies: If the product is “recoverable” or it has perfect quality, then it is reincorporated into the inventory. Most books follow this path. If the product is “not recoverable” the disposition practices are: to sell it through secondary markets, give it for charity, to destroy it or to reject it and return it to the client.

Some books returned pass through a special channel of urgencies. For example, if a book is in stock out and is returned, then this product has priority in all the processes. In this case, the reception, quality assessment and classification of the product and refunding are done quickly in order to reintroduce the book to the inventory as soon as possible.

Table 4 shows the processes followed by each one of the companies analyzed. In order to clarify the RL process followed by each one of the companies, we decided to enumerate the activities performed during the process as follows:

1. Product Reception
2. Refunding
    2.1. Invoicing
    2.2. Discount
3. Quality Assessment
    3.1. Accept - reject inspection
    3.2. Quality level assessment
4. Legal certification for destroying the book
5. Other classifications
    5.1. By references, collections or titles
    5.2. By editors
    5.3. By clients
6. Recovery
    6.1. Take out the ticket
    6.2. Cleaning
    6.3. Change of cover
    6.4. Borders cut
7. Disposition Practices
    7.1. Inventories
    7.2. Secondary markets
    7.3. Charity
    7.4. Returned to the client
    7.5. Elimination

COMPANY	**RL PROCESS**
Company 1	

Company 2	
Company 3	
Company 4	
Company 5	
Company 6	

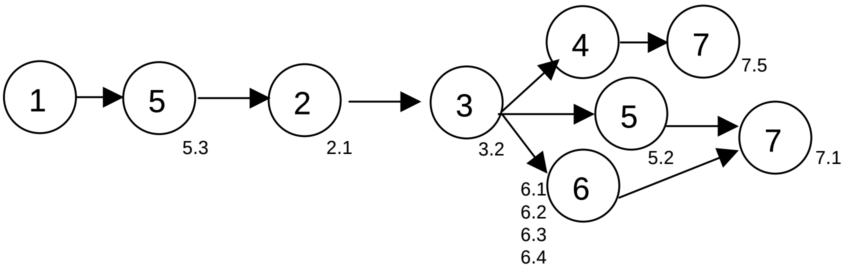
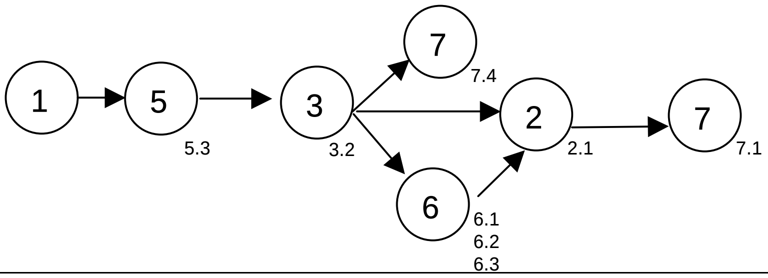
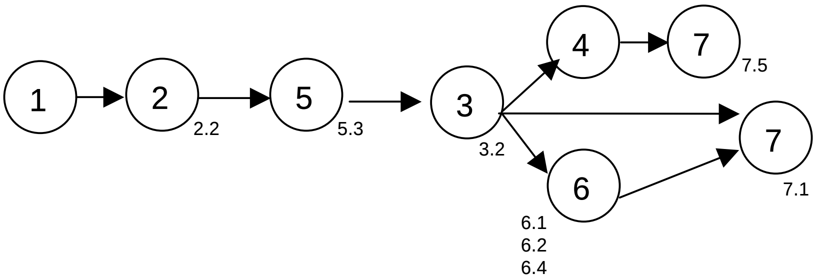
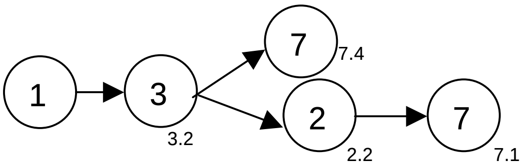
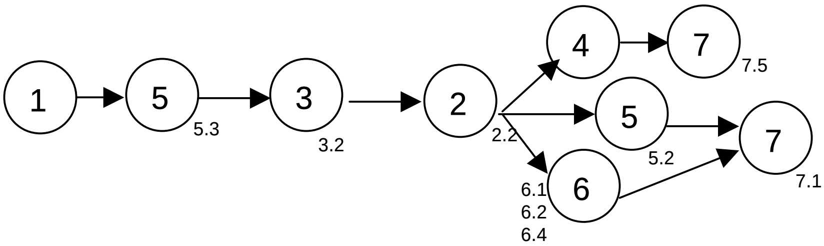
Company 7	
Company 8	
Company 9	
Company 10	
Company 11	

TABLE 8. PROCESS FOLLOWED BY EACH ONE OF THE COMPANIES.

This table shows that five of the eleven companies do the quality assessment before refunding, while six refund the money of the returns despite of the state in which they arrive. As stated before, the order in which the refunding is done has logistical and financial implications. Other issue to remark is that not all the companies follows the same recovery process. All of them usually clean the book and take out the price ticket (if present), but not all of them cut the borders of the books or change the cover. In fact, only five of them change the cover of the books, and they only do this for those books that have a luxury design. Seven editors cut the borders of the books (if needed). Finally, in terms of the disposal activities, it has to be noticed that all the companies usually reincorporate the products to the inventory. There is only one company that sends the books to charity or secondary markets.

2.5.2 RQ2: How are the Spanish editorial firms in each one of the three areas of work within the RL process?

Companies are looking for different strategies and technologies to improve their RL process. Lourenço and Soto (2003) described three main areas of improvement within the RL process. Firstly, companies can reduce the level of returns through the analysis of their causes. Secondly, they can work on the improvement of the return's process and, thirdly, they can create value from the returns. The objective of this research question is to determine how are the Spanish editorial companies in these three areas of work. In order to answer this research question data was gathered using a survey and companies' presentations and visits. In the following sections we analyze each one of these three areas of work.

2.5.2.1 How are the companies in terms of knowledge about the returns and their causes?

One of the areas of work within RL is to reduce the returns through the analysis of their causes. Through the companies' presentations and visits we observed that the main causes of returns were associated with contractual agreements, excess of inventory at the bookstores, order mistakes, end of promotional activities, etc. Also, we could observe that there were different returns rates for different product categories (general editions, text books, etc).

After exploring the main reasons, we conducted the exploratory survey (the questionnaire is in appendix I). Questions 1 and 2 from this questionnaire aimed to respond these questions: which are the main causes of returns and what is the returns rate in different product categories. Tables 5 and 6 summarize the results of this survey.

In Table 9 we can observe that there are three causes that account for 84,8% of the returns. These causes are contractual agreements, inventory excess and finalization of promotional activities.

Which are the main causes of returns?	**Average**
A. Contractual agreements.	42,6%
B. Finalization of Promotional activities. (including samples devolution	20,2%
C. Inventory excess (High amount of inventory in bookstore)	22,0%
D. Obsolete product (life cycle)	7,0%
E. Inventory adjustments (Seasonality effects: close of bookstores on summer)	6,2%
F. Order mistakes	1,6%
G. Product damages	0,4%

TABLE 9. CAUSES OF RETURNS (PERCENTAGE ARE THE AVERAGE)

What are your return percentages in:	**Average**
A. General Editions	25,7%
B. Text books	17,0%
C. Samples	0,3%
D. Others	0,3%
E. Magazines	0,0%

TABLE 10. CLASSIFICATION OF PRODUCTS RETURNED

The impulse sale is very important in the book's market. Companies need to have high levels of inventory at the stores in order to promote sales. Editors establish some legal agreements with retailers in order to introduce as many books as retailers want. In these agreements editors accept to receive all the returned products. Retailers take advantage of these agreements and usually return the unsold products in order to adjust inventory.

The main causes of returns are associated with the commercial policy in the industry. On one hand retailers are not penalized by returns (because in most of the cases the cost of the returns is paid by the editor). And, on the other hand, editors follow a push strategy, pushing inventory to the stores. Editors have high stock levels due to the fact that the economic production batches are very big, and they prefer to have this stock at the stores than in their warehouses.

Table 10 shows an average return percentage of 25,7% in general editions and a 17% in textbooks. The returns percentage in magazines is zero because the companies studied are not working on this area.

2.5.2.2 Which is the performance of the returns process?

The second area of work within RL is the improvement of the RL process itself, in other words, to examine all the activities that have to be done in order to get the product back to the editorial company and look for any potential for improvement. To analyze this area of work, data was gathered from the companies' presentations, visits and the survey. We analyzed the materials, information and monetary flows. From the companies' presentations and the discussions of the work group we detected the following main problems in the RL process:

- Books are send in bad conditions, and therefore, they cannot be recovered and reused.
- There is not information about retailers' and distributors' book sales. Therefore, it is not possible to estimate on time and accurately the success or failure of a book.
- Returned books are not well specified. Clients do not send a detailed information about the books returned. This difficults the return process and leads also to disconformities between editors and clients in terms of the books returned.
- In many cases, there is not a clear information about the causes of the returns.
- Some times, clients send the product back without an authorization and without informing the editor about it. This difficults the forecasting of personnel and resources to manage the returns.

As it can be appreciated, most of the problems pointed out are associated with the information flows: not information about sales, not information about books returned, not information about the causes of the returns and not communication of the return. Only one of the problems stated is related to the material flow: books returned in bad conditions.

Another aspect regarding the performance of the returns process has to do with the main causes of discussion between editors and clients regarding returns. Question 6 of the survey (see appendix I) helped us to identify the main causes of these discussions:

- Return of damaged products (when damage is generated by the client).
- Differences between the quantities informed by the client and the quantities received by the editor.
- Payment of transportation costs of the products returned.
- Return of products and placement of orders for the same books at the same time (some clients do this practice in order to have more lead time for the payment).
- Lack of documentation and return excess (more than the authorized quantity).

The principal cause of discussion is the quality state of the products. There are only three companies that accept all the returned products. The extended policy is to accept only those products in which the client is not responsible for the damage.

Finally, other important issue to consider about the performance of the RL process is the cost of the returns. Questions 8,9 and 10 from the questionnaire (see appendix I) helped us to analyze this aspect. Only seven of the eleven companies calculate the cost of a returned book (Companies 1,3,4,5,6,7 and 11) and they do it in different ways. Company 1 assign a percentage of the overhead costs to each book returned and considers also the direct labor, transportation and general expenditures. Companies 3 and 7 use Activity Based Costing to compute the cost of a book returned. They include the following activities in this calculation: transportation (delivery and recovery), optical reading, classification, relocation and, recovery process. Company 4 adds the annual reverse transportation cost, the personnel costs, the external manipulation cost and the overhead expenditures and then, divides the sum of all these costs by the number of books moved, assigning the same cost to a book returned than to a not-returned book. Finally, companies 6 and 11 did not provide the procedure they used to calculate the cost of the returned book.

Table 11 shows the distribution of costs, between the different activities in the returns process.

As it can be appreciated in table 11, most of the costs are due to the manipulation of the product. The recovery process cost corresponds to the recovery process when it is outsourced; therefore there is also manipulation costs within these costs. Transportation costs are also important, accounting for a 16,5% of the total cost. In general, we can say that the activities conducted to reduce the returns costs should be focused on these three items manipulation, recovery and transportation.

What percentage of the return costs corresponds to:	
A. Transportation costs	16,5%
B. Manipulation costs	41,8%
C. Storage costs	1,8%
D. Recovery process (when it is Outsourced)	27,8%
E. Depreciation and variable equipments and buildings costs	6,3%
F. Other Costs	6,0%

TABLE 11. DISTRIBUTION OF COSTS IN THE RETURNS PROCESS

2.5.2.3 Are companies creating value from the returns?

Rogers (1998) describe some general disposal activities for the returned products. We modified this list in order to adapt it to the editorial sector. These modifications were based on the information collected through the visits and companies' presentations. In the survey, companies were asked about the principal disposal activities they usually perform (see question 4 of the questionnaire). Table 12 shows the main disposal activities and the percentage of books that in average follow these disposal activities.

As we can observe, the products in the editorial sector have basically four types of disposal activities. Most of the products are recovered and returned to inventory, which means that editors probably can recover a high value from the returned products. However, returning products to inventory does not mean to recover the value, because the product must be sold again. If the recovered product is not sold, editors are losing value in the recovery process.

Another disposal activity is to destroy the products. This is mainly done to products that have been classified as “not recoverable”. And finally, other disposal practices are: to sell the products through secondary markets or give them to charity. Given the fact that the highest value from the returned books is to recover them and send them back to inventory, other disposal activities, such as to give them to charity or to sell them through secondary markets, are basically “reserved” to obsolete or not recoverable products.

¿What is the percentage in which you perform each one of the following practices with the returned products in your company?	
A. Product recovery and send back to inventory	88,8%
B. Destroy the product	8,3%
C. Give to charity	1,5%
D. Product recovery and sale to secondary markets	1,3%
E. Storage of the product (without recovery)	0,0%
F. Other activities	0,0%

TABLE 12. PERCENTAGE OF DISPOSAL ACTIVITIES IN THE SECTOR.

2.5.3 RQ3: How can the returns’ management be improved?

One of the main objectives of the work group was to find different possibilities of improvement in the returns management. In the following sections we describe the actions of improvement that can be undertaken in each one of the three areas of work: causes of returns, RL process improvement and value creation from returns.

2.5.3.1 Can the returns be reduced?

To reduce the returns we have to attack their causes. We discussed several alternatives to reduce the volume of returns through controlling the elements that generate them. The main cause of returns is the commercial policy of pushing the books to the stores because of the importance of the impulse sale. The editors participating in the work group recognized the problem but they concluded that they were not able to change this policy: To motivate their clients to buy their books it was very important to have the bookstores' stands plenty of books. However, the work group recognized that there was one possibility to reduce the returns: to have better forecasts. To improve forecasting these companies need appropriate software packages and real time information about sales. This latter aspect requires bookstores to share information about sales, and this means that editors and bookstores have to collaborate and change the actual type of relationship for one of a more partnership style.

2.5.3.2 How can the RL process be improved?

There is a large field of improvement in the operational process of the returns. Some of the ways in which they can work to improve the RL process are: to change some processes, to automate some of them, etc. However, the main area of improvement is in the management of information flows. As stated in section 2.5.2.2, there was not any sharing of information about sales and many of the stores were not informing about returns and neither about the causes of these returns. When asked about the most important information to collect, editors pointed out the following:

Inventory levels in the bookstores.

- Sales forecasting.
- Administrative information about the returns (i.e. number, quality, causes, etc)

Editors consider that the most useful information from the retailers is the point of sale information on real time because it can help them to evaluate if a book is successful or not at the beginning of the sales period. Editors also pointed out that information about returns (such as, number of books returned, causes of returns, quality state, etc) is relevant for the improvement of the RL process. We consider very important to remark that the relationship with suppliers and clients deserve all the editors' attention, given that most of the problems seem to arise from a bad coordination or understanding between the parties.

We asked editors if they should work with clients and distributors and which should be the priorities of their work. They pointed out as priorities of their joint work the following aspects:

- Reduction of returns rate.
- Improvement in the quality state of the products returned.
- Improvement in the returns documentation (clients identification, returns description, etc).
- Improvement in the transportation process.
- Sharing of information in the returns process, (inform about the products that will be returned, make agreements about data exchange).
- Standardization of process, with common procedures of returns for clients and suppliers.
- Improvement in the planning process.

In order to improve the information flow and the quality of the returned products the work group defined common methods for the returns process. The group developed a document called “Best practices for books’ returns” (see document in appendix II). This document was agreed by the editors participating in this study, the Spanish editors association, the bookstores’ association of Madrid, and the National Federation of books’ distributors.

In order to improve the efficiency of the RL process the group is still working on the design of an optimal process of returns. Up to now two things are clear:

- The optimum is to locate the refund before the recovery process of the product. In logistics terms, it is better to do the refund before the quality assessment process, but it implies that the commercial principle of receiving only good quality products (used by some editors) should be revoked.
- The optimum is to recover only those products that have a high probability of being sold again. Editors were spending a lot of money in recovering books, which were not going to be sold.

Regarding the efficiency of the RL process, the group also considered the possibility of creating a Return’s Center, but this solution was finally discarded because of some political and competitive reasons between the editors. However, given that this option has been very successful in some countries, like U.S.A and England[6], there is still a possibility of retaking this issue in the future.

Finally, as stated in section 2.5.2.2 some companies were not calculating the cost of the returns and the ones calculating this cost were using different criteria. The work group decided that in order to improve the returns process it was very important to obtain good measures of the returns costs. Accordingly, we defined a method to calculate these costs. We used a spreadsheet to develop a tool to calculate the real costs of a returned product. Appendix VI shows the bases used to compute the cost. One interesting thing to remark from the cost calculation is that the transportation cost of a returned product is three times the transportation cost of a non-returned book. This is because the product goes and comes back to be sent again to another client. This is better explained with figure 5.

Notice that returned products have been manufactured and distributed like a non-returned product, but in this case there is not money received for the client to compensate all the processes performed. In fact, returned products require additional processes: to take them back to the company, reprocess and reintroduce them into the inventory. Therefore the returned products are clearly more costly and less profitable than the non-returned ones.

2.5.3.3 How to create more value added from the returns?

Creating value from returns is not a priority in this sector. They obtain the highest value they can for most of their products, which is to recover and reintroduce them to the end product inventory.

They can look for some alternatives for the residual part of the products, which are not reintroduced to the inventories (obsolete products, non-perfect quality products, etc.). However, given the low expected profit derived from these activities they are not a priority for them.

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[6] GENCO systems, is a company from USA that provides this service to companies in USA and England. During the development of this work, a meeting was maintained with Mr. John O' Hagan, Managing Director of GENCO in Europe. The financial statements of the company, show the success of this initiative in these countries. For additional information see www.genco.com.

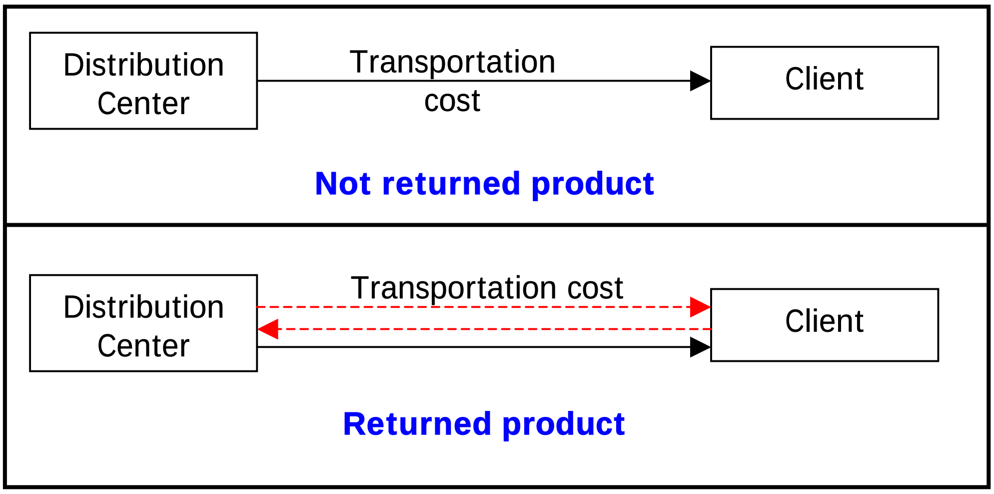

FIGURE 5.TRANSPORTATION COST DIFFERENCES BETWEEN A RETURNED PRODUCT AND A PRODUCT WHICH IS NOT RETURNED.

As it can be observed, in the editorial sector there is a field of improvement in each one of the three areas: Firstly, to reduce the number of returns, the work can be done basically in improving the forecasting and planning methods. The returns volume has to be incorporated in the planning tools to adapt them to the real situation. Secondly, in relation to the RL process improvement, it was concluded that the most important work should be done in the area of information management and costs calculations. And, finally, regarding the third area of work, create value from returns, it has to be stated that some field of improvement exists, but given the high volume of books that are finally reincorporated to the inventory, this area becomes less attractive than the others in terms of profitability.

One issue to remark is that from the teamwork, it was also concluded that something with high priority in the work was to apply those improvement processes to the hypermarkets. And, also, to analyze specifically the return process in this case, given their volume in sales, and also the high quantity of problems arising with them.

2.6 Conclusions And Future Research

In this chapter we explored the actual state of development of the editorial sector in Spain. The authors engaged a process of analysis and some projects and the principal companies in the books' sector, which, up to now, have provided good results for the companies in terms of benchmarking and improvements in the returns process.

One of our objectives was to describe the **state of art** of the RL process in the Spanish book sector. This industry is characterized by a high return rate (nearly 1 of each two books sold is returned) and the high RL costs, the high unitary costs of processing the returned goods and the high return's volume of this sector leads to the high RL costs, being nearly two times the direct logistics costs. The main causes of returns are the contractual agreements, the finalization of promotional activities and the inventory excess, which together generate for the 84,8% of the returns. Other causes, in order of importance, are: obsolete products, inventory adjustments, order mistakes and product damage. This shows that most of the returns are because the contractual agreements and not by inefficiencies in the process. The general edition group has the highest returns rate (25,7%), and has not seasonality. This complicates very much the RL process because increases the uncertainty about when, how and where the books will be returned.

Regarding the performance of the RL process, most of the problems are related with the sharing of information, in fact, retailers' work independently from editors, without sharing sales and forecasting information. This leads to an increase in the inventory levels in the whole supply chain and, in some cases, stock outs, given the high uncertainty about the success or failure of a book.

In most of the cases (88,8%), editors reincorporate the returned products into the inventory obtaining the highest value they can derive from the books returned. Other practices like destroy the products, give them to charity and sale in secondary markets are also performed for some companies but in a lower percentage.

We identified some **potential for improvement**, especially in two areas of work: To reduce the causes of returns and to improve the RL process. To reduce the causes of the returns, it is very important to improve the forecasting and production planning techniques. Introducing the returned books as part of the planning process is a key aspect. In the second area, the most important work should be done in improving the information sharing between the supply chain members and in the standardization of the RL process.

This study has some limitations, first of all some of the companies have not provided all the data requested. This was due to the internal policies of some of them. Another limitation is the reduced sample size. There are 2000 editors in Spain and we have only considered eleven companies. However, it must to be said that given the size of the companies in the study, we covered 50% of the sales of the editorial industry.

But despite of these limitations we believe that this paper will be **insightful** for managers and researchers in the RL area. For managers, we provide some guidelines about how to perform a RL analysis identifying ways of improvement. This should lead to an increase of profitability in the whole business. In this way, managers can see RL as a profit potential area instead of a cost center. This process has been also a benchmarking opportunity for the companies participating in the study and can also be applied to other sectors and companies.

For researchers, the methodology used can also help those who want to develop sector analysis in the RL area. The work also provides some lines of further research: first, it is necessary to develop new models for forecasting and planning. Models where the returns can be considered as part of the planning process. There is also a field of work in developing new cost accounting models based in Activity Based Costing to calculate the real cost of the returns. There is also a wide field of work in developing models that consider the effect of information sharing in planning the returns. And finally, there is also the possibility of investigating the possibility of creating a Central Return's Center and its implications in terms of costs.

2.7 Chapter References

Barros, A.I., Dekker, R. and, Scholtenm, V. (1998). "A two level Network for recycling sand: A case study." European Journal of Operation Research **110**: 199-214.

De Brito, Marisa P. (2004). "Managing Reverse Logistics of Reversing Logistics Management" PhD Thesis. ERI - Erasmus University Rotterdam. 323

FANDE (2003). VIII estudio de perfil del sector de la distribución de libros y publicaciones periódicas, Federación de Asociaciones Nacionales de Distribuidores de Ediciones.

Fraser, P. (1998). "Managing value in Reverse Logistics systems." Logistics and Transports **34**(3): 217-227.

Goodman, A. (2000). "Implementing Sustainability in Service Operations at Scandic Hotels." Interfaces **30**(3): 202-214.

Kokkinaki, A. I., Dekker, R., Van Nunen, J. and Pappis. (1999). "An exploratory study on Electronic commerce for Reverse Logistics." Econometric institute report. Erasmus University of Rotterdam. **EI-9950/A**.

Krikke, H., Van Harten, A., Schuur,P.C. (1999). "Business case Roteb: recovery strategies for monitors." Computer & industrial engineering **36**: 739-757.

Kroon, a. V. (1995). "Returnable containers: an example of Reverse Logistics." International Journal of Physical Distribution & Logistics Management **25**(2): 56-68.

Lourenço, R.H., and Soto, J.P. (2003). Nuevas tendencias en Logística Inversa. Gestión de la cadena de suministro: Visión de futuro.Centro Español de Logística. Barcelona**:** 19.

Malhotra, N. K. (2004). Marketing Research, an applied orientation. International edition, Prentice Hall.

RLEC (1999a). Apparel manufacturers survey. Chicago,IL, RL Executive Council.

RLEC (1999). Consumer electronics manufacturers survey. Chicago, IL, RL Executive Council.

Rogers, D. S. a. T.-L., Ronald S. (1998). Going Backwards: Reverse Logistics Practices and trends. Reno, Nevada, Reverse Logistics Executive Council.

Voss, C. T., Nikos and Frohlich,Mark. (2002). "Case Research in Operations Management." International Journal of Operations & Production Management, **22**(2): 195-219.

Yin, R. K. (2003). Case study research: Design and methods. USA, Sage publications.

Appendix I: RL Survey In The Editorial Sector

1. In which percentage the following causes of return are present in your company? %

A. Contractual agreements. _____
B. Inventory excess (High amount of inventory in bookstore) _____
C. Inventory adjustments (Seasonality effects [Close of bookstores on summer]) _____
D. Obsolete product (life cycle) _____
E. Finalization of Promotional activities. (including samples devolution) _____
F. Product damages _____
G. Order mistakes _____

2. Are there other important causes of returns? If yes, can you mention them? In which percentages?

3. What are the return rates of your company in each one of the following items?:

A. Text books _______
B. General publications _______
C. Magazines _______
D. Samples _______
E. Others _______

4. What kind of useful information can be provided by your clients or distributors in order to improve the RL processes?

5. What is the percentage in which you perform each one of the following practices with the returned products? %

A. Recover the product and send back to inventory _____
B. Recover the product and sale to secondary markets _____
C. Give to charity _____
D. Storage of the product (without recovery) _____
E. Destroy the product _____
F. Other activities (Please describe)

6. If you should work together with clients and distributors in RL, what do you believe are the priorities of your work?

7. What are the main causes of discussion with your clients in terms of return's management?

8. What kind of information do you think is useful to know in returns management?

9. Do you know what is the average cost of returning a book to your company?
Yes ____ No ____

10. In case of yes, how do you calculate it? i.e. What are the elements included in this calculation?.

11. What percentage of the return costs corresponds to: %

A. Transport _____
B. Labour _____
C. Storage _____
D. Manipulation _____
E. Equipments and buildings _____
F. Other costs _____

Appendix II: "Best Practices For Books' Return"[7]

INTRODUCTION

The editorial sector, is highly affected by returns. This document is the result of a conjoint effort from the most representative editors in the Spanish books market. Our goal is to improve all the process regarding the returns activities.

Application of these principles and recommendations will help both editors and retailers. Editors, because it will facilitate the reception process and returns control, and retailers (bookstore owners) because they will benefit from a quicker refund of their money and a reduction of the discrepancies in the quantity and quality of the returned products.

These best practices are based on three critical processes: *returns planning, technical conditions of returns and returns management.* Some key elements are remarked for each one of them.

1. Returns planning

COMUNICATION BETWEEN CLIENT AND SUPPLIER:

Following bookstore requirements, it is recommendable to improve the quality and the fluency of the communication system between clients and suppliers, in order to obtain a better coordination in general and promotional activities.

LOGISTIC CARD:

For each client it will be created a logistic card (see Appendix IV) to write down the established agreements in terms of frequency and returns schedules.

2. Technical conditions for returns

PRODUCT:

Books must be returned in the same conditions in which they have been sent to the bookstores.

PACKAGING:

---

[7] The appendix have only the contents of the document. The format in which it was published is different.

Product must be correctly packaged. Follow all the necessary steps to guarantee that the product won't be damaged during transportation. Take into account the following aspects:

- Adequate packaging dimensions.
- Package the books in horizontal position to avoid transportation damages.
- Use an external card to identify returns. Specify the number of packages and the sender.
- Please check if the box has been correctly closed.
- Complete with paper or other adequate material the spaces between books.
- All boxes should not have more than 15 kgs.

RETURNS PROBLEMS:

If there are bad quality products (if the editor is responsible for the damages), please write down it in the returns card. (see appendix III)

3. Returns management

DELIVERY:

The delivery of a new product, is not conditioned by the reception of the products that the client wants to return.

PRODUCT:

When a product is returned, please identify it by its bar code and the ISBN number. If the product does not have bar codes and neither ISBN, please identify it by the name of the product.

RETURNS CARD:

When returns cards are prepared, please verify that all necessary data are present. Keep a copy of the return card, and leave the original within the return box. To guarantee refunding, check that all information is right.

RECEPTION CONFORMITY:

If return is not accepted, it will be communicated to the client.

Appendix III: Returns Card *

DATE ________________________ SHEET ___OF ____________

EDITOR'S NAME ________________________ AUTHORIZATION: ______

CLIENTS' DATA			
CODE: ____________	NAME: ______________________________________ _______		
ADDRESS: ____	POSTAL CODE:____________		
CITY:	PHONE:		

RETURNED PRODUCT'S REGISTRY

No.	*CODE*	**NAME**	**UNITS**	**OBSERVATIONS**(1)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				

TOTAL PACKAGES: _________

____

Client's signature

(1) Quality state of returned product. (Ok - damaged)

* This is a sample of the data needed in the returns process.

