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Collaborative order management in distributed manufacturing

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Abstract

This paper deals with the construction of a decision assistant tool for order management. Given a factory, which has a certain capacity to satisfy a certain number of orders, our objective is to assign each order to a specific period of time, thus maximizing the level of customers' satisfaction. The optimisation algorithm supports the sales department and forms an interface between the customer's needs and the production system. By combining advances in information technology and optimisation technology, we present in this paper a method based on collaborative planning techniques that optimises customer satisfaction as well as resource utilization. For this purpose, we developed an algorithm based on an integer program model. Our tool was implemented using the Java programming environment and the Cplex optimisation software. The proposed model takes the form of an agent, evolving within a multi-agent system. The proposed algorithm is compared with greedy heuristic. Computational results show that the agent-based method proposed in this paper outperformed the methods usually used today in industry.

Keywords
Collaborative planning, distributed manufacturing, order management, mathematical programming, customers' satisfaction, capable-to promise

1. Introduction

The need to create increasingly customer driven companies endowed with more flexibility and responsibilities has been expressed in various ways. (Hammer and Champy 1993, Hirsch et al. 1998, Maloni and Benton 1997, Poulin et al. 1994, Prasad 1998, Tapscott and Caston 1994). One of them is the network enterprise (Poulin et al. 1994) and its different forms: the integrated enterprise (Tapscott and Caston 1994), the extended enterprise (Platt 1997, Tapscott and Caston

1994) and the virtual enterprise (Ahuja and Carley 1998, Davidow and Malone 1992, D'Amours et al. 1996, DeSanctis and Monge 1998, Montreuil et al. 1992). These network organizations raise the needs for new business models and management tools. The collaboration between various responsible units is the driving element of the decision-making in the network enterprise.

Particularly, the overall performance of the firm is expected to be improved when the demand planning processes are sophisticated and collaborative, and when they permit the integration between resources utilization and customers requirements. Recent studies show that firms that do a better job of demand planning exploiting these data simultaneously have significantly better control over their performance and customer service levels (Christensen 2001, Holmstrom 1999, Siekman 1999*)*. To ensure that work on production lines flows smoothly and that product demand is met according to customer wishes, management in most manufacturing companies needs to nurture a tight linkage between marketing and manufacturing. This tight linkage ensures that the right manufacturing capabilities are available to meet customer requirements, and that demand has been considered in the formation of manufacturing plans, inventory strategies and material handling practices, and vice-versa (DeSanctis and Monge 1998).

Combining advances in information technology and optimisation technology, we present in this paper a method based on collaborative planning techniques that optimises sales delivery commitments so as to maximize customer satisfaction and resource exploitation. The developed collaborative planning engine is now integrated in the NetMan prototype (Cloutier et al. 2000, Cloutier et al. 1999); thus, it is used to manage efficiently the relation between the customers and the sales office of a manufacturing firm.

Generally, a factory has a limited capacity and ultimately cannot readily satisfy the entire volume of orders. Often it is restricted to satisfying only a certain number of orders, partially satisfying others, and not satisfying some. The objective of this study is to maximize the satisfaction of customers by an optimal arrangement of orders realisation, which meets the demand according to available delivery time slots. To do this, a mixed integer program which takes into account on one side of a set of manufacturing and logistics constraints associated to the mix of products, and on the other side of clients expectations and priorities, was developed. This tool is used in an interactive way through the NetMan multi-agents system to help the planning team generate and estimate practical and optimal solutions for satisfying the orders. It has been developed in a Java programming environment and dynamically uses the Cplex optimisation software. Development was applied to the case of a world-class motorcoach manufacturer.

The paper is organized in the following manner. In the next section, we present the developed approach for collaborative planning of delivery dates to customers. Then we elaborate the mathematical model and discuss the problem of satisfying customers in terms of delivery date for the coaches' management. The model is a generalization of the classic assignment problem. The fourth part presents a comparison of different planning methods. Finally, the last section concludes the paper.

2. The model for the collaborative planning commitments in satisfying customers' demands

2.1 The manufacturing context and the problem statement

This paper addresses the planning and promising of delivery dates in order to satisfy customers' demands within the NetMan multi-agent architecture (Cloutier et al. 2000, Cloutier et al. 1999). In the studied context, customers request to receive their products within a target time window. Given current commitments and requests, and taking into account supply and manufacturing capacities, the manufacturing firm needs to decide on the order promising delivery date relative to each customer request, in an attempt to both ensure that what is offered best satisfy customers and is achievable with a high degree of reliability.

The context is here illustrated by a motorcoach manufacturing case. The firm is producing two families of vehicles: the H and V motorcoaches, for a total of about 1000 coaches a year, assembled from more than 10,000 sub-products. It assembles both families on the same coach assembly line. This line is composed of thirteen workstations and has a tack time of 200 minutes, thus completing a coach each 3 hours and 20 minutes as shown in table 1.

TY	**Orders**	Workstation 1	Workstation 2	Workstation 3	Delivery time slot	**Slot #**
H	**4056**	Coach #4056 start				
		Coach #4056 end			15/08/01 12h00	**1843**
H	**4057**	Coach #4057 start	Coach #4056 start			
		Coach #4057 end	Coach #4056 end		15/08/01 15h20	**1844**
HW	**4058**		Coach #4057 start	Coach #4056 start		
			Coach #4057 end	Coach #4056 end	16/08/01 09h40	**1845**
V	**4059**			Coach #4057 start		
				Coach #4057 end	16/08/01 13h00	**1846**
…	**…**				…	

Table 1: Final assembly schedule example

Each coach is parameterised according to the customer's choice. For example, both families (H and V) can be equipped with a wheel chair lift, they offer a choice between distinct overall length, seating can be selected from a wide catalogue, and so on. Each coach has thus its own assembly process and bill of materials. From a capacity perspective, some coaches are much more manpower demanding than others. From a supply perspective, some options involve sub-products having tight supply constraints, including source-to-order policies on specific rare high value items. As illustrated in table 1, a final assembly schedule can be expressed as the assignment of specific coaches to final slots, where a final slot consists of a 200-minute period on the last workstation of the assembly line.

At any time, the firm has a partially frozen final assembly schedule, with some final slots dedicated to specific coaches (assigned slots), other slots still free (free slots), and some customer requested coaches being guaranteed a slot among a specific set of final slots (confirmed slots) in order to insure the delivery commitments made to customers. As time passes, the firm freezes assignments of slots to coaches and has to make new commitments to upcoming customers. In the context of this case, the key decisions addressed in the paper can be stated as follow.

Given a factory, which has a limited capacity, our objective is to assign each order to a period of time, thus maximizing the level of customers' satisfaction. For illustrative purposes, Figure 1 shows on the left the orders for four different models (H, V, HV, VW) of coach that must be assigned, and on the right, the delivery time slots available for orders.

