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# Impacts of a “reference plan” policy on the robustness of a supply chain tactical plan

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## Abstract

Based on linear and linear integer programming techniques, Advanced Planning Systems (APS) enable tactical plan establishing each time a significant event occurs. Thus, planning is more reactive but consequently instable, and hence might lead to a loss of robustness when making a decision (in decision making?).

This article presents a specific approach to increase robustness and stability for tactical plan. Several methods have been already discussed to achieve this robustness target. This proposed new procedure is named “reference plan”.

*Keywords:* Robustness, Stability, Tactical planning, Advanced Planning System

## 1. Introduction

A supply chain is a network of entities which supplies material, transforms it into intermediate and finished product, and distributes finished products to the customers (Lee and Billington, 1995). Historically, these three activities were managed independently. The complex links of the logistic chain were ignored (Thomas and Griffin, 1996). Supply Chain Management (SCM) arose in this context in order to ensure the management of both material and data flows, at the same time within and between those entities, so as to synchronize their activities (Christopher, 1992).

Distribution, production and procurement are coordinated at tactical planning level (Stadtler

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and Kilger, 2000). The resources level to use, the flows between the sites, etc., are determined so as to synchronize the capacities and the flows simultaneously. For this purpose, different scenarios are evaluated by indicators aggregated in a cost function. The resulting plan defines the reasonable and feasible levels in terms of production, transfer between entities, as well as the required resource level in the supply chain for planned finished products. The plan looks for the compromise that minimises service costs (backlogs, non-delivery, profitability of products), inventory levels (holding costs, additional storage capacity) and resources (costs of production, capacity, transport, subcontracting...). Hence tactical planning partially covers Sales and Operations Planning, which ensures the coordination between the various functions of the firm and determines the optimal scenario which will minimize the various expenses and maximize the sales (Vollmann et al., 1997).

APS (Advanced Planning Systems) support tactical planning (Stadtler and Kilger, 2000). The technical progress made in computing power now enables the calculation of a plan within a few minutes. By using these tools, management can hence re-optimize the model each time an event puts the current tactical plan into question. The plan remains always « optimal » for all variations in the input data. This way, we can reach the desired reactivity while maximizing profitability, but without being concerned with modifications made in the plan. However these practices induce strong disturbances on the productive system, but also on the partners of the supply chain by generating the bullwhip effect (Forrester, 1958). The overcosts created by these variations are not taken into account in the system global optimisation.

From another point of view, the calculation of tactical plans by commercial software is

based on linear and linear integer programming techniques of optimisation (Stadtler and Kilger, 2000). These calculation techniques are relatively well adapted to the problem handled (Johnson and Montgomery, 1974), (Yu and Li, 2000), as long as we assume linear relations between costs and volumes. Yet, these techniques are well known for determining optima which are sensitive to fluctuations of the parameters **or the costs** of the model. The above-mentioned method, consisting in re-optimising the model when an event influences its parameters, leads to reactive but also non-robust planning.

Sensitivity analysis is the first approach used to evaluate the effects of changes in the coefficients of the objective function (the costs) and in the members of the constraints vector (the constraints), as well as the range of validity of these effects (Koltai and Terlaky, 2000). It determines the value of the parameters of the model for which a given solution remains optimal. However, this sensitivity analysis studies the impact of parameters that are independent one from the other. It doesn't enable the manager to study sub-optimal solutions which are less sensitive to a simultaneous fluctuation of the factors and therefore more robust.

Thomas and Lamouri (2000) **used experimental** design, and specifically Taguchi's method, to analyze the impact of uncontrollable factors on the plan cost obtained by linear optimisation: level of the beginning inventory, wages costs, storage capacity. It is the first approach which we tested to improve robustness. When the system is subjected to **effects** of "external noncontrollable" factors, Taguchi (1987) recommended to use orthogonal plans. Thus by using this technique, robust optimal solutions can be found. We could determine the strategies with a better plan robustness on the cost function by choosing the set of parameters for controllable variables minimizing the "quality loss" function: strategy with

hiring/dismissals (layoffs) (by influencing the associated costs), strategy without delay, strategy without stock. This application showed that it was possible to find a robust tactical plan. However the time of implementing such a experimental design (even fractional) is limited for industrial use. This led us to seek other possible approaches.

In this paper, we propose to study how the process used to elaborate the tactical plan influence its robustness. Doing so, we compare two different processes changing only the policy used and highlight the effects of each one on several indicators.

For the purposes of our study, the next section defines the terms of robustness and stability. In section 3, we describe the linear model used to compare the two policies. Section 4 presents an iterative method which simulates the elaborating processes. The results of the simulation will be presented in section 5. Section 6 will deal with our conclusions and prospects.

## **2. Underlying concepts of robustness and stability**

In a supply chain, uncertainty appears through demand (volume and mix), process (yield, scrap...) and procurement (quality and reliability of the delivery lead times). It is generally compensated by inventories or buffers. Other researchers have shown that the structure of the supply chains itself could generate fluctuations (Simchi-Levi et al., 2000). Indeed, a decision concerning an industrial activity generally causes adjustment decisions for other activities. The effects of the first decision tend to reduce quickly with time, but the combination of the following decisions taken by the same or other associates influence the system overall. The complexity of managing the supply chain because of the variations was highlighted by the phenomenon usually called “bullwhip effect”, an increasing amplification effect (Forrester, 1958). The solution proposed is a better synchronisation amongst the entities, supported by co-operation and communication reinforced between the entities of the

logistic network (Simchi-Levi et al., 2000). But the compromises looked for have to replace divergent targets (inventory availability, costs...) Moreover, Holmström (1997) shows that these effects amplify as companies cooperate more.

In such a fluctuating and uncertain context where the terms robustness and stability are used, the definition of these words proves to be necessary.

### **a) Stability**

The term *stability* is generally associated, by opposition, with that of nervousness: De Kok and Inderfurth (1997) have defined “nervousness” as “a lack of stability in the material requirements planning”.

