A general approach for hierarchical production planning considering stability

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A general approach for hierarchical production planning considering stability

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Abstract : *Supply Chain Management, considered as a tool for the synchronization of material flow, aims to control the bullwhip effect. This phenomenon is mainly caused by demand uncertainty and is propagated by decision rules at the different stages of the supply chain. The tactical planning level is the most appropriate level to dampen this demand amplification. In particular, Sales and Operations Planning (S&OP) is the first level which consider demand in the planning process while Master scheduling allows to get item production schedules. Thus, the idea is to get a maximum of stability into the planning process in order to dampen the bullwhip effect. This paper propose a global disaggregation approach leading to stable master schedules according to initial global demand forecasts. This approach is based on two levels of disaggregation using MIP models.*

Keywords : *disaggregation, hierarchical production plan, sales and operation planning, master planning*

1 Introduction

Regarding to the recent financial crisis which highlighted an important instability on the global market, manufacturing industry has nowadays to face a continuous changing context. In fact, because of these conjecture considerations, manufacturing area has to answer quickly and efficiently to maintain their market share. In particular, increasing raw material cost and new environment taxes on unclean technologies has to be integrated in the Hierarchical Decision Support System (HDSS). The complextity of the Hierarchical Production Planning imposes to tackle the problem by a multi-level decision-making process. An important effort has been made in the formulation of mathematical models describing the hierarchical production planning. In Hax and Meal (1975) the authors consider four decision levels for individual plants. They used rolling horizon in order to recompute single plan which corresponds to the remaining decision levels. The last work has been improved in Bitran et al. (1981) where single stage production planning is considered. A further contribution has been made in Bitran and Hax (1981) by considering three levels of disaggrega-

tion, *i.e* types, families and product items. They proposed to use the knapsack formulation features to solve the problem. The objective function takes into account set up and inventory costs (Bitran and Tirupati, 2000). Furthermore, disaggregation in the hierarchical production planning has been studied in Mehra et al. (1996) where simultaneous aggregation of parts, work-centers and time periods is proposed. In Özdamar et al. (1998), the authors propose a high level planning tool which enables to use structured planning algorithms. A database is used to ensure feasibility at all planning levels.

The master planning corresponds to the disaggregation process at tactical level in discrete manufacturing environment. The master planning is relative to Sales and Operation Planning (S&OP) and to Master Production Schedule (MPS). The aim of S&OP is to achieve the strategic objectives defined in the Business Plan. So, it has to determine the required global resource needed in the supply chain to cope with families product demand. At the S&OP level, the considered time periods are aggregated periods usually months, refeered later as macro-periods. At a bellow level, the MPS has to determine finished item production schedules in smaller periods, refeered as micro-periods, most often it corresponds to weekly periods (Vollman et al., 1997).

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In Ortiz et al. (2004), the authors have shown that the disaggregation process and the demand fluctuation cause instability of plans. Indeed, all these changing conditions which have to be updated in the decision making process will increase the system nervousness Blackburn et al. (1986); Ho (1989); Minifie and Davis (1990). The main consequences are additional cost which increase as late as these changes came in the planification decision making process. An example of such additional cost could be due to hiring or firing workers to adjust capacity with workload and avoid lack of labor. Thus, reducing instability becomes of major importance in hierarchical production planning decision system.

The master planning instability issue has been already considered in the literature. In Kadipasaoglu and Sridharan (1995) an alternative approach for reducing schedule instability in multi-stage manufacturing under uncertainty is proposed. The instable demand does not allow an effective execution of material requirements planning systems. The authors have shown the effectiveness of three policies on the reduction of nervousness in multi-level MRP systems. In Zhao and Lam (1997) lot-sizing rules and freezing MPS are proposed to reduce instability in multi-level material requirements planning (MRP) systems.