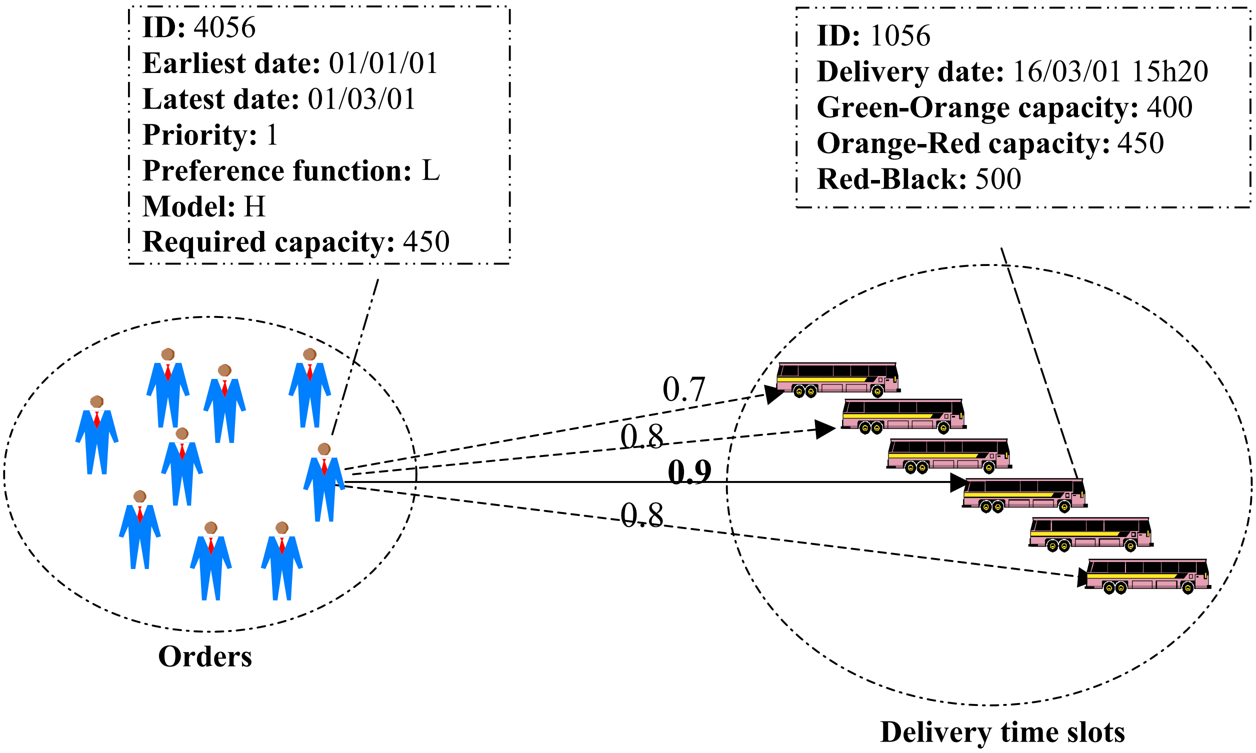

Figure 1. Assignment of vehicles to slots

When the sales department is processing an order; it considers the timeframe defined by the customer, which is set between the earliest acceptable delivery date and the latest acceptable delivery date. It also considers the preference of the customer delivery date, which can be as soon as possible within the timeframe, as late as possible within the timeframe, as close as possible to the mid-period of the timeframe, or indifferent within the timeframe. It also considers the coach's model (H, V, HV, VW), its required capacity in terms of units (man- hours, machines-hours, quantities, etc.). It also considers the order state which tells whether it is still non-assigned (free), assigned or temporary assigned (confirmed).

The orders' parameters are then set to be the order ID, its earliest delivery date, its latest delivery date, its priority weight according to the precedence order, its satisfaction function type (if the customer prefers the earliest delivery date either the latest date, mid-period or he is indifferent; the notion of satisfaction function will be explained later), the coach's model, the required capacity in terms of units, the order state which tells us whether it is still non-assigned (free), assigned or temporary assigned (confirmed).

The sales department manages the production plan by assigning theses orders to final available delivery time slots. Every delivery time slot is characterized by its ID, its delivery date, its capacity model (this notion of capacity model will be detailed later), its state and finally the code of the corresponding demand if it is still non-assigned (free), assigned or temporary assigned (confirmed).

These different states of orders and time slots allow this tool to be dynamic. It gives the planner the opportunity to change and adapt the generated plan. When a change is identified (from the customer or from the production department), the system searches for possible solutions (within non-confirmed orders and time slots), analyses the feasibility of those solutions and puts in place the most efficient solution. The confirmation process takes place just a few times before order realization. The flexibility of this tool is then manifested by incorporating product changeovers more easily without modifying confirmed orders, thus reducing the problem size. This approach is based on the business principle of being open to customer changes.

In the search process for a more efficient solution, the committed customers' orders remain always assigned. To do so, we impose for these decisions constraints making sure that the assigned orders cannot be moved in time slots where the satisfaction level would be decreased. Therefore in the model, the actual satisfaction level of an assigned order becomes a fixed lower bound in the new assignment problem. This is useful when we plan customized (customers' orders) and forthcoming orders in the same time.

To solve this problem, we have built a mathematical model which effectively assigns demands to periods. This tool produces an optimal plan to satisfy a certain number of demands, by assigning them respectively to certain delivery dates. The objective consists of maximizing the satisfaction level that is defined by the difference between the customers' satisfaction and the penalty associated with bad internal resource utilization. The model is a mixed linear program encapsulated in the NetMan multi-agents system. This model is presented at the end of this section. It forms the essence of the NetCTP agent.

2.2 Order satisfaction level

Demand management controls daily interactions between the customers and the company. Efficient demand management has shown to raise significantly profits (Willis 1996). A plan that best satisfies demands is one that plans and organizes the capacity of the factory and at the same time, ensures that the customers are satisfied.

Demand management deals with forecasts, new demands, promised delivery dates, service levels as well as other connected factors. It also concerns other sources that touch upon the firm's production capacity, the inter-company needs and storage capacity. An effective management of demands requires the synchronization of internal as well as external factors.

The link between demand management and production planning depends on the mechanisms of management of the firm as well as its objectives. In this work, the following objectives are simultaneously considered: the maximization of the satisfaction of the customers in terms of delivery date and the minimization of the penalty due to the misadministration of the factory capacity caused by inadequate assignment of orders to delivery time slots.