Planning nervousness is often treated in literature at MRP level (Yano and Carlson, 1987), (Minifie and Davis, 1990), (Sridharan and Laforge, 1990), (Kadipasaoglu and Sridharan, 1995), (Blackburn et al. 1986), (Ho, 1989), (Jensen, 1993), (Heisig, 1998).

Several authors already explained MRP systems’ nervousness (Orlicky, 1975) and the difficulties induced by “schedule nervousness caused by uncertainty in demand or supply or by dynamic lot-sizing that can be an obstacle to effective execution of material requirements planning systems” (Kadipasaoglu and Sridharan, 1995). Several strategies to dampen nervousness or to increase planning stability in MRP systems were proposed:

- to lengthen planning horizon (Carlson et al. 1982), to freeze the Master Production Schedule within this planning horizon (Zhao and Lee, 1993), to position buffers (Blackburn et al. 1986),
- to distinguish between small and large change (Ho, 1989).

The instability of a plan is often defined by the **number of modifications made on the**

**decision variables** of the model between two successive versions of the plan. The term stability is thus related to the decisions variables.

Within the meaning of Lyapunov (1892), a system is known as stable if and only if one disturbance of the initial conditions involves a limited disturbance of the trajectory of the system (Figure 1).

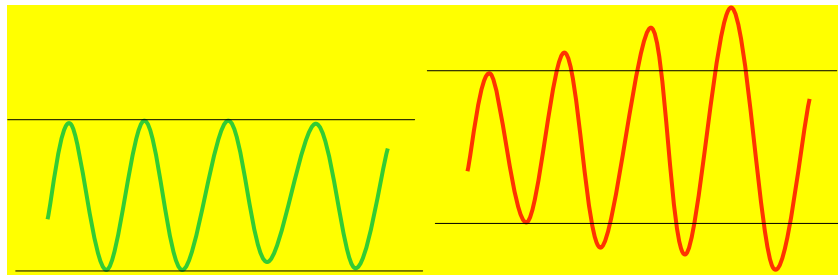


Figure 1.a: Stable system

Figure 1.b: Unstable system

A supply network will be known as stable if the decisions variables evolve in fixed ranges following a variation of the input data.

In their article, De Kok and Inderfurth (1997) study the stability of the plan in volume. They use, just like Kimms (1998), the expected value of variation in the quantities between two periods in the planning. Donselaar et al. (2000) compare the nervousness of the plan generated by MRP with that of their heuristics. The indicator considered is the number of “re-plannings” encountered. The instability studied is the change within the periods. If a quantity appears or disappears during a period, the indicator will be incremented. However, if quantities are only modified, the indicator remains at the same level.

## ***b) Robustness***

The term *robustness* is generally associated with that of risk and decision-making (Kleijnen and Gaury, 2003). The underlying idea of system robustness is that the measured function do not diverge significantly from a given value. A system is known as robust if it makes it

possible to obtain a weak dispersion of the target performances in spite of the variations of the level of the noncontrollable decision variables. The robustness relates to results of several functions and of their dispersion subject to uncertain parameters and costs (Lee and Yu, 1997). In another context that ours, Kleijnen and Gaury (2003) study the robustness of a kanban loop according to two functions: average wip in the loop and the delivery performance.

Thus, a system can give a robust answer, i.e. a weak dispersion of the cost function, but to be unstable by systematically varying the decisions variables of the system to obtain an identical cost. In the same way, a system can be stable, i.e. few variations of the variables of decisions, while not being robust since the function cost can diverge because of too significant fluctuations in conditions.

Taguchi (1987) treats robustness of a function by making the hypothesis that it can be controlled by the quadratic functions "losses" or by the signal-to-noise functions which combine the average and the variance of result.

Nowadays, APS vendors limit themselves to deliver to their customers the mathematical models which will make it possible to determine "optimal" plans (Stadtler and Kilger, 2000). But, the *robustness* of these plans is a significant but neglected subject. An optimal solution for a scenario is not exploitable if it becomes inefficient with the least change in parameters. It will lead to higher costs. More especially that at tactical level, decisions validated in period  $p$  will have effects only in period  $p+n$ ,  $n$  being the time of the decision implementation.

Linear programming requires the user to describe deterministic models. It is complex to



describe the majority of concrete logistic problems containing uncertainty, "noise", and incomplete information with linear programming (Graves et al., 1993). The traditional approach for optimising problems containing probabilistic parameters is stochastic programming. Many theoretical developments were made since the work of the pioneers Dantzig (1955) and Beale (1955). The objective is to optimise the expected value of performance indicators. These techniques are not yet able to solve problems of realistic size at the tactical level (Mulvey and al., 1995).

Mulvey et al. (1995) proposed an approach called "robust programming", able to simulate the sensitivity to risk of a manager or to guarantee a level of service to lead to a series of solutions which are gradually less sensitive to the variations of model data. They introduce penalties into the linear model so that the modifications of the decisions variables are an optimisation criterion.

### **3. Model**

#### ***a) General description***

The studied supply chain **delivers** transportation and power systems (turbochargers) to automotive constructors. This supply chain contains one raw material plant (turbo body) several assembly firms and a distribution system. Thus, for one delivered product, the company need to supply one raw material. In this context, the tactical plan is useful to define the forecasted production, inventory and workforce, essentially for financial objectives.

The model used **allows** to describe a simplified situation of decision-making for production level and capacity changes for a product group. The manager seeks the best compromise between service **level**, inventories and production costs related to the adjustments of capacity.

At each period and for each optimisation of the basic model, all the decisions variables are adjusted according to the modifications in demand. It does not take into account the decisions taken the previous period in supplied quantities, levels of production, the possible recruitment. It can therefore **cancel**, from one period to the **other**, decisions without taking into account the costs associated with these changes (generation of the model  $M_{0n}$  – figure 2).

This basic model is modified to simulate another planning process limiting the modifications made to a “reference plan”. **The reference plan (Figure 2) is the tactical plan validated by the concerned departments, production, commercial, supply chain during a meeting and implemented at the previous period (plan  $M_{Fn-1}$ ).** It is used as a framework to set up the new tactical plan of current period  $n$ .