Appendix IV: Logistics' Card

COMPANY DATA

CLIENT	EDITOR
NAME :	NAME:
Address:	Address:
Phone:	Phone:
Fax:	Fax:
e-mail:	

LOGISTICS' CENTERS

CLIENT	EDITOR
Number:	Number:
Delivery address:	Delivery address:
Picking up address:	Picking up address:
Contact person:	Contact person:
Phone:	Phone:
Fax:	Fax:

RETURNS INFORMATION

OTHER INFORMATION

LOCAL HOLIDAYS:

VEHICLES RESTRICTIONS:

Appendix V : Instructions For Hypermarkets

If it is necessary to use a price ticket, please use easy-removable and easy-cleaning materials.

Locate the price ticket in the back book cover. Do not write the price in the interior pages with pencil or any other mechanism.

Price ticket should be well located. i.e. without covering principal parts of the books (Title, bar code, logos, etc), since they are the identification elements of each book.

Appendix VI: Items Included In The Calculation Of The Costs For The Books Returned

Number of books sold
Number of returned books

% Books destroyed
% Books recovered
% Books in storage without recovery

Transportation costs:

- Total forward transportation costs
- Total costs of backward transportation
- Transportation costs between logistics centers because of returns
- - Income of pallets by returns

Reception of returned books

- Reception and initial preparation of returned products
- Optical reading and quality classification
    - Personnel
    - Maintenance and equipment depreciation
- Other additional classifications
    - Personnel
    - Maintenance and equipment depreciation
- Refund process and authorization
    - Personnel
    - Maintenance and equipment depreciation

Recovery, reintroduction to the inventory, elimination

- Books cleaning (Taking out the price tickets, etc)
    - Personnel
    - Equipment depreciation
    - Other additional costs
- Reintroduction to the inventory
    - Personnel
    - Equipment depreciation
    - Other additional costs
- Other Recovery costs
    - Personnel
    - Equipment depreciation
    - Other additional costs
- - Income by elimination

Other costs

- Charge by overhead expenditures
- Administrative personnel salaries (% of returns)
- Overhead expenditures (services)
- Other expenditures

Returns area:

- Rent costs per warehouse/year
- Depreciation costs of warehouse/year
    - Buildings
    - Equipments
    - Shelves
    - Others
- Maintenance costs per warehouse/year
    - Personnel
    - Equipments
    - Others
- Warehouse space (m^2)
- Returns area within warehouse (m^2)

CHAPTER 3: A Collaborative Production Planning Model With Returns ($\mathrm{CPP_R}$)

3.1 Introduction

At the end of the chapter one, we concluded that one line of future research is study models apply to production planning with remanufacturing, and dealing with multiple products and components. We also consider models dealing with the use of mix strategies, in terms of the utilization of new and reused components in the remanufacturing process.

In chapter two, we also observed that one of the main shortages in RL is the lack of well developed planning systems that account for the remanufactured products when returns are incorporated. In particular, one of the main problems in the editorial sector is the lack of adequate forecasting and planning systems.

In this chapter we present a production planning model with remanufacturing in a multi-product and multi-period collaborative environment. This model is the answer to those gaps found in the literature, and also should be helpful for companies like the editorials, as we observed in section 2.5.1, to improve their planning process in a remanufacturing production environment.

Why a collaborative model?

Since the 1980's firms are becoming conscious about the importance of Supply Chain Management (SCM), companies realized they could derive benefits from its implementation. SCM is defined as "the integration of key business processes from end user through original suppliers that provides products, services, and information that add value for customers and other stakeholders" (Lambert, Cooper & Pagh, 1998). SCM involves integration, coordination and collaboration across organizations and throughout the supply chain. In the literature, we can find many authors who acknowledge that SCM can improve performance Gimenez & Ventura, 2002),

The Collaborative approach makes sense, since companies today are suffering from a logistics function, which is each day more complex, dynamic and uncertain. Competition is in most markets stronger than ever before, product life cycles have shortened, and business conditions change constantly. Those factors have forced companies to reshape their strategies. Numerous new topics like Global Manufacturing, Third Part Logistics, Partnerships, e-Logistics, Supply Chain Management and Reverse Logistics are becoming important issues for all the companies even for small or medium sized businesses.

Traditionally, it has been considered that suppliers compete against suppliers, factories against factories, distributors against distributors, and retailers against retailers, but today this way of thinking is changing; companies have realized that the competition in the market is not between companies but between supply chains. The final product includes all the inefficiencies and over costs generated by each one of the companies that compose a supply chain. If the supplier is not efficient, the inefficiency costs are translated to the manufacturer, if again the manufacturer is not efficient, these costs are translated to the distributor, and finally the product will not be competitive in the market, without caring if the distributor or the retailer is extremely efficient. Therefore, the competitiveness of the product must be the result of an excellent management task in all the companies composing the supply chain, not only in some of them. This generates also new challenges for the management area in general, the logistics in particular and create new lines of research.

Manufacturing companies have applied optimization techniques to production planning with some degree of success, but only in lasts years, companies have been aware of the importance of sharing their plans with the other companies within their supply chain. Moreover, companies are now trying to collaborate in the production planning process, in order to benefit from the different synergies they can derive from this collaboration. Some of the benefits that companies can obtain are inventory reduction, cycle time compression, improvements in the service level, etc. Therefore, there exists the need for production planning models that take into account this collaboration within a supply chain. Our model develops a global manufacturing plan that generates the production and purchasing schedule for all the companies integrating the logistic chain.

Why Remanufacturing?

Another important issue for manufacturing companies is the sustainability. This is primarily important in Europe where laws are becoming more demanding, since, companies are now responsible for the contamination derived from their own products. The general rule is that every company will pay for the contamination their products generate. In this sense, manufacturing companies will be responsible for recycle, destroy or reuse their end-of-life products. The objective of this legislation is to make companies more conscious about the environment and their responsibility with its preservation. Remanufacturing emerge as a great possibility for companies to deal in this new environment of business.

Our goal in this chapter is to study the incidence of collaborative production planning and remanufacturing into the tactical production planning. We consider a production planning model for the global supply chain and the effect over the production planning process by using recycled or reused parts and assemblies during the production of new goods. We consider different situations that are modeled in a general model called **Collaborative Production Planning Model with Returns ($\mathbf{CPP_R}$)**. Also, in the next chapter we derive some special cases of this collaborative model to be able to analyze the impact of the different assumptions in the solution methods proposed to solve the collaborative production planning problem. In chapter 5, we use some examples with different configurations of supply chains varying the number of production plants, distribution centers and recovery plants to analyze the variations and implications of the returns in the models.

The chapter is divided into five sections. Second section states a brief literature review, then third section explain the Collaborative Production Planning model with Returns (CPP_R), for a multi-plant production environment. In fourth section we provide an example of the CPP_R model, solved through a mix strategy combining optimization and simulation techniques. Finally, in section fifth some conclusions and future research are stated.

3.2 Literature Review

We classify the literature review of this chapter in the two main areas of production planning covered by the model proposed: Supply Chain Collaboration and Remanufacturing.

Supply Chain Collaboration has been widely investigated in the literature. Many authors remark the advantages of the collaborative work in the Supply Chain, see for instance Holweg et al.(2005) and Guide Jr et al.(2000).

In terms of production planning, some authors propose models for operational collaborative planning. Kempenaers et al.(1996) worked in the development of an integrated automatic process planning and scheduling system based on the concept of non-linear process plans. Vercellis (1999), proposes a multi-plant production planning model with several items and depots to transport the products. The model considers two stages of production at each plant. However, raw materials and purchasing costs are not considered, and also remanufacturing is not allowed within the model.

Berning et al.(2004), consider a complex scheduling problem in the chemical process industry involving batch production. The application described, comprises a network of production plants with interdependent production schedules, multi-stage production at multi-purpose facilities, and chain production. The model is for operational purposes and does not considers remanufacturing.

In general, we observed that the existent models consider only the process performed from the factory to the distributors, neither of them consider the suppliers nor the integration of returns. Therefore, we have extend the previous work on the area by considering the returns and an external supply chain.

In the area of aggregated production planning most of the research is concerned with traditional manufacturing. However, some authors propose models for remanufacturing environments. Guide Jr et al.(1999) show the main research done in the area of production planning and inventory control. He concludes that not all areas of production planning and control have been researched adequately, and also they concluded that formal work is needed linking production planning and control with product return information.

Jain and Udaka (2005), propose a configuration-based formulation for one manufacturing environment where production may involve dissimilar machines performing similar operations at different rates and equipment can be connected together to form different production lines.

Mazzola et al.(1998), propose a model for multi-product aggregated production planning, but without remanufacturing and without the collaborative scheme.

Guide Jr.(2000a) performed a literature review about the different topics covered in remanufacturing. He describes the most important research done in this area. He states seven complicated characteristics in the remanufacturing environment and how different authors have deal with these characteristics. The seven characteristics are: (1) the uncertain timing and quantity of returns, (2) the need to balance returns with demands, (3) the disassembly of returned products, (4) the uncertainty in materials recovered from returned items, (5) the requirement for a Reverse Logistics network, (6) the complication of material matching restrictions, and (7) the problems of stochastic routings for materials for remanufacturing operations and highly variable processing times. They observed that none of the research performed leads with the solution of more than 4 of these complicating characteristics. They also conclude that exists a need for academics to develop new systems and evaluate the applicability of present systems and that remanufacturing represents a much larger industrial segment than previously thought, and is deserving of full attention by academics from all areas.

The model proposed in this work considers more elements in the collaborative planning process than the existing ones. it incorporates purchasing, transportation and holding costs, and also it considers a multi-plant and, multi-product environment. In addition, we extend the formulation of our model introducing the possibility of planning remanufacturing at the aggregated level.

Next section describes the collaborative production planning model with returns.

3.3 The Collaborative Production Planning Model with Returns (CPP_R)

The development of models considering the whole supply chain, instead of only each individual element, can help companies to improve their global performance.

There are basically three different levels of planning in the production environment: the strategic (long term planning) to which belong the business planning; the tactical (medium term planning) which works at an aggregate level of products, examples of this are the Master Production Schedule and the

Approximated Capacity Planning, and finally, the Operative Planning (short term planning) with the MRP, job-shop scheduling, etc.

In this chapter, we present a model that allows companies to make tactical planning for a global supply chain. This tactical planning involves several **periods** *(t=1...T)*, which can be viewed as weeks, biweeks, months or quarters depending on the industry. The planner problem is to decide some elements for the optimal functioning of the global Supply Chain as, how much to produce of each article to meet the consumers demand, and how much materials to buy at each period, per plant. Our collaborative model allows also to plan remanufacturing, taking into account the estimated number of recycled or reused parts and assemblies available to be used in the production process. To understand better the model we describe first the Supply Chain configuration and functioning and afterwards the hypothesis and assumptions of the system.

3.3.1 Supply Chain configuration and functioning:

Figure 6 shows the general configuration of the supply chain we have considered in the collaborative model. The supply chain is composed by several production plants, a central recovery plant, a distribution center and several suppliers. Four processes are performed within this supply chain, namely:

A. Transportation of **materials** *(p=1..P)* from suppliers and Central Recovery Plant (CRP) to all the **factories** *(j=1..J).*

B. Manufacturing process within the factories

C. Transportation of **final products** *(i=1..I)* from factories to Distribution Center.

D. Products return and recovery in the Central Recovery Plant.

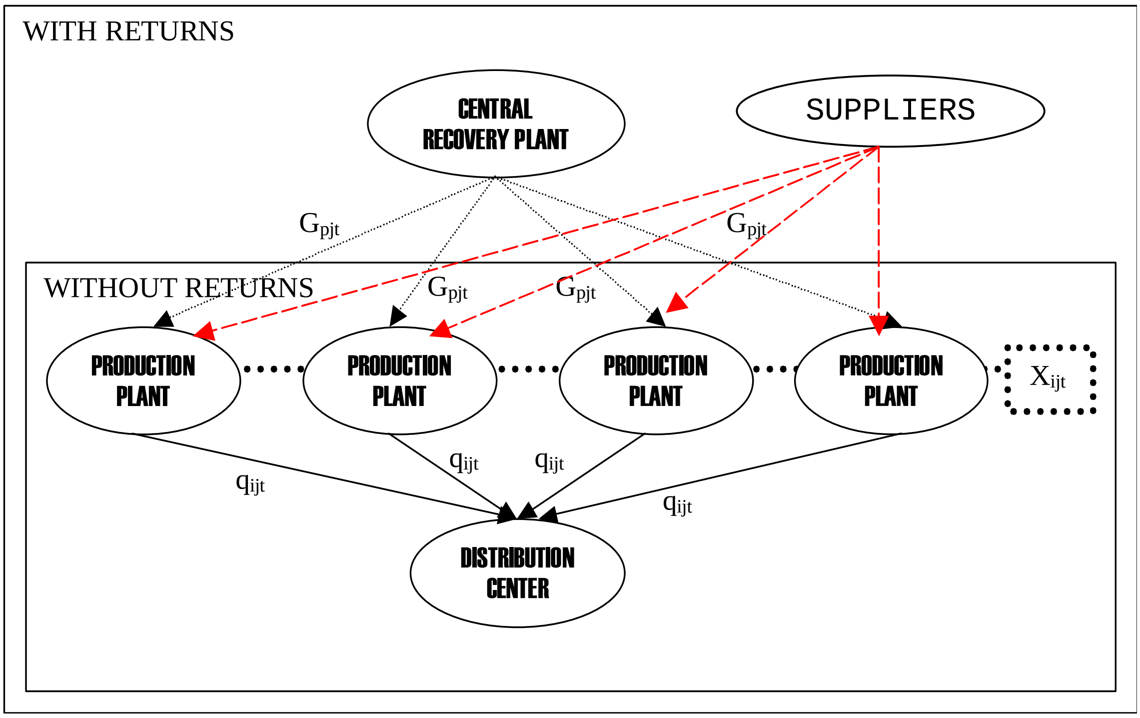

FIGURE 6. SUPPLY CHAIN CONFIGURATION

This is the traditional Supply Chain configuration with a new element, the Central recovery plant (CRP). This CRP receives the returned products, and performs the disassembly and quality assessment processes.

Given that the CRP is a new element, we consider useful to explain in detail in this section what is its role within the Supply Chain. Next we will describe how the operations are performed in the CRP, and we also introduce the Modified Bill of Materials which is a new tool proposed for our model. Finally, at the end of this section, we describe the main assumptions made for the supply chain functioning.

3.3.1.1 The Central Recovery Plant

The Central Recovery Plant is an external center created with the objective of receive the returned products, classify them and perform the adequate operations to either assure the proper disposal of the product or material or, reincorporate the total product or some of its components to the manufacturing process of new products. Figure 7 shows the general structure of the process performed within the CRP.

When a returned product is received at CRP, the company have several options, depending on the reason of the product's return. This process is very well described in Rogers and Tibben-Lembke (1998) and Krikke (1998). One of the options, is to disassemble the product and verify if its components can be used to manufacture new products.

When a product is disassembled, we obtain materials and assemblies. The assemblies are components composed by various parts, that should be disassembled or not depending of their quality. Some authors have studied the disassembly problem within a CRP. Krikke (1998) for instance, has made a very good approach to this problem, obtaining optimal disassembly strategies based on the quality of the products and parts, and the economical viability of the different alternatives. He has obtained the optimal disposal strategies for each product and, in those products where the best alternative is to disassembly, he has determined the optimal level of disassembly for the product. Those alternatives are very different since the quality of the product is unknown and the economical viability of the disassembly process is not the same for all parts and products.

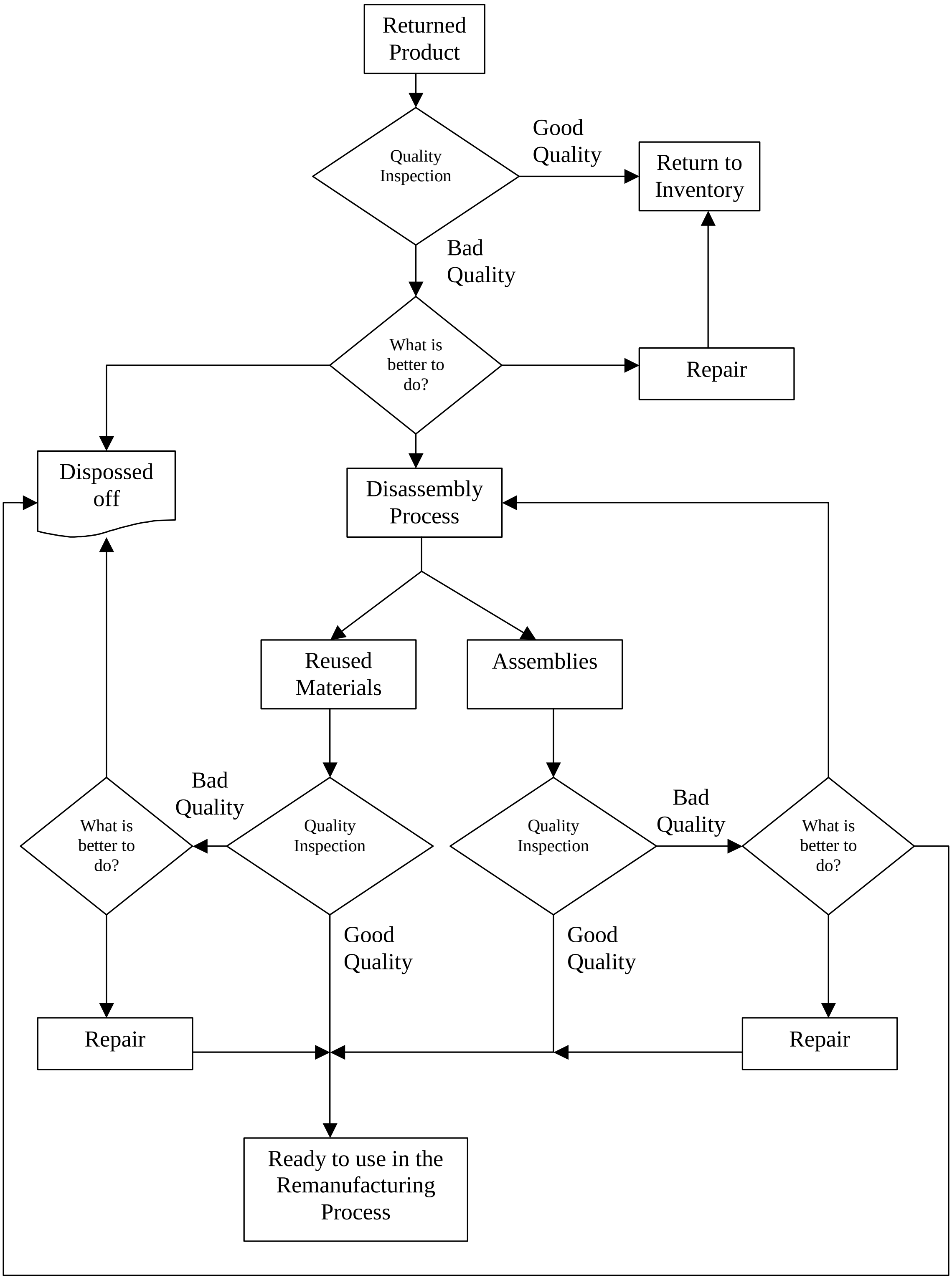

FIGURE 7. THE CRP PROCESS

Figure 8 illustrates the concepts of disassembly levels and disassembly tree. Each product can be divided initially into some parts and assemblies, this is the first level of disassembly. When we disassembly one of those assemblies, then we go to the second level. If in the second level we have an assembly to be disassembled, then we go to the third level and so on. For each product we can make a disassembly tree, illustrating the parts and assemblies we can obtain from each product at each level.

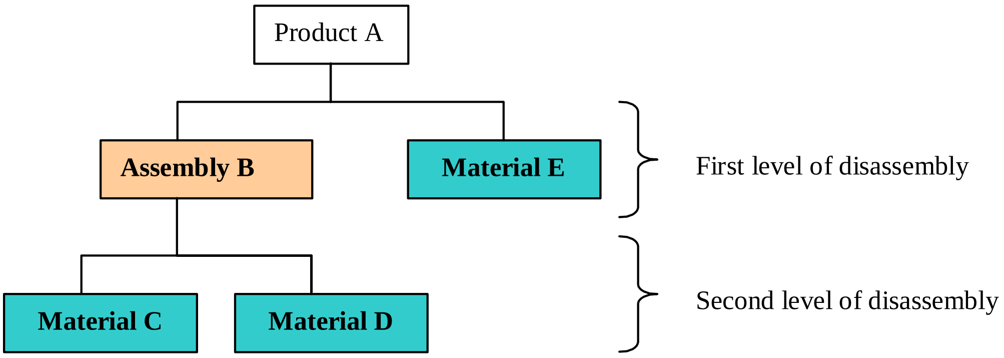

Figure 8: Disassembly tree for product A

Lets exemplify those concepts with an example: Suppose we receive a CPU returned from an old computer. We decide to disassembly the CPU since the expected profit derived from the reuse of materials and components is positive for the company. Then in a first step, we take out the external cover of the CPU, and we find several components and parts: a 3½ disk unit, a CD-Rom unit, the main board, the sound card, etc. If the main board for instance works well, we should decide to use it, without any additional process, in manufacturing a new computer; otherwise, we should again disassembly this main board and obtain other components or assemblies to use in a new product (for instance the RAM memory). In this case the main board is an assembly. Notice that under this assumptions, a new computer should be manufactured in different ways. If we decide to use only new materials, the manufacturing process is the traditional one, but when we introduce the assemblies, we skip several production steps (i.e. we do not need to manufacture the main board, so we avoid all the processes performed to manufacture this main board). Therefore, in an extreme, each new computer should be manufactured by a different production process.

To consider an element as an assembly, one of the conditions is that it cannot be purchased to the suppliers. They only provide components, materials and parts. In this last consideration leads one of the main differences with traditional production planning. The manufacturer does not know in advance the quantity of products to produce with the assemblies, since it is limited by the quantity and quality of products returned, and if the forecast fail, then those assemblies cannot be purchased outside, forcing companies to change the production process and delaying all the production plan.

The preparation of the returned products in the CRP includes all the necessary processes to adequate the materials and assemblies to the manufacturing of new products. However, the introduction of assemblies and reused materials to the production process complicates the formulation and size of the problem. In summary, we should say that the main problems that should be considered in order to adequate the production planning models are:

A. The uncertainty in the quantity and quality of the products returned affects directly the quantity of materials to purchase and the production time.

B. Each product face different production costs and processes (in an extreme case each unit can follow a different production process).

C. One article can be manufactured with new, reusable parts, or both.

D. It is necessary to consider in-process inventories, since we are introducing the assemblies. Therefore, they can be included directly to the in-process inventory and increase its quantity.

To solve these problems, different alternatives were studied. Finally we decided to use the Modified Bill of Materials.

3.3.1.2 The Modified Bill of Materials (MBOM)

As we state in the previous section, with the introduction of the assemblies the production process change. Therefore, factory has different ways to manufacture the same product, in addition, each one of these production processes, should have a different manufacturing time and cost. Under these considerations, the manufacturing planning process change a lot, since now we have, in addition to the uncertainty in the period demand, the uncertainty in both, the materials we will have “ready to use" and, the manufacturing process.

To deal with this situation, we propose the introduction of a Modified Bill of Materials (MBOM), where the components and reusable materials are included as the new materials, but with different codes and, there exists different production processes to manufacture each product. Table 13 shows an example of the Modified Bill of Materials.

		Product 1			**Product 2**	**Product 3**	
Materials		**1a**	**1b**	**1c**	**2**	**3a**	**3b**
New materials	1	1	0	0	2	1	0
	…	2	1	0	5	0	0
	63	0	0	1	0	1	0
Reusable materials	64	0	0	0	0	0	0
	65	0	2	0	0	0	1
	66	0	0	0	0	0	0
	67	0	1	0	0	0	0
	…	0	0	0	0	0	0
	97	…	…	…	…	…	…
Assemblies	98	0	0	1	0	0	0
	99	0	0	0	0	0	1
	100	0	0	2	0	0	1
Materials Cost		15000	13000	12500	25000	14000	12500
Production Cost		7000	6700	5500	18000	9500	10000

Table 13. Modified Bill of Materials

In the MBOM, it is important to notice that assemblies, reused parts and new parts are only differentiated by a code number. In the example of table 13, new parts receive the numbers from 1 to 63, reused from 64 to 97 and assemblies from 98 to 100. Also, each product can be manufactured by one or various production processes. In the MBOM the different production processes are denoted by the a, b or c index. Then, an article can be manufactured by process 1a, 1b or 1c. The cost of used materials and assemblies, is computed from the costs the CRP faces to have them “ready to use". These costs include, the disassembly cost, the quality inspection cost, etc. Notice also that each production process has associated material and production’s costs.

In the example, product 1 has 3 different ways to be produced:

Process 1a, which is the traditional production process, where only new materials are used.

Process 1b, where the company uses both new and reused materials and,

Process 1c, where product uses some assemblies and new materials to be manufactured.

Notice that each production process has a different cost depending on the materials and process used to manufacture it.

For the extend of this thesis we consider the following notation:

t: Index for the planning periods

a: Index for the production processes

i: Index for the articles.

j: Index for the factories.

p: Index for the materials or assemblies.

m: Index for the machinery.

3.3.1.3 The Supply Chain Structure

The supply chain works as follows:

- The CRP receives the returned products at each period. Products are revised, classified and organized by the corresponding disposal and remanufacturing strategy. Products of good quality for remanufacturing are disassembled and processed until they become materials and assemblies ready to be shipped to the manufacturing plants. The CRP has inventories of reused materials and assemblies.

- The Factories manufacture the products based on the sales and returns' forecasts. They purchase the materials to the suppliers and also send the final products to the Distribution Center. This purchasing process is not centralized; however, if there exists a purchasing center for all the factories, the model works assigning the same transportation and purchasing cost to all the factories. Factories hold inventories of raw materials, work in-process and final products.

- Suppliers receive the purchasing orders from factories and serve those orders in the same period of time (Just in time supply).

- The Distribution Center, receives the sales orders and serve the clients from its inventories at each product. We assume that the not covered demand, will be covered in the next period, but there are stock-out costs, derived from the opportunity cost of the sales lost today and in the future and from the lose of image of the company for this situation. DC holds only final product inventories.

We have capacity constraints in inventories and production. Other assumptions of the model are:

A. The CRP needs one period to perform the recovery process. Therefore, parts and assemblies obtained from recovered products arriving in period t will be only available at period $t+1$

B. We allow for stock-out in the DC, therefore if demand for a product cannot be satisfied in a period, it should be served in the next period. However, we use a penalty cost for the stock out state, trying to estimate the lost of image for the company, and the opportunity costs generated by the stock out situation.

C. To manufacture the products, factories can use the materials' inventories from the previous period and materials purchased at the same period.

D. For each factory there are capacity constraints in time of production, storage capacity, and a security stock.

E. The transportation cost from suppliers to the different factories is included in the cost of the new materials.

F. Each plant can manufacture all or a subset of the products.

G. Production, purchasing and transportations costs should vary from one plant to another.

H. For each product the Modified Bill of Materials is known.

I. There is a forecasted product demand for all the periods, (d_{it}). This demand is previously known from the sales forecast.

J. Given the demand, the planner decides (i.e. the variables of the problem):

   a. The quantity to be produced of each article in each factory per period, and also what will be the production process $(a=1..A)$ used to manufacture it, (X_{aijt}).
   b. The quantity of each material to purchase in a period, (P_{pt}).
   c. The quantity of each reused material or assemblies to be send each period from the CRP to each plant, (O_{jpt}).
   d. The quantity of each material to hold in inventory at each plant and period, (M_{jpt}).
   e. The quantity of each final product to hold in inventory at each plant and period, (I_{ijt}).
   f. The quantity of each final product to hold in inventory at each period in the DC, (Y_{it}).
   g. The quantity of products to send from each factory to the Distribution Center at each period (q_{ijt}).

K. To make the above decisions the planner knows the following data:

   a. Production costs per article, depending on the production process, the factory and the period, (C_{aijt}).
   b. Transportation costs:
      i. From the CRP to the factories (G_{pjt}).
      ii. From factories to Distribution Center (T_{ijt}).
   c. Holding costs per period:
      i. For raw materials (at each factory), (L_{jpt}).
      ii. For final products (at factories and distribution center) (H_{ijt}, W_{it}) respectively.
      iii. Reused materials at the CRP (HO_{pt}).
   d. Disassembly costs (DC_{ipt}).
   e. The Materials costs (R_{jpt}).
   f. The Stock out costs per article at each period (S_{it}).

g. The estimated number of parts and assemblies available “ready to use” at each period from the CRP. We estimate the number of reused materials and assemblies for each period, taking into account historical data.

h. The capacity constraints per period:

   i. In hours per production per machine $(m=1..M)$ at each factory, (U_{imt}).

   ii. In storage capacity at the factories. for each material (MAX_{jpt}) and final product (B_{ijt}).

i. The security stock at each period for:

   i. Product at each factory (SS_{ijt}).

   ii. Material at each factory (V_{jpt}).

j. Initial inventories:

   i. Of materials. (IN_{p0}).

   ii. Of final products at each factory (I_{ij0}).

k. The Modified Bill of Materials (MBOM) (K_{aip}).

l. The number of parts and assemblies that should be obtained from the disassembly process of a product. (CF_{ip}).

m. The technical probability to obtain a part or assembly of good quality $([QU_{ip}=1])$ from the disassembly process of a product $(PROB[QU_{ip}=1])$.