2.2.1 Customers' satisfaction level

The prevalent reality in the new industrial environment, where operations are customer driven, forces us to try to improve its satisfaction level. It is for this reason that we introduce this last one as the first objective into our model. This satisfaction level generally includes three main factors: the delivery period, the quality of the product and the after sale services. The action of the manager makes the delivery period the object of improvement, as it is a very important element in preserving the image of the company. This is confirmed by Duguay and Diorio (1993) who declare that: 'delivery period is an important element of the strategic positioning of a company on the market.' Therefore, the satisfaction level has been computed historically on the basis of the response delay without considering the individual preference value scheme of the customer. The computation of this level changes from one firm to another. Generally, it is established in terms of the number of days (or of weeks) of delay. This seems to be insufficient to us, especially when one notices the impact of the new techniques of marketing, the reduced life cycle of products and the increasing requirements of customers. To fulfil these new requirements, we propose a new method of computing it, based on models of needs satisfaction functions. Four functions of satisfactions in terms of the delivery date are integrated into our model. They are presented in figure 2.

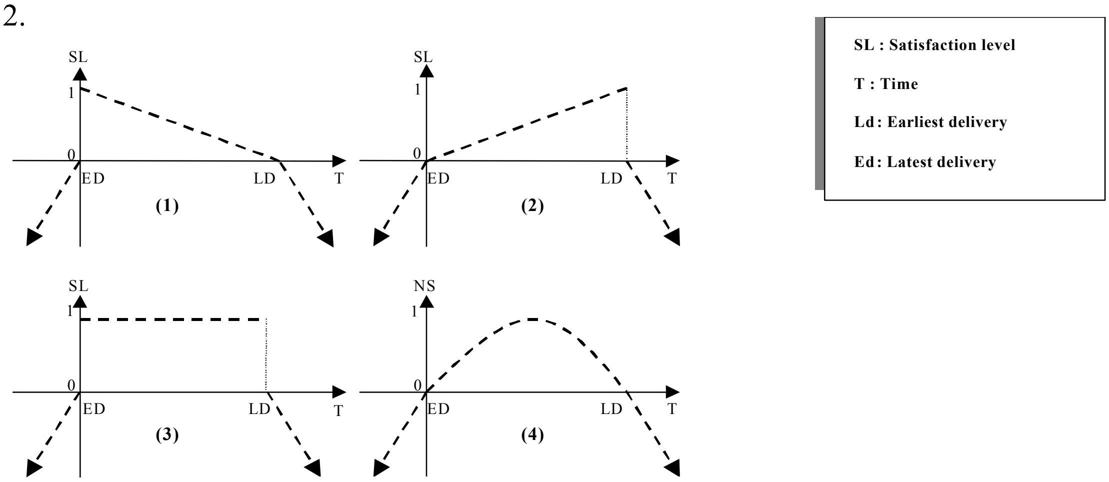

Figure 2. Satisfaction function models in terms of delivery dates

Every model's X-axis represents the time. The earliest delivery date, the latest delivery date and the real delivery date is placed on this axis. The first two dates are chosen by the customer, and the last one is proposed by the manufacturer. The Y-axis represents the customer's satisfaction level.

The first function reflects a preference for an early delivery. It is named 'Quick Delivery' and forces the manager to choose a delivery date as close as possible to the earliest delivery date, while staying inside the delivery interval [Earliest delivery, Latest delivery]. For instance, if the customer wanted a coach for the month of March, the delivery interval would be between the 1st and the 31st of March. If the coach was delivered on the 1st, the customer would be 100% satisfied (represented by the number 1), and if the coach was delivered on the 15th, the customer would be 50% satisfied (represented by 0.5). And finally, if the coach were delivered on the last day of March, the customer would be 0% satisfied (represented by 0). Therefore, when the proposed delivery date corresponds to the latest delivery date, the customer has a level of satisfaction of 0. And so, the satisfaction level varies between 0 and 1, while remaining inside the interval chosen by the customer.

The second preference function reflects a preference for the latest delivery '**L**atest Delivery', i.e., the closer one is to the latest delivery date (by staying inside the interval of delivery), the more satisfied the customer is. When the proposed delivery date corresponds to the latest delivery date the customer will have a level of satisfaction of 1, which means that it is 100 % satisfied.

The third function doesn't reflect any preference. '**Uniform**' for the delivery date as long as one is situated inside the chosen interval. The customer is 100 % satisfied. The important thing for it is to receive the product within this interval.

The fourth model represented with a concave curve reflects a preference for the delivery at a specific time within the allowed period '**Preferred**', i.e. the closer one is to this target delivery date, the more satisfied the customer is. When the proposed delivery date corresponds to the preferred target, the customer will have a satisfaction level of 1, which means that it is 100 % satisfied. Deviation either ways reduces the satisfaction level.

If the delivery date goes out of the preferred interval, the correspondent assignment will be punished. It will be in that case negative. An advance or a delay of a day decreases the customers' satisfaction level of P per cent (P = 10%in our study case).

This approach for computing the satisfaction level has several advantages. The first is in the way the delivery date is determined. This date is fixed by an agreement between the company and the customer, an agreement that considers the interests of the company and the customer. One is not dominant over the other. Furthermore, when the delivery of the product is set at the best time for the manufacturer and the customer, the inventory level will be reduced while customer service will be increased.

2.2.2 Satisfaction level of the manufacturer capacity utilization

In this work we are basically interested in best using available capacity. In the motorcoach case, it corresponds to the best use of assembly capacity. We need to assign the assembly of each order to an assembly launch slot so as to best satisfies the pool of needs by best exploiting the available capacity. To meet the needs of the new industrial environment, a new method determining the capacity of the slots is proposed. This method of determination of the capacity is inspired from the concept of *suppliers models* developed in the NetMan project (Frayret et al. 1999, Montreuil et al. 2000). The idea consists of segregating slots in four distinct groups corresponding to their capacity of satisfying a given order (See figure 3).

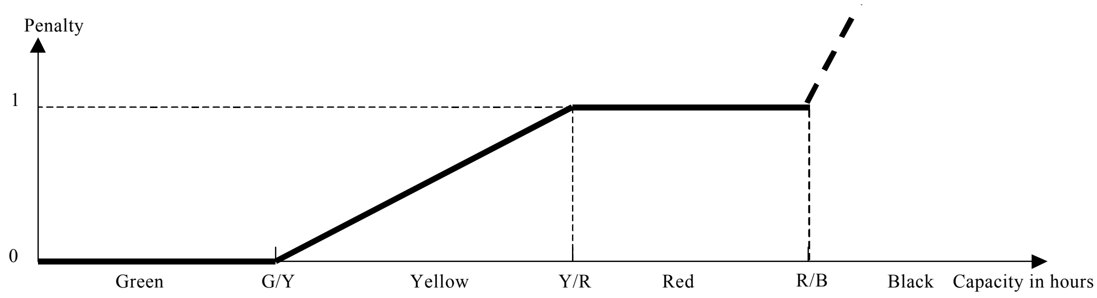

Figure 3. Zones of slots' capacities

These groups present different capacities to satisfy the customer within a specific time frame. To calculate the capacity of a slot in front of a demand (the penalty of the corresponding demand), one projects the capacity of this demand on the use curve of this slot. In this work, we consider the level of use of each slot capacity as being the demand's penalty level generated by the assignment of an order to this slot. For example, if one assigns a demand to delivery time slot that satisfies it in term of capacity, this slot would have a level of use of 100 % corresponding to a zero penalty for this.