This plan remains a reference as long as the control factors influencing it have not evolved significantly.

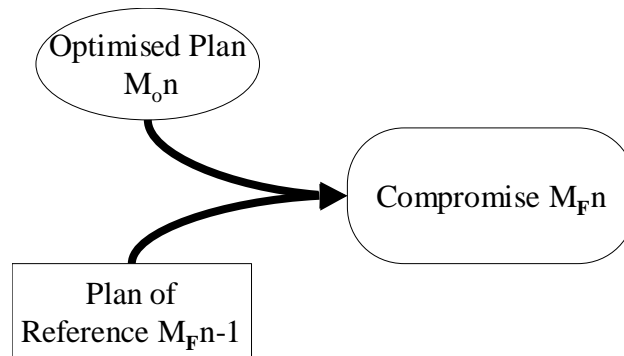


Figure 2: the reference plan

In a strategy of planning with “reference plan”, the model takes into account the decisions taken in this reference plan to find the best compromise between modification of these decisions and optimisation of an “ideal” model. Thus, the **manager aversion** to modifications of these decisions is represented by a weight on the difference between the new level of the

decisions variables and those of the reference plan. The model will seek a compromise by minimizing the cost generated by the variations on the decision variables compared to the reference plan, while minimizing the total cost of the plan.

An alternative approach would be to optimise the model by constraining the number of modifications made to the reference plan. It is then necessary to define what is a modification: it can be a simple variation or a variation exceeding a certain threshold defined by the manager. This last case approaches the theory of the control where exists a "dead" zone around the value of a decision variable in which no action is taken. This approach results in modifying the linear model to introduce integer variables

In this article, we preferred to use weightings to preserve a reasonable processing time for the problem.

Several decision variables can be taken into account (production quantity, overtime, ...). In the model described below, we chose the forecasted supply quantities transmitted to the raw material plant as decision variables to stabilise, because they correspond with one of the top priorities in tactical plans. That is why costs of increasing or decreasing in raw material quantity have been only introduced.

The quality of demand forecasts strongly influences the global optimisation of the logistic processes (Lee and Billington, 1995). In their article Disney et al. (2003) analyze how their original approach of inventory control in a supply chain on the impacts the bullwhip effect. They measure the variations in the behavior of the objective function of their simulation model faced to changes in demand volume. For that, the demand was modelled by a normal

law with an average of 0 and a standard deviation of 1. In an other manner, Rota et al. (2002), modelled the forecasted demand between a mini and maxi in opposition to firmed demands for which the expression was constant.

In our case and in the same experimental logic, uncertainty is created by forecast error. The forecasts generation is made according to the simple exponential smoothing model with a coefficient of sensitivity (fixed at 0.3) reflecting a variable market in order to simulate a certain nervousness. Indeed, the model of exponential smoothing (see Equation (0)) takes into account recent past with a more significant weighting, this leads to more realism in the envisaged values.

$$\begin{aligned} F_{p+1}(t+1) &= \alpha F_{p+1}(t) + (1-\alpha)F_p(t+1) \quad \forall t > p \\ F_{p+1}(p+1) &= \alpha D(p) + (1-\alpha)F_p(p+1) \\ \alpha &= 0.3 \end{aligned} \tag{0}$$

This phenomenon is also explained by Simanpo (2003). This is of course an assumption necessary to the specification of the context. Zhao et al. (2002) worked on the impact of forecasting models on information necessary to manage the supply chain. Our matter being to analyse the impact of a reference plan on the robustness of the tactical plan, we do not desire to vary the parameters of demand. However in a future work, we will complete the experimental analyse by taking into account in a experimental design, all these control factors. This will be the subject of our next paper.

The exponential smoothing model takes into account the recent past (the demand of past period  $D(p)$ ) with a more significant weighting, which leads to more realism in the forecasted values.

But this model induces consequently more nervousness in demand (the phenomenon which

we want to simulate). With regard to the real demand, the normal distribution allows us a good variability. The forecasts established for the subsequent periods are recomputed by taking account of the real demand.

Table 1 shows an example of forecasts calculations for a set of real demand. The forecasts calculated for period  $p$  have been used for model optimisation at period  $p$ .

t\	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Forecast $p = 1$	65	20	30	30	15	20	20	20	60	90	75	55									
Real Demand $p = 1$	62																				
Forecast $p = 2$		33	31	30	20	20	20	20	48	77	76	61	64								
Real Demand $p = 2$		35																			
Forecast $p = 3$			32	31	23	21	20	20	40	66	73	65	64	42							
Real Demand $p = 3$			38																		
Forecast $p = 4$				33	26	22	21	20	34	56	68	66	65	49	37						
Real Demand $p = 4$				29																	
Forecast $p = 5$					27	24	22	21	30	48	62	65	65	54	42	36					
Real Demand $p = 5$					26																
Forecast $p = 6$						24	23	21	27	42	56	62	64	57	46	39	30				
Real Demand $p = 6$						34															
Forecast $p = 7$							26	23	26	37	50	59	62	58	50	42	34	27			
Real Demand $p = 7$							45														
Forecast $p = 8$								29	27	34	46	55	60	59	53	45	37	30	27		
Real Demand $p = 8$								38													
Forecast $p = 9$									30	33	42	51	57	58	54	48	41	33	29	29	
Real Demand $p = 9$									51												
Forecast $p = 10$										38	41	48	54	57	55	50	43	36	31	30	30

Table 1: uncertainty in demand,  $\alpha=0.3$ ,  $h=12$

10'000 sets of rolling forecasts and associated real demands were generated prior to any simulation. These sets were used with both processes of elaborating tactical plan.

