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AGGREGATED BEHAVIORS FOR SUPPLY CHAIN PLANNING PROCESSES SIMULATION AND CHARACTERIZATION OF PLAN DYNAMICS

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ABSTRACT: *Decision making in supply chain context can be a difficult process due to the complexity of the models used to support this decision. We present first results of research project whom the target is to support collaboration decisions. The present study focuses on modelling the dynamics of the customer's planning and market behaviors. We propose an aggregated model of these behaviours and associated impacts on requirement plans. In order to analyze static and dynamic aspect of plan generation, a set of indicators is proposed that evaluate static aspect and mainly dynamics of requirement planning. Model and indicators utilizations are illustrated through an industrial case study.*

KEYWORDS: *abstraction, aggregation, planning behavior, simulation, plan dynamics.*

1 INTRODUCTION

How to tackle the complexity of a decision situation? That is a daily question for the industrial manager having to make decisions and for the academic searcher seeking to propose decision support. For both, the first step is to model the system associated to the decision.

Consequently, as Pidd (1996) argues, models appear as tools for support and extend thinking. Among the existing methods, simulation is an important support for production and supply chain management (Terzi and Cavalieri 2004; Thierry *et al.* 2008).

In this context, Little's assertion "to be used by a manager, a model should be simple" (Little 2004) is the base of the first Pidd's "Five principles of simulation modeling" (Pidd 1996):

- P1: Model simple, think complicated.
- P2: Be parsimonious, start small and add.
- P3: Divide and conquer, avoid mega-models.
- P4: Do not fall in love with data.
- P5: Model building may feel like muddling through.

Pidd's rule P2 refers to the concept, born in 70's, of model abstraction as defined by (Zeigler *et al.* 2000): "method or algorithm applied to a model to reduce its complexity while preserving its validity in a experimental frame."

In this paper, we present the first results of a research project where we are interesting in collaboration protocols between a customer and its 1st tier suppliers. The final objective is to propose a customer's decision support to choose collaboration protocol and to fix associated parameters for each supplier. We propose a risk management methodology supported by a dedicated simulation tool (Marquès *et al.* 2009). It is based on an aggregated view of actors' planning processes. The target is to represent tactic and mainly strategic decision makers' behaviours in order to support collaboration decisions between the partners. In other terms, the targeted model is the gathering of:

- the collaboration protocol that defines decisional processes between the partners. Here, the protocol is defined by two main aspects: the type of forecast (internal based on historical forecasts or external transmitted by the partner) and the type of supply (push, pull or VMI);
- and the union of the partners' decisional behaviours during their decisional activities. Here, we focus on the strategy of inventory security level (expressed in weeks).

According to Pidd's rule P3 we have decomposed the project in three modelling phases: the customer's planning process behaviour, the suppliers' planning process behaviour and the protocols.

The present study focuses on the customer's production planning process modelling. Here, we are interested in modelling the dynamics of raw material requirement plans that result from complex production process. Consequently, the purpose of this paper is to present an aggregated customer's production planning based on the identification of the possible sources of disturbance of a requirement plan. It is organized as follows. A first part is dedicated to a background about elements of abstractions methods. The second part presents the problem understudy. Then we present our abstraction choices to build our aggregated customer's production planning model. The last part depicts the model output characteristics (the dynamics of requirement plans). An industrial case is used to illustrate model utilization and evaluation through output characterization. Finally we conclude and discuss future researches.

2 THE ABSTRACTION CONCEPT

System modeling problematics have been well described in the literature. According to the distinction between the structure of the system (the inner constitution of the system) and its behavior (relation between input and output states imposed by the system) three main kinds of problems can be distinguished:

- *Systems analysis*: the system exists. The modeler tries to understand its behavioral characteristics.
- *Systems inference*: the system exists. The modeler tries to infer how it works from observations of its behavior.
- *Systems design*: the system does not exist. The modeler tries to come up with a good design for it.

Behavioral or structural, an information about the system observed is used by the modeler to build a representation of it. However, the modeler can be confronted to the complexity of the reality that he has to analyze.

Furthermore, the modeler has to delimit the analysis scope in which he can demonstrate and maintain the validity of its simulation. This delimitation is called *experimental frame*. It is defined as the specification of the input, output and operating domain conditions under which the modeler observes or experiments the system (Zeigler *et al.* 2000).

Abstraction is a "technique that derives simpler conceptual models while maintaining the validity of the simulation results with respect to the question being addressed by the simulation" (Frantz 1995). It "refers to a method or algorithm applied to a model to reduce its complexity while preserving its validity in a experimental frame" (Zeigler *et al.* 2000). Frantz (1995) proposes a taxonomy of model abstraction techniques in three main non-exclusive families.

- *abstraction of behavior within the model* are based on aggregation within the model. These aggregations by time, function, states or entities are not mutually exclusive;
- *abstraction of the model boundary* are based on reduction of the input variable space. It could be either a modeler's a priori decision or deduced from a particular analyze such as sensitivity analysis ;
- *abstraction of model formulation* through which model forms modification, the modeler seeks to simplify the manner in which parameter values are determined (look-up table, probability distribution, linear function interpolation, metamodelling,…).