An assignment which falls within the green group signifies that the customer assignment demand will be satisfied and that the risk of not delivering the product on time is negligible. This means that the manufacturing system should be able to meet this demand. The only time when it is not possible to satisfy this demand is in the case of an unforeseen event occurring at the last minute (for instance a machine breakdown). At the opposite, a demand that falls within the black zone represents an impossible assignment. The red zone indicates that the demand requirements in terms of capacity are not available at that time. In that case, assigning a demand to that delivery time slot would result in a 100% penalty. The yellow zone is an intermediate case between the green and red zones. This intermediate case indicates that a supplementary cost (effort) has to be counted to satisfy this assignment. In such case, the satisfaction level would be set between 0 and 100%. If an assignment falls within this zone, it is better to express this assignment possibility (in term of capacity) to the production department (or to the coordination center of the assembly lines) to determine if this demand can be satisfied according to the capacity available during that specific period.

Before trying to assign a coach to a time slot, availability of the principal raw materials is also checked. To do that, a green lead-time is defined for each critical supplier beyond which this supplier is assumed to be able to supply the correspondent material.

2.2.3 Global satisfaction level

The global satisfaction level of an assignment is computed as the difference between the customer's satisfaction level and the penalty associated to capacity utilization (level of use of slots capacities).

The level of global satisfaction of set of assignments is computed as the total sum of the satisfaction of all weighted assignments. The weight of an assignment is related to the customer demand. It is a number between 0 and 1 chosen by the decision-maker according to the importance of the customer and the particular order.

2.3 Generalized assignment model adapted for managing the demand of the coach manufacturer

This sub-section is dedicated to the description of the generalized assignment model developed for the case of a coach manufacturer. According to Savelsbergh (Savelsbergh 1997) 'The Generalized Assignment Problem (GAP) examines the maximum profit assignment of n jobs to n agents such that every job is assigned to precisely one agent subject to capacity restrictions on the agents. Although interesting and useful in its own right, it's developed to solve real-world problems in areas such as vehicles routing, plant location, resource scheduling, and flexible manufacturing systems'.

To solve the problem of assignment of orders to slots, we have developed the generalized assignment model described below, which takes into account constraints associated with the mix of products, the customers' requirements, the delivery time slots' capacities and various factory's constraints.

2.3.1 Model description

Index

o Index of product order, $o \in U_t$.

t Index of product type, $t \in T$.

h Index of period in the planning horizon, $h \in H$.

m Index of unconfirmed slot, $m \in M$.

r Index of subset of products types in the set C, r =1,.., |C|

Sets

T Set of product types.

J Set of couples of incompatible products types.

M Set of non-confirmed slots that can satisfy at least one product.

M_o Set of non-confirmed slots that can satisfy the o product order ($M_o \subset M$).

A Set of non-confirmed product orders that can be assigned to at least one slot.

A_m Set of non-confirmed product orders that can be assigned to slot m ($A_m \subset A$)..

U_t Set of all non-confirmed product orders of product of type t.

C Set of subset of products type which have restrictions in production quantity in periods of the planning horizon.

Cr Subset of products type which have a shared restriction in production quantity in periods of the planning horizon.

H Set of periods in the planning horizon.

B_h Set of slots in the period h of the planning horizon.

Parameters

Ph_o Priority between 0 and 1, accorded to the product order o, according to the priority of customer given by the decision-maker.

S_{om} Satisfaction level by assigning product order o to slot m .

P_{om} Penalty by assigning product order o to slot m .

$n_{t,t'}$ The great number of minimum numbers of product orders between the two incompatible products type t and t'; $(t,t') \in J$.

b_o Minimal satisfaction level of the product order o imposed by the decision-maker.

Lb_t Lower bound on total assignments of product of type t per period, $t \in C_r$.

Ub_t Upper bound on total assignments of product of type t per period $t \in C_r$.

Decisions variables

$$A_{o\,m} = \begin{cases} 1, & \text{if we assign product order } o \text{ to slot m}, \ \forall\, o \in \text{A} \ ; \ \text{m} \in \text{M}_o \\ 0, & \text{otherwise} \end{cases}$$

$D_{o\,m}$ = deviation between the minimal satisfaction required (b) and that's found, proposed by the agent. $\forall o \in A$; $\forall m \in M_o$

2.3.2 Mathematical program

Maximize

Maximize the difference between the sum of global weighted satisfactions and the sum of the weighted deviations.

$$\sum_{\forall o \in A}\sum_{m \in M_o} Ph_o * (S_{om} - P_{om}) * A_{om} \ - \sum_{\forall o \in A}\sum_{m \in Mo} Ph_o * D_{o\,m} \qquad (1)$$

Subject to

A product order can be assigned to one slot only:

$$\sum_{m \in Mo} A_{om} = 1 \qquad \forall o \in A \qquad (2)$$

A slot can be assigned to only one product order:

$$\sum_{o \in A_m} A_{om} \leq 1 \qquad \forall m \in M \qquad (3)$$

Interference constraints: *at least $n_{t,t'}$ products order between two incompatibles products type*

$$\begin{aligned} & A_{om} + A_{o'_{m+i}} \leq 1 \quad \forall (t,t') \in J \ ; \forall (o,o') \in (\{U_t\},\{U_{t'}\}); \text{such that } o \neq o'; \\ & \qquad \forall m \in M_o \quad \text{such that } m+i \in M_{o'}; \quad i = 1,\ldots, n_{t,t'} \end{aligned} \qquad (4)$$

Bounds constraints: *at least Lb_t products order and no more than Ub_t product order in every period s in the planning horizon*

$$Lb_t \leq \sum_{o \in U_t / t \in C_r} \sum_{m \in B_h \cap M_o} A_{om} \leq Ub_t \quad \forall h \in H \quad \forall C_r \in C \tag{5}$$

Optional constraint according to the choice of the user to impose an inferior limit (b_o) on the o[th] order satisfaction level:

$$(S_{om} - P_{om}) * A_{om} \; + \; D_{om} \; \geq \; b_o * A_{om} \quad \forall o \in A; \quad m \in M_o \tag{6}$$

This option is very useful when we plan customized (customers' orders) and forthcoming product orders in the some times.