## b) Notation

$n$ : number of periods incremented during simulation,  
 $h$ : horizon of the tactical plan,  
 $p$ : the current period index of simulation  $p = 1, 2 \dots n$ ,  
 $t$ : index of the period of the plan  $t = p, p+1 \dots, p+h-1$ ,  
 $F_p(t)$ : demand forecast for period  $t$  calculated in period  $p$ ,  
 $D_p$ : real demand for period  $p$ ,  
 $CR(t)$ : maximum resource capacity usable in period  $t$  in production unit,  
 $CS(t)$ : maximum storage capacity usable in period  $t$  in production unit,  
 $u(t)$ : quantity of production units in period  $t$  per operator,  
 $uo(t)$ : quantity of production units per overtime hour in period  $t$ ,  
 $CO(t)$ : maximum of overtime hours per operator in period  $t$ ,  
 $I_0$ : Beginning inventory (positive or null),  
 $B_0$ : Beginning backorders (positive or null),  
 $IM_0$ : Raw material beginning inventory (positive or null),  
 $O_0$ : beginning number of operators (positive or null),

$I_h$ : target level of inventory (positive or null),  
 $R_h$ : target level of backorders (positive or null),  
 $O_h$ : target numbers of operators (positive or null),  
 $C_S(t)$ : storage cost per production unit in period  $t$ ,  
 $C_B(t)$ : cost of backorders per production unit for one period in period  $t$ ,  
 $C_H(t)$ : cost of hiring one operator in period  $t$ ,  
 $C_L(t)$ : cost of one layoff in period  $t$ ,  
 $W(t)$ : wages per operator in period  $t$ ,  
 $C_O(t)$ : cost of one overtime hour in period  $t$ ,  
 $C_{SU}(t)$ : supply cost of one unit in period  $t$ ,  
 $C_{MS}(t)$ : storage cost per unit of raw material in period  $t$ ,  
 $OH_p(t)$ : numbers of overtime hours in period  $t$  planned in period  $p$ ,  
 $O_p(t)$ : numbers of operators in period  $t$  planned in period  $p$ ,  
 $H_p(t)$ : number of hired operators in period  $t$  planned in period  $p$ ,  
 $L_p(t)$ : number of layoffs in period  $t$  planned in period  $p$ ,  
 $I_p(t)$ : level of inventory at the end of period  $t$  planned in period  $p$ ,  
 $B_p(t)$ : level of backorders at the end of period  $t$  planned in period  $p$ ,  
 $IM_p(t)$ : level of raw material inventory at the end of period  $t$  planned in period  $p$ ,  
 $P_p(t)$ : numbers of production units manufactured in period  $t$  planned in period  $p$ ,  
 $S_p(t)$ : numbers raw material units to be supplied in period  $t$  planned in period  $p$ .

### c) Linear model

The manager seeks to optimise resource use, minimising the costs over the whole horizon of his plan  $CT(p)$  at each period  $p$  under constraints of the equations (2)-(10).

$$CT(p) = \sum_{t=p}^{p+h} C_S(t) \times I_p(t) + C_B(t) \times B_p(t) + C_H(t) \times H_p(t) + C_L(t) \times L_p(t) + W(t) \times O_p(t) - \forall p \quad (1)$$

$$+ C_O(t) \times OH_p(t) + C_{MS}(t) \times IM_p(t) + C_{SU}(t) \times S_p(t)$$

These costs are the storage cost, the cost of backorders, the costs of hiring and layoffs, wages, overtime, storage cost and supply costs of raw materials. Equation (1) can also be rewritten in equation (1'):

$$CT(p) = \sum_{t=p}^{p+h} C_p(t) \quad \forall p \quad (1'),$$

where  $C_p(t)$  is the monthly cost in period  $t$  of the optimised plan in period  $p$ :

$$C_p(t) = C_S(t) \times I_p(t) + C_B(t) \times B_p(t) + C_H(t) \times H_p(t) + C_L(t) \times L_p(t) + W(t) \times O_p(t) + C_O(t) \times OH_p(t) + C_{MS}(t) \times IM_p(t) + C_{SU}(t) \times S_p(t) - \forall p, t \quad (1'')$$

$$\begin{aligned} \text{Inventories balance: } I_p(t-1) - B_p(t-1) + P_p(t) &= I_p(t) - B_p(t) + F_p(t) \quad \forall p, t \\ IM_p(t-1) + S_p(t) &= IM_p(t) + P_p(t) \quad \forall p, t \end{aligned} \quad (2)$$

$$\text{Material availability: } P_p(t) \leq IM_p(t-1) \quad \forall p, \forall t \quad (3)$$

$$\text{Number of operators balance: } O_p(t-1) + H_p(t) = L_p(t) + O_p(t) \quad \forall p, t \quad (4)$$

$$\begin{aligned}
& I_p(p+h-1) = I_h \quad \forall p \\
\text{Targets for inventory, backorders, and number of operators: } & B_p(p+h-1) = B_h \quad \forall p \quad (5) \\
& O_p(p+h-1) = O_h \quad \forall p \\
\text{Resource constraint: } & 0 \leq P_p(t) \leq CR(t) \quad \forall p, t \quad (6) \\
\text{Labour constraint: } & 0 \leq P_p(t) \leq u(t) \times O_p(t) + uo(t) \times OH_p(t) \quad \forall p, t \quad (7) \\
\text{Storage constraint: } & 0 \leq I_p(t) + IM_p(t) \leq CS(t) \quad \forall p, t \quad (8) \\
\text{Overtime constraint: } & 0 \leq OH_p(t) \leq CO(t) \times O_p(t) \quad \forall p, t \quad (9) \\
\text{Positive variables: } & 0 \leq O_p(t), H_p(t), L_p(t), B_p(t), P_p(t), S_p(t), OH_p(t) \quad \forall p, t \quad (10)
\end{aligned}$$

Equation (3) assumes that one unit of product will use one unit of raw material. It is also introduced to model one period lead-time between supply and consumption of raw material: production in period t is constrained by raw material put in stock I period t-1. These two hypothesis can easily be changed depending of the industrial context.

In the first policy, the costs induced by cancellations or additional purchases are not taken into account when elaborating the plan but are calculated as a result of the decision so as to compared the two policies.