In the hierarchical production planning context, stability issue has been addressed in Thomas et al. (2008). The authors proposed a two level disaggregation approach in discrete manufacturing environment. The first level is used to decompose the S&OP which determine families volumes per macro-periods into several plans corresponding to finished items per macro-periods. The authors suggest a second disaggregation level which deals with detailed plan for each item regarding to micro-periods. This second level is the MPS and is tackled with a simple heuristic in order to smooth the production items quantities within the micro-periods. Our present works consider the same disaggregation schema than the last cited works. Nevertheless, several contributions ars proposed here, for instance a first contribution corresponds to the generalization of the S&OP model to consider several families. A second contribution deals with the introduction of backorders in the first level of disaggregation in addition to inventories and production quantities. This level is performed with a quadratic model which allows to ensure balance disaggregation by one hand and consistency with the previous level by the other hand. The last contribution consists in the formulation of a lot-sizing mixed integer model to perform the last disaggregation level. The proposed lot sizing model allows to generate master production schedules by maintaining both consistency and stability.

The paper is organized as follows: section 2 is used to describe the global disaggregation approach. Section 3 is devoted to the description of the S&OP model. Section 4 concerns the first level of disaggregation, we propose a description of the modified quadratic formulation to determine finished items quantities per macro-period. Section 5 deals

with the Master Production Schedules formulation which allows to determine items quantities per micro-period by maintaining stability. In section 6, preliminary results are presented and discussed. Finally, perspectives and conclusion are provided in section 7.

2 A general disaggregation approach

In the literature, the disaggregation procedure mainly concern three levels corresponding to: types, families and items Bitran and Hax (1977); Özdamar et al. (1996). However, in discrete manufacturing environment the types level is out of concerns. Thus, our study deals with disaggregation process considering only families and items stages as described in Figure (1), corresponding to S&OP and MPS levels in the classical HDSS or MPCS (Manufacturing Planning and Control System). As the figure shows, the S&OP model allows to obtain families volumes and inventories per macro-period regarding to the global cost. Then, the first disaggregation level determines the quantities of finished items for each family considering the same periods. At this level, the disaggregation is performed for items in such way that items quantities is smoothened and balanced with relative to demand. This model is considered as intermediate model which ensures consistency between decisions made in the S&OP and the MPS. More precisely, the families volumes, inventories and backorders are integrated in the intermediate level as additional constraints. In the same way, the results of the first disaggregation model have to be respected in the MPS model. Thus, the finished items quantities, inventories and backorders are considered as additional constraints in the formulation of the lot-sizing model used to determine MPS.
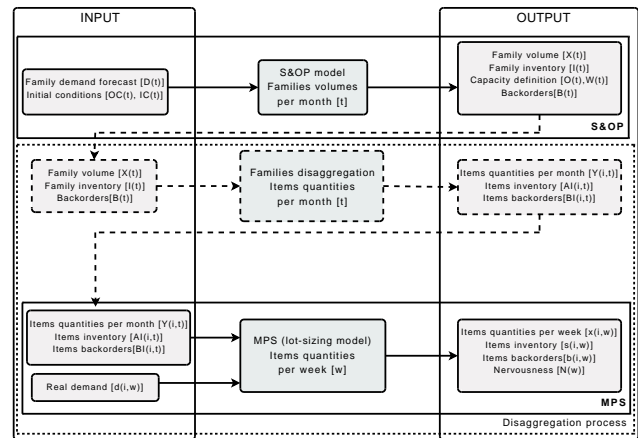

Figure 1: Disaggregation global schema

3 S&OP

At tactical level, Sales and Operation Planning (S&OP) allows to make decisions in order to cope with the strategic objectives defined in the Business Plan. Thus, the S&OP model is used to determine product families volumes, inventories, expected backorders and the required resources needed to satisfy families forecasts by minimizing global cost. The considered resources at this level correspond mainly to human ressources. Nevertheless, at this decision level, inventories are also considered as resources according to the budget point of view since they could be expressed as a number of working hours. In some cases, industrial groups including different geographical sites have to precise furthermore families volumes for each site (Mukhopadhyay et al., 1998). Without loss of generality, the presented model deals with one site and an assignment problem could be formulated in that case.

In the following, we present the generalisation of the S&OP model initialy presented in Thomas et al. (2008) in order to consider several families instead of just one family. So, we describe the parameters that have been considererd in the formulation of the MIP model.