Constraints for that all the variable $A_{o,m}$ are binary:

$$\mathrm{A}_{o,m} \;\in\; \{0,1\} \; \forall \; o \in A, \; \forall \; m \in M_o \tag{7}$$

To be sure that the basic materials are available, we only use the time slots which assure that the needed materials will be available in time. These slots have the delivery times after a certain period of the assignment process (the run of the mathematical program). This period of time is the largest green led-time of all the green time of these correspondent suppliers.

<u>Satisfaction level</u> (S_{om}) (sea figure 2):

$$\mathrm{Q}_o, L_o, I_o, MP_o \begin{cases} 1, & \text{if client of order o prefer Quick/Latest/Indiffrent/Mid - period delivery} \\ 0, & \text{Otherwise} \end{cases}$$

Every chosen customer one and a single model of delivery so:

$\forall$o $Q_o + L_o + I_o + MP_o = 1$

Et_o/ Ld_o Earliest/Latest delivery date expressed by the customer of product order o

L_m Delivery date of slot m

Satisfaction level by assigning product order o to slot m is:

$$S_{om} = \begin{cases} \frac{L_m - Et_o}{Et_o - Ld_o} + 1 & if \quad Q_o = 1 \\ \frac{Et_o - L_m}{Et_o - Ld_o} & if \quad L_o = 1 \\ 1 & if \quad I_o = 1 \\ -4\left(\frac{Et_o^{\ 2} - (Et_o + Ld_o)Et_o + Et_o * Ld_o}{(Et_o - Ld_o)^2}\right) & if \quad MP_o = 1 \end{cases}$$

<u>Penalty</u> $P_{\alpha m}$ (sea figure 3)

P_{om} Penalty by assigning o' order to slot m .

C_{α} Required capacity to satisfy product order o .

Cvo_m Green/Yellow capacity of slot m .

Cor_m Orange/Red capacity of slot m .

Crn_m Red/Black capacity of slot m .

p penalty per unit in more than the Red/Black capacity.

$$P_{om} = \begin{cases} 0 \quad if \quad C_o \le Cvo_m \\ \frac{C_o - Cvo_m}{Cvo_m - Cor_m} \quad if \quad Cvo_m < C_o < Cor_m \\ 1 \quad if \quad Cor_m \le C_o \le Crn_m \\ \mathrm{p}(C_o - Crn_m) \quad if \quad C_o > Crn_m \end{cases}$$

3. Agent for the collaborative planning commitments of satisfaction of customers' orders

In this section of the paper, the implantation of the model within a Java environment is discussed. In the next two sub-sections, we present our tool successively as a planning agent in the planning team of the NetMan unit and as a decision assistant tool for the demand management of our industrial partner.

Multi-agent technologies allow us to approach this particular problem of decentralized planning (Tapscott and Caston 1994). Multi-agents systems, a field of distributed artificial intelligence, consists of several software agents, which interact to resolve common problems, such as the sharing of resources and the coordination of activities. Multi-agents systems have been developed and used widely in several domains, including industrial supply chain management (e.g. Lefrançois and Montreuil 1994, Sikora and Shaw 1997, Shen And Norrie 1999).

3.1 Planning agent in the planning team of the NetMan unit

The NetMan paradigm formalizes the network enterprise as a responsibility-based network. A prototype inspired a world-class coach manufacturer is developed to experiment ours concepts. It is based on the simplified vision of the network of products realization (figure 4). Three plants compose the internal network of this coach manufacturer, each being organized with functional centers as represented in the figure. In the main plant (Plant 1), the H and V models of motorcoach are assembled, as well as other sub-assemblies (seats, luggage holders, etc.). In the second plant (Plant 2), XL structures are assembled from components provided by an internal center of parts manufacturing and by the third plant (Plant 3), which also feeds the H structure assembly line in the main plant.

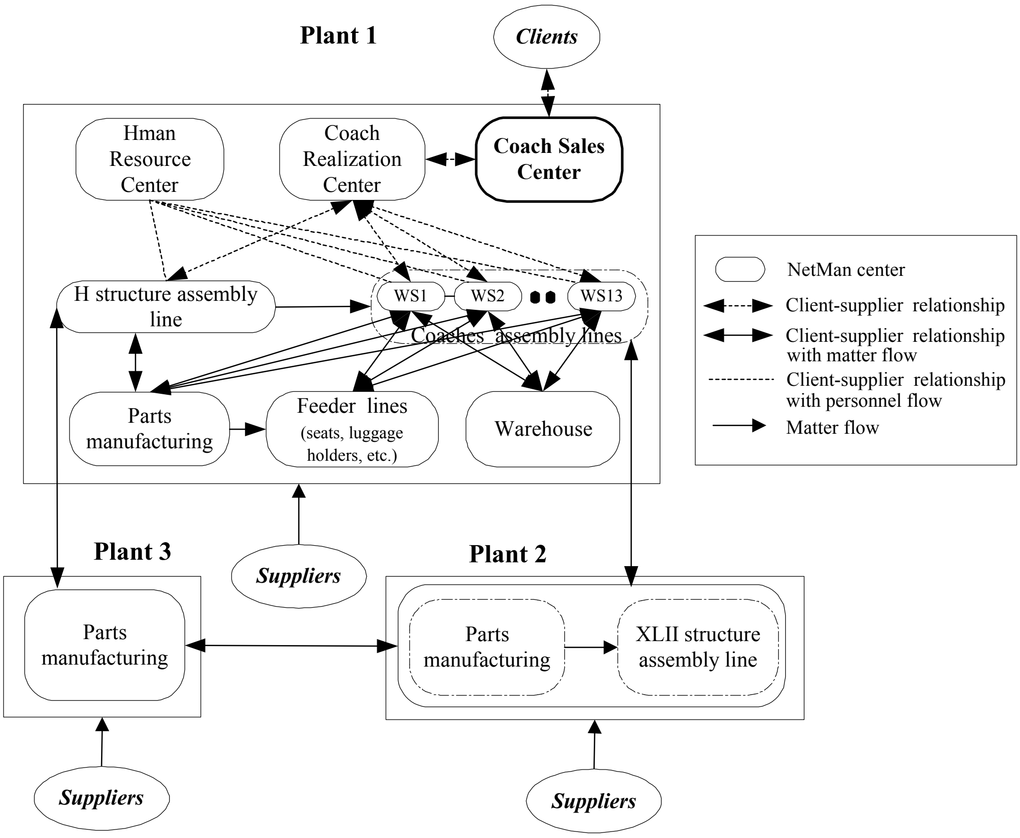

Figure 4. Organizational structure of the prototype of NetMan operation system

This prototype is composed of different NetMan centers connected by links that translate their business relationships and can support different kind of flows (information, material and resource). It's principally composed of:

(1) An order management planner (Coach Sale Center) is responsible for the demand management. It forms an interface between the clients and the production system.
(2) An assembly line coordinator center (the Coach Realization Center) is responsible for supplying finished coaches without doing anything itself.
(3) Thirteen workcenters of the assembly line.
(4) The human resource center.
(5) The Sub-structure Center Coordinator.
(6) The H Structure Line Coordinator.
(7) The XL Structure Line Coordinator.