The model is proposed for medium and long term planning. It is useful to make decisions about the production configuration in terms of production processes used to met the demand, the scheduling of the labor force and also to set the production and purchasing plan. The plan must be revised for operational purposes, adjusting the variables to the specific situation arising daily.

Next section describes the mathematical formulation of the CPP_R model.

3.3.2 Mathematical Formulation of the CPP$_R$ model

The objective of the model is to minimize the production, inventory and transportation costs for the whole supply chain. Before to show in detail the mathematical formulation of the model, we want to clarify some elements introduced in the model:

3.3.2.1 Estimation of Returned products, materials and assemblies.

The number of assemblies and parts available “ready to use" are estimated as follows: from historical data of the company‘s returns, we found a probability distribution, for each assembly or part obtained from a returned product, about the possibility of having a good quality assembly or part from the disassembly process of this specific product. So, we are assuming that the probability of having a good quality part of assembly from the disassembly of a product i is known.

Each company needs to decide how many historical periods will use to calculate the technical probabilities. For the purpose of our work we assume the company uses the data from the last 12 months. However, depending on the life cycle of the product, the quantity of periods considered can vary.

The return of products per period is a random variable, defined in the following way:

F_{it} = number of products i to be returned on period t.

We assume that the distribution function of F_{it} is Poisson distributed, since F_{it} is a random variable which takes discrete values from 0 to n with non-zero probability of parameter $\lambda>0$.

On the other hand, from the disassembly tree, we know the number of materials or assemblies that can be obtained from one unit of each product during the disassembly process. This quantity is defined as CF_{ip}, which means the number of materials or assemblies p that should be obtained from disassembly of the product i.

From probability theory we know that λ should be estimated from observed values of the variable. In our case we estimate λ from historical data of products returned by the recovery center. Notice that we are interested in calculate the number of materials returned. Therefore, at each period we should multiply F_{it} times CF_{ip} and from random variables theory we can say that the resulting random variable will be also Poisson distributed. Finally, let $E[F_{it}]$ the expected number of product i to be returned on period t, we can say that $E[F_{it}*CF_{ip}]$ is equal to λ_{ipt}. Some authors assumes a similar approach to this problem, however they use a normal distribution, and they assume the mean and standard deviation are known for the products, see Kelle (1989) and Toktay (1997).

We classify each material or assembly p obtained from returned product i of good quality or bad quality for remanufacturing. Other classifications are possible, like repairable or recoverable. They can be easily included in the model if they are necessary for specific industries where the value of the materials is too high and it compensates to repair them.

We define QU_{ip} as the quality state of material p obtained from the disassembly process of article i. This variable QU_{ip} have the values 0 or 1 where $QU_{ip}=0$ means bad quality, and $QU_{ip}=1$ good quality for remanufacturing.

QU_{ip} is a random variable that follows a Binomial distribution with parameters n and $\underline{p}$ (notice we underlined $\underline{p}$ to differentiate it from notation of materials p). n is the number of experiments performed, and $\underline{p}$ the probability of success at each experiment. In our case, n corresponds to the number of returned materials at each period (i.e. $E[F_{it}*CF_{ip}]=\lambda_{ipt}$) , and $\underline{p}$ is a technical probability of having $QU_{ip}=1$.

This technical probability, can be estimated in the following way:

$$PROB[QU_{ip}=1]=\frac{\text{number of materials } p \text{ with good quality for remanufacturing}}{\text{total number of materials } p \text{ received}} \quad \forall i=1..I;\ \forall p=1..P$$

This probability is calculated for the last T most recent periods. This number T of periods is established for each company. In practical applications we recommend to actualize this probability at each planning period. This actualization helps to maintain the consistency of the probability, since in a certain moment, the products returned to the factory will be those products manufactured with reused components and therefore, the technical probabilities of obtaining a good quality material vary.

In summary we have that $E[F_{it}^{*} CF_{ip}] = n_{pt} = \lambda_{ipt}$ and, $PROB[QU_{ip}=1] = \underline{p}_{ipt}$.

Therefore, the average quantity of good quality material obtained from all products returned at each period is calculated by

$$\sum_{i=1}^{I} \lambda_{ipt} \underline{p}_{ipt} \qquad \forall t = 1..T$$

To calculate the disassembly cost, we multiply this average number of materials returned by the disassembly cost set by each material depending of the product of which it is coming from DC_{ipt}. This cost for all materials, products and periods is:

$$\sum_{t=1}^{T} \sum_{i=1}^{I} \sum_{p=1}^{P} \lambda_{ipt} \underline{p}_{ipt} DC_{ipt}$$

3.3.2.2 The introduction of the MBOM

The MBOM is expressed by the parameter K_{aip}, that is interpreted as the quantity of material p needed to manufacture the product i under process a. This allows us to have the different materials requirements for each process. Table 14 shows an example of how this parameter is set for a product (A1). Let's assume that new materials are N1 and N2, and that N3 is an assembly. In this table we can observe that if product A1 is manufactured through process 1, then it will need 2 units of material N1, 1 unit of material N2 and 0 unit of assembly N3. On the other hand, to manufacture the same product A1 through process 2, it is necessary to have 1 unit of material N1, 0 units of material N2 and 1 unit of assembly N3.

K			
a	**i**	**p**	**Value**
1	A1	N1	2
1	A1	N2	1
1	A1	N3	0
2	A1	N1	1
2	A1	N2	0
2	A1	N3	1

TABLE 14. THE PARAMETER K_{AIP}

Using this formulation for the MBOM, we introduce the mathematical formulation for the CPP_R model as is showed below.

3.3.2.3 Reused materials and assemblies' Inventories

In the CPP_R model we need to separate the inventories of new materials and reusable materials and parts. To do it, we divided the set of materials $p=1,...,P$ in two groups, the first group from material 1 to material n which contains only the new materials, and the second group from $n+1$ to P which has the reusable materials and the assemblies. It is important to remark that in the model we do not considered directly the materials costs for the reusable materials, because we are calculating it by the sum of quality, disassembly and transportation costs.

In the next sections we present the details of the mathematical formulation.

3.3.2.4 The Objective Function

In this section describe the formulation of the CPP_R model. First of all the Objective function is composed by the following costs:

a. Production costs (C_{aijt}): they are differentiated by production process (a), article (i), plant (j) and period of time (t), and they are multiplied by the number of units produced (X_{aijt}):

$$\sum_{a=1}^{A}\sum_{j=1}^{J}\sum_{i=1}^{I}\sum_{t=1}^{T} C_{aijt} X_{aijt}$$

b. Holding costs of raw materials in the CRP and Factories (HO_{pt} and L_{jpt} respectively) per each period t, material p, and factory j. They are multiplied by the respective units to hold in inventory at each period.

$$\sum_{j=1}^{J}\sum_{p=1}^{P}\sum_{t=1}^{T} L_{jpt} M_{jpt} + \sum_{p=1}^{P}\sum_{t=1}^{T} HO_{pt} IN_{pt}$$

c. Holding costs of final products in factories and the DC. (H_{ijt} ,W_{it} respectively) per product i, period t and factory j.

$$\sum_{j=1}^{J}\sum_{i=1}^{I}\sum_{t=1}^{T} H_{ij} I_{ijt} + \sum_{i=1}^{I}\sum_{t=1}^{T} W_{it} Y_{it}^{+}$$

d. The transportation cost of material p from central recovery plant to each one of the production plants j at period t (G_{jpt}). This cost is multiplied by

$$\sum_{j=1}^{J}\sum_{p=1}^{P}\sum_{t=1}^{T} G_{jpt} O_{jpt}$$

the quantity of materials p shipped from central recovery plant to each one of the factories j at period t (O_{jpt}).

e. The transportation cost of product i from each one of the production plants j at period t (T_{ijt}) to the DC. This cost is multiplied by the quantity of products i shipped from each one of the factories j at period t to the DC (q_{ijt}).

$$\sum_{j=1}^{J}\sum_{i=1}^{I}\sum_{t=1}^{T} T_{ijt}\, q_{ijt}$$

f. The cost of the materials p purchased at each plant j and period t to the suppliers (R_{jpt}), multiplied by the number of units of material p purchased at plant j at period t (P_{jpt}).

$$\sum_{j=1}^{J}\sum_{p=1}^{P}\sum_{t=1}^{T} R_{jpt}\, P_{jpt}$$

g. The disassembly cost, computed multiplying the average quantity of material p obtained from all products returned at period t times the disassembly cost of obtaining material p from product i in period t (DC_{ipt}).

$$\sum_{t=1}^{T}\sum_{i=1}^{I}\sum_{p=1}^{P} \lambda_{ipt}\, \underline{p}_{ipt}\, DC_{ipt}$$

h. Finally the stock out costs in the DC. The unitary costs are established by article i and period t (S_{it}) and then, they are multiplied by the number of units of article i in stock-out at period t.

$$\sum_{i=1}^{I}\sum_{t=1}^{T} S_{it}\, Y_{it}^{-}$$

3.3.2.5 The model constraints

Next, we introduce the model constraints:

1. Calculation of Inventory for reusable materials and assemblies: These set of constraints allow us to compute the inventory of materials at each period. The inventory of material p in period t (IN_{pt}) is equal to the inventory of this material p at the end of the previous period $t\text{-}1$ $(IN_{p(t-1)})$, plus the estimated returned materials quantity during the present period t, minus the quantity of materials p shipped to the plant j at period t (O_{jpt}).

The estimated returned materials quantity is calculated as explained before for all the reusable materials $(p=n+1,\ldots,P)$ and for all the periods.

$$IN_{pt} = IN_{p(t-1)} + \sum_{i=1}^{I} \lambda_{ipt} \underline{p}_{ipt} - \sum_{j=1}^{J} O_{jpt} \qquad p = n+1,\ldots,P; t = 1,\ldots,T;$$

2. Control of shipments: We assume that parts recovered in a period are shipped to the manufacturing plants in the next period. These constraints force the quantity of materials p returned to all the factories j in period t (O_{jpt}) to be less than or equal to the inventory of materials p at the CRP in the previous period $t-1$ $(IN_{p(t-1)})$.

$$\sum_{j=1}^{J} O_{jpt} \le IN_{p(t-1)} \qquad p = n+1,\ldots,P; \quad t = 1,\ldots,T;$$

3. Inventory capacity for reusable materials and assemblies: The inventory of material p at period t in the Central Recovery Plant (IN_{pt}) is limited by a maximum stock quantity (MRM_p) (holding capacity), and it must be greater than or equal to 0. This is calculated for all the reusable materials and for all the periods.

$$IN_{pt} \le MRM_p \qquad p=n+1,\ldots,P; t=1,\ldots,T;$$

4. Inventory equation for purchased materials: Purchased materials are those that manufacturing plants can acquire from external suppliers. These constraints allow us to compute the inventory level of each material, period and, factory. The inventory of material p at plant j at the end of period t (M_{jpt}), is equal to the inventory of this material p at this plant j at the end of the previous period $t-1$ $(M_{jp(t-1)})$, plus the purchased quantity of this material p at this plant j during the present period t (P_{jpt}), minus the sum of the number of units to produce by all production processes a of product i at plant j at period t (X_{aijt}), times the number of materials p needed to produce one unit of product i by process a (K_{aip}) plus the quantity returned of material p to plant j at period t (O_{jpt}). Notice that the set of materials p is composed only by those that are susceptible to be purchased (from 1 to n).

$$M_{jpt} = M_{jp(t-1)} + P_{jpt} - \left[\sum_{i=1}^{I} \sum_{a=1}^{A} (K_{aip} * X_{aijt}) \right] + O_{jpt} \qquad j = 1,\ldots,J; t = 1,\ldots,T; p = 1,\ldots,n;$$

5. Inventory equation for assemblies: Assemblies cannot be purchased to external suppliers. Therefore the equation is similar to the previous one, but without the purchasing variable (P_{jpt}). Notice that the set of materials p is composed only by those that are not susceptible to be purchased (from $n+1$ to P).

$$M_{jpt} = M_{jp(t-1)} - \left[\sum_{i=1}^{I} \sum_{a=1}^{A} (K_{aip} * X_{aijt}) \right] + O_{jpt} \qquad j = 1,\ldots,J; t = 1,\ldots,T; p = n+1,\ldots,P;$$

6. Inventory capacity for materials: There is a maximum storage capacity for each raw material p at each factory j (A_{jp}). Also the minimum number of units of material p at each factory j, is limited by a security stock (V_{jp}).

$$V_{jp} \leq M_{jpt} \leq A_{jp} \qquad j=1,\ldots,J; \quad t=1,\ldots,T; \quad p=1,\ldots,P;$$

7. Control of materials: These constraints ensure that production will not exceed the number of products we can produce with the available materials. To do it, we multiply the sum of the number of units to produce by all production processes a of product i at plant j at period t (X_{aijt}), times the number of materials p needed to produce one unit of product i by process a (K_{aip}). We force this quantity of materials resulting from the previous multiplication to be less than or equal to the inventory of materials p at plant j at the previous period $t-1$ $(M_{jp(t-1)})$ plus the quantity of material p purchased at plant j at period t (P_{jpt}).

$$\sum_{a=1}^{A} \sum_{i=1}^{I} K_{aip} X_{aip} \leq M_{jp(t-1)} + P_{jpt} \qquad j = 1,\ldots, J; t = 1,\ldots,T; p = 1,\ldots, P;$$

8. Inventory equation for products: These constraints compute the quantity of products hold in inventory at each plant and period. The inventory of product i at plant j at the end of period t (I_{ijt}), is equal to the inventory of this product i in this plant j at the end of the previous period $t-1$ $(I_{ij(t-1)})$, plus the production quantity of this product i in this plant j by all the production processes a during

$$I_{ijt} = I_{ij(t-1)} + \sum_{a=1}^{A} X_{aijt} - q_{ijt} \qquad i = 1,\ldots, I; j = 1,\ldots, J; t = 1,\ldots,T;$$

the present period t (X_{aijt}), minus the quantity of product i shipped from this plant j to the central warehouse at period t (q_{ijt}).

9. Shipment control: These constraints control the quantity of products sent to the DC from the factories. This quantity is limited by the availability of final products in the factories' inventories. Formally the constraints state that the quantity of product i shipped from the factories j to the distribution center at period t (q_{ijt}), must be less than or equal to the inventory of product i at plant j at the end of the previous period $(t-1)$,($I_{ij(t-1)}$) plus the quantity produced at each plant j in this period t by all the production processes a (X_{aijt}).

$$\sum_{a=1}^{A} X_{aijt} + I_{ij(t-1)} \ge q_{ijt} \qquad i=1,\dots,I;\ j=1,\dots,J;\ t=1,\dots,T;$$

10. Inventory capacity for products: There is also a security stock and a maximum holding capacity for the products at each plant and period.

$$SS_{ij} \le I_{ijt} \le B_{ij} \qquad i=1,\dots,I;\ j=1,\dots,J;\ t=1,\dots,T;$$

11. Stock-out or Inventory units on central warehouse: Stock out or inventory units are allowed at the DC. Notice that variable Y_{it} could be positive or negative (Inventory or stock out). Therefore, we have divided it into two variables, Y_{it}^{+} and Y_{it}^{-} in such way that, if there are units of stock out, then $Y_{it}^{+}=0$ and $Y_{it}^{-}>0$ and, if there are units of stock, then $Y_{it}^{+} \ge 0$ and $Y_{it}^{-}=0$. This division allows us to assign different costs to each one of the cases and have only variables taking values greater than or equal to 0.

$$Y_{i(t-1)} + \sum_{j=1}^{J} q_{ijt} - d_{it} = Y_{it} \qquad i=1,\dots,I;\quad t=1,\dots,T;$$

Replacing in the formula above, we have:

$$Y^{+}_{i(t-1)} - Y^{-}_{i(t-1)} + \sum_{j=1}^{J} q_{ijt} - d_{it} = Y^{+}_{it} - Y^{-}_{it} \qquad i=1,\dots,I;t=1,\dots,T;$$

12. Production capacity: This constraint limits the production capacity expressed in hours of production available in each plant and machine. There is a parameter PT_{aim} which represent the hours of production needed in machine

m to manufacture one unit of product i by process a, multiplied by the number of units produced of product i by process a at period t (X_{aijt}). For each period t and each factory j, the sum of these multiplications for all the products i and all the production processes a, must be less than or equal to the total production time available in machine m and each factory j per period time t (U_{jmt}).

$$\sum_{a=1}^{A}\sum_{i=1}^{I} PT_{aim}X_{aijt} \le U_{jmt} \qquad j=1,\ldots,J;m=1,\ldots,M;t=1,\ldots,T;$$

Other production capacity constraints can be easily incorporated if necessary.

13. Integer and non-negativity constraints.

All variables are integer and greater than zero.

In summary the new model is the following:

$$\min \underbrace{\sum_{a=1}^{A}\sum_{j=1}^{J}\sum_{i=1}^{I}\sum_{t=1}^{T} C_{aijt}X_{aijt}}_{\text{Production Costs}} + \underbrace{\sum_{j=1}^{J}\sum_{i=1}^{I}\sum_{t=1}^{T} H_{ij}I_{ijt}}_{\text{Holding Costs of final products at factories}} + \underbrace{\sum_{i=1}^{I}\sum_{t=1}^{T} S_{it}Y_{it}^{-}}_{\text{Stock-out Costs at Distribution Center}} + \underbrace{\sum_{j=1}^{J}\sum_{p=1}^{P}\sum_{t=1}^{T} R_{jpt}P_{jpt}}_{\text{Purchasing Costs}} +$$

$$\underbrace{\sum_{j=1}^{J}\sum_{p=1}^{P}\sum_{t=1}^{T} L_{jpt}M_{jpt}}_{\text{Holding Costs of raw materials at factories}} + \underbrace{\sum_{j=1}^{J}\sum_{i=1}^{I}\sum_{t=1}^{T} T_{ijt}q_{ijt}}_{\text{Transportation Costs from factories to D.C.}} + \underbrace{\sum_{i=1}^{I}\sum_{t=1}^{T} W_{it}Y_{it}^{+}}_{\text{Holding Costs of final products at DC}} + \underbrace{\sum_{j=1}^{J}\sum_{p=1}^{P}\sum_{t=1}^{T} G_{jpt}O_{jpt}}_{\text{Transportation costs of reused materials from CRP to the factories}} +$$

$$\underbrace{\sum_{p=1}^{P}\sum_{t=1}^{T} HO_{pt}IN_{pt}}_{\text{Holding Costs for reused materials at CRP}} + \underbrace{\sum_{t=1}^{T}\sum_{i=1}^{I}\sum_{p=1}^{P} \lambda_{ipt}\underline{p}_{ipt}DC_{ipt}}_{\text{Disassembly costs based on the expected number of products disassembled at CRP.}}$$

Subject to:

1. $$IN_{pt} = IN_{p(t-1)} + \sum_{i=1}^{I}\lambda_{ipt}\underline{p}_{ipt} - \sum_{j=1}^{J} O_{jpt} \qquad p=n+1,\ldots,P;t=1,\ldots,T;$$

2. $$\sum_{j=1}^{J} O_{jpt} \le IN_{p(t-1)}; \qquad p=n+1,\ldots,P;t=1,\ldots,T;$$

3. $$IN_{pt} \le \mathrm{MRM}_{\mathrm{p}} \qquad p=n+1,\ldots,P;t=1,\ldots,T;$$

4. $M_{jpt} = \mathrm{M}_{\mathrm{jp(t\text{-}1)}} + \mathrm{P}_{\mathrm{jpt}} - \left[\sum_{i=1}^{I}\sum_{a=1}^{A}(K_{aip} * X_{aijt})\right]$ $\qquad j = 1,\ldots, J;\ p = 1,\ldots, n; t = 1,\ldots, T;$

5. $M_{jpt} = \mathrm{M}_{\mathrm{jp(t\text{-}1)}} + \mathrm{P}_{\mathrm{jpt}} - \left[\sum_{i=1}^{I}\sum_{a=1}^{A}(K_{aip} * X_{aijt})\right] + \mathrm{O}_{\mathrm{jpt}}$ $\qquad j = 1,\ldots, J;\ p = n+1,\ldots, P; t = 1,\ldots, T;$

6. $V_{\mathrm{jp}} \le \mathrm{M}_{\mathrm{jpt}} \le MAX_{\mathrm{jp}}$ $\qquad j = 1,\ldots, J;\ p = 1,\ldots, P; t = 1,\ldots, T;$

7. $\sum_{a=1}^{\mathrm{A}}\sum_{i=1}^{I} k_{aip} X_{aijt} \le \mathrm{M}_{\mathrm{jp(t\text{-}1)}} + \mathrm{P}_{\mathrm{jpt}} + \mathrm{O}_{\mathrm{jpt}}$ $\qquad j = 1,\ldots, J;\ p = 1,\ldots, P; t = 1,\ldots, T;$

8. $I_{ijt} = I_{\mathrm{ij(t\text{-}1)}} + \sum_{a=1}^{A} X_{aijt} - q_{\mathrm{ijt}}$ $\qquad j = 1,\ldots, J;\ i = 1,\ldots, I; t = 1,\ldots, T;$

9. $\sum_{a=1}^{A} X_{aijt} + I_{ij(t-1)} \ge q_{\mathrm{ijt}}$ $\qquad j = 1,\ldots, J;\ i = 1,\ldots, I; t = 1,\ldots, T;$

10. $SS_{\mathrm{ijt}} \le I_{\mathrm{ijt}} \le B_{\mathrm{ijt}}$ $\qquad j = 1,\ldots, J;\ i = 1,\ldots, I; t = 1,\ldots, T;$

11. $Y^{+}_{i(t-1)} - Y^{-}_{i(t-1)} + \sum_{\mathrm{j=1}}^{\mathrm{J}} \mathrm{q}_{\mathrm{ijt}} - \mathrm{d}_{\mathrm{it}} = Y^{+}_{it} - Y^{-}_{it}$ $\qquad i = 1,\ldots, I; t = 1,\ldots, T;$

12. $\sum_{\mathrm{a=1}}^{\mathrm{A}}\sum_{\mathrm{i=1}}^{\mathrm{I}} PT_{aim} X_{aijt} \le U_{jmt}$ $\qquad j = 1,\ldots, J;\ m = 1,\ldots, M; t = 1,\ldots, T;$

13. $X_{aijt} \ge 0$ *and* integer;
14. $P_{jpt} \ge 0$ *and* integer;
15. $q_{ijt} \ge 0$ *and* integer;
16. $I_{ijt} \ge 0$ *and* integer;
17. $Y^{+}_{it} \ge 0$ *and* integer;
18. $Y^{-}_{it} \ge 0$ *and* integer;
19. $M_{jpt} \ge 0$ *and* integer;
20. $O_{jpt} \ge 0$ *and* integer;
21. $IN_{pt} \ge 0$ *and* integer;

Parameters:

A= Number of production process that has the product with the maximum number of production processes.

I= Number of articles.

J= Number of plants.

M= Number of machines.

T= Number of periods of time to planning.

C_{aijt}= Production cost of one unit of article i at plant j by process a on period t.

H_{ij}= Holding cost per unit of article i at plant j.

S_{it}= Stock out cost per unit of article i at period t.

R_{jpt}= Cost of purchase one unit of material p at plant j at period t.

L_{jpt}= Holding cost per unit of material p at plant j at period t.

SS_{ij}= Security stock of product i at plant j.

B_{ij}= Maximum allowed stock of product i at plant j.

K_{aip}= Quantity of material p needed to manufacture one unit of product i by process a.

W_{jp}= Maximum allowed stock of material p at plant j.

V_{jp}= Security stock of material p at plant j.

T_{ijt}= Transportation cost per unit of product i shipped from plant j to central facility on period t.

G_{pjt}= Transportation cost per unit of material p shipped from central recovery plant to plant j on period t.

d_{it}= Demand of product i at period t.

W_{it}= Holding cost of product i at period t on central warehouse.

V_{ai}= Production time of one unit of product i by process a.

U_{jt}= Hours of production capacity in plant j at period t.

HO_{pt}= Holding cost of material p at period t on central recovery plant.

p_{ip}= Probability of material p resulting from the disassembly process of product i is of quality QU_{ip} for remanufacturing.

λ_{ipt}= Number of parts p obtained from returned products i at period t

DC_{ipt}= Disassembly cost for material or assembly p from product i at period t.

Variables:

X_{aijt}= Number of units of product i to produce in plant j by process a on period t.

P_{jpt}= Number of units of material p to purchase in plant j at the beginning of period t.

q_{ijt}= Quantity of product i shipped to central facility from plant j on period t.

I_{ijt}= Inventory units of product i in plant j at the end of period t.

M_{jpt}= Inventory units of material p in plant j at the end of period t.

Y_{it}^{-}= Number of units of stock out of article i at period t at central warehouse.

Y_{it}^{+}= Inventory units of product i at period t at central warehouse.

O_{jpt}= Quantity of material p shipped from central recovery plant to plant j on period t.

IN_{pt}= Inventory units of material p at period t on central recovery plant.

MRP_{p}= Holding capacity of reusable material or assembly p at Central Recovery Plant.

Random Variables

λ_{ipt}= Number of units of material p obtained from article i returned to central recovery plant at period t.

$$QU_{ip}= \begin{cases} 1 & \text{if material } p \text{ obtained from product } i\text{, is of good quality for remanufacturing process.} \\ 0 & \text{if material } p \text{ obtained from product } i\text{, is not of good quality for remanufacturing process} \end{cases}$$

The CPP_R model serves to do a collaborative production planning in a company or set of companies within a supply chain configured with a certain degree of complexity considering also remanufacturing processes.

Next section explores a solution proposed for the CPP_R model, but as we shall see, this is suitable only for small networks, as the problem increases in size, the computational time is not operative.

In the next chapter, we will describe 3 models that are special cases of the CPP_R model. The objectives of describing these special cases are twofold. For one side, there exists some factories with special configuration in their supply chains, where for instance the companies do not have returns and just want to do a collaborative production planning, or perhaps when there is only one factory in the supply chain. On the other hand, we want to evaluate what are the factors that have high incidence in the computational time when the CPP_R model is solved. As we shall see, when the size of the CPP_R problem increases in size, the computational time also increases, and therefore optimization became not useful to solve the model. So, we want to investigate which are the constraints or elements that have a higher impact in the running time. In chapter 5 we will describe a heuristic proposed to solve the CPP_R model in a reasonable running time, useful for business purposes.

3.4 An Example of Solution Strategies for the CPP_R model

In chapter 5 we will address other methodologies to solve the CPP_R model. However, we want to show in this section some preliminary results we got with two small networks with the following configuration:

	Example 1	**Example 2**
Number of Factories:	3	2
Number of Articles:	5	3
Number of Materials:	10	15
Number of Periods:	12	12
Number of Production Processes:	5	3

TABLE 15. CONFIGURATION OF THE NETWORKS

The CPP_R model is a stochastic integer programming model, but since this is used for tactical and strategic planning, we decided to estimate the random variables λ_{ipt} and p_{ip} before to solve the model. In this sense, those variables became parameters and the model becomes an integer linear programming model. To solve the model, our first choice was to solve it using the Lingo software version 6. In addition, to reduce the computational time, we have used a model where only the variable X_{aijt} was integer, but relaxing the remaining integer variables to be real. This model has resulting in a integer optimal solution, therefore it is the optimal solution for the original integer model. With this relaxed model, the computational time was reduced to 3 seconds in average (for the examples we ran).

3.4.1 The simulation-optimization process

The results of the examples gave us very good results. However, given the uncertainty in the variables involved in this model, we considered that it was possible to improve the solution found in the optimization model in a simulated scenario. Cheung (2001), uses a similar approach in an iterative way, improving the results of optimization with the simulation process.

We create a simulation process in order to combine it with the optimization process, and then we evaluate the results obtained. Under this scheme we can measure the performance of the plan provided by the optimization process under different scenarios of returns, with low, medium and high level of returns.

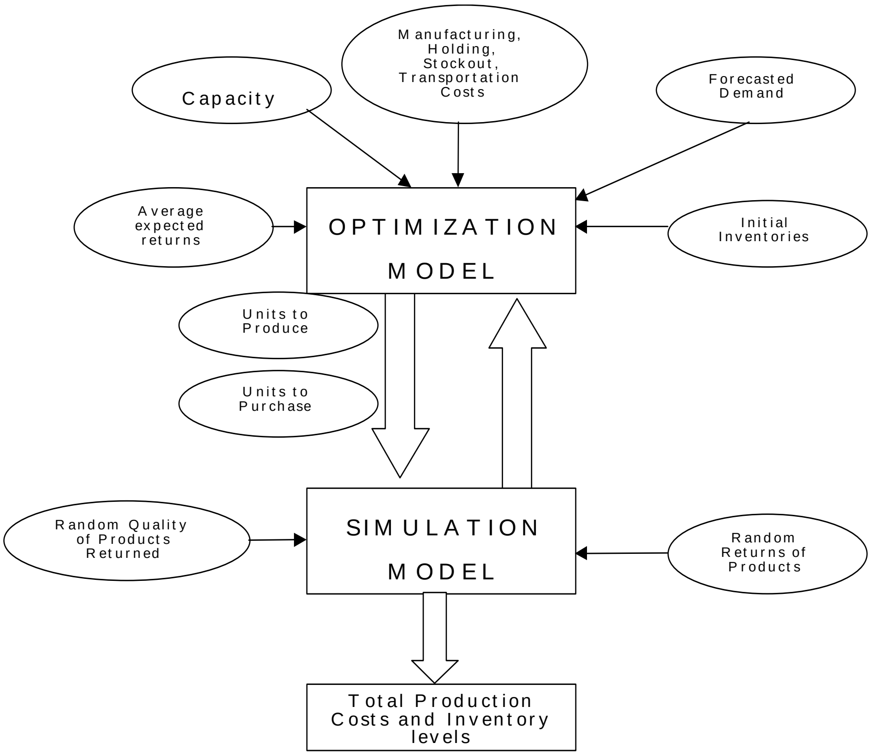

FIGURE 9: OPTIMIZATION - SIMULATION PROCESS

Then, the idea was to evaluate how this optimal production and purchasing schedule should vary under these three scenarios and how we can anticipate those variations using the simulation results to adjust again the optimization process. Figure 9 shows the characteristics of the optimization-simulation process (based on Cheung (2001)). We have run two different strategies and then we compare the performance of the examples under both strategies.