3.1 Parameters and input data

T	:	S&OP planning horizon,
t	:	index corresponding to time period within the planning horizon,
F	:	number of families,
f	:	index for family within the set of Families,
D_{ft}	:	family forecast demand for familiy f in period t (units),
OC_t	:	overtime capacity in period t (hours),
IC_t	:	inventory capacity in period t (units),
Is_f, Ie_f	:	initial inventory level respectively final inventory level for familiy f (units),
Bs_f, Be_f	:	initial backorders respectively final backorder for familiy f (units),
Ws, We	:	initial number of workers respectively final number of workers (at the end of planning horizon),
up_f	:	number of units produced by one hour-worker for familiy f (units / hour),
op_f	:	number of units produced by one hour in overtime for any worker (units / hour) for familiy f, it is supposed to be different from upw_f , it has been noticed that workers are generaly less productive in overtime hours.
h_t	:	maximum number of hours for any worker at each period t (hours).

The marginal costs are described as follows :

3.2 Costs

i_{ft}	:	family inventory unitary cost for family f per period t [€],
ri_{ft}	:	raw material inventory unitary cost for family f for period t [€],
rd_{ft}	:	delivered raw material unitary cost for family f for period t [€],
b_{ft}	:	backorder unitary cost for family f for period t [€],
w_t	:	worker wage for period t [€],
h_t	:	hiring cost for period t [€],
f_t	:	firing cost for period t [€],
o_t	:	overtime cost per hour for period t [€].

In the following, we define the decision variables used in the mixed integer model.

3.3 Decision variables

X_{ft}	:	volume produced of family f in period t (units).
I_{ft}	:	inventory level at the end of family f in period t (units),
RI_{ft}	:	raw material inventory level of family f at the end of period t (units),
RD_{ft}	:	delivered raw material of family f in period t (units),
B_{ft}	:	backorders of family f at the end of period t (units),
W_t	:	total number of workers in period t,
H_t	:	number of hired workers at the beginning of period t,
F_t	:	number of fired workers at the beginning of period t,
O_t	:	total overtime in period t (hours).

3.4 S&OP formulation

In the following, we provide the generalisation of the S&OP model using a mixed integer model. The constraints and the objective function have been modified to take into account several families simultaneously.

$$\min \sum_{t=1}^{T} \sum_{f=1}^{F} i_{ft} I_{ft} + ri_{ft} RI_{ft} t + rd_{ft} RD_{ft} + b_{ft} B_{ft}$$

$$+ \sum_{t=1}^{T} w_t W_t + h_t H_t + f_t F_t + o_t O_t.$$

$$(1)$$

subject to :

$$I_{f(t-1)} - B_{f(t-1)} + X_{ft} = I_{ft} - B_{ft} + D_{ft}, \tag{2}$$
$$\forall f, t,$$

$$RI_{f(t-1)} + RD_{ft} - X_{ft} = RI_{ft}, \quad \forall f, t, \tag{3}$$

$$X_{ft} \le RI_{f(t-1)}, \quad \forall f, t, \tag{4}$$

$$W_{t-1} + H_t - F_t = W_t, \quad \forall t, \tag{5}$$

$$I_{f0} = Is_f, \; I_{fT} = Ie_f, \quad \forall f, \tag{6}$$

$$B_{f0} = Bs_f, \; B_{fT} = Be_f, \quad \forall f, \tag{7}$$

$$W_0 = Ws, \; W_T = We, \tag{8}$$

$$\sum_{f=1}^{F} X_{ft} \le \sum_{f=1}^{F} (up_f h_t) W_t + \sum_{f=1}^{F} op_f O_t, \quad \forall t, \tag{9}$$

$$\sum_{f=1}^{F} I_{ft} + RI_{ft} \le IC_t, \quad \forall t, \tag{10}$$

$$O_t \le OC_t W_t, \quad \forall t, \tag{11}$$

$$I_{ft}, RI_{ft}, X_{ft}, B_{ft}, O_t, W_t \ge 0 \quad \forall f, t, \tag{12}$$

$$H_t, F_t \in \mathbb{N}, \quad \forall f, t. \tag{13}$$

The objective function is provided by expression (1) where global cost is minimized. Equalities (2) correspond to inventory production balance constraint considering backorders. The constraints refeered by (3) are inventory raw material balance constraints. Equations (4) ensure that raw material inventory at the end of the precedent period allows production in the next period. Constraints (5) update the number of workers considering hired and fired ones. Constraints (6), (7) and (8) fixe initial and final levels of families inventories, backorders and number of workers, respectively. Constraints (9) consider the whole capacity of production with both overtime and regular working time. Inequalities (10) correspond to a limitaion of capacity inventory, it could represent a space limitation for example. The last constraints given by (11) represent the capacity of available overtime, it could be the legal allowed overtime.