Our tool is integrated as a planning agent (slots planning agent) in the planning team of the NetMan unit representing the Coach Sales Center. It is in direct communication with the planning team of the NetMan unit of the coach realization center. An assembly line balancing agent is integrated in the planning team of this center.
The model discussed in this paper is the 'intelligence' capability of the slots planning agent. This agent is used in an interactive way through the NetMan multi-agents system to help the planning team to generate and estimate practical and optimal solutions of the demand satisfaction..

When the customers send orders to the sales department according to their requirements (earliest delivery possible, latest delivery date and satisfaction function type), the orders planner (NetCTP) has to elaborate a production plan by assigning confirmed orders to specific delivery time slots.

The agent structure of the planning is presented in the figure 5.

- ***The assembly calendar generator*** generates slots according to the current capacities of the factory. The assembly calendar generator is encapsulated in the form of agent in our prototype.
- ***The planner*** is the key entity in this operation. The main task of the planner is to assign orders to slots, by the generation of a linear file.
- ***Cplex*** solves mathematical program files (because we base ourselves on an integers programming model). Cplex is encapsulated in the form of agent in our prototype.

➢ ***The planning coordinator*** is mainly responsible for managing the interactions of the planning team with others teams of the NetMan unit.

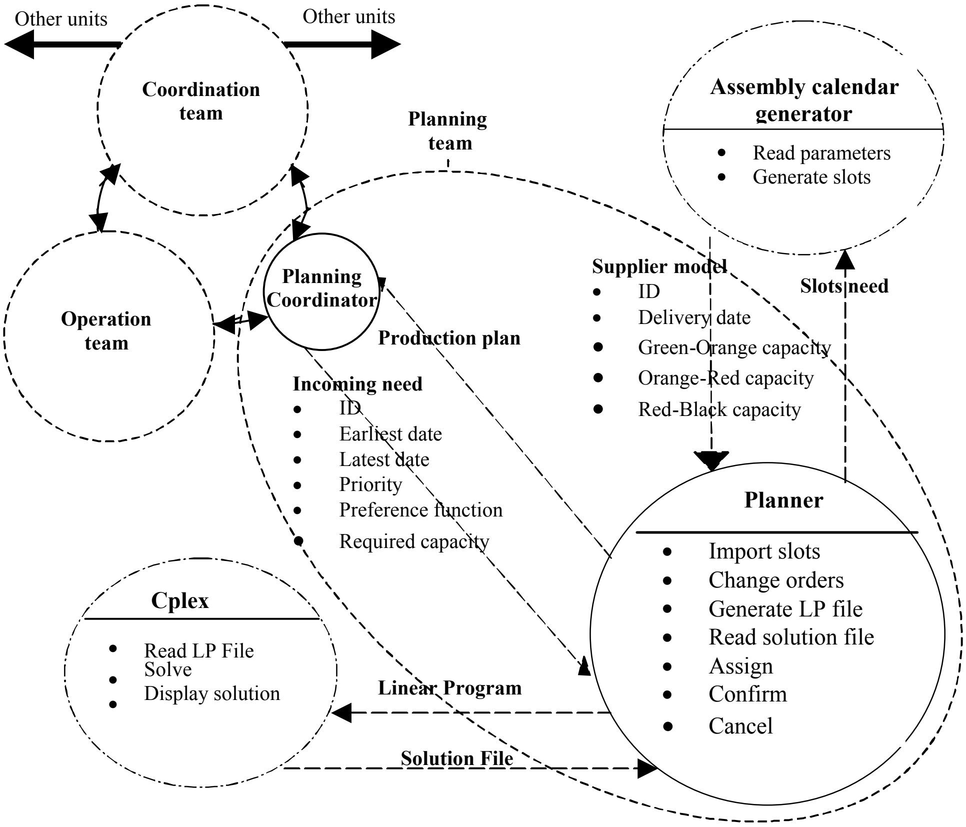

Figure 5. Sales departments NeMan unit

The customers communicate with the monitoring agent in the operations team of the NetMan unit (figure 6), which interacts with the planning coordinator through the operations coordinator of this unit to inform it about new orders to be planned.

The planning coordinator sends his planning needs to the planning agent to generate a production plan. To do this, the planning agent sends a slots need necessary to plan this new need (set of orders). When it receives the new slots, it generates a Linear Programming File (LP File) (developed in the previous section). To resolve this linear program, the planning agent sends it to Cplex optimisation software. This software solves the problem and returns the Solution File to it. The planning agent can now return the elaborated Production Plan to the operations team each containing slots corresponding to each of the needs and its satisfaction level.

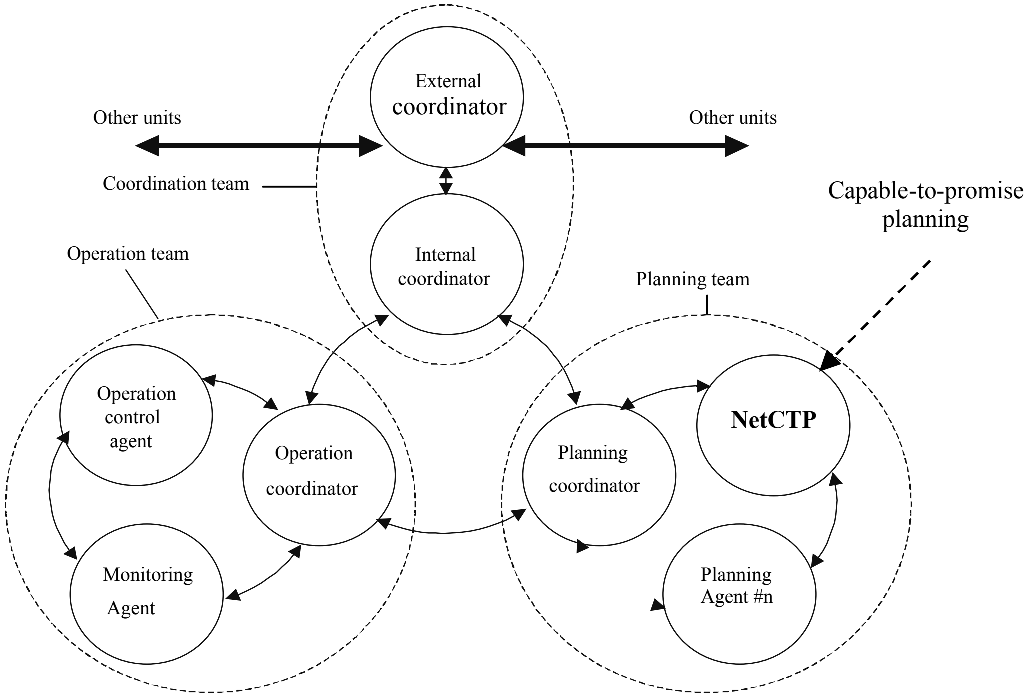

Figure 6. Agents in the NetMan unit, adapted from Cloutier et al. 1999 p. 91

3.2 Planning agent as an assistant tool in the decision for the demand management of the coach company

This planning agent is represented also as an interactive assistant tool for the decision of order planning. A user interface offering several options of analyses was developed for this purpose. It is presented in figure 7.