The first strategy, was to run the optimization model, from the results of optimization we get the expected number of returns and, based on it, the optimal production and purchasing schedule. From this optimal plan we also obtain an estimation of the inventories and final costs. We assume the company accepts the optimal plan as the production and purchasing strategy. Then, we start the simulation process. In the simulation model, we simulate the quantity of returns for each product (at the three scenarios: high, medium and low number of returns), and the quality of the products returned. We use the manufacturing and purchasing schedule provided by the optimization model and, we analyzed the inventory behavior for the returned materials and assemblies and, the total costs of the model.

Second strategy was to run the optimization model as before, but the simulation model only for half of the periods. After that, we use the results of the simulation and to feed again the optimization model but only for the remaining number of periods. In this form the production and purchasing schedule change for the remaining periods. At the end we use the results from the second optimization and run again the simulation model for the remaining number of periods. Figure 10 show graphically the second strategy used.

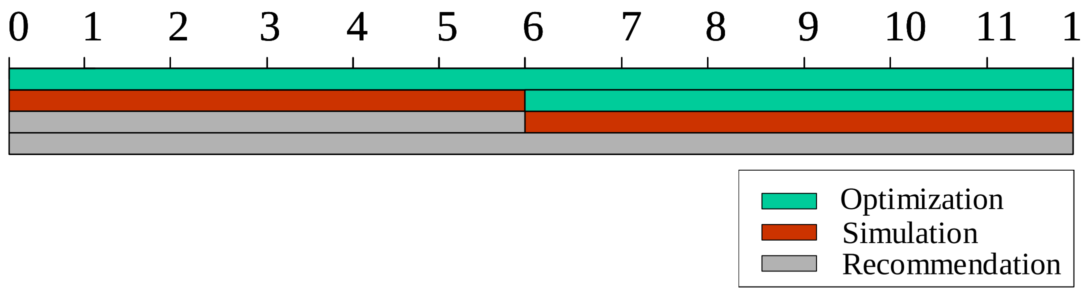

FIGURE 10 . SECOND STRATEGY PROPOSED

We have compared the results from the different optimization-simulation strategies and obtained some conclusions. The inputs and outputs obtained from the optimization and simulation model are summarized in table 16.

In both strategies, we considered the examples used. Figure 11 illustrates the recoverable production system.

The interest of this approach is to compare the possible performance of different scenarios and allow the plan maker to take a better decision. As we explained above, in our example we have established three different scenarios, with a low, medium and high rate of returns. They are defined in terms of the number of returns and quality of products returned.

Optimization	Simulation
Inputs: Production, holding, stock out and transportation costs. Holding and production capacities. Expected number and quality of returns. Demand (from sales forecast) Initial levels of inventories. Technical factors (Conversion data, production processes)	Inputs: Production schedule (from optimization) Purchasing strategy (from optimization) Units of products returned (Simulated) Quality of products returned (Simulated)
Outputs: Optimal production schedule Optimal purchasing strategy Estimated inventory levels Total costs for the planning exercise	Outputs: Inventory Levels Total cost for the system

TABLE 16: INPUTS AND OUTPUTS FROM OPTIMIZATION AND SIMULATION MODELS

We are interested in the total costs of the model and also in the inventory behavior, since they are a good indicator of the service level of the company. In the next section, we briefly describe some characteristics of both, optimization and simulation model, and we present some results.

3.4.1.1 The Optimization Model

As we explain before, optimization was done with Lingo software. For the first instance, Lingo has taken 13 minutes of running time, in a Pentium IV with 1,5 Gghs and 256 Mb of RAM memory. We have increased the size of the problem in one additional article or material, then, the problem becomes too large and the running time increases to more than 60 hours. Therefore, we believe that a heuristic procedure should be useful to obtain results in less time.

The optimization model has the following parameters: the production costs, the average expected demand per each period, and also the estimation of products returns and materials quality. The model output is the expected number of units to manufacture and the units of material to purchase at each plant and period. These values are used to make decisions in the quantity of products to be manufactured by each plant and the quantity of materials to be purchased.

Once the results have been obtained, we use these results as inputs for the simulation process.

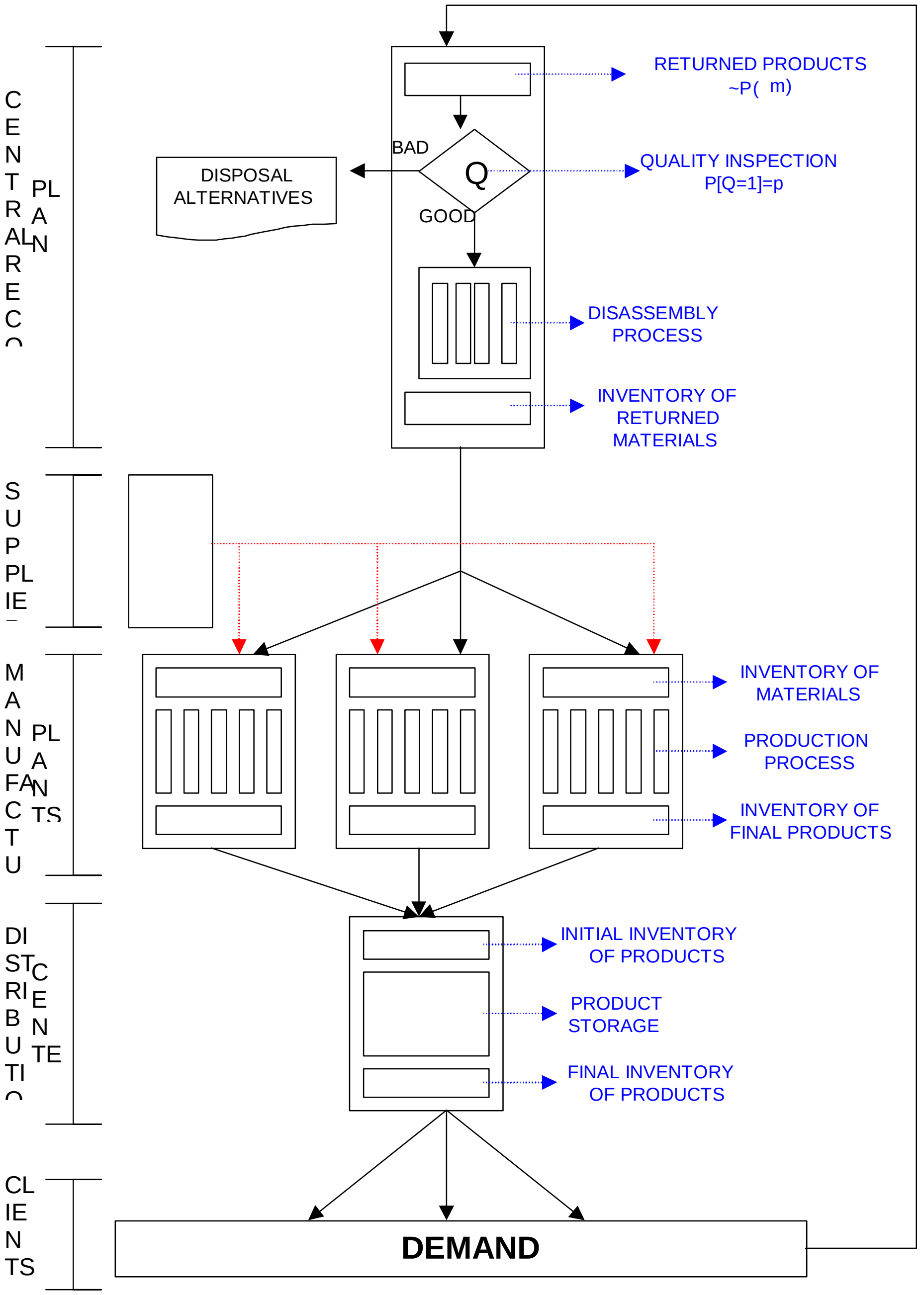

FIGURE 11: THE RECOVERABLE PRODUCTION SYSTEM

3.4.1.2 The Simulation Model

In order to run the simulation model we developed a program in C++. An additional assumption is made to run correctly the simulation model. When the simulated number of returned products is lower than the ones planned by the optimization model, the program considers an additional purchase order of materials in that period and charge additional costs. This is because in reality companies must buy urgently those materials to meet the planned production scheduling.

The simulation schedule is the following one:

1. Initialization:
    a. Set the number of replications to run the simulation.
    b. Take the initial inventories and parameters from the optimization model.(Repeat for each replication)
2. For each period:
    a. Simulate the number of products returned.
    b. Simulate the quality of the products.
    c. Calculate production costs and inventory levels for this period.
3. Evaluation:
    a. Calculate the average costs and inventories of all the replications.

We estimate the quantity and quality of the returned products in the same way as they were estimated in the CPP_R model, i.e. assuming a Poisson distribution for the number of products returned, and a Binomial distribution to simulate the quality of the materials obtained.

3.4.2 Computational Results

We elaborate two different strategies and three different scenarios to observe the performance of the model as was explained above.

The first scenario considers a low rate of returns. We assume that returns follow a Poisson distribution where λ corresponds to the 5% of the average expected demand. The second scenario considers a medium rate of returns, and we define a mean for the product return of 15% of the average expected demand; and the third scenario considers a high level of return, the average returns rate is for the 30% of the average expected demand.

For each strategy, we have run a total of 5000 replications of the simulation process. The following tables are a summary of the results we have obtained from this process. All the results, are the averages over the 5000 replications of the simulation process.

Strategy 1: Optimization + Simulation

The results from this strategy were obtained from running once the optimization model, and using these results to make the decisions on the simulation process. Table 17 shows the results obtained from this process. We are interested in observing the performance of the reusable materials inventories and the total cost of the system. In both models the demand is known in advance. Also, notice that the results obtained from the optimization is used to set the production scheduling and purchases decision on the simulation model.

In table 17 we present the total costs for the whole process under the following alternatives: CPP_R model and, the three scenarios of the simulation (low, medium and high level of returns). Second and third line, shows the Mean and Standard deviation of the number of returns used at each scenario. The remaining number of lines shows the average number of units of materials and assemblies hold on inventories under each process. The idea of the evaluation of the materials on inventory is to observe what happens if the returns are lower or higher than expected. It is an indirect evaluation of the economic implications of the different scenarios, compared with the optmization process.

We have considered 2 examples as we explained before. Network configuration of both examples are showed in table 15, section 3.4.

Example 1:

The results obtained were the following:

AVERAGE INVENTORIES OF REUSABLE MATERIALS				
	CPP_R model	Simulation		
Total Cost	212.210.700	397.723.000	338.931.000	333.437.000
Mean		1000	3000	6000
Std. Deviation		356,54	1069,61	2139,22
Material	Value	low	Medium	High
M7	6000	-124,0	2800,6	9202,5
M8	8250	-122,5	9723,2	24399,3
M9	17637,5	520	28576,6	70427,1
M10	37375	-10419,8	26948,2	82655,8

TABLE 17: RESULTS FROM EXAMPLE 1 UNDER STRATEGY 1.

Example 2:

The results obtained were the following:

AVERAGE INVENTORIES OF REUSABLE MATERIALS				
	Opt with returns	Simulation		
Total Cost	216.972.000	350.820.000	322.567.000	320.997.000
Mean		600	1800	3600
Std. Deviation		85,87	257,6	515,19
Material	Value	low	Medium	High
M11	98143,6	9366,9	31004,4	63246,8
M12	87757,7	5161,4	21964,4	47018,7
M13	19455,3	-687,8	21388,6	54287,1
M14	5787,5	622,5	8968,4	21413,1
M15	24652,7	-7320,6	-4638,1	-640,0

TABLE 18: RESULTS FROM EXAMPLE 2 UNDER STRATEGY 1

In the first example the consideration of the returns process into the optimization model, produce better economical results for the company. The reason is the fact that by considering the returns, the plants can use simple and less expensive production processes. It is also important to remark that traditionally the cost of disposal were not consider in the production planning process, therefore the optimization without considering the returns underestimate the real costs of the production process for the company.

In the results from the simulation model, we found that third scenario (high number of returned products) produce better economical results for the company. This is because the stock-out costs of the returned materials are very high. When there is stock-out of returned materials, it is expected to produce a change in the production plan, because some of these materials cannot be purchased, and therefore the articles must be produced under the traditional production process. Also the company will be forced to purchase new materials urgently at higher costs.

As expected, the inventories behavior shows high rates of stock-out in first scenario, medium in second, and high level of inventories under the third scenario studied.

The results presented in table 18 for the second example, show basically the same performance than in the previous example. In the simulation, the unique variation was in the scenario with medium level of returns where were obtained lower costs. The reason is the number of materials in stock was lower than in the scenario with high level of returns, and the stock-out costs the number of units in stock-out is also lower than in the case of low level of returns.

Strategy 2: Optimization (with returns)- Simulation (half of the Periods) - Optimization - Simulation (remaining periods)

Second strategy, consists in running the optimization model, and with this results we simulate the behavior for half of the total number of periods. Then, we use again the results obtained from the simulation to run the optimization model for the remaining half of periods and with the results we run again the simulation process for those last periods. In table 19 we present the results for this strategy.

Example 1:

AVERAGE INVENTORIES OF REUSABLE MATERIALS				
	Opt with returns	Simulation		
Total Cost	212.210.700	378.470.000	276.918.000	303.568.000
Mean		1000	3000	6000
Std. Deviation		356,54	1069,61	2139,22
Material	Value	low	Medium	High
M7	5716	221,5	12902,8	21785,2
M8	7327	-1976,4	1127,9	4180,1
M9	15254	-7529,1	-2942,5	2146,1
M10	33019	-7220,8	12260,0	40768,0

TABLE 19: RESULTS FROM EXAMPLE 1 UNDER STRATEGY 2.

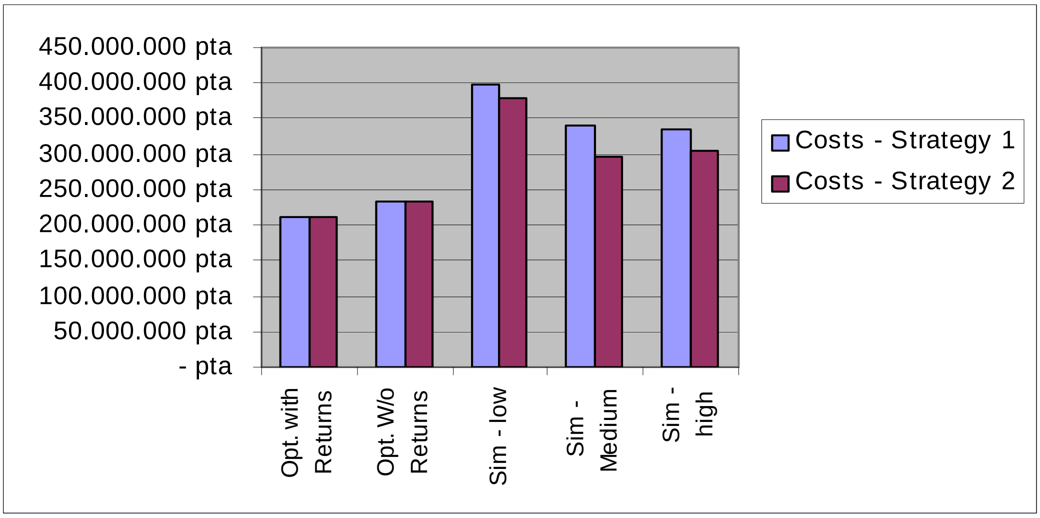

FIGURE 12: COMPARISON BETWEEN TOTAL COSTS UNDER STRATEGIES 1 AND 2.

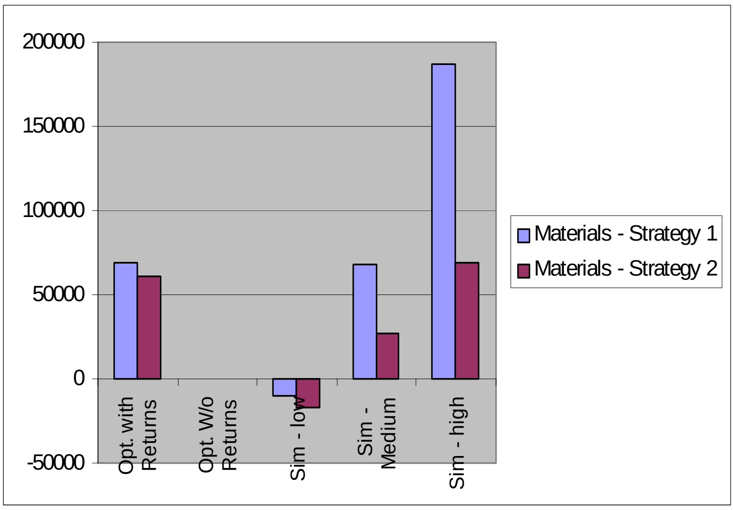

FIGURE 13: COMPARISON BETWEEN INVENTORY LEVELS UNDER STRATEGIES 1 AND 2.

Example 2:

AVERAGE INVENTORIES OF REUSABLE MATERIALS				
	Opt with returns	Simulation		
Total Cost	216.972.000	329.782.000	293.580.000	284.735.000
Mean		600	1800	3600
Std. Deviation		85,87	257,6	515,19
Material	Value	low	Medium	High
M11	71791,3	25192,1	40472,9	61657,5
M12	62669,6	17596,6	30629,7	48470,4
M13	19455,3	-8028,7	-4244,5	2927,2
M14	5787,5	-622,1	1954,2	5750,5
M15	21180,9	-2949,5	1415	9107,7

TABLE 20: RESULTS FROM EXAMPLE 2 UNDER STRATEGY 2

Figures 14 and 15 shows the same comparison between strategies one and two for the second example:

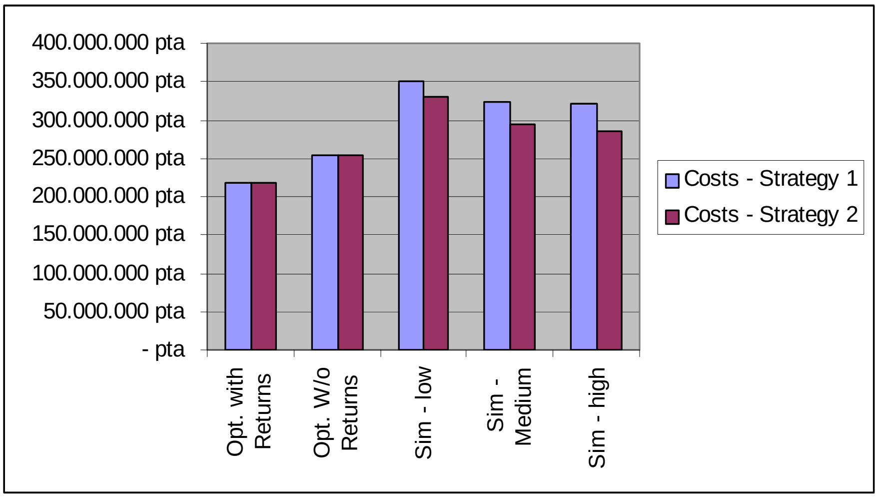

FIGURE 14: EX.2 - COMPARISON BETWEEN TOTAL COSTS UNDER STRATEGIES 1 AND 2

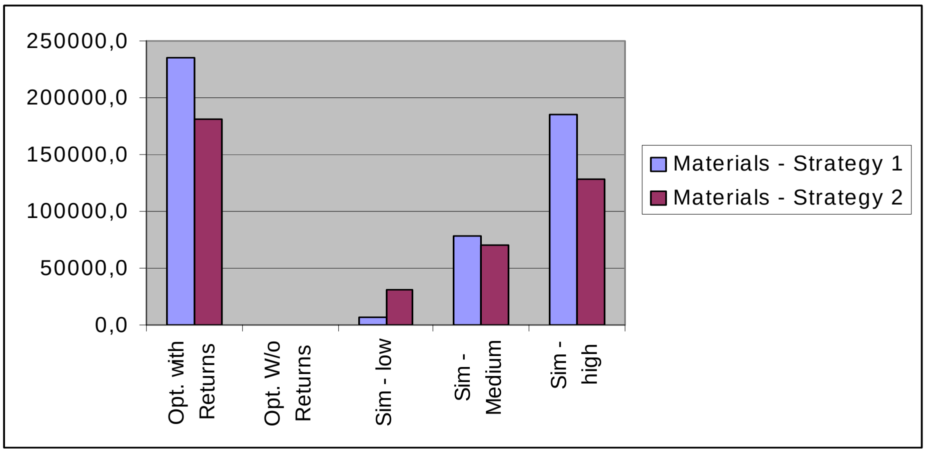

FIGURE 15: COMPARISON BETWEEN INVENTORY LEVELS UNDER STRATEGIES 1 AND 2.

As expected, in the first example, the results obtained by this strategy have improved in comparison with the first strategy. In the same three scenarios of the simulation the total costs have been reduced. Figures 12 and 13, are a comparison between both strategies, in costs and inventory units for this first example.

We can appreciate in table 20 that, under the second strategy both, units and costs, have been reduced. Therefore, the use of the simulation process to feedback the optimization process can improve the production schedule and purchasing programming.

Second example, provides the same behavior than the first one, the results from the second strategy presents better results than the ones obtained by first one.

We can appreciate under both examples, that the use of the second strategy can improve the production and purchasing programming. The optimization-simulation procedure is a good way to improve the decisions made by the company. In the future we plan to extend this model to an iterative process, where the optimization process will be feedback at each period to adapt the results better to the business environment.

As we stated before these two examples have been showed only to see the potential benefit derived from mix strategies of combining optimization and simulation processes. In big size networks the use of optimization becomes unpractical, as we saw some problems get more than 60 hours to obtain the optimal solution. It makes necessary to develop heuristic procedures to solve the CPP_R model. In chapter 5 we present a heuristic to solve the CPP_R model in a reasonable running time.

3.5 Conclusions and directions of future research

In this chapter we presented a mathematical model for a recoverable production planning system in a collaborative environment of work, called the Collaborative Production Planning Model with Returns (CPP_R).

This model considers a production plan at the aggregate level for a multiple factories environment. This allows factories to benefit from synergies of an integrated logistics network, obtaining better results for all the partners within the network. The model provides an aggregated production total schedule and also a purchasing planning for each factory during the planning period. Other important characteristic of the CPP_R model is the introduction of remanufacturing, where each product can be manufactured by different production processes, depending on the materials used: new, reusable or both. The set of production alternatives arising from this different processes, bring to the companies the possibility to choose less costly strategies to manufacture its products. Therefore, the CPP_R model provides the best combination of manufacturing processes to reduce the total costs for the company.

To deal with this remanufacturing environment a Modified Bill of Materials (MBOM) was proposed by the authors, which simplify the formulation and size of the problem.

The model was formulated as a stochastic integer programming, but it was transformed into an integer linear programming model. Two small instances were solved using Lingo Software. Given the uncertainty of the model, we have used a combination of optimization and simulation procedures to solve those instances. We considered two different examples under two different strategies and three different simulation scenarios. In first strategy, we ran an optimization model for all the periods and use the results obtained as inputs for the simulation model. Finally we calculated the total costs of the production process and the inventory performance. In second strategy, we ran the optimization model, but the simulation process was run only for half of the periods. With the results obtained from the simulation model, we feedback the optimization model and ran it again for the remaining periods, adjusting the purchase and manufacturing schedule. Finally, we ran the simulation process for the second half of periods. We have summarized the results from two strategies and we observed that the introduction of the simulation process can improve the planning process. Simulation helps the companies to adapt the results of the optimization allowing the planner to make better decisions.

The size of real problems complicates the solution of the model, increasing the running time of the optimization. Therefore one of the main conclusions of the model is that optimization is only a good method to solve the problem in small network configurations, but when the size increases, it is necessary to look for other ways of solving the problem. This chapter have several contributions; first, the introduction of the returns to the aggregate planning model, allowing to plan with mixed strategies using both reused and new materials, second, the collaborative approach where suppliers, the CRC, the factories and the DC are took in to account, reducing the total costs of planning and gaining from the synergies derived from the integration of this different parties in the supply chain. Finally, although it is necessary to study more in detail this technique, the utilization of the optimization + simulation procedure to solve this multi-period problem is also innovative. There is a lot of problems found in literature with the convergence of this processes of simulation – optimization. We propose here a new approach where convergence is not necessary, since in the multi-period problems both programs can feed one from the other until the periods are covered. From this preliminary results we can conclude that the combination of the optimization and simulation procedures can improve the performance of the planning process for the companies. This combination of optimization + simulation give insights to the decision maker about how to configure a production planning and, on the relationship between the several elements of the production process in terms of the quantity of product on inventory, the production and purchasing schedule, and the total costs of the systems.

As a future topic of research, we believe that combination of heuristic procedures and simulation, should be also a very good alternative to improve the planning process, in a reasonable running time.

It would be also interesting to use the optimization + simulation process in a strategy where at each period optimization or heuristic procedures will be feedback by the simulation process, resulting in a plan more accurate to the possible behavior of the products returned.

3.6 Chapter References

Berning, G., Brandenburg, M., Gürsoy,G., Kussi,J.S., Mehta,V., Tölle, F.J. (2004). "Integrating collaborative planning and supply chain optimization for the chemical process industry (I)—methodology." Computers and Chemical Engineering 28: 913–927.

Cheung, W., Leung, L., and Wong, Y.M. (2001). "Strategic Service Network Design for DHL Hong Kong." Interfaces 31(4): 1-14.

Guide Jr, V. D. R., Vaidyanathan Jayaraman, Rajesh Srivastava, and W.C. Benton. (2000). "Supply-Chain Management for Recoverable Manufacturing Systems." Interfaces 30: 125- 142.

Guide Jr, V.D.R.(2000a). "Production planning and control for remanufacturing: industry practice and research need." Journal of Operations Management 18: 467–483.

Guide Jr, V. D. R., Jayaraman, V., Srivastava, R., (1999). "Production planning and control for remanufacturing: a state-of-the-art survey." Robotics and Computer-Integrated Manufacturing 15(3): 221–230.

Holweg, M., Disney, S., Holmström, J. and Småros, J. (2005). "Supply Chain Collaboration: Making Sense of the Strategy Continuum." European Management Journal 23(2): 170-181.

Jain, A., Udaka, S. P. (2005). "Aggregate production planning for a continuous reconfigurable manufacturing process." Computers & Operations Research 32: 1213–1236.

Kempenaers, J. P., Detand, J. and, Kruth, J.-P. (1996). "A collaborative process planning and scheduling system." Advances in Engineering Software 25: 3-8.

Kelle, P. a. E. A. S. (1989). "Forecasting the Returns of Reusable Containers." Journal of Operations Management 8: 17-35.

Krikke, H. (1998). Recovery strategies and reverse logistic network design. Institute for Business Engineering and Technology Application. Enschede,The Netherlands, University of Twente: 254.

Lambert, D.M.; Cooper, M.C. & Pagh, J.D. (1998) “Supply Chain Management: Implementation issues and research opportunities”, *The International Journal of Logistics Management*, Vol 9 No 2, pp. 1-19.

Mazzola, J. B., Neebe, A. W., Rump, C. M. (1998). "Multiproduct production planning in the presence of work-force learning." European Journal of Operational Research 106: 336-356.

Rogers, D. S. a. T.-L., Ronald S. (1998). Going Backwards: Reverse Logistics Practices and trends. Reno, Nevada, Reverse Logistics Executive Council.

Toktay, B. L., L. M. Wein, And S. A. Zenios (1997), Inventory Management of Remanufacturable Products; Working Paper, Operations Research Center, MIT (1997)

Ventura, Eva,. and Gimenez, C., (2003). " Supply Chain Management as A Competitive Advantage in the Spanish Grocery Sector." The International Journal of Logistics Management, 14 (1): 77- 88.

Vercellis, C. (1999). "Multi-plant production planning in capacitated self-configuring two-stage serial systems." European Journal of Operational Research 119: 451-460.

CHAPTER 4: Models For Specific Manufacturing Environments

4.1 Introduction

In chapter 3 we introduced the CPP_R model, which was designed for a collaborative supply network with multiple products, multiple materials, several periods of time planning and also allows us to introduce the reused materials and assemblies into the tactical planning.

In this chapter, we propose 3 additional models, adapted from the CPP_R model to deal with specific manufacturing environments.

The objectives of creating those models are twofold, first to provide models adapted to some specific manufacturing situations and, second to explore the elements that have more incidence in the running time when solving the CPP_R model.

The chapter is stated as follows: second section will present a brief literature review, then next 3 sections present the 3 models proposed and finally in section 6 some conclusions and future research is presented.

4.2 Literature Review

Tactical production planning is an issues widely covered in the literature, since it was firstly formulated in the 1950s. Most of the research on this problem has been focused on models for discrete parts manufacturing. These models typically permit storage of in-process inventory between different stages of manufacturing, see Jain and Udaka (2005). However, few models consider collaborative planning or aggregate planning with remanufacture.

