21st European Symposium on Computer Aided Process Engineering – ESCAPE 21
E.N. Pistikopoulos, M.C. Georgiadis and A. Kokossis (Editors)

Improving supply chain management in a competitive environment

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Abstract

This work addresses the development of a multi-objective MILP (Mixed Integer Linear Programming), devised to optimize the planning of supply chains introducing the use of game theory for decision making in cooperative and/or competitive scenarios. The model developed is tested in a real-world case study, based on the operation of two different supply chains; three different optimization criteria are consider, and both cooperative and non cooperative way of working between supply chain´s is considered.

Keywords: Supply chain planning, multi-objective, MILP-based model, game theory.

1. Introduction

The problem of decision making in the chemical process industry is becoming more complex as the scope covered by these decisions is extended. This increasing complexity is additionally complicated by the need to consider a greater degree of uncertainty in the models used to forecast the events that should be considered in this decision making. The problem of decision making associated to supply chain (SC) operational management (procurement of raw materials in different markets, allocation of products to different plants and distributing them to different customers), which is attracting the attention of the scientific community in the last years, is, in this sense, on the top level of complexity. And, in the case of the Chemical Processes Industry, the complexity associated to chemical operations and the market globalization should be added to the usual difficulties related to the integration of various objectives to be considered for Supply Chain planning

But in this scope, it is not enough to study the problems that industry deals with and to apply optimization techniques to find isolated robust solutions. SCs are embedded in a competitive market, and managers have to take care of the decisions of the others, since these decisions will impact to the profit of their own SC.

In such complex systems, some researchers have used the Game Theory (GT) to make predictions to assist decisions makers (Mahesh and Greys, 2006). Two important sections can be found in the GT: the cooperative games and the non-cooperative games, and this second section specifically deals with situations like the one described in the previous paragraph.

The different concepts associated to Game Theory can be found in the literature, but nowadays only some aspects of this theory have been successfully applied to supply chain management: it is easy to find applications related to non-cooperative games and zero different sum, while the use of cooperative games, dynamics or asymmetric games for decision making has not been exploited yet (Cachon and Netessine, 2003). In this sense, GT has not been extensively used to analyze the behavior between SCs yet, and only some works can be found which address specific situations: Leng and Parlar

(2009) use Nash and Stackelberg Equilibriums to determine production levels, playing different scenarios to fix the price between seller and buyer; this kind of game has been also successfully used by other authors (Cachon, 20004; Granot and Yin, 2008; Leng and Zhu, 2009; Wang, 2006), each one using different techniques from the GT.
This paper addresses the problem of SC`s planning, where decisions are inventory and production levels, for independent supply chains working in a common scenario. The cases of their eventual cooperative work, and also their eventual competition, are analyzed using both traditional mathematical programming tools and also tools from non-cooperative Game Theory.

2. Problem statement.

2.1. Supply Chain planning

The scope of the planning of SC`s problem is typically to determine the optimal production levels, inventories and product distribution in a organized network of production sites, distribution centers, consumers, etc., taking care of constraints associated to products and raw materials availability, storage limits, etc in such network nodes. The mathematical model associated to this problem is usually leading to a mixed-integer linear program (MILP) whose solution determines the optimal values for the variables mentioned before.

In this paper it will be assumed the existence of a set of supply chains that may work in a cooperative or a competitive environment. In both cases, the mathematical constraints associated to the material balances and production/distribution capacities will be the same, as well as the cost structures, so the same basic model can be used. The model originally proposed by Liang (2008) has been adopted as a basis for the formulation presented in this paper, which will be complemented with additional constraints and will seek to minimize different Objective Functions according to the considered scenario.

The logistic network considered in the model consist of several SCs that have multiple production sites and distribution centers (fixed locations and capacities) to produce several products to cover a common market demand over a planning horizon H. The capacity of the process is given by available labor levels and machine capacity for each production site; the transport between nodes is modeled as it was carried out by a set of trucks with fixed capacity whose costs and required transports time are related to the distance between nodes.

2.2. Supply Chain planning in a cooperative environment.

On the basis of the previously cited model, this paper develops a multipurpose MILP-based model for the cooperative case of supply chains. The problem is equivalent to the one which should be formulated to solve the common SC formed by each one of the SCs in the original set.

So, to determine the optimal production planning and distribution decisions, the original formulation (Liang, 2008) can be used. In order to better compare the different scenarios, the subcontracting service considered in the original work has not been considered. Also, in order to better reproduce a real scenario maximum and minimum of distribution capacities for each source *i* at the destiny *j* have been considered, Eq. (1). In the same way, also minimum and maximum production capacities in each source or production center have been considered, Eq. (2).

(1)

(2)

The SC management is then characterized by the quantities produced in each source Q_{inh}, the inventory levels, W_{inh}, the quantities arriving to each distribution center, T_{inhj}, and the undelivered orders E_{inh}.

2.3. Non-cooperative game theory.

The GT is based on the simulation of the results obtained by a set of players ($i = 1, ..., I$) following different strategies (S_n; $n = 1, .., N$). These results are represented through a sort of payments ($P_{i,n}$; $i=1...I$; $n=1...N$) received by each player. In simultaneous games, the feasible strategy for one player is independent from the strategies chosen by each of the other players. Optimum strategies depend on the risk aversion of the players, so different strategies can be foreseen, as for example max-min strategy (which maximizes the minimum gain that can be obtained). Depending on the knowledge about the strategy of the other players, other solutions resulting from the concept of Nash equilibrium can be devised.

The players (suppliers) can consider two types of games: zero-sum and nonzero sum. This article uses the nonzero-sum game, since the SC of interest will not try to maintain the overall benefit of the system; the strategy is implemented through a payoff matrix, which is made up by the different potential strategies and shows the behavior for each action of the SC against the actions of its competitors.