This tool is based on principles clarified in this document for the demand planning. However, needs are insured by the user instead of being expressed by the other agents of the system. It is the same for the results, which are directly displayed in the user interface. The user is able to realize various analyses.

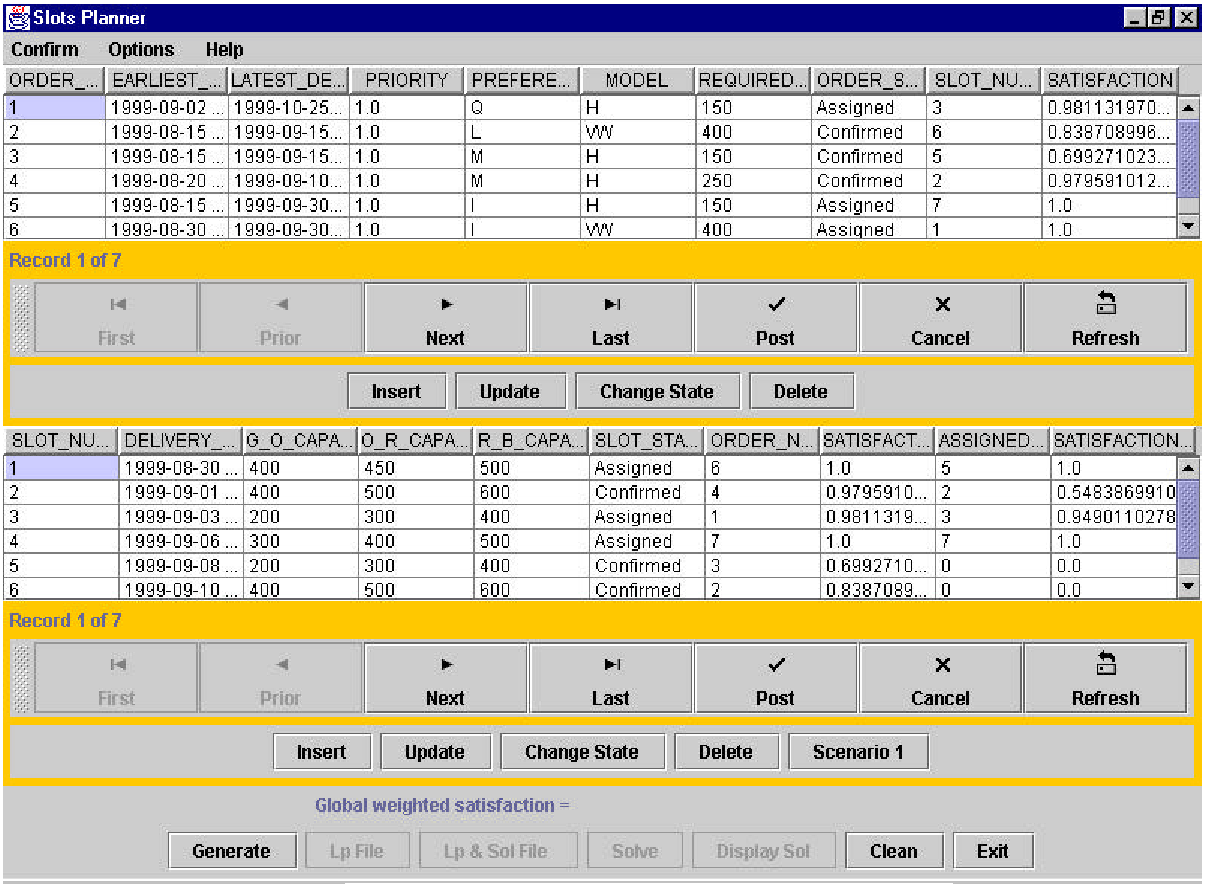

Figure 7. Decision support system

4. Numerical analysis

The purpose of this section is to evaluate the performance of our method. To do so, we conducted a series of computational experiments. In this section, the proposed model is compared to a method commonly used in the industry.

4.1 A heuristic approach for managing the demand

In this sub-section, we present our heuristic solution (greedy heuristic) for the case of a coach manufacturer. To resolve the problem of assigning orders to time slots, using a heuristic approach which takes into account constraints associated with the mix of products, the customers' requirements, the delivery time slots' capacities and various factory constraints. This heuristic is conceived to take into account the same parameters considered by the mathematical program: we have the same categories of coaches to plan H and V, which can be provided with wheel chair lift. The computation of the satisfaction level is done by using the objective function of our mathematical model described above. Actually, the satisfaction level of assigning an order to a slot is simply the coefficient of the binary variable representing the eventual assignment of this order to that slot. Figure 8 describes the different stages of this heuristic, used as a benchmark for the mathematical programming model suggested in this paper.

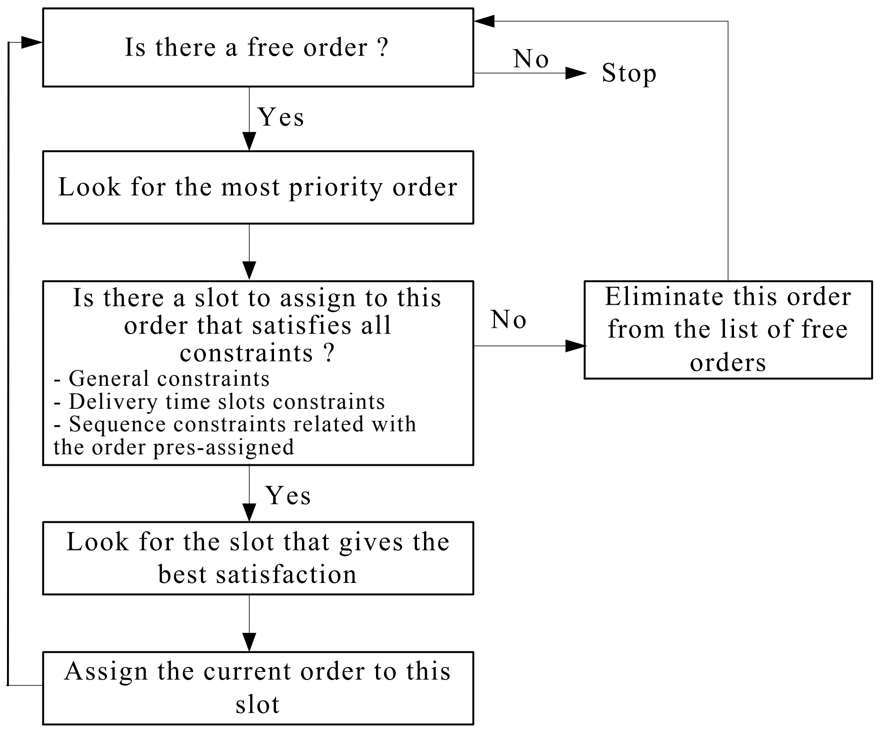

Figure 8. Heuristic method

These two methods have been implemented using object-oriented programming and tests have been performed on a Pentium III, 800 Mhz, personnel computer.