4 First disaggregation level

Since several families are considered in the global approach, the proposed model should be performed for each family in an independant way. Thus, the model is presented for the disaggregation of a particular family $f \in \{1, \ldots, F\}$. This first level of disaggregation defines the quantities for each finished item belonging to a given family. The decomposition is done such that the difference between the disaggregated quantities and the family volume is smoothened. In the proposed quadractic model, we propose to modify the classical formulation in order to consider the backorders to save consistency with the previous decisions.

Let's define the parameters and the input data of the quadratic model:

4.1 Parameters and input data

$FI(f)$: set of finished items of the family f,

d_{pt} : demand forecast for finished item p in the month t,

ss_p : safety stock for finished item p,

os_p : inventory limitation for finished item p it could be a space limitation,

X_{ft} : volume or family f in period t computed in the S&OP level,

I_{ft} : inventory level for family f computed in the S&OP level,

B_{ft} : backorders or family f computed in the S&OP level.

4.2 Decision variables

AI_{pt} : available inventory for finished item p in the macro-period t,

Y_{pt} : production quantity for finished item p in the macro-period t,

BI_{pt} : backorders for finished item p in the macro-period t.

4.3 A reformulation of the quadratic disaggregation model

$$\min \sum_{t=1}^{T} \sum_{p \in FI(f)} \left[\frac{X_t + \sum_{p \in FI(f)} (AI_{pt} - BI_{pt} - ss_p)}{\sum_{p \in FI(f)} d_{pt}} - \frac{Y_{pt} + AI_{pt} - BI_{pt} - ss_p}{d_{pt}} \right]^2 \tag{14}$$

subject to :

$$\sum_{p \in FI(f)} Y_{pt} = X_{ft}, \quad \forall t, \tag{15}$$

$$\sum_{p \in FI(f)} AI_{pt} = I_{ft}, \quad \forall t, \tag{16}$$

$$\sum_{p \in FI(f)} BI_{pt} = B_{ft}, \quad \forall t, \tag{17}$$

$$Y_{pt} \le os_p - AI_{pt}, \quad \forall p \in FI(f), \forall t, \tag{18}$$

$$Y_{pt} \ge d_{pt} - AI_{pt} + BI_{pt} + ss_p, \quad \forall t, \tag{19}$$

$$AI_{pt} \le os_p, \quad \forall t, \tag{20}$$

$$AI_{pt} \ge ss_p, \quad \forall t, \tag{21}$$

$$AI_{pt}, Y_{pt}, BI_{pt} \ge 0 \quad \forall t. \tag{22}$$

The objective function provided in (14) is quadratic for two reasons : first to keep positive the differences between the

quantities and second to emphasize the penality on theses differences. Indeed, the objective function allows to smooth the disaggregation in such way that the distance between the available items quantities brought back to demand is as small as possible. This is to balance the production volumes among items of the same family. Constraints (15), (16) and (16) ensure consistency between the S& OP and the family disaggregation level, *i.e* the disaggregated amounts correspond to the aggregated values obtained for the corresponding family. These constraints avoid to the diaggregation process to deviate from the decisions taken previously, in other words it forbids further costs. In particular, the cumulated items quantities corresponding to family volume should not be exceeded as well as the inventory volume for the family should be respected. Inegalities (18) correspond to an upper bound on the items quantities which should respect the space inventory limitation. Constraints (19) ensure that the available items quantities considering inventories would satisfy items demand considering disaggregated backorders. Constraints (20) and (21) provides a lower bound and an upper bound for items quantities.

5 Master Production Schedule

The second level of disaggregation is used in order to obtain quantities of finished items to be produced in microperiods. In practice, this level corresponds to the Master Production Schedule (MPS). This disaggregation level has been studied in Ortiz et al. (2004) where a simple heuristic is used to smooth production quantities.

