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An Heuristic for the Collaborative Production Planning Model with Returns

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Summary

Aware of the importance of developing new alternatives to improve the performance of the companies, our purpose in this paper is to develop a heuristic for a medium term production-planning model called the Collaborative Production Planning model with returns (CPP_R) that deals with the concepts of Supply Chain Collaboration and Integration and, Reverse Logistics. This model takes advantage of the synergies of integration, considering a global production planning that generates the optimal production and purchasing schedule for all the companies integrating a logistic chain. The model also considers the introduction of reusable parts and assemblies to the manufacturing process, serving for a remanufacturing environment. The heuristic proposed in this paper 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. Finally, some conclusions and future research is stated.

The structure of the paper is the following: in section two we present the literature review, then section three describes the CPP_R model, in section fourth we introduce the heuristic algorithm, section five shows the computational experiments and finally section six state some conclusions and future research.

1. 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, P. et al. (2004), Holweg, M. 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, H.L. et al., (1997), Chen, F. et al., (2000). Some authors in fact, attribute the success of the Japanese manufacturing model to the collaborative scheme with their suppliers, Hines, P., (1998), Liker, J. and Wu, Y.C., (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, C. and Potts, C., (1989);,Pinedo, M., (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, V., and Daniel, R.Jr., (2000).

For those reasons, heuristics algorithm have became widely used in production planning, Berning, G., et al, (2004); Akhil, J., and Udatta, S., (2005), Jian-Hung, C. and Shinn-Ying, H., (2005).

2. The Collaborative Production Planning Model with Returns (CPP_R)

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.

chain. In this sense, companies should gain from the joint planning process, avoiding the excess of costs generated by the traditional planning process where each one of the channel members is concerned with its own optimal production, inventory and transportation schedule which in most of the cases leads to a sub-optimal solution for the whole supply chains. The tactical planning involves several periods, that can be viewed as weeks, 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 also how much materials to buy at each period per plant.

Our collaborative model also allows to plan remanufacturing, taking into account the estimated number of recycled or reused parts and assemblies available to initiate the production process. The planner should

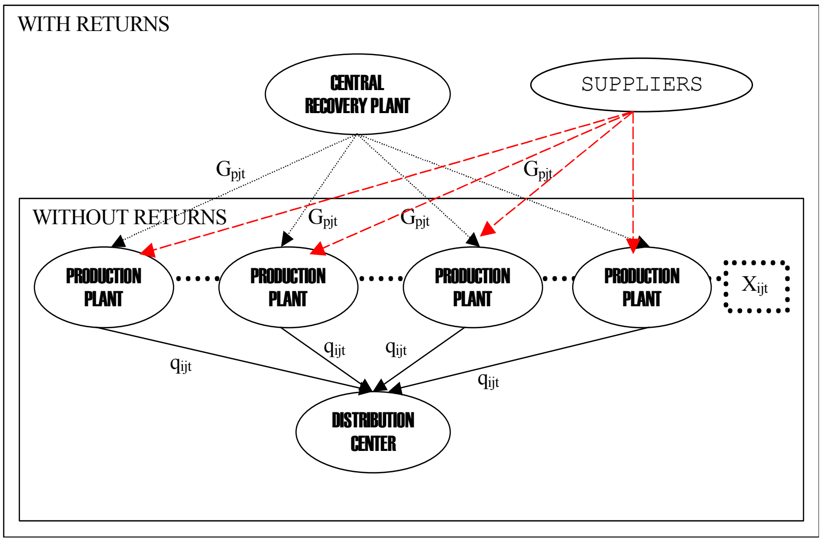

Figure 1. Supply Chain associated with the CPP_R model

The model we propose in this work is a medium term production-planning model that allows companies to plan their production and also their inventory levels along the total supply chain. To do it the model includes the production, transportation and holding costs of multiple factories and a distribution center that conform a supply chain. The model allows companies to make the tactical planning for a global supply

introduce reused parts and assemblies to the production planning process. In addition, it evaluates the convenience of manufacture a new product using only new materials, using only reused materials or using both.

We denote this model as the **Collaborative Production Planning with returns** (CPP_R) model, since it models the production planning within a supply chain within a collaborative approach between factories and remanufacturing, see Figure 1.

There are three actors basically in the Supply Chain we have considered which are the following ones: A Central Recovery Plant (CRP), which receive the returned products, do the disassembly process and send materials and assemblies to the factories; several Production Plants that can manufacture the products; Finally, the third entity is the Distribution Center (DC) where the products are received from factories and sent to the retailers and consumers.

The assumptions of the model are:

- CRP receives the returned product, and performs the recovery process. It takes one period to do it. Therefore, the parts obtained from products arriving in period *t* are only available at period *t+1*. The model decides when and to which production plants are sent the available reused materials and assemblies.
- The transportation cost from suppliers to the different factories is included in the cost of the new materials.
- Each plant can manufacture all or a subset of the products, and they can hold inventories from the previous period. Materials purchased can be used to produce the article in the same period.
- For each production plant, there are capacity constraints in time of production, storage capacity, and a security stock to be maintained.
- For each product a Modified Bill of Materials is known. This Bill of Materials is different from the traditional one in the introduction of different production processes to manufacture a product, which allow us to plan also the remanufacturing process.
- Factories send the final products to the DC where it is distributed to the retailers or consumers. We allow for stock out in the DC, therefore if the 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.