To play this game, each player should deal with the demand that customers really offer to him (from the total demand), and this can be managed basically through their service policy: prices and delivery times. So, additionally to the cost of the supply chains, it is necessary to introduce as an objective the reduction of the buyers' expenses (cost for the distribution centers). This has been done through the price rates ($Prate_g$), thus to play with the prices associated at the source and the destiny of the products, Eq. (3).

(3)

3. Case study

These concepts have been applied to a supply chain case study adapted from (Wang and Liang, 2004, 2005 and Liang 2008). The factory's strategy is to maintain a constant work force level over the planning horizon, and supply as much product as possible (demand), playing with inventories and backorders. Two products are considered, P1 and P2, with a market demand for a 3 months horizon period from 4 distribution centers (Distr1 to Distr4). The information about the considered scenarios, production, etc. and the rest of problem conditions (initial storage levels, transport capacities, etc.) can be found at http://cepima.upc.edu/papers/Competitive_SCs.pdf (Tables 1-4).

Figure 1 shows the considered SCs basic configuration, composed by 2 SCs (2+2 plants, Plant1/Plant2 and Plant3/Plant4) which collaborate or compete to fulfill the global demand from the 4 distribution centers.

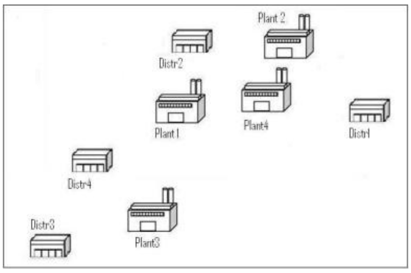

Figure 1. Description of the problem. Plant1-4 serve Distr1-4.

4. Case study Results.

To compare how the different supply chains interact in both cooperative and competitive frameworks, Tables 5 and 6 show the different obtained results:

Table 5: Comparative results between supply chains (standalone cases)

	SC1 Liang 2008	SC1 Original data	SC1 standalone	SC2 standalone
Obj. Funct.	min z1	min z1	min z1	min z1
z1($)	788 224	700 621	838 212	840 904
Z1total ($)				
z2(hours)	2115	2300	1681	1747
Benefit ($)		3 803 378	3 665 787	3 663 095
CST ($)		5 204 621	5 342 213	5 344 904

- The optimal solution for SC1 (standalone) is driven by the geographical conditions (nearest delivery), although different solutions are obtained according to the specific objectives considered. Differences between SC1 and SC2 standalone solutions are associated to the different distances from the production sites of SC2 to the markets. Detailed results can be found at http://cepima.upc.edu/ papers/Competitive_SCs.pdf (Figures 2 and 3, and Table 7).
- The optimal solution for SC1 when coexisting with SC2 is driven by the kind of relation (cooperative/competitive) and its margin/capacity to adapt the prices. Two cases have been analyzed: when the original demand is maintained (so both SCs are oversized), and when double demand is assumed (the global capacity is on the line of the global demand, and additional budget and storage limit at the distribution centres. For the competitive case (Table 6b), the model should take into account the consumers' preferences. These preferences have been modelled as just based on service (due dates maintenance) and customers' cost, so these elements have been introduced in the final objective function (overall cost CST) as previously indicated. A nominal selling price has been also introduced to maintain data integrity.

Table 6a: Comparative results (cooperative case)

	Coop. (original dmd)		Coop. (double dmd)	
	SC1	SC2	SC1	SC2
Obj. Funct.	min CST (SC1+SC2)		min CST (SC1+SC2)	
z1($)	515 516	286 997	1 051 348	592 487
Z1total ($)	802 513		1 643 835	
z2(hours)	1 138		2295	
Benefit ($)	2 319 483	1 382 002	4 618 651	2 745 512
CST ($)	3 350 516	1 955 997	6 721 348	3 930 487

Table 6b: Comparative results (non-cooperative case)

Compet. (original dmd)		Compet. (double dmd)	
SC1	SC2	SC1	SC2
min CST (SC1)		min CST (SC1)	
702 559	100 734	1 274 981	370 421
803 293		1 645 402	
1117		2268	
3 148 722	544 265	5 750 339	1 598 178
4 553 841	745 734	8 300 302	2 339 021

Obviously, in both cases the expected SCs' benefits (- z1) are reduced for both SCs respect the corresponding cooperative cases (Table 6a).
If the demand is maintained (both SCs are oversized), both SCs are able to play the game maintaining their respective geographical influence but, when demand is approaching to the SCs global capacity, a proper pricing policy is basic to reduce the loses associated to competition, as it can be seen in Tables 6a and 6b. In the case of competitive scenario, this corresponds to the Nash equilibrium point: SC1 selling price is computed in such a way that further reductions on the selling price of SC2 will not modify best choose for the buyers or, if so, this will not increase SC2 benefits. Detailed results, including the corresponding payoff matrix, are reported in http://cepima.upc.edu/papers/Competitive_SCs.pdf.

5. Conclusions

This work introduces the use of GT as decision technique that determines the optimal SC production, inventory and distributions levels in a competitive planning scenario, when there is a change in the competition behaviour. The problem was modelled using a multi-objective MILP-based approach by introducing the use of game theory, obtaining improved solutions in typical SC planning problems.

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[1] Complementary material can be found at: http://cepima.upc.edu/papers/Competitive_SCs.pdf

Acknowledgements

Financial support received from the “Agencia Española de Cooperación Internacional para el Desarrollo” (Acción AECID PCI D-024726/09), the Erasmus Mundus Program (“External Cooperation Window”, Lot 18 Mexico) and the Spanish “Ministerio de Ciencia e Innovación” and the European Regional Development Fund (both funding the research Project EHMAN, DPI2009-09386) is fully appreciated.