Vercellis (1999), proposes a multi-plant production planning model with several items and depots to transport the products. The model considers two stages of production at each plant. However, raw materials and purchasing costs are not considered, and also remanufacturing is not allowed within the model.

In terms of remanufacturing, Guide Jr. et al.(1999) conclude that not all the areas of production planning and control have been researched adequately, and also they concluded that formal work is needed linking production planning and control with product return information.

Guide Jr. and Srivastava (1998) based on observations and on discussions with managers in remanufacturing facilities, state several managerial propositions for remanufacturing. They examine those propositions via a simulation model of an operating facility, and make some recommendations in terms of the inventory buffer to use in conjunction with the disassembly - release policy for parts for the remanufacturing environment.

Kiesmüller and Van der Laan (2001) propose an inventory model for a single reusable product, in which the random returns depend explicitly on the demand stream. Further, the model distinguishes itself from most other research in this field by considering lead times and a finite planning horizon.

Mazzola et al. (1998), propose a model for multi-product aggregated production planning, but without remanufacturing and without the Collaborative scheme.

Finally, a good summary of the research done in the remanufacturing area should be found in Fleischmann et al.(1997), which is later complemented with the research performed by Guide Jr. (2000).

The models proposed in this section are concerned basically with sixth topics: multi-plant planning (collaborative planning), multi-period planning, multi-product planning, multi-machine planning and the planning of several production processes. None of the existing studies covered such a wide number of variables as our models do. Some of them consider at most two of the issues, but not the combined effect of most of them.

The models we propose will serve the companies in facilitating their tactical production planning considering most of the relevant elements used in the manufacturing environment today.

4.3 Collaborative Multi-period model without returns (CPP)

First model proposed, considers a Collaborative scheme, i.e. multiple factory planning, but without returns. This supply chain configuration is quite common nowadays, since there are a lot of industries where returns are not a problem, or where they have no options of remanufacturing, however they should benefit from the collaborative approach of planning with the other supply chain members. We denote this model as the ***CPP*** *model*. In this model multiple production plants are allowed but products are only manufactured with new materials. This network configuration, differ from the CPP_R model basically in two things:

A. We use only one process to manufacture the products, therefore we limit the Modified Bill of Materials to one unique process, becoming the traditional BOM. Mathematically, we have that parameter K_{aip} becomes K_{1ip}.

B. CRP disappears, with all the disassembly, holding, and transportation costs. In this simplified model, factories acquire the products only from suppliers.

Although this model is a simplification of the CPP_R model, it includes new elements with respect to the traditional manufacturing production planning. In this case we are including suppliers, the factories and the distribution center. The idea is to use this model when having a set of factories belonging to the same company or different companies collaborating to improve their production plan. As in the CPP_R model we allow factories to manufacture all or a subset of the products, taking into account the capacity constraints and the different costs at each factory.

Another very interesting characteristic of this model is that this model is suitable for planning an outsourced production. Today it is very common to find that companies are outsourcing their production process. In fact, some countries like China are emerging as biggest manufacturers for occidental companies. Some sectors like the toys sector or the textile sector are now manufacturing most of the products in Asian countries.

This model brings a very good opportunity for companies to plan the outsourcing production in a global scheme, receiving several benefits from this joint planning as explained in chapter 3. The outsourcing model used in the CPP model, implies that outsourced production manufacture totally the product; and therefore should also receive parts and assemblies directly from the suppliers. When the outsourcing operation is only performed in part of the process or, products and materials are sent by the factories to the outsourced plant, then the most appropriate model is the CPP_{R1F}, which is described in the next section.

The Supply Chain in the CPP model work as follows: The Central Distribution Facility receives the demand for the products, then each plant can manufacture all or a subset of the products to meet the demand requirements. For each product, the bill of materials is known, but in this case we eliminate the differentiation for production processes, given that products are manufactured only by one production process, using only new materials.

The production plants acquire the materials from their suppliers. They must decide the quantity of materials they will purchase at each period, depending on the quantity of products to manufacture. Once the factories have manufactured their products, they can ship all or part of them to the DC.

The factories should hold inventories of final products and materials. When the DC receives the products, it also prepares and sends the products to the consumers following the orders that are represented in the model by the forecasted demand.

The DC has only inventories of final products, but it is allowed to incur in stock out if necessary. We assume that the demand that is not covered in a period, will be covered in the next period, and also that there are stock out costs derived from the opportunity cost of the sales lost today and in the future.

In this model we keep the general assumptions made for the collaborative production planning model presented before. The decisions to make are:

- The quantity of each product to produce at each factory and period (X_{1ijt}).
- The quantity of each product to ship from each factory to the warehouse at each period (G_{ijt}).
- The number of units of each product to ship from each plant to the central distribution center per period q_{ijt},
- The quantity of each material to purchase per plant at each period (P_{jpt}), and
- The inventory units of final products and materials to hold per period at each factory and in the central distribution center (I_{ijt},M_{jpt},Y_{it} respectively).

As in the general model, each factory has holding and production capacity. We consider also security stocks at each factory. Costs can vary from one plant to another.

We consider the following unitary costs:

- Production costs C_{1ijt},
- Holding costs for products:
  - In the manufacturing plants H_{ij},
  - In the distribution center W_{it},
- Holding costs for materials L_{jpt}
- Transportation costs between plants and distribution center T_{ijt},
- Stock-out cost in the distribution center S_{it},
- Purchasing costs for materials R_{jpt}.

The objective is to minimize the total costs of the whole system.

With these considerations, we now can describe the mathematical formulation of the ***CPP*** model. First of all let's present all data and variables:

Data

I= Number of articles.

J= Number of plants.

T= Number of periods of time to planning.

M= Number of machines

P= Number of materials

C_{1ijt}= Production cost of one unit of article i at plant j on period t.

H_{ij} = Holding cost per unit of article i at plant j.

S_{it} = Stock out cost per unit of article i at period t.

R_{jpt}= Cost of purchase one unit of material p in plant j at period t.

L_{jpt}= Holding cost per unit of material p in plant j at period t.

SS_{ijt}= Security stock of product i at plant j and period t.

B_{ijt}= Maximum allowed stock of product i at plant j and period t.

K_{1ip}= Quantity of material p needed to manufacture one unit of product i.

CF_{ip}= Quantity of material p obtained from disassembly process of product i.

MAX_{jp}= Maximum allowed stock of material p at plant j.

V_{jp}= Security stock of material p at plant j.

T_{ijt}= Transportation cost per unit of product i shipped from plant j to central facility on period t.

d_{it}= Demand of product i at period t.

W_{it}= Holding cost of product i at period t on central warehouse.

PT_{1im}= Production time of one unit of product i in machine m.

U_{jmt}= Hours of production capacity in plant j at period t in machine m.

I_{ij0}= Inventory units of product i in plant j at period 0.

Variables

X_{1ijt}= Number of units of product i to produce in plant j on period t.

P_{jpt}= Number of units of material p to purchase in plant j at the beginning of period t.

q_{ijt}= Quantity of product i shipped to central facility from plant j on period t.

I_{ijt}= Inventory units of product i in plant j at the end of period t.

M_{jpt}= Inventory units of material p in plant j at the end of period t.

Y_{it}^{-}= Number of units of stock out of article i at period t in DC.

Yit^{+}= Inventory units of product i at period t on DC.

The objective function of the model is to minimize the total costs of the whole system. Formally we have:

$$\min \underbrace{\sum_{j=1}^{J}\sum_{i=1}^{I}\sum_{t=1}^{T} C_{1ijt} X_{1ijt}}_{\text{Production Costs}} + \underbrace{\sum_{j=1}^{J}\sum_{i=1}^{I}\sum_{t=1}^{T} H_{ij} I_{ijt}}_{\text{Holding Costs of final products at factories}} + \underbrace{\sum_{i=1}^{I}\sum_{t=1}^{T} S_{it} Y_{it}^{-}}_{\text{Stock-out Costs at Distribution Center}} + \underbrace{\sum_{j=1}^{J}\sum_{p=1}^{P}\sum_{t=1}^{T} R_{jpt} P_{jpt}}_{\text{Purchasing Costs}} +$$

$$\underbrace{\sum_{j=1}^{J}\sum_{p=1}^{P}\sum_{t=1}^{T} L_{jpt} M_{jpt}}_{\text{Holding Costs of raw materials at factories}} + \underbrace{\sum_{j=1}^{J}\sum_{i=1}^{I}\sum_{t=1}^{T} T_{ijt} q_{ijt}}_{\text{Transportation Costs from factories to D.C.}} + \underbrace{\sum_{i=1}^{I}\sum_{t=1}^{T} W_{it} Y_{it}^{+}}_{\text{Holding Costs of final products at DC}}$$

Where $i=1,\ldots,I$, is the index related with the number of manufactured products, and I is the total number of products; $j=1,\ldots,J$, is the index related to the production plants, being J the total number of factories; $p=1,\ldots,P$ is the set of materials used; $\mathrm{m}=1,\ldots,\mathrm{M}$ is the set of machines and M the Total number of machines and, $t=1,\ldots,T$ the planning periods.

The constraints of the model are:

1. **Materials Inventory:** These constraints compute the final inventory of materials at each period, becoming the initial inventory for the next period.

$$M_{\mathrm{jpt}} = \mathrm{M}_{\mathrm{jp(t-1)}} + \mathrm{P}_{\mathrm{jpt}} - \left[\sum_{i=1}^{I} (K_{1ip} * X_{1ijt})\right] \qquad j=1,\ldots,J;\ p=1,\ldots,P; t=1,\ldots,T;$$

2. **Inventory capacity and security stock for materials:** Each factory has a maximum holding capacity and a minimum security stock for each material.

$$V_{\mathrm{jp}} \le \mathrm{M}_{\mathrm{jpt}} \le MAX_{\mathrm{jp}} \qquad j=1,\ldots,J;\ p=1,\ldots,P; t=1,\ldots,T;$$

3. **Materials capacity constraints:** The number of products to be produced is constrained by the availability of the materials.

$$\sum_{i=1}^{I} k_{1ip} X_{1ijt} \le \mathrm{M}_{\mathrm{jp(t-1)}} + \mathrm{P}_{\mathrm{jpt}} + \mathrm{O}_{\mathrm{jpt}} \qquad j=1,\ldots,J;\ p=1,\ldots,P; t=1,\ldots,T;$$

4. **Products Inventory:** These constraints calculate the final inventory of products at each period, becoming the initial inventory for the next period.

$$I_{ijt} = I_{\mathrm{ij(t-1)}} + X_{1ijt} - q_{\mathrm{ijt}} \qquad j=1,\ldots,J;\ i=1,\ldots,I; t=1,\ldots,T;$$

5. **Shipment Control:** The quantity of the products shipped from factories to the DC is limited by the quantity produced of the respective article at that period plus the quantity in inventory.

$$X_{1ijt} + I_{ij(t-1)} \geq q_{\mathrm{ijt}} \qquad j=1,\ldots,J;\ i=1,\ldots,I; t=1,\ldots,T;$$

6. **Inventory capacity for products:** Each factory has a maximum holding capacity and a minimum security stock for each product.

$$SS_{\mathrm{ijt}} \leq I_{\mathrm{ijt}} \leq B_{\mathrm{ijt}} \qquad j=1,\ldots,J;\ i=1,\ldots,I; t=1,\ldots,T;$$

7. **Stock-out or Inventory units of final products in Distribution Center:** Stock out or inventory units are allowed at the DC. Notice that variable Y_{it} could be positive or negative (Inventory or stock out). Therefore, we have divided it into two variables, Y_{it}^{+} and Y_{it}^{-} in such way that, if there are units of stock out, then $Y_{\mathrm{it}}^{+} = 0$ and $Y_{it}^{-} > 0$ and, if there are units of stock, then $Y_{\mathrm{it}}^{+} \geq 0$ and $Y_{it}^{-} = 0$. This division allows us to assign different costs to each one of the cases and have only variables taking values greater than or equal to 0.

$$Y_{i(t-1)} + \sum_{\mathrm{j=1}}^{\mathrm{J}} \mathrm{q}_{\mathrm{ijt}} - \mathrm{d}_{\mathrm{it}} = \mathrm{Y}_{\mathrm{it}} \qquad i=1,\ldots,I; t=1,\ldots,T;$$

Replacing in the formula above, we have:

$$\mathrm{Y}_{i(t-1)}^{+} - Y_{i(t-1)}^{-} + \sum_{\mathrm{j=1}}^{\mathrm{J}} \mathrm{q}_{\mathrm{ijt}} - \mathrm{d}_{\mathrm{it}} = Y_{it}^{+} - Y_{it}^{-} \qquad i=1,\ldots,I; t=1,\ldots,T;$$

8. **Production Capacity:** We have limited the production capacity per machine to a specified number of hours per period. Each unit of product has previously assigned the number of minutes necessary to manufacture each unit of the product for each one of the available machines.

$$\sum_{\mathrm{i=1}}^{\mathrm{I}} PT_{1im} X_{1ijt} \leq U_{jmt} \qquad j=1,\ldots,J;\ t=1,\ldots,T;$$

Other production capacity constraints can be easily incorporated if necessary.

9-15. Integer and non-negativity constraints

All variables are integer and greater than zero.

In summary the model is the following:

$$\min \sum_{j=1}^{J}\sum_{i=1}^{I}\sum_{t=1}^{T} C_{1ijt} X_{1ijt} + \sum_{j=1}^{J}\sum_{i=1}^{I}\sum_{t=1}^{T} H_{ij} I_{ijt} + \sum_{i=1}^{I}\sum_{t=1}^{T} S_{it} Y_{it}^{-} + \sum_{j=1}^{J}\sum_{p=1}^{P}\sum_{t=1}^{T} R_{jpt} P_{jpt} +$$
$$\sum_{j=1}^{J}\sum_{p=1}^{P}\sum_{t=1}^{T} L_{jpt} M_{jpt} + \sum_{j=1}^{J}\sum_{i=1}^{I}\sum_{t=1}^{T} T_{ijt} q_{ijt} + \sum_{i=1}^{I}\sum_{t=1}^{T} W_{it} Y_{it}^{+}$$

Subject to:

1. $M_{\mathrm{jpt}} = \mathrm{M}_{\mathrm{jp(t\text{-}1)}} + \mathrm{P}_{\mathrm{jpt}} - \left[\sum_{i=1}^{I} (K_{1ip} * X_{1ijt})\right]$ $\quad p = n+1,\ldots,P; t = 1,\ldots,T;$

2. $V_{\mathrm{jp}} \le \mathrm{M}_{\mathrm{jpt}} \le MAX_{\mathrm{jp}}$ $\quad j = 1,\ldots,J;\ p = 1,\ldots,P; t = 1,\ldots,T;$

3. $\sum_{i=1}^{I} k_{1ip} X_{1ijt} \le \mathrm{M}_{\mathrm{jp(t\text{-}1)}} + \mathrm{P}_{\mathrm{jpt}} + \mathrm{O}_{\mathrm{jpt}}$ $\quad j = 1,\ldots,J;\ p = 1,\ldots,P; t = 1,\ldots,T;$

4. $I_{ijt} = I_{\mathrm{ij(t\text{-}1)}} + X_{1ijt} - q_{\mathrm{ijt}}$ $\quad j = 1,\ldots,J;\ i = 1,\ldots,I; t = 1,\ldots,T;$

5. $X_{1ijt} + I_{ij(t-1)} \ge q_{\mathrm{ijt}}$ $\quad j = 1,\ldots,J;\ i = 1,\ldots,I; t = 1,\ldots,T;$

6. $SS_{\mathrm{ijt}} \le I_{\mathrm{ijt}} \le B_{\mathrm{ijt}}$ $\quad j = 1,\ldots,J;\ i = 1,\ldots,I; t = 1,\ldots,T;$

7. $Y_{i(t-1)}^{+} - Y_{i(t-1)}^{-} + \sum_{\mathrm{j=1}}^{\mathrm{J}} \mathrm{q}_{\mathrm{ijt}} - \mathrm{d}_{\mathrm{it}} = Y_{it}^{+} - Y_{it}^{-}$ $\quad i = 1,\ldots,I; t = 1,\ldots,T;$

8. $\sum_{\mathrm{i=1}}^{\mathrm{I}} PT_{1im} X_{1ijt} \le U_{jmt}$ $\quad j = 1,\ldots,J;\ i = 1,\ldots,I; t = 1,\ldots,T;$

9. $X_{1ijt} \ge 0 \quad and \ \text{integer};$

10. $P_{jpt} \ge 0 \quad and \ \text{integer};$

11. $q_{ijt} \ge 0 \quad and \ \text{integer};$

12. $I_{ijt} \ge 0 \quad and \ \text{integer};$

13. $Y_{it}^{+} \ge 0 \quad and \ \text{integer};$

14. $Y_{it}^{-} \ge 0 \quad and \ \text{integer};$

15. $M_{jpt} \geq 0 \quad and \ \text{integer};$

As we state before, the CPP model is suitable to use for medium term planning in those environments where collaboration is possible between supply chain members, in special in just in time production and production outsourcing. These kind of models has been used each time more frequently in manufacturing companies, since collaboration is acquiring high importance in business today. Solution methods for this model are discussed in chapter five.

4.4 Collaborative Production Planning Model With Returns for one factory (CPP_{R1F})

Other useful extension of the CPP_R model is when we need to plan returns but only in one factory. Actual trends in the business world claim for integration, coordination and optimization of resources within a supply chain. This collaboration should be vertically and (or) horizontally. The CPP_R model considers both of them. However, reality shows that most of companies are not horizontally integrated, i.e. factories for instance, keep doing most of the planning process independently of others factories. Therefore, it is necessary to know how to plan the production process in this kind of companies if remanufacturing is adopted. The model is denoted as the Collaborative Production Planning model with Returns for one factory (CPP_{R1F}). Notice that although the model is only for one factory, we should also include the possibility of considering outsourcing options in manufacturing. We do it, including the external production as other production process available to manufacture a new product; of course in this outsourcing case, production costs will vary and include all the transportation, materials and other related costs of the outsourced production.

The outsourcing model used in the CPP_{R1F} model, implies that outsourced plant should manufacture all or a part of the product; and receives the parts and assemblies from the factory.

The model follows the same configuration of the CPP_R model, including the CRC, one manufacturing plant and the DC. Variables and costs are defined as in the CPP_R model. For simplicity, we replace all the sub index j, corresponding to the factories in the CPP_R model, for the number *1*, representing that is only for factory number *1*. The supply chain and the data and variables of the model are similar to the ones of the CPP_R model, but considering only one factory.

The supply chain works as follows:

- The CRP receives the returned products at each period. Products are revised, classified and organized by the corresponding disposal and remanufacturing strategy. The products that are of good quality for remanufacturing are disassembled and processed until they become materials and assemblies ready to be shipped to the factory. The CRP has inventories of raw materials.
- The Factory manufacture all the products based on the sales' and returns' forecasts. It purchases the materials to the suppliers and also sends the final products to the Distribution Center. The factory holds inventories of raw materials, work in-process and final products.
- Suppliers receive the purchasing orders from the factory and serve those orders in the same period of time (Just in time supply).
- The Distribution Center, receives the sales orders and serve the clients from its inventories at each product. We assume that the not covered demand, will be covered in the next period, but there are stock-out costs, derived from the opportunity cost of the sales lost today and in the future and from the lose of image of the company for this situation. DC holds only final product inventories.

We have capacity constraints in inventories and production. Other assumptions of the model are:

A. The CRP takes one period to perform the recovery process. Therefore, parts and assemblies obtained from recovered products arriving in period t will be only available at period $t+1$.

B. We consider the possibility of stock-out in the DC, therefore if demand for a product cannot be satisfied in a period, it should be served in the next period. However, we use a penalty cost for the stock out state, trying to estimate the lost of image for the company, and the opportunity costs generated by the stock out situation.

C. To manufacture the products, the factory should use the inventories of materials from the previous period and materials purchased in the same period.

D. The factory has capacity constraints in time of production, storage capacity, and a security stock.

E. The transportation cost from suppliers to the factory is included in the cost of the new materials.

F. For each product the Modified Bill of Materials is known.

G. There is a forecasted product demand for all the periods, (d_{it}). This demand is previously known from the sales forecast.

H. Given the demand, the planner decides (i.e. the variables of the problem):

   a. The quantity to be produced of each article and period, and also what will be the production process ($a=1..A$) used to manufacture it, (X_{ai1t}).

   b. The quantity of each material to purchase in a period, (P_{pt}).

   c. The quantity of each reused material or assemblies to be send each period from the CRP to the factory, (O_{1pt}).

   d. The quantity of each material to hold in inventory at each period, (M_{1pt}).

   e. The quantity of each final product to hold in inventory at each period, (I_{i1t}).

   f. The quantity of each final product to hold in inventory at each period in the DC, (Y_{it}).

   g. The quantity of products to send from each factory to the Distribution Center at each period (q_{ijt}).

L. To make the above decisions the planner knows the following data:

a. Production costs per article, depending on the production process, and the period, (C_{ai1t}).

b. Transportation costs:

    i. From the CRP to the factory (G_{p1t}).

    ii. From the factory to Distribution Center (T_{i1t}).

c. Holding costs per period:

    i. For raw materials, (L_{1pt}).

    ii. For final products (at the factory and the DC) (H_{i1t} ,W_{it}) respectively.

    iii. Reused materials at the CRP (HO_{pt}).

d. Disassembly costs (DC_{ipt}).

e. The Materials costs (R_{1pt}).

f. The Stock-out costs per article at each period (S_{it}).

g. The estimated number of parts and assemblies available "ready to use" at each period in the CRP. We estimate the number of reused materials and assemblies for each period, taking into account historical data.

h. The capacity constraints per period:

    i. In hours per production per machine ($m=1..M$), (U_{1mt}).

    ii. Storage capacity in the factory, for each material (MAX_{1pt}) and final product (B_{i1t}).

i. The security stock at each period for:

    i. Product (SS_{i1t}).

    ii. Material (V_{1pt}).

j. Initial inventories:

    i. Of materials. (IN_{p0}).

    ii. Of final products (I_{i10}).

k. The Modified Bill of Materials (MBOM), described in the CPP_R model (K_{aip}).

l. The number of parts and assemblies that should be obtained from the disassembly process of a product. (CF_{ip}).

m. The technical probability to obtain a part or assembly of good quality $([QU_{ip}=1])$ from the disassembly process of a product (p_{ipt}).This probability is calculated as in the CPP_R model. For a detailed description see section 3.3.2.1

Next we describe the mathematical formulation of the Collaborative model. First of all let's present all data and variables:

Data

A= Number of production process that has the product with the maximum number of production processes.

I= Number of articles.

T= Number of periods of time to planning.

M= Number of machines

P= Number of materials

C_{ai1t}= Production cost of one unit of article i by process a on period t.

H_{i1} = Holding cost per unit of article i.

HO_{pt}= Holding costs per unit of material p in CRP at period t.

S_{it} = Stock out cost per unit of article i at period t.

R_{1pt}= Cost of purchase one unit of material p at period t.

L_{1pt}= Holding cost per unit of material p at period t.

SS_{i1t}= Security stock of product i in period t.

B_{i1t}= Maximum allowed stock of product i at period t.

K_{aip}= Quantity of material p needed to manufacture one unit of product i by process a.

CF_{ip}= Quantity of material p obtained from disassembly process of product i.

MAX_{1p}= Maximum allowed stock of material p.

V_{1p}= Security stock of material p.

T_{i1t}= Transportation cost per unit of product i shipped to central facility on period t.

G_{1pt}= Transportation cost per unit of material p shipped from central recovery plant on period t.

d_{it}= Demand of product i at period t.

W_{it}= Holding cost of product i at period t on central warehouse.

PT_{aim}= Production time of one unit of product i by process a in machine m.

U_{1mt}= Hours of production capacity at period t in machine m.

p_{ipt}= Probability of material p obtained from product i, to be of quality $QU=1$ (good quality) for remanufacturing.

DC_{ipt}= Cost of obtain part p disassembled from product i in period t.

λ_{ipt}= Expected number of parts p obtained from all products i returned to the central recovery plant on period t.

QU= Quality assessment for materials where $QU=0$ means bad quality for remanufacturing and $QU=1$ means good quality for remanufacturing.

I_{i10}= Inventory units of product i at period 0.

IN_{p0}= Inventory units of material p in CRP at period 0.

MRM_{p}= Holding capacity for material p at CRP.

Variables

X_{ai1t}= Number of units of product i to produce by process a on period t.

P_{1pt}= Number of units of material p to purchase at the beginning of period t.

q_{i1t}= Quantity of product *i* shipped to central facility on period *t*.

I_{i1t}= Inventory units of product *i* at the end of period *t*.

IN_{pt}= Inventory units of material *p* in CRP at the end of period *t*.

M_{1pt}= Inventory units of material *p* at the end of period *t*.

Y_{it}^{-}= Number of units of stock out of article *i* at period *t* in DC.

Yit^{+}= Inventory units of product *i* at period *t* on DC.

O_{1pt}= Quantity of material *p* shipped from CRP on period *t*.

The objective function of the model is to minimize the total costs of the system. Formally we have:

$$\min \underbrace{\sum_{a=1}^{A}\sum_{i=1}^{I}\sum_{t=1}^{T} C_{ai1t} X_{ai1t}}_{\text{Production}} + \underbrace{\sum_{i=1}^{I}\sum_{t=1}^{T} H_{i1} I_{ij1}}_{\text{Holding Costs of final products at factories}} + \underbrace{\sum_{i=1}^{I}\sum_{t=1}^{T} S_{it} Y_{it}^{-}}_{\text{Stock-out Costs at Distribution Center}} + \underbrace{\sum_{p=1}^{P}\sum_{t=1}^{T} R_{1pt} P_{1pt}}_{\text{Purchasing Costs}} +$$

$$\underbrace{\sum_{p=1}^{P}\sum_{t=1}^{T} L_{1pt} M_{1pt}}_{\text{Holding Costs of raw materials at factories}} + \underbrace{\sum_{i=1}^{I}\sum_{t=1}^{T} T_{i1t} q_{i1t}}_{\text{Transportation Costs from factories to D.C.}} + \underbrace{\sum_{i=1}^{I}\sum_{t=1}^{T} W_{it} Y_{it}^{+}}_{\text{Holding Costs of final products at DC}} + \underbrace{\sum_{p=1}^{P}\sum_{t=1}^{T} G_{1pt} O_{1pt}}_{\text{Transportation costs of reused materials from CRP to the factories}} +$$

$$\underbrace{\sum_{p=1}^{P}\sum_{t=1}^{T} HO_{pt} IN_{pt}}_{\text{Holding Costs for reused materials at CRP}} + \underbrace{\sum_{t=1}^{T}\sum_{i=1}^{I}\sum_{p=1}^{P} \lambda_{ipt} \underline{p}_{ipt} DC_{ipt}}_{\text{Disassembly costs based on the expected number of products disassembled at CRP.}}$$

The constraints of the model are:

1. **Reusable materials and assemblies Inventory:** Calculation of the available inventories at each period.

$$IN_{pt} = IN_{p(t-1)} + \sum_{i=1}^{I} \lambda_{ipt} \underline{p}_{ipt} - O_{1pt} \qquad p = n+1,\ldots, P; t = 1,\ldots, T;$$

2. **Control of shipments:** Control the reused materials sent to the factory.

$$O_{1pt} \le IN_{p(t-1)} \qquad p = n+1,\ldots,P; t = 1,\ldots,T;$$

3. **Inventory capacity for reusable materials and assemblies:**

$$IN_{pt} \leq \mathrm{MRM_p} \qquad p = n+1,...,P; t = 1,...,T;$$

4. **Materials Inventory:** Calculation of purchased materials' inventories at the factory.

$$M_{1\mathrm{pt}} = \mathrm{M_{1p(t\text{-}1)}} + \mathrm{P_{1pt}} - \left[\sum_{i=1}^{I} \sum_{a=1}^{A} (K_{aip} * X_{ai1t}) \right] \qquad p = 1,...,n; t = 1,...,T;$$

5. **Reusable materials and assemblies inventory:** Calculation of non purchased materials' inventories at the factory.

$$M_{1\mathrm{pt}} = \mathrm{M_{1p(t\text{-}1)}} + \mathrm{P_{1pt}} - \left[\sum_{i=1}^{I} \sum_{a=1}^{A} (K_{aip} * X_{ai1t}) \right] + \mathrm{O_{1pt}} \qquad p = n+1,...,P; t = 1,...,T;$$

6. **Inventory capacity and security stock for materials:**

$$V_{1\mathrm{p}} \leq \mathrm{M_{1pt}} \leq MAX_{1\mathrm{p}} \qquad p = 1,...,P; t = 1,...,T;$$

7. **Production constraint:** The production of a product is constrained by the number of materials available to manufacture it.

$$\sum_{a=1}^{\mathrm{A}} \sum_{i=1}^{I} k_{aip} X_{ai1t} \leq \mathrm{M_{1p(t\text{-}1)}} + \mathrm{P_{1pt}} + \mathrm{O_{1pt}} \qquad p = 1,...,P; t = 1,...,T;$$

8. **Products Inventory:** Calculation of the products' inventories in the factory.

$$I_{i1t} = I_{\mathrm{i1(t\text{-}1)}} + \sum_{a=1}^{A} X_{ai1t} - q_{\mathrm{i1t}} \qquad i = 1,...,I; t = 1,...,T;$$

9. **Shipment Control:** Controls the shipment of final products to the DC.

$$\sum_{a=1}^{A} X_{ai1t} + I_{i1(t-1)} \geq q_{\mathrm{i1t}} \qquad i = 1,...,I; t = 1,...,T;$$

10. **Inventory capacity for products:**

$$SS_{\mathrm{i1t}} \leq I_{\mathrm{i1t}} \leq B_{\mathrm{i1t}} \qquad i = 1,...,I; t = 1,...,T;$$

11. **Stock-out or Inventory units of final products in DC:**

$$Y^{+}_{i(t-1)} - Y^{-}_{i(t-1)} + \mathrm{q_{i1t}} - \mathrm{d_{it}} = Y^{+}_{it} - Y^{-}_{it} \qquad i = 1,...,I; t = 1,...,T;$$

12. **Production Capacity:** Established in hours of production available per machine.

$$\sum_{\mathrm{a}=1}^{\mathrm{A}}\sum_{\mathrm{i}=1}^{\mathrm{I}} PT_{aim} X_{ai1t} \le U_{1mt} \qquad i=1,...,I;t=1,...,T;$$

Other production capacity constraints can be easily incorporated if necessary

13-21. **Integer and non-negativity constraints**

All variables are integer and greater than zero.