#### ***d) Linear Model with reference plan***

To model this mode of decision-making, the following notations are introduced:

$C_{EX}(t)$ : overcost per additional raw material unit purchased compared to the reference plan,

$C_{CA}(t)$ : overcost per raw material unit cancelled compared to the reference plan,

$EX_p(t)$ : number of raw material units supplied in addition to the quantity of reference in period t planned in period p,

$CA_p(t)$ : number of raw material units cancelled in period t planned in period p

$EX_p(t)$  et  $AN_p(t)$  represent the difference to the reference plan. A variation exists if one of these variables is positive. These additional variables are determined by optimisation of the model. This optimisation consists in seeking a compromise between the stability ( $EX_p(t)$  and  $AN_p(t)$  are null) and the delays costs.

The planning objective remains the same: to minimize the costs on the planning horizon. But, now, the costs induced by cancellation or additional purchases are taken into account when elaborating the plan. They represent weightings or the manager aversion to carry out these modifications.

The optimised cost function becomes:

$$CT(p) = \sum_{t=p}^{p+h} C_S(t) \times I_p(t) + C_B(t) \times B_p(t) + C_H(t) \times H_p(t) + C_L(t) \times L_p(t) + W(t) \times O_p(t) + C_O(t) \times OH_p(t) + C_{MS}(t) \times IM_p(t) + C_{SU}(t) \times S_p(t) + C_{EX}(t) \times EX_p(t) + C_{CA}(t) \times CA_p(t) - \forall p \quad (11)$$

It is optimised under constraints of the equations (2)-(10) and (12)-(13).

$$\text{Raw material balance: } IM_p(t) = IM_{p-1}(t) - CA_p(t) + EX_p(t) \quad \forall p, t \quad (12)$$

$$\text{Positive variables: } 0 \leq EX_p(t), CA_p(t) \quad \forall p, t \quad (13)$$

### e) Indicators

The real costs generated on the n simulated periods are obviously followed. The robustness will be described by the standard deviation of the induced costs. This indicator allows one to observe the variability of the measured function.

The service performance,  $I_{SP}$ , is the average over n simulated periods of the quantity delivered divided by the quantity to be delivered,  $I_{pSP}$ . The quantity to be delivered is the backorders of the previous period plus the demand of the period.

$$\begin{aligned} \text{if } I_p(t) \geq 0 \text{ then } I_{pSP} &= 1 \quad \forall p \\ \text{if } I_p(t) < 0 \text{ then } I_{pSP} &= \frac{B_{p-1}(t) + D_p - B_p(t)}{B_{p-1}(t) + D_p} \quad \forall p \end{aligned}$$

In our case, the measured instability,  $I_s$ , relates to the volume supplied over each period. The indicator that we follow is different from that of Kok and Inderfurth (1997) or of Kimms (1998). It relates to the variation of volume between the forecast of period t+1 decided in t, and the quantity really supplied in t+1 period.



## f) Values and costs used

	1	2	3	4	5	6	7	8	9	10	11	12
Holding costs	20	20	20	20	20	20	20	20	20	20	20	20
Backorders costs	60	60	60	60	60	60	60	60	60	60	60	60
Hiring costs	400	400	400	400	400	400	400	400	400	400	400	400
Layoff costs	500	500	500	500	500	500	500	500	500	500	500	500
Regular Wages	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600
Overtime costs	15	15	15	15	15	15	15	15	15	15	15	15
Supply costs	200	200	200	200	200	200	200	200	200	200	200	200
Material holding costs	10	10	10	10	10	10	10	10	10	10	10	10
Qty. cancel cost	60	30	0	0	0	0	0	0	0	0	0	0
Qty. Express supply costs	60	30	0	0	0	0	0	0	0	0	0	0

$n=12$   $h=12$

$\alpha=0.3$

Beginning inventory (UN) $t=0$ :	0	Ending inventory	0
Beginning Nbr of workers $t=0$ :	5	Ending number of workers :	5
Hours/month/worker :	160		
UN/month/worker	8		
Max. overtime/month/worker :	20	Resource capacity (UN/mois) :	200
Labour hours (H/UN) :	20	Storage capacity (UN):	400
alpha	0.3		
Material Beginning inventory (UN) $t=0$ :	0		

As quoted previously, controllable factors exist for a tactical plan. By using an experimental design, these controllable factors can be fixed at levels which make it possible to minimize the total cost of the plan.

In this article, we chose the values of these factors resulting from this analysis minimizing the cost of the plan.

## 4. Simulation

Simulation is the analytical approach which reproduces the dynamic behaviour of the decision-making model. To examine the dynamic nature of the supply chain, an approach using a rolling horizon is adopted. That means that when time increases, new information become available (the current demand and new forecasts), the decision variables and performance indicators are thus re-valued.

The current demand is obtained from a normal distribution with an average equal to the forecast and a standard deviation equal to 6 that is to say a coefficient of variation of 0.2. The forecasts established for the following periods are recomputed by taking into account

the current demand according to an exponential model with a coefficient  $\alpha$ . The initial forecasts  $F_o(t)$  are represented on figure 3.