4.2 Parameters

Test problems were generated by two generators: one for the orders and another for the slots. The different parameters of the orders generator are presented in table 2. These parameters were chosen to fit at the best the case of our coach manufacturer.

Earliest delivery	Latest delivery	Priority	Preference function	Model	Required capacity	Probability
				H	150	0,2
				H	250	0,45
				V	200	0,1
Random	Random	Random	Random: Q-L-I-M	V	300	0,15
		between 0-1		HW	350	0,03
				HW	450	0,02
				VW	400	0,02
				VW	500	0,03

Table 2. The parameters of the orders generator

Three different blocks of slots' capacity are generated with different probabilities (table 3).

Delivery date	Green /Orange capacity	Orange /red capacity	Red /Black capcity	Probability
	200	300	400	0,33
Random	300	400	500	0,33
	400	450	500	0,34

Table 3. The parameters of the slots generator

4.3 Results

Table 4 shows the parameters of the different tests:

- In the first test we attempt to plan the orders for a period of three months. 81 slots are generated. We begin to plan a first batch of orders (27 orders). In the second test we continue with a second batch of orders expected to fill the rest of the slots (54 slots).
- In the third test we attempt to plan the orders for a period of six months. We have 78 slots generated with a frequency of 6h40. We begin to plan the first batch of orders (26 orders). In the second test we continue with a second batch of orders supposed to fill for the rest of slots (52 slots).

Test	Period	Number of slots	Number of free slots	Number of orders	Number of free orders
1	3 months	81	81	27	27
2	3 months	81	54	81	54
3	6 months	78	78	26	26
4	6 months	78	52	78	52

Table 4. Tests parameters

The same sets of data are used for testing the two methods.

Table 5 shows the results of the tests for the two methods (mathematical formulation: M1 and the heuristic: M2) in terms of:

- The number of assigned orders
- The percentage of assigned orders: the number of assigned orders divided by the number of free orders.
- The global satisfaction: the sum of satisfactions of each order-slot assignment (The satisfaction of one order-slot assignment is the sum of the customer satisfaction level and the slot satisfaction level.). The global satisfaction divided by the number of free orders is the global satisfaction of all orders.
- The global weighted satisfaction: the sum of weighted satisfaction of every order-slot assignment (The weighted satisfaction of one order-slot assignment is the sum of the customer satisfaction level and the slot satisfaction level.). The global satisfaction divided by the number of free orders is the global satisfaction of all orders.
- Execution time: the time in seconds of the execution. The execution time of the first method includes the time of generation of the mathematical program and the resolution with Cplex software.

	Number assigned		% assigned		Global satisfaction		Global weighted satisfaction		Execution time	
Test	M1	M2	M1	M2	M1	M2	M1	M2	M1	M2
1	27	27	100	100	23,5/27 = 87,03%	23,11/27 = 85,6%	9,99/27 = 37,03%	9,94/27 = 36,84%	314	354
2	54	54	100	100	16,15/54 = 29,91%	-20,41/54 = -37,8%	14,56/54 = 26,97%	4,19/54 = 7,76%	814	367
3	26	26	100	100	13,47/26 51,81%	13,8/26 = 53,08	11,06/26 = 42,54%	3,30/26 = 12,71	304	354
4	52	46	100	88,46	12,06/52 = 23,19%	Non realisable	5,92/52 = 11,39%	Non realisable	1015	559

Table 5. Tests results

For all tests, the first method assigns more orders than the second method and has a better global satisfaction, except for two of them. The deterioration of these two satisfaction levels is due to the negative satisfactions generated by the orders assigned in more compared to those assigned by the second method. This is natural because the first method optimises for the whole orders in the same time. In fact, the first method tries to assign all orders and to maximize their weighted satisfactions. The second method tries first to maximize the individual weighted satisfaction and second to maximize the number of assigned orders. However, this advantage necessitates more time in execution for some tests.

The first method outperforms the second one in both Test 1 and Test 3. Though this outperformance is showed in all parameters, there is a slight difference between the two tests. This result is common to both tests because both of them have more orders than slots; these cases are relatively less rigorous than other tests which are restricted by a limited number of slots.

By comparing the two methods we can conclude that the first method most often provides better results than the second one.

5. Conclusion

In this paper, a demand management tool was presented for a specific case of distributed manufacturing. The order management controls daily interactions between the customers and the company. As long as a factory only has a certain capacity to satisfy a certain number of demands, our purpose is to maximize the customers' satisfaction level by an optimal assignment of orders to the available delivery time slots.

The proposed technology finds its importance in the fact that it allows the firm a better planning of its capacity in assuring an optimal satisfaction of its customers. In fact, these objectives refer to a context that involves two parts, the customer and the firm, driven by multiple requirements, such as a promised delivery date, a better utilization of the capacity, etc.

The development of this tool puts into use mixed linear programming at the level of the stage of conception and formulation, as well as the concepts of multi-agents systems, a field of distributed artificial intelligence, in the phase of implementation. Implementation was realized in the Java programming environment by dynamically using the Cplex optimisation software.

The use of this model aims to improve the relation between the sales and the production department, which directly results in a better use of the workstations. This would seem to be the best objective to satisfy because all the others depend on it in some way or another. A better use of workstations has a direct effect on other business objectives, such as: the maximization of outputs, the minimization of works-in-process, the minimization of stock shortages and the minimization of idle time.

Among the advantages of the proposed approach is that the methodology of computing the customers' satisfaction level as well as that of the slots' capacities is generic to all companies. Only the specific constraints in the factory which change from one company to the other are different.

To test the proposed tool, we have proceeded to use comparisons with a second method developed for the same problem. Computational results show that the method based on mathematical programming outperformed the second method in the majority of the cases.

The proposed model and tool is essentially focusing on the capacity availability defined in terms of man-hours. The problems related to material availability will be better addressed in future work.

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