In summary the model is the following:

$$\min \sum_{a=1}^{A}\sum_{i=1}^{I}\sum_{t=1}^{T} C_{ai1t} X_{ai1t} + \sum_{i=1}^{I}\sum_{t=1}^{T} H_{i1} I_{ij1} + \sum_{i=1}^{I}\sum_{t=1}^{T} S_{it} Y_{it}^{-} + \sum_{p=1}^{P}\sum_{t=1}^{T} R_{1pt} P_{1pt} +$$

$$\sum_{p=1}^{P}\sum_{t=1}^{T} L_{1pt} M_{1pt} + \sum_{i=1}^{I}\sum_{t=1}^{T} T_{i1t} q_{i1t} + \sum_{i=1}^{I}\sum_{t=1}^{T} W_{it} Y_{it}^{+} + \sum_{p=1}^{P}\sum_{t=1}^{T} G_{1pt} O_{1pt} +$$

$$\sum_{p=1}^{P}\sum_{t=1}^{T} HO_{pt} IN_{pt} + \sum_{t=1}^{T}\sum_{i=1}^{I}\sum_{p=1}^{P} \lambda_{ipt}\, \underline{p}_{ipt} DC_{ipt}$$

Subject to:

1. $IN_{pt} = IN_{p(t-1)} + \sum_{i=1}^{I} \lambda_{ipt}\, \underline{p}_{ipt} - O_{1pt}$ $\qquad p = n+1,..., P; t = 1,..., T;$

2. $O_{1pt} \le IN_{p(t-1)}$ $\qquad p = n+1,..., P; t = 1,..., T;$

3. $IN_{pt} \le \mathrm{MRM}_{\mathrm{p}}$ $\qquad p = n+1,..., P; t = 1,..., T;$

4. $M_{\mathrm{1pt}} = \mathrm{M}_{\mathrm{1p(t-1)}} + \mathrm{P}_{\mathrm{1pt}} - \left[\sum_{i=1}^{I}\sum_{a=1}^{A} (K_{aip} * X_{ai1t})\right]$ $\qquad p = 1,..., P; t = 1,..., T;$

5. $M_{\mathrm{1pt}} = \mathrm{M}_{\mathrm{1p(t-1)}} + \mathrm{P}_{\mathrm{1pt}} - \left[\sum_{i=1}^{I}\sum_{a=1}^{A} (K_{aip} * X_{ai1t})\right] + \mathrm{O}_{\mathrm{1pt}}$ $\qquad p = n+1,..., P; t = 1,..., T;$

6. $V_{\mathrm{1p}} \le \mathrm{M}_{\mathrm{1pt}} \le MAX_{\mathrm{1p}}$ $\qquad p = 1,..., P; t = 1,..., T;$

7. $\sum_{a=1}^{\mathrm{A}}\sum_{i=1}^{I} k_{aip} X_{ai1t} \le \mathrm{M}_{\mathrm{1p(t-1)}} + \mathrm{P}_{\mathrm{1pt}} + \mathrm{O}_{\mathrm{1pt}}$ $\qquad p = 1,..., P; t = 1,..., T;$

8. $I_{i1t} = I_{\mathrm{i1(t-1)}} + \sum_{a=1}^{A} X_{ai1t} - q_{\mathrm{i1t}}$ $\qquad i=1,...,I;t=1,...,T;$

9. $\sum_{a=1}^{A} X_{ai1t} + I_{i1(t-1)} \geq q_{\mathrm{i1t}} \qquad i=1,\ldots,I; t=1,\ldots,T;$

10. $SS_{\mathrm{i1t}} \leq I_{\mathrm{i1t}} \leq B_{\mathrm{i1t}} \qquad i=1,\ldots,I; t=1,\ldots,T;$

11. $Y^{+}_{i(t-1)} - Y^{-}_{i(t-1)} + \mathrm{q}_{\mathrm{i1t}} - \mathrm{d}_{\mathrm{it}} = Y^{+}_{it} - Y^{-}_{it} \qquad i=1,\ldots,I; t=1,\ldots,T;$

12. $\sum_{\mathrm{a}=1}^{\mathrm{A}} \sum_{\mathrm{i}=1}^{\mathrm{I}} PT_{aim} X_{ai1t} \leq U_{1mt} \qquad i=1,\ldots,I; t=1,\ldots,T;$

13. $X_{ai1t} \geq 0 \quad and \ \text{integer};$

14. $P_{1pt} \geq 0 \quad and \ \text{integer};$

15. $q_{i1t} \geq 0 \quad and \ \text{integer};$

16. $I_{i1t} \geq 0 \quad and \ \text{integer};$

17. $Y^{+}_{it} \geq 0 \quad and \ \text{integer};$

18. $Y^{-}_{it} \geq 0 \quad and \ \text{integer};$

19. $M_{1pt} \geq 0 \quad and \ \text{integer};$

20. $O_{1pt} \geq 0 \quad and \ \text{integer};$

21. $IN_{pt} \geq 0 \quad and \ \text{integer};$

As we should observe, the $\mathrm{CPP}_{\mathrm{R1F}}$ model is very useful for companies today. In especial for those companies who have outsourcing production, or use to plan independently their production. The MBOM is also used in this model, and companies receives the benefits of working with reused materials and assemblies. As in the CPP model, the solution methods proposed and some examples will be covered in the next chapter. Next section describes the third model proposed for specific manufacturing environments.

4.5 One period collaborative model with returns (CPP_{R1P})

Last model proposed, considers the production planning for only one period. In this model, collaborative planning and remanufacturing are also considered. Basically, this model should be used for tactical planning where one period means six months or one year. This model facilitates the production planning when a detailed programming is not necessary. For investment decisions, or as an initial state in the forecasting process, this model can be of great help. In fact, this model without returns is widely used in business for strategic planning purposes. As we shall see in the next chapter, one of the main benefits of this model is it can be solved through optimization in a reasonable running time. Therefore, for practical reasons, companies should be very interested in obtaining the optimal solution of the plan in a reduced computational time.

This model allows companies to include all the returns in the traditional production planning and the collaboration within their supply chain. The model follows the same assumptions as the CPP_R model.

For simplicity, we replace in the original formulation the sub-index *t*, for the number *1*, indicating that all the formulation corresponds only for one period.

The supply chain works as follows:

- The CRP receives the returned products in a previous period. Therefore, it has the reused materials and assemblies available at the beginning of the period. The CRP has inventories of raw materials.
- The Factories manufacture the products based on the sales' and returns' forecasts. They purchase the materials to the suppliers and also send the final products to the Distribution Center. This purchasing process is not centralized. Factories hold inventories of raw materials, work in-process and final products.
- Suppliers receive the purchasing orders from factories and serve those orders in the same period of time (Just in time supply).
- The Distribution Center, receives the sales orders and serve the clients from its inventories at each product. In this case the not covered demand is lost and company incurs in stock-out costs derived from the opportunity cost of the sales lost, and from the lose of image of the company for this situation. DC holds only final product inventories.

We have capacity constraints in inventories and production. Other assumptions of the model are:

A. The CRP uses one period to perform the recovery process. Therefore, parts and assemblies obtained from recovered products arriving in period t will be only available at period $t+1$. Which implies that factories can use for planning purposes only those products available at the beginning of the period.

B. To manufacture the products, factories can use the materials' inventories from the previous period and materials purchased at the same period.

C. For each factory there are capacity constraints in time of production, storage capacity, and a security stock.

D. The transportation cost from suppliers to the different factories is included in the cost of the new materials.

E. Each plant can manufacture all or a subset of the products.

F. Production, purchasing and transportations costs should vary from one plant to another.

G. For each product the Modified Bill of Materials is known.

H. There is a forecasted product demand, (d_{i1}). This demand is previously known from the sales forecast.

I. Given the demand, the planner decides (i.e. the variables of the problem):

   a. The quantity to be produced of each article in each factory during the planning period, and also what will be the production process ($a=1..A$) used to manufacture it, (X_{aij1}).

   b. The quantity of each material to purchase, (P_{p1}).

   c. The quantity of each reused material or assemblies to be send during the period from the CRP to each plant, (O_{jp1}).

   d. The quantity of each material to leave in inventory at each plant at the end of the period, (M_{jp1}).

   e. The quantity of each final product to leave in inventory at each plant at the end of the period, (I_{ij1}).

f. The quantity of each final product to leave in inventory at the end of the period in the DC, (Y_{i1}).

g. The quantity of products to send from each factory to the Distribution Center during the planning period (q_{ij1}).

J. To make the above decisions the planner knows the following data:

a. Production costs per article, depending on the production process, and the factory, (C_{aij1}).

b. Transportation costs:

i. From the CRP to the factories (G_{pj1}).

ii. From factories to Distribution Center (T_{ij1}).

c. Holding costs per period:

i. For raw materials (at each factory), (L_{jp1}).

ii. For final products (at factories and distribution center) (H_{ij1}, W_{i1}) respectively.

iii. Reused materials at the CRP (HO_{p1}).

d. Disassembly costs (DC_{ip1}).

e. The Materials costs (R_{jp1}).

f. The Stock out costs per article at each period (S_{i1}).

g. The estimated number of parts and assemblies available “ready to use” at the beginning of the planning period from the CRP. We estimate the available number of reused materials and assemblies taking into account historical data.

h. The capacity constraints:

i. In hours per production per machine $(m=1..M)$ at each factory, (U_{im1}).

ii. Storage capacity at the factories. for each material (MAX_{jp1}) and final product (B_{ij1}).

i. The security stock for:

    i. Product at each factory (SS_{ij1}).
    ii. Material at each factory (V_{jp1}).

j. Initial inventories:

    i. Of materials. (IN_{p0}).
    ii. Of final products at each factory (I_{ij0}).

k. The Modified Bill of Materials (MBOM) (K_{aip}).

l. The number of parts and assemblies that should be obtained from the disassembly process of a product. (CF_{ip}).

m. The technical probability to obtain a part or assembly of good quality $([QU_{ip}=1])$ from the disassembly process of a product (p_{ipt}). This probability is calculated as in the CPP_R model. For a detailed description see section 3.3.2.1

With these considerations, we now can describe the mathematical formulation for the **CPP_{R1P}** Model. First of all let's present all data and variables:

Data

A= Number of production process that has the product with the maximum number of production processes.

I= Number of articles.

J= Number of plants.

M= Number of machines

P= Number of materials

C_{aij1}= Production cost of one unit of article i at plant j by process a.

H_{ij} = Holding cost per unit of article i at plant j.

HO_{p1}= Holding costs per unit of material p in CRP.

S_{i1} = Stock out cost per unit of article i.

R_{jp1}= Cost of purchase one unit of material p in plant j.

L_{jp1}= Holding cost per unit of material p in plant j.

SS_{ij1}= Security stock of product i at plant j.

B_{ij1}= Maximum allowed stock of product i at plant j.

K_{aip}= Quantity of material p needed to manufacture one unit of product i by process a.

CF_{ip}= Quantity of material p obtained from disassembly process of product i.

MAX_{jp}= Maximum allowed stock of material p at plant j.

V_{jp}= Security stock of material p at plant j.

T_{it1}= Transportation cost per unit of product i shipped from plant j to central facility.

G_{jp1}= Transportation cost per unit of material p shipped from central recovery plant to plant j.

d_{i1}= Demand of product i.

W_{i1}= Holding cost of product i on central warehouse.

PT_{aim}= Production time of one unit of product i by process a in machine m.

U_{jm1}= Hours of production capacity in plant j in machine m.

p_{ipt}= Probability of material p obtained from product i, to be of quality $QU=1$ (good quality) for remanufacturing.

DC_{ip1}= Cost of obtain part p disassembled from product i.

λ_{ipt}= Expected number of parts p obtained from all products i returned to the central recovery plant on period t.

QU= Quality assessment for materials where $QU=0$ means bad quality for remanufacturing and $QU=1$ means good quality for remanufacturing

I_{ij0}= Inventory units of product i in plant j at the beginning of the period.

IN_{p0}= Inventory units of material p in CRP at the beginning of the period.

MRM_p= Holding capacity for material p at CRP.

Variables

X_{aij1}= Number of units of product i to produce in plant j by process a.

P_{jp1}= Number of units of material p to purchase in plant j at the beginning of the period.

q_{i1t}= Quantity of product i shipped to central facility from plant j at the beginning of the period.

I_{ij1}= Inventory units of product i in plant j at the end of the period.

IN_{p1}= Inventory units of material p in CRP at the end of period.

M_{jp1}= Inventory units of material p in plant j at the end of period.

Y_{i1}^{-}= Number of units of stock out of article i at the end of the period in DC.

Y_{i1}^{+}= Inventory units of product i at the end of the period on DC.

O_{jp1}= Quantity of material p shipped from CRP to plant j.

The objective function of the model is to minimize the total costs of the system.

Formally we have:

$$\begin{aligned}
\min\; & \underbrace{\sum_{a=1}^{A}\sum_{j=1}^{J}\sum_{i=1}^{I} C_{aij1} X_{aij1}}_{\text{Production Costs}} + \underbrace{\sum_{j=1}^{J}\sum_{i=1}^{I} H_{ij} I_{ij1}}_{\text{Holding Costs of final products at factories}} + \underbrace{\sum_{i=1}^{I} S_{i1} Y_{i1}^{-}}_{\text{Stock-out Costs at Distribution Center}} + \underbrace{\sum_{j=1}^{J}\sum_{p=1}^{P} R_{jp1} P_{jp1}}_{\text{Purchasing Costs}} + \\
& \underbrace{\sum_{j=1}^{J}\sum_{p=1}^{P} L_{jp1} M_{jp1}}_{\text{Holding Costs of raw materials at factories}} + \underbrace{\sum_{j=1}^{J}\sum_{i=1}^{I} T_{ij1} q_{ij1}}_{\text{Transportation Costs from factories to D.C.}} + \underbrace{\sum_{i=1}^{I} W_{i1} Y_{i1}^{+}}_{\text{Holding Costs of final products at DC}} + \underbrace{\sum_{j=1}^{J}\sum_{p=1}^{P} G_{jp1} O_{jp1}}_{\text{Transportation costs of reused materials from CRP to the factories}} + \\
& \underbrace{\sum_{p=1}^{P} HO_{p1} IN_{p1}}_{\text{Holding Costs for reused materials at CRP}} + \underbrace{\sum_{t=1}^{T}\sum_{i=1}^{I}\sum_{p=1}^{P} \lambda_{ipt}\, \underline{p}_{ipt}\, DC_{ipt}}_{\text{Disassembly costs based on the expected number of products disassembled at CRP.}}
\end{aligned}$$

The constraints of the model are:

1. **Reusable materials and assemblies Inventory:** These constraints allow us to calculate the final inventory to leave at the end of the planning period.

$$IN_{p1} = IN_{p0} + \sum_{i=1}^{I} \lambda_{ip1} \underline{p}_{ip1} - \sum_{j=1}^{J} O_{jp1} \qquad p = n+1,\dots,P;$$

2. **Control of shipments:** Basically the CRP should send at most the reusable units and assemblies available at the beginning of the planning period.

$$\sum_{j=1}^{J} O_{jp1} \le IN_{p0} \qquad p = n+1,\dots,P;$$

3. **Inventory capacity for reusable materials and assemblies:** It controls the maximum quantity to leave of reusable materials at the end of the planning period.

$$IN_{p1} \le \mathrm{MRM_p} \qquad p = n+1,\dots,P;$$

4. **Materials Inventory:** To calculate the final inventory of purchased materials.

$$M_{\mathrm{jp1}} = \mathrm{M_{jp0}} + \mathrm{P_{jp1}} - \left[\sum_{i=1}^{I} \sum_{a=1}^{A} (K_{aip} * X_{aij1}) \right] \qquad j = 1,\dots,J;\ p = 1,\dots,n;$$

5. **Reusable materials and assemblies inventory:** To compute the final inventory of reused materials and assemblies.

$$M_{\mathrm{jp1}} = \mathrm{M_{jp0}} + \mathrm{P_{jp1}} - \left[\sum_{i=1}^{I} \sum_{a=1}^{A} (K_{aip} * X_{aij1}) \right] + \mathrm{O_{jp1}} \qquad j = 1,\dots,J;\ p = n+1,\dots,P;$$

6. **Inventory capacity and security stock for materials:** Limits the minimum and maximum inventories to leave at the end of the planning period.

$$V_{\mathrm{jp}} \le \mathrm{M_{jp1}} \le MAX_{\mathrm{jp}} \qquad j = 1,\dots,J;\ p = 1,\dots,P;$$

7. **Materials capacity constraints:** Assures that the factory will produce only those products it should manufacture with the available materials.

$$\sum_{a=1}^{A}\sum_{i=1}^{I} k_{aip} X_{aij1} \le \mathrm{M}_{\mathrm{jp0}} + \mathrm{P}_{\mathrm{jp1}} + \mathrm{O}_{\mathrm{jp1}} \qquad j=1,\ldots,J;\ p=1,\ldots,P;$$

8. **Products Inventory:** Serves to calculate the final inventory of products at each factory at the end of the planning period.

$$I_{ij1} = I_{\mathrm{ij0}} + \sum_{a=1}^{A} X_{aij1} - q_{\mathrm{ij1}} \qquad j=1,\ldots,J;\ i=1,\ldots,I;$$

9. **Shipment Control:** Control the quantity of products to send from the factories to the DC.

$$\sum_{a=1}^{A} X_{aij1} + I_{ij0} \ge q_{\mathrm{ij0}} \qquad j=1,\ldots,J;\ i=1,\ldots,I;$$

10. **Inventory capacity for products:** Control the security stock and maximum inventory to leave at the end of the period.

$$SS_{\mathrm{ij1}} \le I_{\mathrm{ij1}} \le B_{\mathrm{ij1}} \qquad j=1,\ldots,J;\ i=1,\ldots,I;$$

11. **Stock-out or Inventory units of final products in Distribution Center:** Computes the inventory of final products at the end of the planning period.

$$Y_{i0}^{+} - Y_{i0}^{-} + \sum_{\mathrm{j}=1}^{\mathrm{J}} \mathrm{q}_{\mathrm{ij0}} - \mathrm{d}_{\mathrm{i0}} = Y_{i1}^{+} - Y_{i1}^{-} \qquad i=1,\ldots,I;$$

12. **Production Capacity:** Limits the production capacity per available hours of each machine.

$$\sum_{\mathrm{a}=1}^{\mathrm{A}}\sum_{\mathrm{i}=1}^{\mathrm{I}} PT_{aim} X_{aij1} \le U_{jm1} \qquad j=1,\ldots,J;\ i=1,\ldots,I;$$

13-21. **Integer and non-negativity constraints**

All variables are integer and greater than zero.

In summary the model is the following:

$$\min \sum_{a=1}^{A} \sum_{j=1}^{J} \sum_{i=1}^{I} C_{aij1} X_{aij1} + \sum_{j=1}^{J} \sum_{i=1}^{I} H_{ij} I_{ij1} + \sum_{i=1}^{I} S_{i1} Y_{i1}^{-} + \sum_{j=1}^{J} \sum_{p=1}^{P} R_{jp1} P_{jp1} +$$
$$\sum_{j=1}^{J} \sum_{p=1}^{P} L_{jp1} M_{jp1} + \sum_{j=1}^{J} \sum_{i=1}^{I} T_{ij1} q_{ij1} + \sum_{i=1}^{I} W_{i1} Y_{i1}^{+} + \sum_{j=1}^{J} \sum_{p=1}^{P} G_{jp1} O_{jp1} +$$
$$\sum_{p=1}^{P} HO_{p1} IN_{p1} + \sum_{i=1}^{I} \sum_{p=1}^{P} \lambda_{ip1} \underline{p}_{ip1} DC_{ip1}$$

Subject to:

1. $IN_{p1} = IN_{p0} + \sum_{i=1}^{I} \lambda_{ip1} \underline{p}_{ip1} - \sum_{j=1}^{J} O_{jp1}$ $\qquad p = n+1,\ldots,P;$

2. $\sum_{j=1}^{J} O_{jp1} \le IN_{p0}$ $\qquad p = n+1,\ldots,P;$

3. $IN_{p1} \le \mathrm{MRM}_{\mathrm{p}}$ $\qquad p = n+1,\ldots,P;$

4. $M_{\mathrm{jp1}} = \mathrm{M}_{\mathrm{jp0}} + \mathrm{P}_{\mathrm{jp1}} - \left[\sum_{i=1}^{I} \sum_{a=1}^{A} (K_{aip} * X_{aij1}) \right]$ $\qquad j = 1,\ldots,J;\ p = 1,\ldots,n;$

5. $M_{\mathrm{jp1}} = \mathrm{M}_{\mathrm{jp0}} + \mathrm{P}_{\mathrm{jp1}} - \left[\sum_{i=1}^{I} \sum_{a=1}^{A} (K_{aip} * X_{aij1}) \right] + \mathrm{O}_{\mathrm{jp1}}$ $\qquad j = 1,\ldots,J;\ p = n+1,\ldots,P;$

6. $V_{\mathrm{jp}} \le \mathrm{M}_{\mathrm{jp1}} \le MAX_{\mathrm{jp}}$ $\qquad j = 1,\ldots,J;\ p = 1,\ldots,P;$

7. $\sum_{a=1}^{\mathrm{A}} \sum_{i=1}^{I} k_{aip} X_{aij1} \le \mathrm{M}_{\mathrm{jp0}} + \mathrm{P}_{\mathrm{jp1}} + \mathrm{O}_{\mathrm{jp1}}$ $\qquad j = 1,\ldots,J;\ p = 1,\ldots,P;$

8. $I_{ij1} = I_{\mathrm{ij0}} + \sum_{a=1}^{A} X_{aij1} - q_{\mathrm{ij1}}$ $\qquad j = 1,\ldots,J;\ i = 1,\ldots,I;$

9. $\sum_{a=1}^{A} X_{aij1} + I_{ij0} \ge q_{\mathrm{ij0}}$ $\qquad j = 1,\ldots,J;\ i = 1,\ldots,I;$

10. $SS_{\mathrm{ij1}} \le I_{\mathrm{ij1}} \le B_{\mathrm{ij1}}$ $\qquad j = 1,\ldots,J;\ i = 1,\ldots,I;$

11. $Y_{i0}^{+} - Y_{i0}^{-} + \sum_{\mathrm{j=1}}^{\mathrm{J}} \mathrm{q}_{\mathrm{ij0}} - \mathrm{d}_{\mathrm{i0}} = Y_{i1}^{+} - Y_{i1}^{-}$ $\qquad i = 1,\ldots,I;$

12. $\sum_{\mathrm{a=1}}^{\mathrm{A}} \sum_{\mathrm{i=1}}^{\mathrm{I}} PT_{aim} X_{aij1} \le U_{jm1}$ $\qquad j = 1,\ldots,J;\ i = 1,\ldots,I;$

13. $X_{aij1} \ge 0$ *and* integer;

14. $P_{jp1} \geq 0 \quad and$ integer;

15. $q_{ij1} \geq 0 \quad and$ integer;

16. $I_{ij1} \geq 0 \quad and$ integer;

17. $Y_{i1}^{+} \geq 0 \quad and$ integer;

18. $Y_{i1}^{-} \geq 0 \quad and$ integer;

19. $M_{jp1} \geq 0 \quad and$ integer;

20. $O_{jp1} \geq 0 \quad and$ integer;

21. $IN_{p1} \geq 0 \quad and$ integer;

4.6 Conclusions and future Research

The three special models considered in this chapter are only some of the possible modifications and adaptations of the CPP_{R} model. Notice that, for instance, a production planning model without returns and for one factory (not considered here) is one of most traditional production planning models proposed for tactical planning in the literature. Therefore, the selection of the most suitable model depends on the supply chain configuration and practices. These models allows planners to fulfill better the planning requirements of some supply chain configurations.

The first model proposed was the CPP model, which allows companies to do collaborative planning when they do not need to work with reused parts and assemblies. Second model, the CPP_{R1F} model, has been developed for those companies who want to introduce the returns in their planning process without sharing their production plans with other factories. Third model is suitable for more general planning purposes where the companies want to plan one period of time. The advantages of this last model is that optimization routines can be used to solve the model in a reasonable running time.

First two models also serve for those companies using outsourcing, in the first case the model is used when all the production process is outsourced and, the second model is used when only a part of the production process is outsourced.

Those characteristics make these models really important for business today.

As mentioned at the beginning of this chapter, one of the main objectives of developing these special cases is to analyze the impact of number of periods, number of factories and returns on the difficulty of solving the CPP_R model. The solution methods and the computational experiments made to solve these models are showed in the next chapter.

4.7 Chapter References

Fleischmann, M., B.-R., Jacqueline M., Van der Laan, Erwin Van Nunen, Jo A.E.E. and Van Wassenhove, Luck N. (1997). "Quantitative models for Reverse Logistics: A review." European journal of Operational Research **103**: 1-17.

Guide Jr, V.D.R. (2000). "Production planning and control for remanufacturing: industry practice and research need." Journal of Operations Management **18**: 467–483.

Guide Jr, V.D.R., Jayaraman, V., Srivastava, R., (1999). "Production planning and control for remanufacturing: a state-of-the-art survey." Robotics and Computer-Integrated Manufacturing **15**(3): 221–230.

Guide Jr., V.D.R., Srivastava,R. (1998). "Inventory buffers in recoverable manufacturing." Journal of Operations Management **16**: 551-568.

Jain A., Udaka. S. (2005). "Aggregate production planning for a continuous reconfigurable manufacturing process." Computers & Operations Research **32**: 1213–1236.

Kiesmüller, G. P., Van der Laan, E. A. (2001). "An inventory model with dependent product demands and returns." International Journal of Production Economics **72**(2001): 73-87.

Mazzola, J. B., Neebe, A. W., Rump, C. M. (1998). "Multiproduct production planning in the presence of work-force learning." European Journal of Operational Research **106**: 336-356.

Vercellis, C. (1999). "Multi-plant production planning in capacitated self-configuring two-stage serial systems." European Journal of Operational Research **119**: 451-460.

CHAPTER 5: Solution Techniques for the Production Planning Models

5.1 Introduction

Chapter 5 considers the solution strategies for the production planning models proposed in chapters 3 and 4. We propose here two methods to solve the CPP_R model and the specific models. First method is the Branch and Bound, which gives us the optimal solution for the models, but as we shall see the computational time is not good for practical purposes. We decided then to propose a second method through a heuristic procedure. One special characteristic of this heuristic, is that uses the branch and bound method as a part of the solution procedure.

The chapter is structured as follows: second section present a brief literature review, third section describes the optimization procedure with some examples and results. Fourth section describes the heuristic algorithm, also with some examples and results. Finally section five states some conclusions and future research.

5.2 Literature Review

Production planning is an important task in manufacturing companies. A very good production-planning program can make the difference between the success or failure of a company.

For many years, manufacturing companies have applied optimization techniques to production planning with some degree of success, but only in the last years, companies have been aware of the importance of sharing their plans with the other companies within their supply chain. This has been called in the literature Collaborative Planning, Forecasting and Replenishment (CPFR), Danese et al.(2004), Holweg et al.(2005).

Several studies have also identified the problems caused by a lack of coordination, and to what extent competitive advantage can be gained from a seamless supply chain, Lee et al.(1997), Chen et al.(2000). Some authors in fact, attribute the success of the Japanese manufacturing model to the collaborative scheme with their suppliers, Hines (1998), Liker and Whu (2000).

However, due to uncertainty in cost and production parameters, the methods looking for the optimum show to be less effective in handling industrial applications. Many production constraints, such as sequence dependencies, capacity restrictions or resource allocations, lead to NP-hard optimization problems, Monma and Potts (1989), Pinedo (1995), for which cost optimum solutions cannot be computed within a reasonable CPU time.

The problem is complicated when we add the returns, which increase the level of uncertainty and generates new conditions to take into account to deal with the problems arising in the remanufacturing environment, Guide Jr (2000).

For those reasons, heuristics algorithm have became widely used in production planning, Berning et al.(2004), Jain and Udaka (2005), Jian-Hung and Shinn-Ying (2005).

5.3 Optimization

In order to evaluate the difficulty of solving the production planning models proposed in the previous chapters, we randomly generate sixty supply chains with 17 different network configurations. We used the commercial software LINGO to solve the models. The networks configuration where generated taking into account the elements of the model. We vary the number of factories, articles, production processes, materials and periods of time. Table 20 illustrates the networks considered to perform the work.

Next we will describe the results for each model in the same order they have been presented in this work. i.e. first we will consider the CPP_R, then we will consider the CPP model, later the CPP_{R1F} model and, finally the CPP_{R1P} model.

5.3.1 The CPP_R model

As we expected, the results were quite different depending on the model and the network configuration. For the CPP_R model, we obtained the optimal solution in the 43,33% of the models. In the remaining examples, we have stopped the algorithm because the time was too large, and therefore not useful in practice. The criteria selected to stop the optimization process was the following: If a feasible (but not optimal) solution is found, stop at 1 hour of running time, otherwise we wait until a feasible solution is found.