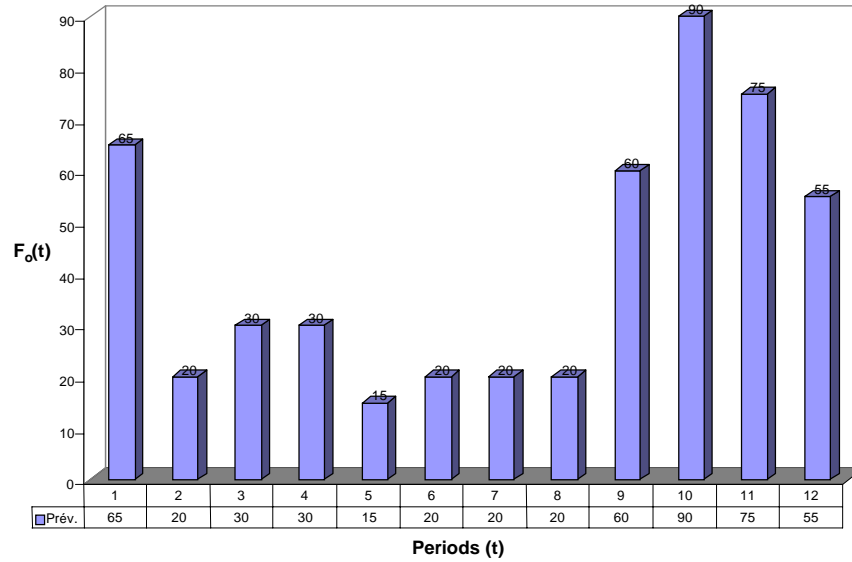


Figure 3: Initial Forecasts  $p=0$

10'000 simulations were carried out for each of the two cases, with or without reference plan according to the values indicated previously. They were held in an identical manner in each case. At each period, the model is optimised according to the calculated forecasts. That give the tactical plan from which the first period is implemented, i.e, production, overtime, hiring executed and raw material forecasts transmitted. Then, the current demand is indicated making it possible to calculate the real costs for the period. New forecasts are given, and the index is incremented (Figure 4).

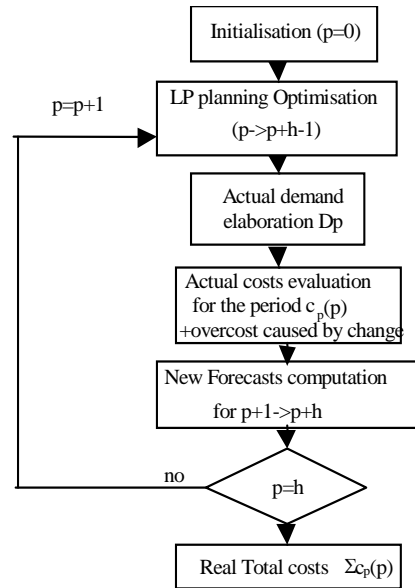


Figure 4: simulation Process with the basic model

In the case of simulation with a “reference plan”, the plan of the period is preserved in order to be used as input for the model optimised in the following period (Figure 5).

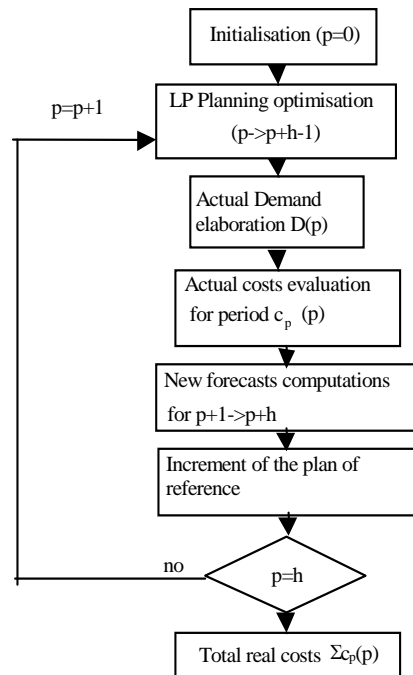


Figure 5: simulation Process with reference plan model

At each period, the indicators are incremented.

The only parameters that changes from one simulation to another, is the set of demand and forecasts. But the same sets were used for each case. So, Only the process to establish the tactical plan change from one case to the other.

The difference between the two processes is in the way costs of change in variables enclosed in the reference plan are taken into account. In process with reference plan, costs of change are clearly evaluated in the decision making procedure. For the other process, they are evaluated after the decision making.

## 5. Results

We are comparing two different processes of establishing a tactical plan and highlights their impacts on several indicators. Figure 6 resumes the impact of each process on each indicator.

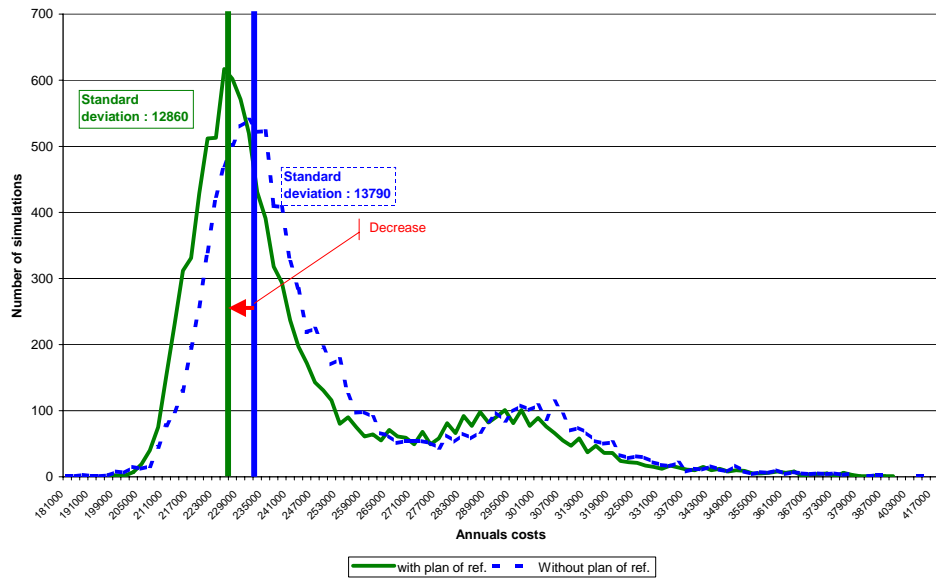
Indicators	Without Reference plan	With reference plan
Costs	235 000	228 000 (decrease)
Robustness	13 790	12860 (increase)
Customer service	62%	71% $\mu$ (increase)
Stability	3	11 (increase)

Figure 6: Indicators comparison

The first graph (Figure 7) represents the number of simulations which led to annual costs in the same range of values. Each curve represents one of the processes.