The variables of the model are related with the optimal policies for production goods, the purchasing materials, the holding inventories and the transportation between factories and DC

For a detailed discussion of the model, and the mathematical formulation see Lourenço, R.H. and Soto, J.P., (2003).

3. The heuristic procedure

Initially we solve the CPP_R model by branch-and-bound method using the Lingo software. To solve the model, we use 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). The remaining integer variables became continuous variables. This relaxed model results also in an integer optimal solution, being therefore the optimal solution for the original integer model. With this relaxed model, the computational time was reduced, however these times are still relatively large 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. These kinds of methods have been recently used by researchers, Cheung, W. et al, (2003), but we still obtain very large computational times. At the end we decided to develop a heuristic procedure to solve the CPP model in a reasonable running time.

Our heuristic combines optimization routines with a Local Search techniques, 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, C., 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. Notice that new products under these considerations can be manufactured from several processes. Each process is associated with the material used, which can be only new materials, or reused materials and assemblies, or both. This multi-process approach creates a lot of problems in terms of the uncertainty in the quality and quantity of the reused materials, or in terms of the production path or process 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. The Collaborative Production-Planning model with returns (CPP_R) was designed to solve the whole problem in one run, but as we shall see, we decide as part of the heuristic, to create some sub models, simplifying the process and reducing the computational time.

The heuristic consist in general terms in four steps:

- Partial Aggregation.
- Optimization.
- Disaggregation.
- Local search.

Figure 2 summarizes the heuristic process. Next we will describe each one of the steps, in detail.

3.1.1. 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, Lourenço, R.H. and Soto, J.P., (2004). 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.

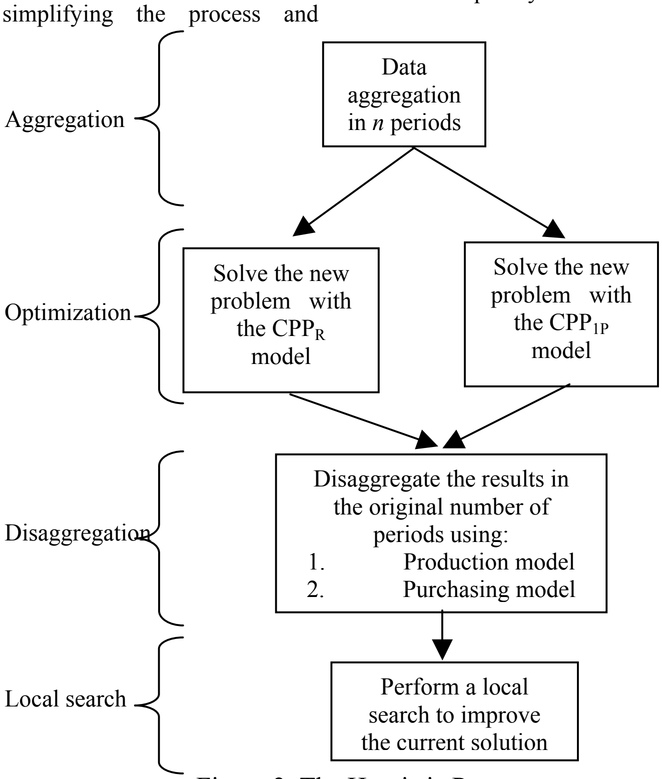

Figure 2. The Heuristic Process

A new model, the CPP_{1P} model was then created, which is a particular case of the CPP_R model. The basic difference is that CPP_{1P} 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_{1P} 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_{1P} problem or the CPP_R problem depending on which one we decide to use in the next step.

3.1.2. Optimization step: The CPP_{1P} 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 new model proposed: the CPP_{1P} model.

First choice is always the CPP_R model for the reduced number of periods, only in those problems where we observe that it takes more than one minute to be solved, we decide to use the CPP_{1P}.

In fact, the CPP_R model is a set of various CPP_{1P} models. Therefore, depending on the complexity of the problem, it is preferable to use one or the other. In other words, if the model is really complex, in terms of the number of variables and constraints, it is better to use the CPP_{1P} 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. Notice that solving the CPP_R problem, you only need to solve it once, whilst using the CPP_{1P} model you need to solve as much problems as periods of aggregation you have created.

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.

3.1.3. Disaggregate the results obtained into the general 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.

3.1.3.1. 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.

Once we have obtained the production plan for all the periods (12 months in our example), we run the purchasing model.

3.1.3.2. 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 production and the purchasing models are solved using a branch-and-bound method that leads to good solution to the global problem. However notice that this global solution was obtained by disaggregating the CPP_R model in simple model and combine the solutions of these ones to obtain a global solution. To be able to improve this global solution, at the end we propose a Local Search method.

3.1.4. 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.
- 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 disaggragation 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 two conditions:

- Local search stop when after 30 seconds of run 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.

This double requirement is 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).

4. Results of the Experiments

The heuristic method described in the previous section has been applied to several instance of 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 part, we linked the C++ program with the Lingo 8.0 software.

The average results for the different network configurations are presented in Table 1.

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.

% 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 1. 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 why the comparison between the heuristic solution and the best solution known have a negative percentage. 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

5. Conclusions

In this paper we have 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.

The heuristic procedure developed includes two optimization routines that help the heuristic to improve the computational results of the model.

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.

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