Table 21 shows some statistics obtained from the examples where the optimal solution was found. In appendix B, we present the summarized results for this model. On the other hand, table 22 shows the same statistics for those cases where the optimal solution was not found.

Network Number	Periods	Factories	Articles	Materials	Production Processes	Machines
1	2	2	2	2	2	2
2	12	2	5	5	3	5
3	12	2	8	8	5	5
4	12	3	15	8	10	10
5	6	2	10	10	5	5
6	12	1	5	5	3	3
7	2	5	15	6	3	3
8	12	3	5	5	10	10
9	12	1	5	5	15	15
10	12	1	100	5	10	10
11	24	2	5	5	5	5
12	24	1	1	10	5	5
13	12	1	5	15	5	5
14	12	1	5	5	5	5
15	12	2	20	20	2	10
16	12	1	20	20	5	5
17	12	5	50	10	10	10

TABLE 20. SUPPLY CHAIN CONFIGURATIONS

% Cases with optimal solution found	43,33%
Minimum computational time	1 sec
Maximum computational time	47 min 27 sec
Average time	8 min 16 sec
Medium time	40 sec
Standard deviation	14 min 22 sec
% cases over 1 minute	34.61%
% cases under 1 minute	65.38%

TABLE 21. STATISTICS OF CASES WHERE OPTIMAL SOLUTION WAS FOUND.

% Cases with optimal solution not found	56,67%
Minimum computational time	1 hrs 00 min 00 sec
Maximum computational time	36 hrs 06 min.52 sec
Average time	7 hrs 8 min 20 sec
Medium time	5 hrs 3 min 11 sec
Standard deviation	8 hrs 13 min 15 sec

TABLE 22. STATISTICS OF CASES WHERE OPTIMAL SOLUTION WAS NOT FOUND.

As we can observe, the use of the branch-and bound approach to solve this problem is not effective since the computational times and the standard deviation are too large to be used in real business. This means that there is not security about how much time will spend the branch and bound method to achieve the optimal solution.

To examine the reason of those large computational times, we performed a binary logistic regression. We consider as dependent variable a binomial variable expressing if optimal solution was found or not. As independent variables, we use the network configuration elements (i.e. factories, periods, articles, materials, production processes and machines) plus five additional variables namely: a capacity measure, one variable reflecting the number of examples of each network configuration, and the number of variables, constraints and integer variables of the problem. Although average time should be also used as dependent variable, in our case it is not possible because those examples which have not reach the optimum where stopped prior to completion, therefore this time is not representative.

We also studied the relation between the number of constraints, variables and integer variables with the dependent variable. We applied a logistics regression where the dependent variable was a binary variable with the value of 1 if in the particular problem the optimal solution was found, and 0 otherwise. As independent variables we use the number of constraints, variables and integer variables. We also studied the relation between those independent variables and the running time. This second analysis was performed only for those experiments where the optimal solution was found. From those statistical experiments, we found that the significant variables affecting the running time and the fact of achieving the objective function are: The number of plants, the number of production processes and the number of periods.

In fact, periods, plants and production processes where the significant variables at a 95% of confidence. On the other hand, articles, materials or machines, have little influence on the results. As we shall see, the results obtained from practical experiments, showed that number of periods is the most important variable in increasing the computational time. Results of the binary logistic regression are showed in Appendix A.

The results obtained from the binary logistic regression show us that when the number of factories, production processes and periods increases, the computational time to solve the model also increases. Therefore, reducing those factors, we can gain from the reduction in computational time.

These three elements coincide exactly with the models proposed for the specific manufacturing situations explained in chapter 4. In other words, CPP model only has one production process, CPP_{R1F} only has one factory to plan and, CPP_{R1P} model only serves to plan one period of time. Therefore, if results are correct then the computational time spent to solve those models will be lower than the computational time used to solve the CPP_R model.

Our ultimate goal is to analyze the possibility of solving the CPP_R model in a reasonable computational running time. Then following our findings we explore the idea of using those specific models as part of a solution procedure to the CPP_R model.

Next, we describe the results obtained for the other three models proposed.

5.3.2 The CPP model

We have made a program in C++ to aggregate the data of the CPP_R model to be able to run the specific models to the same instances.

The first model was the CPP model, as was explained in chapter 4, in this model remanufacturing is not allowed. It means that there is only one production process to manufacture the products. In the experiments for this model, running times were also very large and therefore the model becomes not useful for practical purposes. However, surprisingly, the results are the worst results within the three specific models, only a 6,7 % of the cases found the global optimum; although the times we allow the program to run the operation, were reduced. Tables 23 and 24 show the results obtained from these models and the results of the computational experiments are showed in Appendix B. In table 23, the minimum computational time is zero, it means that the solution was immediately found, in less than one second.

% Cases with optimal solution found	6.7%
Minimum computational time	0
Maximum computational time	19 sec
Average time	5,0 sec
Standard deviation	9,0 sec
% cases under 1 minute	6,7 %
% cases over 1 minute	93.,3%

TABLE 23. STATISTICS OF CASES WHERE OPTIMAL SOLUTION WAS FOUND.

% Cases with optimal solution not found	93.3%
Minimum computational time	1 hr 06 min 54 sec
Maximum computational time	8 hrs 49 min.42 sec
Average time	2 hrs 21 min 56 sec
Standard deviation	1 hrs 56 min 7 sec

TABLE 24. STATISTICS OF CASES WHERE OPTIMAL SOLUTION WAS NOT FOUND.

5.3.3 The CPP$_{R1F}$ model

The results obtained from this model were similar to the previous case. From the binary logistic regression we observe that reduction in plants was a significant variable in finding the global optimum solution. However, when we used branch and bound to solve the problem, we observe that in most of the cases, running times were very large. The reason of that should be that there is a combined effect between this variable and another one. At the end, this model leads to an inefficient approach when branch and bound is used. Notice that in the case where the network configuration have only 1 factory, the CPP$_R$ is equal to this specific CPP$_{R1F}$ model. The results of the computational experiments are summarized in table 25 and 26.

% Cases with optimal solution found	31.66%
Minimum computational time	0
Maximum computational time	1 hrs 04 min.42 sec
Average time	6 min 19 sec
Standard deviation	17 min 43 sec
% cases over 1 minute	10.56%
% cases under 1 minute	89.44%

TABLE 25. STATISTICS OF CASES WHERE OPTIMAL SOLUTION WAS FOUND.

As we can observe, the branch-and-bound procedure is not a efficient method for this model, perhaps in the future it is possible to develop a heuristic method to solve it in lower computational times. An interesting issue is that, in those instances where the global optimum was easily founded, the number of periods was also a determinant factor. Appendix B shows the summarized results of this model.

% Cases with optimal solution not found	69.44%
Minimum computational time	1 hr 13 min 03 sec
Maximum computational time	15 hrs 12 min.33 sec
Average time	5 hrs 54 min 09 sec
Standard deviation	4 hrs 24 min 16 sec

TABLE 26. STATISTICS OF CASES WHERE OPTIMAL SOLUTION WAS NOT FOUND.

5.3.4 The CPP_{R1P} model

The results of the CPP_{R1P} model were quite good, all the examples reached the optimal solution in short computational times. Table 27 summarizes the results and Appendix B shows the results of this model

% Cases with optimal solution found	100.00%
Minimum computational time	0 sec
Maximum computational time	01 min.40 sec
Average time	11 sec
Standard deviation	21,183 sec
% cases over 1 minute	8.33%
% cases under 1 minute	91.77%

TABLE 27. STATISTICS OF THE CPP_{R1P} MODEL.

The results obtained show that this kind of aggregation should be useful as one of the steps in solving the CPP_R model. This model by itself should be very useful in companies, in fact traditional manufacturing tactical planning, assumes as one unique period all the time horizon as a first step in calculating the possible resources needed. The variation with our model is that although it also use one period of planning horizon, it also includes returns and the possibility of planning the machines capacity, which provides a more real approximation to tactical planning in companies.

Therefore, given the results obtained in the CPP_{R1P} model, we can see that periods are a critical factor that affect the running times.

Network Number	CPP_R	CPP	CPP_{R1F}	CPP_{R1P}
1	100%	100%	100%	100%
2	100%	0%	50%	100%
3	0%	0%	0%	100%
4	0%	0%	0%	100%
5	0%	0%	0%	100%
6	100%	0%	0%	100%
7	100%	0%	0%	100%
8	0%	0%	0%	100%
9	100%	0%	40%	100%
10	50%	0%	50%	100%
11	60%	0%	60%	100%
12	0%	0%	0%	100%
13	40%	0%	60%	100%
14	0%	0%	0%	100%
15	0%	0%	0%	100%
16	25%	0%	25%	100%
17	100%	0%	60%	100%

TABLE 28. % OF CASES WHERE OPTIMAL SOLUTION WAS FOUND IN EACH MODEL.

Table 28 shows the percentage of the experiments that obtained the optimal solution at each network configuration.

If we compare the solutions obtained, we can see that the unique network configuration that performs well under all the production planning models, is the first one. This is because it is the most simple, composed only by two factories, two articles, two plants, two periods, two machines and two production processes. In the other examples the results are well differentiated between the models, but we also must take into consideration that although the optimal solution has been found, the time spent in the process was really large. Appendix B shows the results for all the experiments.

5.3.5 Conclusions of Optimization

In chapters 3 and 4 we have introduced four tactical production planning models to deal with different situations presented in manufacturing firms. In this section we presented the solution of the models through branch-and-bound optimization methods using LINGO software. Although depending on the network configuration the CPP_R model and 2 out of 3 special cases required very large computational times which makes this approach not suitable to be implemented in real manufacturing planning.

At the beginning of this chapter, we ran a logistics regression to analyze the impact of different variables over the computational times. From this logistic regression we found that number of periods, production processes and number of factories had a significant impact on computational time.

We obtain 60 instances by random generation and the results obtained showed that the CPP_{R1P} model had the best performance in terms of running time and percentage of optimal solutions found. Therefore, in corroborates our statistical findings about the number of periods has a significant impact on the computational time when solving the CPP model.

As a conclusion of this section, we find that it is very important to develop a heuristic algorithm to obtain good solutions in a reasonable running time for the production planning models. Also, given the results obtained with the branch and bound method, a possible alternative is to use the CPP_{R1P} model as part of the heuristic algorithm, mainly because the size of the models and the iteration between all variables of the model will lead to a complex heuristic. Therefore, the use of branch and bound as part of the solution should improve both the time and the quality of the solution.

Next section describes the heuristic developed for the CPP_R model.

5.4 An Heuristic for the CPP_R model

Aware of the importance of developing new alternatives to improve the performance of the companies, our purpose in this section is to develop a heuristic for the Collaborative Production Planning model with returns (CPP_R) that deals with the concepts of Supply Chain Collaboration and Integration and, Reverse Logistics. The heuristic proposed in this section combines optimization with a local search algorithm to solve the CPP_R, evaluating some instances with different configurations of supply chains, varying the number of production plants, products, materials, processes and machines.

Next we will introduce the heuristic algorithm then, we show the computational experiments and, at the end, some conclusions and future research is stated.

5.4.1 The heuristic procedure

As we observed in previous section, initially we solve the CPP_R model by branch-and-bound method using a relaxation of the integer constraints for all the variables except for the variable X_{aijt} (the number of units to produce at each period, factory and under a specific production process). With this relaxed model, the computational time was reduced, however these times are still relatively high for large dimension instances, in particular for large dimension network configurations or products portfolio (3 hours and 55 minutes in average for our instance's network with a maximum instance stopped at 36 hours and 7 minutes without finding the optimal solution).

In a first trial to reduce the computational time, we decided to use a combination of optimization and simulation processes as was showed in chapter 3. These kinds of methods have been recently used by researchers, Cheung (2001), but we still obtaining very large computational times for large instances. At the end, we decided to develop a heuristic procedure to solve the CPP_R model in a reasonable running time.

Our heuristic combines Optimization routines with a Local Search technique, in order to improve the solutions obtained. This kind of combined methods has been used in the literature to solve very large scale problems leading to good results, Vercellis (1999).

The CPP_R model has two general objectives: Firstly, we need to find the optimal quantity of production, and inventory to hold at each period for the whole system; and, secondly within each period, we need to find the optimal quantity to produce, inventory to hold and, material to purchase at each factory. This multi-period, multi-factory scheme is complicated with the addition of the returns problem. Also the multi-process approach creates a lot of problems in terms of the uncertainty in the quality and quantity of the reused materials and, in terms of the production path or processes associated with the production of each product, leading to great complexity in the production planning.

Next, we will describe the principles of the heuristic proposed; to do it, we will use an example of a planning horizon of 12 periods. Given the results of the experiments developed with the 3 models of the chapter 4, we decide to use the CPP_{R1P} model as part of the solution of the Collaborative Production-Planning model with returns (CPP_R). In this way, we simplify the process and reduce the computational time.

In general terms, the heuristic consist in four steps:

- Partial Aggregation.
- Optimization.
- Disaggregation.
- Local search.

Figure 16 summarizes the heuristic process. Next we will describe each one of the steps, in detail.

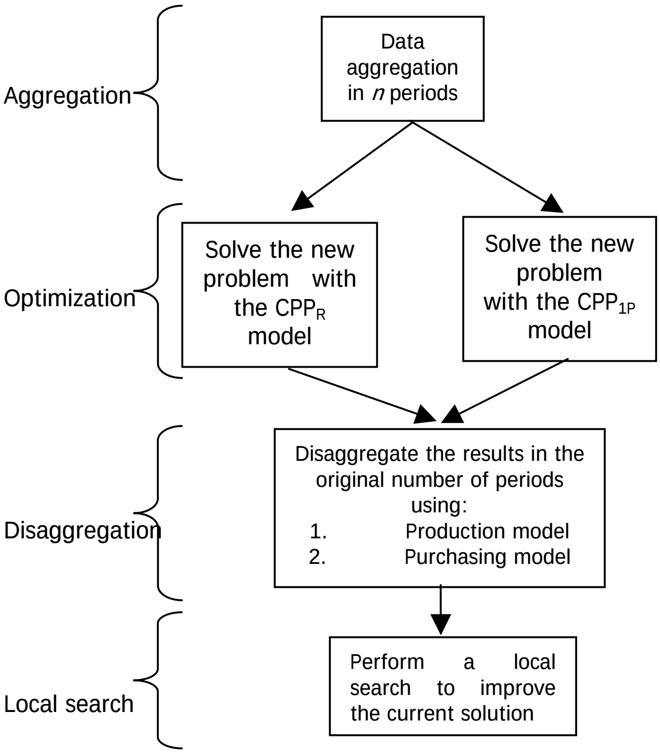

FIGURE 16. THE HEURISTIC PROCESS

5.4.1.1 Aggregate data of the CPP_R Model

The main idea of the heuristic is to simplify the model by aggregating the data and solve a simple model and solve to optimality the simpler model. Afterwards, we apply several techniques do disaggregate. After the application of several criteria of aggregation (number of factories, periods of time, production processes, etc), we decided to do the aggregation by time, given that it was the one with best results in terms of quality and speed, as concluded in the previous chapter. This aggregation consist in grouping the data of several periods into a reduced number of periods, obtaining a problem with less variables and constraints, which consequently is easier to solve and, therefore will be solved in less computational time.

A new model, the CPP_{R1P} model was then created, which is a particular case of the CPP_R model. The basic difference is that CPP_{R1P} evaluates only one period of planning.

Therefore, the first step is the aggregation of all the data in order to reduce the size of the problem, allowing us to use the CPP_{R1P} model to optimize each period at a time, or the CPP_R model for a reduced number of periods (as the data is grouped).

To group the data by periods an algorithm was created using C++. The result of this algorithm is the data organized for the desired periods of production planning. We introduce the original data of the problem and then, we specify the number of periods we want. The program groups the data following the criteria of adding consecutive periods. i.e. in our example of 12 periods, if we ask the program to group the data in a resulting four groups of data, the resulting groups will be:

Group 1: periods 1, 2 and 3.

Group 2: periods 4, 5 and 6.

Group 3: periods 7, 8 and 9

Group 4: periods 10, 11 and 12.

The algorithm allows us to summarize data from different production networks and periods, keeping the networks with their original configuration (except for the number of periods). These data are the inputs for the CPP_{R1P} problem or the CPP_R problem depending on which one we decide to use in the next step.

5.4.1.2 Optimization step: The CPP_{R1P} or the CPP_R model

Once we have grouped the data, we have two options:

- One, we can solve the model as a 4 period problem (in our example) or,
- We can solve each period separately with the CPP_{R1P} model.

First choice is always the CPP_R model for the reduced number of periods. Since we need only to run it once for the for periods. Notice that using the CPP_{R1P}, implies that we will run it several times, one for each planning period. Therefore, we set the criteria of only when the CPP_R model takes more than one minute to be solved, we use the CPP_{R1P}.

The CPP_R model is a set of various CPP_{R1P} models. Therefore, depending on the complexity of the problem, it is preferable to use one or the other. At the end what will happen is that if the model is really complex, in terms of the number of variables and constraints, it is better to use the CPP_{R1P} model, because it considers each period independently. On the other hand, if the problem is not really large, then the CPP_R problem should be used.

At the end of this step, we have calculated the total quantity to produce for each article, production process and factory during the grouped periods.

5.4.1.3 Disaggregate the results obtained into the CPP_R model structure

Third step is the disaggregation of the results obtained from the optimization into the original number of periods. The resulting solution is a solution for original CPP_R model. The production quantities obtained from the optimization step are maintained for each grouped period; i.e. in a specific group, when we disaggregate the data, one of the conditions is that the quantity of production for this group must be equal to the production during corresponding periods in that group.

To split the quantity along the original periods we create also two new mathematical models: the production model and the purchasing model.

5.4.1.3.1 The production model.

The main objective of the production model is to calculate the quantity to produce of each product at each period but without considering the purchasing capacity. The production model helps us to split the produced quantity between the periods without caring about the purchasing cost. This model considers also the constraints of production given the actual forecast of returned products. In other words, we assume that all the materials needed will be available. In this model we already know from the first step of the heuristic the total quantity of one article to produce per each factory and each production process in the whole planning period. The decision we need to take is when (i.e. in which period) to manufacture the products.

The objective of this model is to minimize the total production, transportation and holding costs. Subject to: (The constraints are equal to the ones of model CPP_R in page 97, only number 5 is new).

1. **Products Inventory:** These constraints calculates the final inventory of products at each period, becoming the initial inventory for the next period.
2. **Shipment Control:** The quantity of the products shipped from factories to the DC is obviously limited by the quantity produced of the respective article at that period plus the quantity in inventory.
3. **Inventory capacity for products:** Each factory has a maximum holding capacity and a minimum security stock for each product.
4. **Stockout or Inventory units of final products in Distribution Center:** Stock out or inventory units are allowed at the DC. We divided variable Y_{it} into Y_{it}+ and Y_{it}- as in the CPP_R model.
5. **Production limit:** The production of all the periods, per each article, factory and production process, must be less than or equal to the total production of that factory during all the planning period (X_{aij}) (This comes from the results of the CPP_{R1P} model).
6. **Production Capacity:** We have limited the production capacity per machine to a specified number of hours per period. Each unit of product

have previously assigned the number of minutes necessary to manufacture each unit of the product for each one of the available machines. This is represented by the parameter PT_{aim}.

7. **Integer and non-negativity constraints:** All variables are integer and greater than zero.

This model has the following variables:

X_{aijt}= Production units of article i in period t and factory j by production process a.

q_{ijt}= Quantity of product i shipped to central facility from plant j on period t.

I_{ijt}= Inventory units of product i in plant j at the end of period t.

Y_{it}^{-}= Number of units of stock out of article i at period t in DC.

Yit^{+}= Inventory units of product i at period t on DC.

The data are:

C_{aijt}= Production cost of one unit of article i at plant j by process a on period t.

H_{ij} = Holding cost per unit of article i at plant j.

S_{it} = Stock out cost per unit of article i at period t.

T_{ijt}= Transportation cost per unit of product i shipped from plant j to central facility on period t.

d_{it}= Demand of product i at period t.

W_{it}= Holding cost of product i at period t on central warehouse.

X_{aij}= Total production of product i in factory j by production process a during all the planning period.

PT_{aim}= Production time of one unit of product i by process a in machine m.

U_{jmt}= Hours of production capacity in plant j at period t in machine m.

Formally we have:

$$\min \sum_{a=1}^{A}\sum_{j=1}^{J}\sum_{i=1}^{I}\sum_{t=1}^{T} C_{aijt}X_{aijt} + \sum_{j=1}^{J}\sum_{i=1}^{I}\sum_{t=1}^{T} H_{ij}I_{ijt} + \sum_{i=1}^{I}\sum_{t=1}^{T} S_{it}Y_{it}^{-} +$$
$$\sum_{j=1}^{J}\sum_{i=1}^{I}\sum_{t=1}^{T} T_{ijt}q_{ijt} + \sum_{i=1}^{I}\sum_{t=1}^{T} W_{it}Y_{it}^{+}$$

Subject to:

1. $I_{ijt} = I_{\mathrm{ij(t-1)}} + \sum_{a=1}^{A} X_{aijt} - q_{\mathrm{ijt}}$ $\quad j=1,\ldots,J;\ i=1,\ldots,I; t=1,\ldots,T;$

2. $\sum_{a=1}^{A} X_{aijt} + I_{ij(t-1)} \geq q_{\mathrm{ijt}}$ $\quad j=1,\ldots,J;\ i=1,\ldots,I; t=1,\ldots,T;$

3. $SS_{\mathrm{ijt}} \leq I_{\mathrm{ijt}} \leq B_{\mathrm{ijt}}$ $\quad j=1,\ldots,J;\ i=1,\ldots,I; t=1,\ldots,T;$

4. $Y_{i(t-1)}^{+} - Y_{i(t-1)}^{-} + \sum_{\mathrm{j=1}}^{\mathrm{J}} \mathrm{q_{ijt}} - \mathrm{d_{it}} = Y_{it}^{+} - Y_{it}^{-}$ $\quad i=1,\ldots,I; t=1,\ldots,T;$

5. $\sum_{\mathrm{a=1}}^{\mathrm{A}}\sum_{\mathrm{i=1}}^{\mathrm{I}} PT_{aim}X_{aijt} \leq U_{jmt}$ $\quad j=1,\ldots,J;\ i=1,\ldots,I; t=1,\ldots,T;$

6. $\sum_{t=1}^{T} X_{aijt} \leq X_{aij}$ $\quad j=1,\ldots,J;\ i=1,\ldots,I; a=1,\ldots,A;$

7. $X_{aijt} \geq 0$ *and* integer;

8. $q_{ijt} \geq 0$ *and* integer;

10. $I_{ijt} \geq 0$ *and* integer;

11. $Y_{it}^{+} \geq 0$ *and* integer;

12. $Y_{it}^{-} \geq 0$ *and* integer;

Once we have obtained the production plan for all the periods (12 months in our example), we run the purchasing model.

5.4.1.3.2 The purchasing model.

The purchasing model uses the quantities to produce from the production model and calculates the inventory levels and purchasing schedule. This model also equilibrates the production quantities in case that purchasing and inventories constraints had not been meet.

The objective of this model is to minimize the purchasing costs given the production schedule obtained from the production model.

This is subject to:

1. **Reusable materials and assemblies Inventory:** These constraints calculates the final inventory of reusable materials at each period, which becomes the initial inventory for the next period.
2. **Control of shipments:** We assume that parts recovered in a period are shipped to the manufacturing plants in the next period. With these set of constraints we guarantee that we only ship from the CRP to the factories at most the products we have in inventory at the end of the previous period. Remember that we have assumed that recovery process take one period.
3. **Inventory capacity for reusable materials and assemblies:** We have capacity constraints per each material at the CRP.
4. **Materials Inventory:** These constraints calculates the final inventory of materials at each period, becoming the initial inventory for the next period.
5. **Reusable materials and assemblies inventory:** This is the same as the previous one, but for the recovered parts and assemblies received from the CRP. Therefore we do not have the purchasing variable P_{jpt}, but the number of reusable materials and assemblies received at each period from the CRP (O_{jpt}).
6. **Inventory capacity and security stock for materials:** Each factory has a maximum holding capacity and a minimum security stock for each material.
7. **Materials capacity constraints:** The number of products to be produced is constrained by the availability of the materials.
8. **Integer and non-negativity constraints**

All variables are integer and greater than zero.

Variables:

P_{jpt}= Number of units of material p to purchase in plant j at the beginning of period t.

IN_{pt}= Inventory units of material p in CRP at the end of period t.

M_{jpt}= Inventory units of material p in plant j at the end of period t.

O_{jpt}= Quantity of material p shipped from CRP to plant j on period t.

Data:

d_{it}= Demand of product i at period t.

X_{aijt}= Total production of product i in factory j by production process a during the period t.

K_{aip}= Quantity of material p needed to manufacture one unit of product i by process a.

P_{ipt}= Probability of material p obtained from product i, to be of quality QU for remanufacturing.

QU= Quality assessment for materials where:

$QU=0$ means bad quality for remanufacturing and

$QU=1$ means good quality for remanufacturing

CF_{ip}= Quantity of material p obtained from disassembly process of product i.

λ_{ipt}= Number of parts p obtained from returned products i at period t

Formally we have:

$$\min \sum_{j=1}^{J}\sum_{p=1}^{P}\sum_{t=1}^{T} R_{jpt} P_{jpt} + \sum_{j=1}^{J}\sum_{p=1}^{P}\sum_{t=1}^{T} L_{jpt} M_{jpt} + \sum_{j=1}^{J}\sum_{p=1}^{P}\sum_{t=1}^{T} G_{jpt} O_{jpt} +$$
$$\sum_{p=1}^{P}\sum_{t=1}^{T} HO_{pt} IN_{pt} + \sum_{t=1}^{T}\sum_{i=1}^{I}\sum_{p=1}^{P} \lambda_{ipt}\, \underline{p}_{ipt} DC_{ipt}$$

1. $$IN_{pt} = IN_{p(t-1)} + \sum_{i=1}^{I} \lambda_{ipt}\, \underline{p}_{ipt} - \sum_{j=1}^{J} O_{jpt} \qquad p = n+1,\dots, P; t = 1,\dots, T;$$

2. $\sum_{j=1}^{J} O_{jpt} \le IN_{p(t-1)};$ $\qquad p = n+1,\ldots, P; t = 1,\ldots, T;$

3. $IN_{pt} \le \mathrm{MRM}_{\mathrm{p}}$ $\qquad p = n+1,\ldots, P; t = 1,\ldots, T;$

4. $M_{\mathrm{jpt}} = \mathrm{M}_{\mathrm{jp(t-1)}} + \mathrm{P}_{\mathrm{jpt}} - \left[\sum_{i=1}^{I}\sum_{a=1}^{A}(K_{aip} * X_{aijt})\right]$ $\qquad j=1,\ldots,J; p=1,\ldots,n; t=1,\ldots,T;$

5. $M_{\mathrm{jpt}} = \mathrm{M}_{\mathrm{jp(t-1)}} + \mathrm{P}_{\mathrm{jpt}} - \left[\sum_{i=1}^{I}\sum_{a=1}^{A}(K_{aip} * X_{aijt})\right] + \mathrm{O}_{\mathrm{jpt}}$ $\qquad j=1,\ldots,J; p=n+1,\ldots,P; t=1,\ldots,T;$

6. $V_{\mathrm{jp}} \le \mathrm{M}_{\mathrm{jpt}} \le MAX_{\mathrm{jp}}$ $\qquad j=1,\ldots,J; p=1,\ldots,P; t=1,\ldots,T;$

7. $\sum_{a=1}^{\mathrm{A}}\sum_{i=1}^{I} k_{aip} X_{aijt} \le \mathrm{M}_{\mathrm{jp(t-1)}} + \mathrm{P}_{\mathrm{jpt}} + \mathrm{O}_{\mathrm{jpt}}$ $\qquad j=1,\ldots,J; p=1,\ldots,P; t=1,\ldots,T;$

8. $P_{jpt} \ge 0 \quad and \ \text{integer};$

9. $M_{jpt} \ge 0 \quad and \ \text{integer};$

10. $O_{jpt} \ge 0 \quad and \ \text{integer};$

11. $IN_{pt} \ge 0 \quad and \ \text{integer};$

The production and the purchasing models are solved using a branch-and-bound method that leads to a good solution for the global problem. However, notice that this global solution is not optimal, since was obtained by a solving combination of partial optimization models, each one covering one aspect of the $\mathrm{CPP}_{\mathrm{R}}$ model. To be able to improve this global solution, we propose a local search algorithm. Next section shows the local search step.

5.4.1.4. The fourth step: Local search to improve the solution found

Once we have a feasible initial solution, we perform a local search to find out improved solutions for the problem. The steps followed are:

The neighborhoods we consider in this problem are the following:

- A quantity of products can be manufactured in the previous period. This is only possible if the manufacturing cost difference between these two periods is greater than the unitary storage cost. Otherwise, this change will not be profitable for the company. This condition is analyzed before evaluating the neighborhood.

- Products can be manufactured in other factory. This will provide benefits for the company, only if the reduction in costs by transportation, and storage compensate the differences in manufacturing costs. Also in the case of lack of capacity, it will helps the company to meet the demands requirements, by producing in a different facility. This avoid therefore to incur in stock out costs.
- Products can be manufactured by a different production process.