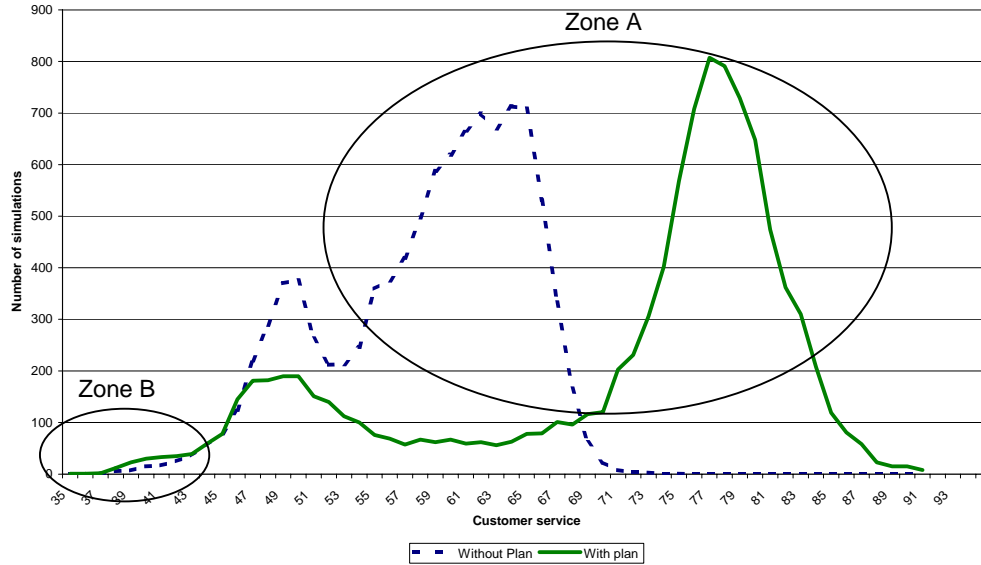
The first notable result is that a strategy of planning with reference plan led to lower annual costs, the whole while improving the robustness in costs. Indeed, the standard deviation for this strategy is smaller.

As in our experimental method, the only factor that changes is the process to elaborate a tactical planning, we can conclude here that this factor influences the robustness of tactical planning.



Annuals costs	Whitout Plan	With plan	Annuals costs	Whitout Plan	With plan	Annuals costs	Whitout Plan	With plan
181000	0	1	257000	75	97	327000	17	29
185000	0	1	259000	61	98	329000	15	22
189000	0	3	261000	64	90	331000	12	18
191000	0	1	263000	55	66	333000	17	16
195000	0	1	265000	71	62	335000	14	21
197000	3	2	267000	61	51	337000	11	8
199000	2	8	269000	59	54	339000	10	12
201000	2	6	271000	49	54	341000	15	11
203000	7	15	273000	68	54	343000	10	16
205000	19	12	275000	49	51	345000	12	11
207000	40	16	277000	58	44	347000	8	8
209000	75	45	279000	81	63	349000	10	17
211000	153	78	281000	66	53	351000	9	8
213000	231	99	283000	92	65	353000	5	4
215000	312	130	285000	77	58	355000	5	7
217000	331	195	287000	98	68	357000	6	6
219000	429	258	289000	82	84	359000	8	10
221000	512	341	291000	91	97	361000	6	4
223000	513	425	293000	101	85	363000	8	7
225000	617	471	295000	81	99	365000	1	5
227000	602	502	297000	101	108	367000	4	4
229000	571	530	299000	77	101	369000	4	5
231000	520	540	301000	89	108	371000	5	4
233000	431	522	303000	76	87	373000	1	5
235000	391	523	305000	66	114	375000	6	3
237000	318	410	307000	55	94	377000	3	5
239000	294	408	309000	47	70	379000	1	
241000	237	325	311000	58	74	381000	1	1
243000	197	284	313000	37	66	385000	2	2
245000	172	219	315000	47	54	387000	1	2
247000	143	224	317000	36	50	391000	1	0
249000	131	196	319000	36	52	401000	0	1
251000	116	170	321000	24	33	403000	1	0
253000	80	178	323000	22	28	409000	0	1
255000	90	124	325000	21	31	411000	0	1

Figure 7: annual costs variability



Service level	Without Plan	With plan	Service level	Without Plan	With plan	Service level	Without Plan	With plan
35	0	1	55	212	76	75	3	568
36	0	1	56	213	69	76	3	708
37	0	2	57	246	57	77	1	807
38	0	12	58	359	67	78	1	791
39	0	23	59	375	62	79	0	729
40	1	30	60	419	67	80	0	648
41	6	33	61	497	59	81	0	474
42	7	35	62	588	62	82	0	362
43	15	39	63	619	56	83	0	310
44	17	59	64	666	63	84	0	208
45	25	78	65	699	78	85	0	119
46	36	145	66	670	79	86	0	81
47	56	181	67	713	101	87	0	58
48	79	182	68	709	96	88	0	23
49	124	190	69	531	116	89	0	15
50	220	190	70	333	120	90	0	15
51	289	151	71	166	203	91	0	8
52	370	140	72	62	231	92	0	0
53	376	112	73	23	306	93	0	0
54	263	100	74	8	402	94	0	2

Figure 8: Customer service indicator

The  $I_{SP}$  indicator, service performance, shows a strong difference between strategies (Figure 8). Strategy with reference plan led to an increase of more than 10% in service performance with the data set used (Zone A). This result is obtained by the constitution of a strategic buffer of raw materials (Figure 9). Indeed, the model supports additional raw material inventory even if it means high storage costs. It makes it possible to react more quickly to unforeseen demand without risking costs of change. A service level around 80% can appear low compared to current standards. The data file makes the simulation begin with a null stock in the period of high demand. The initial conditions thus impose a degraded service level. Further work will be done to analyse the impact of initial conditions on robustness of the plan.