In Herrera and Thomas (2009), the authors suggest to compute the MPS by reformulating a lot-sizing MIP in order to integrate instability minimization in the objective function. The authors introduce the term instability to refer to the item quantities differences between periods in the same cycle (period of rescheduling). At the opposite, the less different are the items quantities in a cycle the more smoothened is the production schedule. The results show that the minimization of the quantities differences in a same cycle leads to an effective reduction of the differences between rescheduling which is commonly called nervousness. The nervousness reduction by instability minimization (or production smoothing), allows to obtain a good trade-off between nervousness and costs. Indeed, the most common way to integrate demand fluctuation and to update planning production at the second level is to compute a production plan at the begining of each time interval Δw where w is a micro-period from 1 to n' the planning horizon.

In this paper, we propose to adapt this model to the general disaggregation approach in order to maintain stability. The adaptation can be achieved by formulating constraints to use the output of the previous disaggregation level. More precisely, additional constraints considering items quantities per macro-periods are added to the model.

So, we obtain disaggregated items quantities per microperiods, the model should take into account both accurate real demand and disaggregated items quantities obtained in previous level.

Let's describe the model parameters and the decision variables.

5.1 Parameters and input data

p : index for finished items, $p = 1, 2, \ldots, P$,

w : index for weeks, $w = 1, 2, \ldots, n$,

n : MPS planning horizon,

t : index for macro-periods, $t = 1, 2, \ldots, T$,

$n(t)$: set of micro-periods w in the macro-period t,

Y_{pt} : quantity for item p in the macro-period t which is computed thanks to precedent level of disaggregation,

d_{pw} : effective or real demand for finished item p in the micro-period w which has to be considered at this last level,

μ_{pw} : production cost of item p in the micro-period w,

h_{pw} : inventory cost of item p in the micro-period w,

b_{pw} : backorder cost of item p in the micro-period w,

ν_{pw} : setup cost of item p in the micro-period w,

C_w : available capacity in the micro-period w,

α_p : marginal consumption of capacity by production of item p,

β_p : setup time of item p,

M : a big number, it's an upper bound on item quantity, in this case (Y_{pt}) is taken as this value to allow fixing setup variables.

5.2 Decision variables

Q_{pw} : production of finished item p in microperiod w,

s_{pw} : inventory of finished items p in microperiod w,

r_{pw} : backlog of finished item p in micro-period w,

y_{pw} : setup for finished item p in micro-period w, ($y_{pw} = 1 \iff Q_{pw} > 0, \forall i, \forall w$),

z_{pw} : smoothing production variable for product i in micro-period $w : w > 1$.

5.3 MPS model

In this section, we propose a parametric MIP model for the MPS level in order to compute the production quantities for each item in smaller periods than in the precedent level. Indeed, in the previous level we consider a family disaggregation into items in macro-periods which are usually considered as months. Thus, the second level of disaggregation

deals with decomposing items quantities per months into items quantities per weeks.

The parametric nature of this model leads to less nervousness by iterative production smoothness improvements. The model is formulated as follows:

$$\min \sum_{p=1}^{P} \sum_{w=1}^{n} (\mu_{pw} Q_{pw} + h_{pw} s_{pw} + b_{pw} r_{pw} + \nu_{pw} y_{pw})$$
$$+ \phi \sum_{p=1}^{P} \sum_{w=2}^{n(t)} z_{pw} \tag{23}$$

$$s_{p0} = s_{ini}, \; r_{p0} = r_{ini}, \quad \forall p \tag{24}$$

$$\sum_{w=1}^{n(t)} Q_{pw} = Y_{pt}, \quad \forall p, \forall w \tag{25}$$

$$\sum_{w=1}^{n(t)} s_{pw} = AI_{pt}, \quad \forall p, \forall w \tag{26}$$

$$\sum_{w=1}^{n(t)} r_{pw} = BI_{pt}, \quad \forall p, \forall w \tag{27}$$

$$s_{p(w-1)} - r_{p(w-1)} + Q_{pw} = d_{pw} + s_{pw} - r_{pw}, \\ \forall p, \forall w \tag{28}$$

$$Q_{pt} \leq M y_{pt}, \quad \forall p, \forall w \tag{29}$$

$$\sum_{p=0}^{P} \alpha_p Q_{pw} + \beta_p y_{pw} \leq C_w, \quad \forall w \tag{30}$$

$$Q_{p(w+1)} - Q_{pw} \leq z_{pw}, \quad \forall p, \forall w \tag{31}$$

$$Q_{pw} - Q_{p(w+1)} \leq z_{pw}, \quad \forall p, \forall w \tag{32}$$

$$Q_{pw}, s_{pw}, r_{pw}, z_{iw} \geq 0, y_{pw} \in \{0,1\}, \quad \forall p, \forall w. \tag{33}$$