The Local Search algorithm is the following:

1. Let *x* be the current solution. Initially the current solution is the one obtained by the aggregation and disaggregation optimization steps.
2. While the stopping criteria is not verified, obtain the next neighbor of solution *x*.
3. If new solution improves the total cost, update the current solution (which is also the best solution obtain from the local search method);
4. Repeat from step 2.

Notice that local search continues until a stop criterion is satisfied. In our case, the stop criteria for the local search is composed by three conditions:

- Local search stop when after 30 seconds of run if there is not a improvement in the total solution, and,
- At least 5 different movements have been performed where the solution has not improved at all, and all neighborhood types have been checked.
- A local optimal solution has been obtained.

The first two stopping criteria guarantee a short running time.

The established requirements are necessary to assure the evaluation of a sufficient number of alternatives. At the end of this process, we get an improved final global solution for the original problem, the Collaborative Production Planning with returns (CPP_R).

5.4.2 Results of the Experiments

The heuristic method described in the previous section was applied to the instances proposed for the CPP_R problem. In the computational experiment we evaluated 60 different networks under 17 different network configurations to observe the performance of the heuristic in those instances. These networks were obtained through a random generation process designed in C++. We also created a program to aggregate the data, perform the optimization procedure and the local search. In the optimization step, we linked the C++ program with the Lingo 8.0 software. All the instances were first solved by branch and bound method and then using the heuristic algorithm.

The average results for the different network configurations are presented in Table 29.

% of solution	Number of cases	% over total instances	Average Time (in seconds) Branch and bound	Average time (in seconds) of the heuristic	% of Objective Function
Improved the best solution known	7	11,67%	30113,3	520,6	-4,69%
under 3%	14	23,33%	6593,5	376,0	1,51%
Between 3% and 7%	14	23,33%	7020,9	409,3	4,75%
Between 7% and 10%	6	10,00%	16635,0	5656,2	8,87%
Between 10% and 13%	7	11,67%	9377,4	2914,0	11,61%
More than 13%	10	16,67%	26145,4	650,3	21,68%

TABLE 29. RESULTS OF COMPUTATIONAL EXPERIMENTS

In average, we can observe that the heuristic is at 6,61% of distance of the optimum (or the best solution founded) by the branch-and-bound method. But notice that for some network configurations the heuristic was able to improve the best solution founded by the branch-and-bound method (stopped after some time), so that is the reason of the negative percentages in the comparison between the heuristic solution and the best solution known. In fact, in seven of the 60 instances, the results were slightly better than the best solution obtained by the branch-and-bound method stopped after a large amount of running time without obtaining an optimal solution.

Basically in the 70% of the results we achieve the 90% of the best solution known. It is also important to remark that the average time of completion of the heuristic procedure is 1275,28 seconds, which at the beginning should sound not so good, but notice that the average time through optimization is 14808,7 seconds, which means that the heuristic takes in average the 8,61% of the time of the branch and bound method. However, it is important to remark that in some problems the time under branch and bound is not representative since there were some instances where the optimization was stopped prior to completion. Notice also that there are five instances with large running time for the heuristic method, if we do not consider these three instances, the average running time is around 527 seconds. The table with the complete results is presented in appendix C.

5.4.3 Conclusions of the heuristic algorithm

We developed a new heuristic to solve the Collaborative Production Planning Model with Returns CPP_R. This model deals with the collaborative planning to the whole supply chain introducing not only the production plan, but also the calculation of the optimal level of inventories to hold and products to transport during a period of time. The model deals also with the Reverse Logistics Field because allows planner to incorporate within the plan the possibility of using new materials, reused materials or both of them.

Due to the complexity of the model in terms of the number of variables and constraints, it became necessary to develop the heuristic algorithm. The computational times were reduced and in part of the problems the heuristic deal to a solutions that improve the best solution known.

The heuristic procedure developed includes two optimization routines that help the heuristic to improve the computational results of the model. This optimization routines were derived from the CPP_R model, introducing reduced models in terms of variables and constraints, that were solved by branch and bound in low computational time.

As part of future research, we consider it is very important to explore in more detail the use of optimization, simulation and, heuristic methods, combined in order to improve the solutions obtained when they are used independently.

5.5 Conclusions and Future Research

In this chapter, we applied two different solution methods for the production planning problems presented in the previous chapters. First part of the chapter was the utilization of branch-and-bound methods to solve the problems. As expected, we observed that for those examples where the network was large, the computational time increases. From a statistical analysis, it was concluded that basically the variables that affect more the computational time were the number of production processes, the number of factories and the number of periods. After the evaluation of some instances generated through a simulation program, we concluded that the variable that affects more the computational time was the number of planning periods.

With this information, we propose to create a heuristic algorithm to solve the models. The heuristic was proposed to solve the CPP_R model, since it is the most extended one

To evaluate the heuristic algorithm, a new set of 60 networks was created. These networks were first solved through Branch & Bound, and then using the heuristic proposed. The results obtained from this evaluations were good, serving as a way to solve the production planning models proposed.

As future research, we plan to extend these solution methods, combining simulation with the heuristic algorithm (and therefore optimization) to evaluate how well it works. Also we want to apply those methodologies to some real cases to evaluate the benefits these new planning models will provide to the companies.

5.6 Chapter References

Berning, G., Brandenburg, M., Gürsoy,G., Kussi,J.S., Mehta,V., Tölle, F.J. (2004). "Integrating collaborative planning and supply chain optimization for the chemical process industry (I)—methodology." Computers and Chemical Engineering **28**: 913–927.

Chen, F., Drezner, Z., Ryan, J. and Simichi-Levi, D. (2000). "Quantifying the Bullwhip Effect in a Simple Supply Chain: The Impact of Forecasting, Lead Times, and Information'." Management Science **46**(3): 436–443.

Cheung, W., Leung, L., and Wong, Y.M. (2001). "Strategic Service Network Design for DHL Hong Kong." Interfaces **31**(4): 1-14.

Danese, P., Romano, P., and Vinelli, A., (2004). "Managing business processes across supply networks: the role of coordination mechanisms." Journal of Purchasing and Supply Management, **10**(4-5): 165-177.

Guide Jr, V.D.R. (2000). "Production planning and control for remanufacturing: industry practice and research need." Journal of Operations Management **18**: 467–483.

Hines, P. (1998). "Benchmarking Toyota's Supply Chain: Japan vs UK." Long Range Planning **31**(6): 911-918.

Holweg, M., Disney, S., Holmström, J. and Småros, J. (2005). "Supply Chain Collaboration: Making Sense of the Strategy Continuum." European Management Journal **23**(2): 170-181.

Jain A., Udaka. S. (2005). "Aggregate production planning for a continuous reconfigurable manufacturing process." Computers & Operations Research **32**: 1213–1236.

Jian-Hung, C. and Shinn-Ying, H., (2005). "A novel approach to production planning of flexible manufacturing systems using an efficient multi-objective genetic algorithm." International Journal of Machine Tools & Manufacture **45**: 949-957.

Lee, H. L., Padmanabhan, V. and Whang, S. (1997). "Information Distortion in a Supply Chain: The Bullwhip Effect." Management Science **43**(4): 546-558.

Liker, J. and Wu, Y.C. (2000). "Japanese Automakers, U.S. Suppliers and Supply-Chain Superiority." MIT Sloan Management Review. **42**(1): 81-93.

Lourenço, R.H., and Soto, J.P. (2003). Nuevas tendencias en Logística Inversa. Gestión de la cadena de suministro: Visión de futuro.Centro Español de Logística. Barcelona**:** 19.

Monma, C., and Potts, C. (1989). "On the complexity of scheduling with batch setup times." Operations Research **37**(798-804).

Pinedo, M. (1995). Scheduling—theory, algorithms, and systems. Englewood Cliffs, NJ, Prentice Hall.

Vercellis, C. (1999). "Multi-plant production planning in capacitated self-configuring two-stage serial systems." European Journal of Operational Research **119**: 451-460.

Appendix A. Binary Logistics regression results

```
Binary Logistic Regression

Link Function:  Logit

Response Information

Variable      Value     Count
C13           SI         36  (Event)
              NO         69
              Total     105

Logistic Regression Table
                                     Odds     95% CI
Predictor     Coef       StDev        Z    P        Ratio   Lower        Upper
Constant       3,378     1,322       2,55  0,011
Periods       0,14279    0,06356     2,25  0,025  1,15    1,02         1,31
Plants        -1,3209    0,4269     -3,09  0,002  0,27    0,12         0,62
Articles      0,04783    0,03298     1,45  0,147  1,05    0,98         1,12
Prod Proc     -0,5684    0,1569     -3,62  0,000  0,57    0,42         0,77
Material      -0,9868    0,6660     -1,48  0,138  0,37    0,10         1,38
Machines      1,0649     0,6405      1,66  0,096  2,90    0,83         10,18

Log-Likelihood = -33,264
Test that all slopes are zero: G = 68,485; DF = 6; P-Value = 0,000

Goodness-of-Fit Tests

Method               Chi-Square     DF     P
Pearson               42,976        14    0,000
Deviance               38,055       14    0,001
Hosmer-Lemeshow 16,691              8     0,033
```

Appendix B. Collaborative Production Planning Models

CPP$_R$ model					CPP model			CPP$_{R1F}$ model			CPP$_{R1P}$ model		
No.	**Capacity**	**Objective**	**Op.**	**Time**	**Objective**	**Op.**	**Time**	**Objective**	**Op.**	**Time**	**Objective**	**Op.**	**Time**
1	282,35%	3,24E+07	Yes	1	3,13E+07	No	19	2,72E+07	Yes	2	2,60E+07	Yes	0
2	80,89%	1,23E+08	Yes	1	8,94E+07	Yes	0	1,13E+08	Yes	1	8,13E+07	Yes	1
3	56,75%	4,80E+06	Yes	1	4,40E+06	Yes	1	4,08E+06	Yes	3	3,22E+06	Yes	1
4	75,83%	7,36E+07	Yes	1	5,65E+07	Yes	0	5,26E+07	Yes	2	8,53E+06	Yes	1
5	72,89%	4,20E+08	Yes	66	2,37E+08	No	7342	3,10E+08	Yes	43	4,63E+06	Yes	0
6	93,31%	4,73E+08	Yes	34	4,05E+08	Yes	5148	4,54E+08	Yes	34	1,88E+07	Yes	0
7	87,37%	8,47E+09	No	29269	5,99E+09	Yes	14234	7,46E+09	No	33648	2,43E+09	Yes	4
8	78,75%	9,15E+09	No	36300	8,85E+09	Yes	13441	4,16E+09	No	40679	2,18E+09	Yes	2
9	69,84%	9,78E+09	No	110760	7,35E+09	Yes	10977	7,57E+09	No	54753	9,77E+09	Yes	3
10	93,15%	2,20E+10	No	3665	1,72E+10	Yes	6733	1,97E+10	No	8044	6,10E+09	Yes	2
11	86,69%	2,08E+10	No	14403	1,58E+10	No	5575	1,38E+10	No	18782	1,73E+10	Yes	2
12	64,14%	2,29E+10	No	64006	8,55E+09	No	5234	1,21E+10	No	38946	3,65E+09	Yes	1
13	91,88%	2,19E+10	No	60100	1,39E+10	No	5713	1,92E+10	No	52043	1,77E+10	Yes	0
14	79,39%	2,36E+10	No	4062	1,96E+10	No	5176	1,09E+10	No	8441	9,78E+09	Yes	1
15	67,60%	1,93E+10	No	4252	1,01E+10	Yes	4980	1,86E+10	No	8631	1,87E+09	Yes	2
16	67,08%	2,16E+10	No	5402	8,50E+09	Yes	4272	1,96E+10	No	9781	1,94E+10	Yes	1
17	97,56%	97864010	Yes	4	5,46E+07	Yes	4215	53351732	No	9383	22013307	Yes	13
18	73,24%	2,33E+09	Yes	10	1,14E+09	Yes	4830	1,27E+09	No	5660	1,86E+09	Yes	9
19	72,06%	8,54E+10	No	26497	2,77E+10	No	7675	4,53E+10	No	30876	2,98E+10	Yes	0
20	75,10%	7,42E+10	No	16340	4,36E+10	No	6749	7,24E+10	No	20719	5,97E+10	Yes	0
21	69,45%	1,41E+09	Yes	41	7,24E+08	Yes	5266	6,39E+08	No	4420	6,66E+08	Yes	2
22	62,61%	1,48E+09	Yes	41	8,24E+08	Yes	8209	1,10E+09	No	4420	7,69E+08	Yes	0
23	75,36%	1,39E+09	Yes	40	9,58E+08	Yes	4701	1,19E+09	Yes	40	1,26E+09	Yes	1
24	87,77%	1,43E+09	Yes	40	9,12E+08	Yes	4180	1,06E+09	No	4419	3,44E+08	Yes	2
25	81,67%	1,54E+09	Yes	41	7,81E+08	Yes	5864	6,53E+08	Yes	41	8,34E+08	Yes	1
26	81,54%	1,69E+10	Yes	183	1,31E+10	Yes	5376	1,46E+10	Yes	55	8,22E+09	Yes	3
27	63,92%	7,37E+10	Yes	2	2,99E+10	Yes	6789	7,20E+10	Yes	16	5,87E+10	Yes	0
28	26,58%	2,21E+08	No	6113	1,65E+08	Yes	5112	1,28E+08	No	10492	9,24E+07	Yes	0
29	26,86%	2,08E+08	No	3638	4,48E+07	Yes	6783	1,15E+08	No	8017	2,86E+07	Yes	1
30	91,19%	1,08E+09	No	5921	3,07E+08	Yes	4014	7,68E+08	No	10300	5,72E+08	Yes	3
31	95,23%	3,77E+10	Yes	1505	2,76E+10	Yes	4056	2,81E+10	Yes	34	5,54E+09	Yes	4
32	86,81%	3,22E+10	Yes	26	1,56E+10	Yes	4120	1,29E+10	Yes	26	2,18E+10	Yes	2
33	87,78%	3,45E+10	Yes	13	1,10E+10	Yes	4078	2,22E+10	Yes	19	1,22E+10	Yes	1
34	83,02%	3,00E+10	No	3794	2,80E+10	Yes	4032	1,88E+10	No	8173	1,99E+10	Yes	6
35	84,62%	1,89E+10	No	38525	1,74E+10	Yes	15887	1,48E+10	No	42904	9,36E+09	Yes	49
36	87,05%	1,90E+10	No	31960	5,63E+09	Yes	12876	1,18E+10	No	36339	9,52E+09	Yes	43
37	75,35%	8,67E+10	No	3937	6,90E+10	Yes	12847	8,39E+10	No	9316	8,50E+10	Yes	32
38	99,18%	3,15E+11	Yes	2068	1,36E+11	No	9223	1,85E+11	Yes	2829	7,37E+10	Yes	2
39	82,33%	1,05E+11	Yes	8	4,58E+10	Yes	9536	8,60E+10	Yes	33	5,04E+10	Yes	1
40	76,11%	1,11E+11	No	7640	8,94E+10	No	6533	9,65E+10	No	12019	3,47E+10	Yes	2
41	73,85%	7,16E+10	No	23086	6,21E+10	No	5636	4,22E+10	No	27465	6,55E+10	Yes	3
42	79,21%	7,71E+10	No	6324	2,62E+10	No	11857	3,70E+10	No	10703	6,31E+10	Yes	2
43	95,53%	7,03E+10	No	130012	2,69E+10	Yes	9731	5,94E+10	No	44379	4,55E+10	Yes	3
44	90,80%	6,35E+10	No	33062	6,13E+10	Yes	9353	3,02E+10	No	37441	3,08E+10	Yes	3
45	97,95%	6,87E+10	No	36535	2,13E+10	Yes	7617	4,01E+10	No	40914	2,45E+10	Yes	3
46	94,38%	6,77E+10	No	34282	5,79E+10	Yes	6999	5,63E+10	No	38661	1,96E+10	Yes	3
47	78,02%	2,63E+11	No	51198	9,26E+10	No	5206	1,31E+11	No	51198	2,18E+11	Yes	9
48	67,39%	2,64E+11	No	3227	1,53E+11	No	4501	2,39E+11	No	8106	6,84E+10	Yes	7
49	75,22%	2,55E+11	No	6590	1,93E+11	No	5300	1,96E+11	No	10969	2,44E+11	Yes	8
50	80,84%	2,75E+11	No	23086	1,88E+11	No	4255	1,28E+11	No	27465	2,38E+11	Yes	7
51	80,73%	2,71E+11	No	3862	2,43E+11	No	4538	2,18E+11	No	8241	1,57E+10	Yes	11
52	76,38%	9,40E+10	Yes	2521	3,63E+10	No	31782	8,51E+10	Yes	3882	2,56E+10	Yes	6
53	92,71%	6,61E+10	No	23964	2,41E+10	No	30877	4,71E+10	No	28343	5,14E+10	Yes	7
54	91,24%	9,78E+10	No	20043	4,47E+10	No	31530	7,83E+10	No	24422	4,13E+10	Yes	7
55	88,49%	9,34E+10	No	3756	1,90E+10	No	30491	6,86E+10	No	8135	5,70E+10	Yes	10
56	75,23%	7,67E+10	Yes	993	3,65E+10	No	5312	7,02E+10	No	5372	4,08E+09	Yes	100
57	69,90%	7,49E+10	Yes	2847	2,64E+10	No	6143	4,45E+10	no	8226	7,41E+10	Yes	65
58	81,30%	7,95E+10	Yes	5	3,63E+10	No	4755	5,81E+10	Yes	36	3,52E+09	Yes	68
59	88,16%	9,55E+10	Yes	1114	9,10E+10	No	4800	7,45E+10	Yes	47	3,57E+09	Yes	67
60	78,39%	2,10E+11	Yes	1310	1,19E+11	No	4415	1,08E+11	Yes	58	1,43E+11	Yes	62

Capacity: % of occupation of the capacity for all the periods. Notice that it can be greater than 100%, since stock-out is allowed in the model.

Objective: Is the value of the objective function

Op: If optimal solution has been found or not.

Time: Running time in seconds

Appendix C. Heuristic Results

	Optimization			Heuristic		Comparison
Example	Objective Function	Time (in seconds)		Objective Function	Time (in seconds)	% of Objective Function
1	3,24E+07	1	*	32477360	141	0,23%
2	1,23E+08	1	*	123229000	193	0,04%
3	4,80E+06	1	*	5287241	145	10,18%
4	7,36E+07	1	*	74443770	156	1,10%
5	4,20E+08	66	*	431930000	235	2,85%
6	4,73E+08	34	*	485130000	347	2,47%
7	8,47E+09	29269		9875740000	435	16,56%
8	9,15E+09	36300		11421900000	373	24,86%
9	9,78E+09	110760		12293300000	252	25,72%
10	2,20E+10	3665		21254159800	243	-3,32%
11	2,08E+10	14403		21698363300	339	4,57%
12	2,29E+10	64006		23494718300	275	2,52%
13	2,19E+10	60100		22756983200	386	3,94%
14	2,36E+10	4062		27868733100	237	18,11%
15	1,93E+10	4252		20161595400	268	4,28%
16	2,16E+10	5402		22385895000	164	3,83%
17	9,79E+07	4	*	104625600	362	6,91%
18	2,33E+09	10	*	2357614120	111	1,23%
19	8,54E+10	26497		71942450000	237	-15,75%
20	7,42E+10	16340		71698400000	268	-3,42%
21	1,41E+09	41	*	1585183070	572	12,64%
22	1,48E+09	41	*	1555925600	375	5,01%
23	1,39E+09	40	*	1436716700	597	3,17%
24	1,43E+09	40	*	1568761800	180	9,42%
25	1,54E+09	41	*	1547992900	392	0,78%
26	1,69E+10	183	*	17368303200	174	2,80%
27	7,37E+10	2	*	75683556800	261	2,71%
28	2,21E+08	6113		242666000	2725	9,78%
29	2,08E+08	3638		256073000	3601	23,09%
30	1,08E+09	5921		1300590700	138	19,90%
31	3,77E+10	1505	*	39558800000	231	4,88%
32	3,22E+10	26	*	39461400000	174	22,63%
33	3,45E+10	13	*	38797300000	130	12,56%
34	3,00E+10	3794		31824500000	1801	6,11%
35	1,89E+10	38525		21757200000	116	15,20%
36	1,90E+10	31960		23814700000	465	25,03%
37	8,67E+10	3937		95890820000	176	10,66%
38	3,15E+11	2068	*	334080462800	223	6,12%
39	1,05E+11	8	*	106391833100	214	1,79%
40	1,11E+11	7640		110558000000	2409	-0,08%
41	7,16E+10	23086		71647890600	230	0,06%
42	7,71E+10	6324		76479405200	166	-0,86%
43	7,03E+10	130012		67926800000	165	-3,44%
44	6,35E+10	33062		68545000000	2803	8,02%
45	6,87E+10	36535		65759700000	440	-4,28%
46	6,77E+10	34282		73497200000	93	8,54%
47	2,63E+11	51198		297304000000	4668	12,91%
48	2,64E+11	3227		286526000000	8502	8,53%
49	2,55E+11	6590		283153000000	3778	10,96%
50	2,75E+11	23086		299693000000	19634	8,93%
51	2,71E+11	3862		301589000000	10929	11,33%
52	9,40E+10	2521	*	97752500000	632	4,04%
53	6,61E+10	23964		64740500000	467	-2,06%
54	9,78E+10	20043		89033500000	290	-8,97%
55	9,34E+10	3756		93548200000	803	0,19%
56	7,67E+10	993	*	96444700000	712	25,74%
57	7,49E+10	2847	*	79877714420	109	6,59%
58	7,95E+10	5	*	81958627000	121	3,06%
59	9,55E+10	1114	*	97755700000	1732	2,32%
60	2,10E+11	1310	*	218199570000	122	4,00%

CHAPTER 6: General Conclusions and Future Research

The aim of this thesis is to provide a further development of the Reverse Logistics area. The basic objectives are:

- To provide a clear idea about the state of development of the research in the RL area.
- To understand the characteristics and needs of editorial companies in terms of RL practices.
- To provide useful planning models incorporating elements as collaborative planning or multiproduct environment joint with remanufacturing more adapted to the real situations companies face.
- To develop adequate techniques to solve the models proposed
- To propose some areas of future research to continue the development of the RL area.

In the rest of this chapter we offer a brief summary of the main contributions of the thesis and, propose some opportunities to continue with future research.

6.1 Summary and Conclusions

We present the main findings of this thesis considering each chapter:

6.1.1 Chapter 1. A Brief Review of Reverse Logistics

This chapter provides some basic concepts about Reverse Logistics. The chapter initially analyses the main definitions of Reverse Logistics and compare them, considering different elements provided by the literature. Then, some sub-areas of research were proposed and, the difference between models in direct and reverse logistics was stated. We also performed a literature review classified by the areas proposed and finally some conclusions and future research areas were considered. Main conclusions were:

- There is a lack of more practitioner related research, where experiences in particular sectors where the return level is a problem should be studied.
- The conceptual, quantitative, and application-case-based papers do not provide an extensive treatment of RL topics. There still a gap in some areas where research can be performed.
- There is also a lack of appropriate models for the actual manufacturing operations where various products and materials are considered at the same time. Also another elements like collaborative planning are not considered in the remanufacturing environment.
- The majority of articles are short and lack the depth to demonstrate the level of integration necessary to implement RL across various functional areas.
- We provided some framework of analysis with six areas of research within Reverse Logistics.

The following topics should be in our opinion object of future research:

- Models treating Forward and Reverse distribution issues simultaneously; these models could consider for example, location of joint facilities for both networks.
- Models considering routing aspects for the Forward and Reverse Logistics.
- Studies on the comparison between traditional versus specifically adapted inventory control methods in a return flow environment,
- There are few alternatives developed to solve the MRP problem in a remanufacturing environment.

Clearly there are many areas to be investigated in the RL field, both empirically and theoretically. The actual research in this science is still growing and each day there are more companies who decide to introduce a RL system within them. The legislation also helps to increase the importance of this field, given that companies are being forced to be responsible for the packages and the end of life products they had sold. In Europe, Germany has the most advanced legislation in this sense, but is expected in few years that some other countries within the European union start copying the German laws.

6.1.2 Chapter 2. Reverse Logistics in the Editorial Sector: An Exploratory Study

In chapter 2 we explored the actual state of development of the editorial sector in Spain. We engaged a process of analysis and some projects and the principal companies in the books' sector, which, up to now, have provided good results for the companies in terms of benchmarking and improvements in the returns process.

One of our objectives was to describe the **state of art** of the RL process in the Spanish book sector.

Regarding the performance of the RL process, most of the problems are related with the sharing of information, in fact, retailers' work independently from editors, without sharing sales and forecasting information. This leads to an increase in the inventory levels in the whole supply chain and, in some cases, stock outs, given the high uncertainty about the success or failure of a book.

In most of the cases (88,8%), editors reincorporate the returned products into the inventory obtaining the highest value they can derive from the books returned. Other practices like destroy the products, give them to charity and sale in secondary markets are also performed for some companies but in a lower percentage.

We identified some **potential fields for improvement**, especially in two areas of work: To reduce the causes of returns and to improve the RL process. To reduce the causes of the returns, it is very important to improve the forecasting and production planning techniques. Introducing the returned books as part of the planning process is a key aspect. In the second area, the most important work should be done in improving the information sharing between the supply chain members and in the standardization of the RL process.

We believe that this chapter will be **insightful** for managers and researchers in the RL area. For managers, we provide some guidelines about how to perform a RL analysis identifying ways of improvement. This should lead to an increase of profitability in the whole business. In this way, managers can see RL as a profit potential area instead of a cost center. This process has been also a benchmarking opportunity for the companies participating in the study and can also be applied to other sectors and companies.

For researchers, the methodology used can also help those who want to develop sector analysis in the RL area. The work also provides some lines of further research: first, it is necessary to develop new models for forecasting and planning. Models where the returns can be considered as part of the planning process. There is also a field of work in developing new cost accounting models based in Activity Based Costing to calculate the real cost of the returns. There is also a wide field of work in developing models that consider the effect of information sharing in planning the returns. And finally, there is also the possibility of investigating the possibility of creating a Central Return's Center and its implications in terms of costs.

6.1.3 Chapter 3.A Collaborative Production Planning Model

In this chapter we presented a mathematical model for a recoverable production planning system in a collaborative environment of work, called the Collaborative Production Planning Model with Returns (CPP_R).

This chapter have several contributions:

- First, the introduction of the returns to the aggregate planning model, allowing to plan with mixed strategies using both reused and new materials,
- Second, the collaborative approach where suppliers, the CRC, the factories and the DC are took in to account, reducing the total costs of planning and gaining from the synergies derived from the integration of this different parties in the supply chain.
- Finally, although it is necessary to study more in detail this technique, the utilization of the optimization + simulation procedure to solve this multi-period problem is also innovative.

The model proposed considers a production plan at the aggregate level for a multiple factories environment. The model provides an aggregated production total schedule and also a purchasing planning for each factory during the planning period. Other important characteristic of the CPP_R model is the introduction of remanufacturing, where each product can be manufactured by different production processes, depending on the materials used: new, reusable or both. Therefore, the CPP_R model provides the best combination of manufacturing processes to reduce the total costs for the company.

To deal with this remanufacturing environment a Modified Bill of Materials (MBOM) was proposed, which simplify the formulation and size of the problem.

One of the main conclusions of the model is that optimization is only a good method to solve the problem in small network configurations, but when the size increases, it is necessary to look for other ways of solving the problem. As a future topic of research, we believe that combination of heuristic procedures and simulation, should be also a very good alternative to improve the planning process, in a reasonable running time.

6.1.4 Chapter 4. Models for Specific Manufacturing Environments

The three special models considered in this chapter are only some of the possible modifications and adaptations of the CPP_R model. Notice that, for instance, a production planning model without returns and for one factory (not considered here) is one of most traditional production planning models proposed for tactical planning in the literature. Therefore, the selection of the most suitable model depends on the supply chain configuration and practices. These models allows planners to fulfill better the planning requirements of some supply chain configurations.

The first model proposed was the CPP model, which allows companies to do collaborative planning when they do not need to work with reused parts and assemblies. Second model, the CPP_{R1F} model, has been developed for those companies who want to introduce the returns in their planning process without sharing their production plans with other factories. Third model is suitable for more general planning purposes where the companies want to plan one period of time. The advantages of this last model is that optimization routines can be used to solve the model in a reasonable running time.

First two models also serve for those companies using outsourcing, in the first case the model is used when all the production process is outsourced and, the second model is used when only a part of the production process is outsourced. Those characteristics make these models really important for business today.

As mentioned at the beginning of this chapter, one of the main objectives of developing these special cases is to analyze the impact of number of periods, number of factories and returns on the difficulty of solving the CPP_R model. The solution methods and the computational experiments made to solve these models are showed in the next chapter.

6.1.5 Chapter 5. Solution Strategies for the Production Planning Models

In this chapter, we applied two different solution methods for the production planning problems presented in the previous chapters. In the first part of the chapter we have solved the models by the application of a branch-and-bound method based on a commercial software. As expected, we observed that for those examples where the network was large, the computational time was also large. From a statistical analysis, it was concluded that basically the variables that affect more the computational time were the number of production processes, the number of factories and the number of periods. After the evaluation of some instances generated through a simulation program, we concluded that the variable that affects more the computational time was the number of planning periods.

With this information, we proposed an heuristic algorithm to solve the CPP_R model. We evaluate the heuristic algorithm, with the set of 60 networks proposed previously for the CPP_R model. The results obtained show that the heuristic is an efficient way to solve the production planning model proposed.

As future research, we plan to explore the impact of simulation in the heuristic proposed, as an extension of the experiments made in chapter 3. We want also to experiment the proposed methodologies in real cases to evaluate the economical benefits that companies can obtain from its implementation.