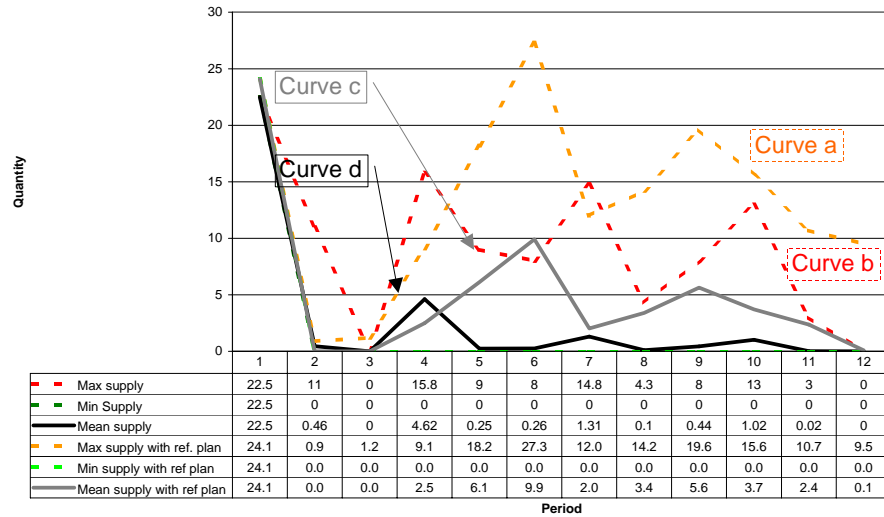


Figure 9: Raw material inventory level at the end of each period

The curve “c” represents the average level of raw material inventory over all the scenarios for periods with a reference plan. The curve “d” represents that obtained without reference plan. Figure 9 shows that this inventory is, on average, more significant with a reference plan. It is the same conclusion when the maximum raw material inventory is analysed. Curve “a” represents the maximum inventory generated on all the simulations using the model with reference plan. Curve “b” represents the same data for the other case. The first curve is higher than the second. If the storage costs are higher than the costs of change, or if demand is decreasing, the model reacts as in the basic case.

We can also observe, on figure 8, that the model with reference plan generates some cases of a bad service performance (Zone B). The model chooses in these cases stability by keeping the quantity of raw material to be supplied unchanged, and thus degrades the service performance, by limiting the production.

With regard to the indicator of stability,  $I_s$ , the profit of a strategic "reference plan" is obvious. Figure 10 represents the number of simulations according to the number of changes in the supplied quantities of raw materials. From permanent modifications, a quasi stability

is reached. It should be noted however that the model allows changes when the difference is too significant. With this kind of model, a degree of freedom is conserved. This is not possible with the frozen time fences used traditionally to reduce nervousness (Vollmann et al., 1997).

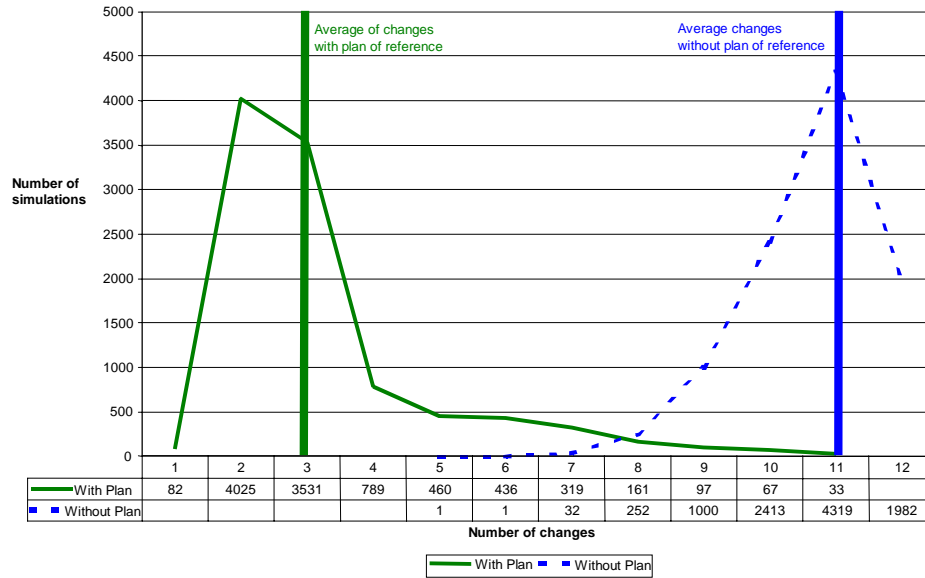


Figure 10: distribution of the number of changes in supplied quantities

## 6. Conclusions

In this article, we have analysed the influence on robustness of the tactical planning process. We also propose an approach to reduce planning nervousness while allowing a certain level of reactivity. Tactical planning establishment uses a reference plan from the previous cycle as a constraint during the re-optimisation of the model. A limited number of modifications will be done by this way, according to the horizon, thus making it possible to ensure stability in supply while improving the robustness in costs.

Always based on linear or mixed-integer programming, this planning logic can be implemented in a APS by adapting the models already employed.



Being a promising approach, our work will have to be checked on more extreme cases by experimental design to study the impact of controllable factors as the standard deviation of the demand ( $\alpha$ ), the holding costs, the delays cost, the modifications and the demand pattern ... It will have also to be adapted to other decisional situations to model in APS.

However it should be noted that in many cases, the impact of plan instability cannot be evaluated in terms of cost. Indeed, the expenditure associated with re-planning depends on the level on flexibility in capacities at various horizons. This comment is also valid in regard to the modifications of production in the short-term which are induced by re-planning processes. Moreover, the loss of confidence in the planning system or in the supply chain department can only be expressed financially with difficulty. The suggested approach thus does seem to have the potential for considerable benefit, if not always easy to evaluate financially. It is however necessary to study the impact of these changes to current practices, for example:

- on the variability of demand on a supplier which is an external capacity constraint,
- on confidence in the case of annual contract,
- on the utilisation rate of the related departments (warehousing, purchasing, ...)

Other approaches to the reduction of planning nervousness can be adapted to our case by modifying the model and then not using the concepts of cost. In particular, robustness and “smoothed” plan changes under constraints were calculated by fuzzy logic. Future work will apply this method to the tactical planning model used in this article.

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