The objective function to minimize represents the associated cost of production, inventory, backorders and setup (23). Moreover, the differences between weekly production quantities weigthed by the ϕ parameter are also minimized. As in Ermol'ev et al. (1973); Feiring and Sastri (1989); Kimms (1998), ϕ is an user defined parameter used to search the best trade-off between cost and nervousness. This is done by successive computations of the model for several ϕ values. Otherwise, constraint (24) sets the initial amount of inventory and backorders coming from the last implemented period. Constraints refeered by (25), (26) and (27) allow to maintain consistency with decisions of previous level. Constraint (28) represents the inventory balance, constraint (29) the relationship between production and setup ($y_{it} = 1 \iff Q_{it} > 0$) and constraint (30) sets the available capacity by period. Finally, constraints (31)

and (32) set the production quantity differences to its absolute value.

6 Computation experiments

Computations experiments are performed for a S&OP planning horizon of $T = 12$ months, with a monthly replanning. The MPS planning horizon was fixed to $n = 8$ weeks with a rescheduling interval of $\Delta w = 1$. Parameters $\mu_{pw}, h_{pw}, b_{pw}, \nu_{pw}$ are randomly generated and uniformly distributed between a fixed interval.

6.1 Instability and nervousness measures

In a rolling planning horizon, MPS computes production quantities for a given planning horizon (n) with a specific periodicity Δw (cycles). Table 1 shows an example of scheduled quantities resulting of a MPS, where quantity Q_w^k represents the scheduled production quantity for an arbitrary end item, for period w obtained by the MPS computed in the cycle k. In this example the parameters are: $n = 4$ and $\Delta w = 1$.

k / w	1	2	3	4	5	6	7	8
1	Q_1^1	Q_2^1	Q_3^1	Q_4^1				
2		$\mathbf{Q_2^2}$	$\mathbf{Q_3^2}$	$\mathbf{Q_4^2}$	$\mathbf{Q_5^2}$			
3			Q_3^3	Q_4^3	$\mathbf{Q_5^3}$	Q_6^3		
4				Q_4^4	$\mathbf{Q_5^4}$	Q_6^4	Q_7^4	
5					$\mathbf{Q_5^5}$	Q_6^5	Q_7^5	Q_8^5

Table 1: Example of MPS execution in a rolling horizon.

We define nervousness as the differences between quantities scheduled by the MPS in different cycles (i.e. in table 1, for period $n = 5$, differences between $\mathbf{Q_5^2}, \mathbf{Q_5^3}, \mathbf{Q_5^4}, \mathbf{Q_5^5}$). Notice that, at the period 5, manager have to implement Q_5^5. To produce this quantity, it has been necessary to check raw material availability or bottleneck capacity. For that, at the period 2, for example, some decisions have probably been made based on Q_5^2, that highlights the main issue of nervousness plans.

Several formulas to measure nervousness have been proposed by Kimms (1998); Pujawan (2004) and more recently by Kabak and Ornek (2009). Nevertheless, the most used was proposed by Sridharan et al. (1988). This formula has been extensively used as performance variable in several works as Zhao and Lam (1997); Xie et al. (2003, 2004) and can be expressed as:

$$N0_{pk} = \Big[\sum_{\forall k > 1} \sum_{w=k}^{k+n-2} |Q_{pw}^k - Q_{pw}^{k-1}| (1-\alpha) \alpha^{w-k} \Big] / O, \tag{34}$$
$$\forall p, \forall k.$$

where,

w	:	time period (generally weeks).
p	:	item.
k	:	cycle.
Q_w^k	:	scheduled order quantity for period w in cycle k.
n	:	planning-horizon length.
α	:	weight parameter ($0 < \alpha < 1$).
O	:	total number of orders over all planning cycles.

According to the classical exponential smoothing formula, (Sridharan et al., 1988) proposed to use the parameter α which allows "*emphasize the relative importance of more distant future periods over the importance of the immediate future*". The resulting value of this formula can be interpreted as the average differences of the quantities calculated at each cycle. Nevertheless, in our case, we are interested in a minimum rescheduling interval ($\Delta w = 1$), where the implemented quantity corresponds only to the first period. Hence, the rest of the planning horizon is useful to make decisions about other issues but, are not directly related to nervousness. Therefore, to measure nervousness considering the above facts we define the following formula:

$$N1_{pk} = \frac{1}{n-1} \sum_{j=k-1}^{k-n-1} |Q_{pk}^k - Q_{ip}^j|, \quad \forall p, \forall k, \qquad (35)$$

This measure gives the average of the difference between the planned quantity for the first period and all planned quantities computed in precedent plans for the same period. We do not add weights because, we consider that all planned quantities have the same importance due to all the potential decisions which could have been taken.

On the other hand, as said before, smoothness improving corresponds to a reduction of the quantity differences between periods for the same cycle. Thus, to have a good planning management, we have to reduce the nervousness and to improve (increase) the smoothness. That could lead to some problems in the interpretation of these indicators. To avoid this problem, we define the term instability, that corresponds to the differences between production quantities scheduled by a MPS in a cycle (e.g., in table 1, for the cycle $k = 2$, differences between $\mathbf{Q_2^2}$, $\mathbf{Q_3^2}$, $\mathbf{Q_4^2}$, $\mathbf{Q_5^2}$). Therefore, instability is opposed to smoothness. We clarify this because, it seems that, many authors use interchangeably the terms nervousness and instability. A instability measure can be formulated as:

$$I_{pk} := \frac{1}{n} \sum_{w=k}^{k+n-2} |Q_{p(w+1)}^k - Q_{pw}^k|, \quad \forall p, \forall k. \qquad (36)$$

This measure represents the average of the differences of scheduled quantities between each period and its immediately next period for all item p and for all cycle k. Many

production systems aim to reduce these differences in order to reduce associated costs among which include productivity, staff turnover, etc.

6.2 Results

Figure 2 and 3 show the differences using a classic lot size model and the proposed model in the last level of disaggregation. The performance measures are: total cost and instability (figure 2) and nervousness (figure 2). These values have been obtained for a demand variation of 5%. Instability and nervousness are obtained by the sum of the individual values of each item.
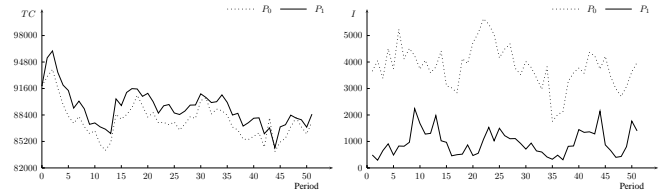

Figure 2: Differences between a classic lot-size model and the proposed lot-size model considering total cost (a) and instability (b).
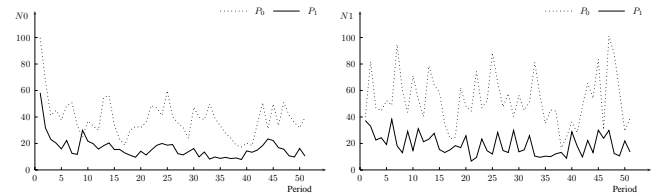

Figure 3: Differences between a classic lot-size model and the proposed lot-size model considering nervousness ($N0$ and $N1$).

Results show that with a smaller cost increase we can obtain significative reduction in terms of instability and smoothness.

7 Conclusion and perspectives

In this paper, a global approach for disaggregation in hierarchical production planning context is proposed. Two levels of disaggregation are suggested, the first level consider families disaggregation into finished items within the same periodicity, while the second level of disaggregation computes quantities items for smaller time period. In Thomas et al. (2008), we proposed the "reference plan" strategy to obtain stable S&OP. In the present paper, we have improved the way to keep this initial S&OP quality. Indeed, a lot-sizing formulation is suggested to determine the optimal stable plans. The preliminary results show the reduction of instability obtained with the proposed formulation. The

proposed approach is a crucial step in order to propose a global decision making tool in production planning. In fact, our futur work will focus on the improvement of formulation in order to smooth furthermore the production considering both forecasts and effective demand.

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