Klir (1991) proposes another list of some common abstractions :

- *Aggregation*: it combines groups of components into a single component that represents their combined behaviors when interacting with other groups.
- *Omission*: leaving out: components variables interactions.
- *From determinist to stochastic transformation*: replacing deterministic descriptions by stochastic ones can result in reduced complexity when algorithms, taking many factors into account, are replaced by samples from easy to compute distributions .
- *From stochastic to determinist transformation*: replacing a distribution by its average.
- *Formalism transformation*: mapping from one formalism to another, more efficient one. For example: mapping differential equation models into discreet event models

Table 1 below presents a comparison between Frantz's and Klir's classifications. Klir and Frantz classifications are equivalent about aggregation and omission (with different class name). Move between stochastic and deterministic models (Klir) belongs to a larger Frantz's family, the model form modification.

Klir's classification	**Frantz's classification**
Aggregation	Model behavior modification
Omission	Model boundary modification
From Determinist to stochastic replacement	Model form modification
From Stochastic to deterministic replacement	

Table 1: Frantz's and Klir's abstraction techniques mapping

3 PROBLEM UNDER STUDY

Figure 1 summarizes the general problematics of our research project: to support collaboration decision in a customer-supplier relationship. The main objective of the management of the collaboration is to create and preserve value, i.e. maximize the performance of the collaboration from a given point of view (customer, supplier, both). However, this performance is impacted by different risks sources:

- the behavior of the market linked to the raw material under study;
- the customer's characteristics and planning behaviors;
- the choice of collaboration protocol;
- the supplier's characteristics and planning behaviors;

The target is to build a model of the chain that allows the protocol and/or actor's behaviors to be adapted to the risk sources. We propose a two steps reasoning.

Firstly, partners' and protocol models are built in order to simulate different protocols associated with different partners' internal planning behaviors. The set of possible protocols associated to the possible partners' behaviors defines a set of scenarii that will be simulated during a given simulation time.

Secondly, results of the simulation are analyzed to support collaboration decisions, i.e. protocol and/or behavior adaptation.

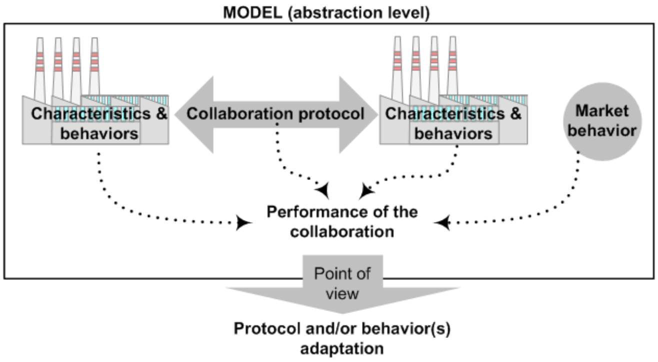


Figure 1: Problematic

In this paper, we are interested in a particular point of this modeling problem: the question of the abstraction level of the customer's model.

3.1 General problematic

The production process of an actor of the manufacturing industry could be decomposed in a given quantity of main production activities, as presented in Figure 2. These activities can be in line or in parallel. Let P be the set of production activities of the actor ($P = [1,\ldots p]$).

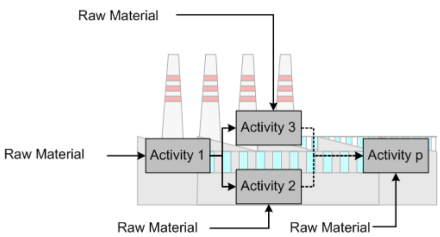


Figure 2: actor's production activities decomposition

Each actor can be characterized through:
- a set *FC* of finished products *fc* produced by the actor;
- a set *RM* of raw material(s) *rm* ;
- a set *S* of suppliers *s(rm)* associated to each *rm* of *RM*;

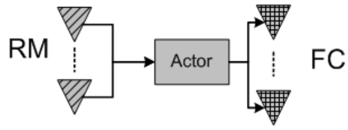


Figure 3: notations associated to an actor

Figure 4 illustrates the complexity of the problem under study. The target is to support collaboration decision in order to manage the relation between the customer and a particular supplier of a given reference (or family of references).

For a given raw material *rm*, the supply decision is function of the associated Gross Requirement plan (*GR*). We focus on the model that generates $GR^{\theta}(rm)$ at a given time θ, with a given periodicity *fr* (for example each week). A $GR^{\theta}(rm)$ can be represented as a plan of gross requirements (*gr*) of *rm* spread out over the planning horizon (*PH*). Thus, $GR^{\theta}(rm)$ is the set $\left\{gr_{rm}^{\theta}(t)/\, t \in PH\right\}$ planned at θ. Each $gr_{rm}^{\theta}(t)$ is function of:
- the planned demand through the bill of material;
- the finished products inventories levels associated to *rm*;
- a set of constraints issued from the actor's planning processes of all activities (smoothing, subcontracting, detailed scheduling…) and physic characteristics (limited time storage, production time,…).

A first solution to compute $GR^{\theta}(rm)$ would be to build a complete model of the customer (see Figure 4). However, this detailed model is in contradiction with Pidd's principles. It would compute planning processes of each production activity ("model simple"). It would allow a good representation of the real production flow to be obtained, but it would not be adapted to our problematic that is focused on a tactic/strategic horizon ("be parsonimous").

Furthermore, it would need a great number of data and information concerning the supplier, at the end of the simulation, would have to be extracted from the great number of information about other finished components ("avoid mega-models"). Finally, in addition to the validation difficulty, this model would need large computational capacities.

In this paper, a second solution is investigated. It consists in building an abstracted view of the set of disturbances sources of *rm* requirement plan through a mix of different abstraction techniques presented in part 2:

- *omission* (model boundary);
- *aggregation* (model behavior modification);
- *from determinist to stochastic replacement* (model form modification: random number generation).

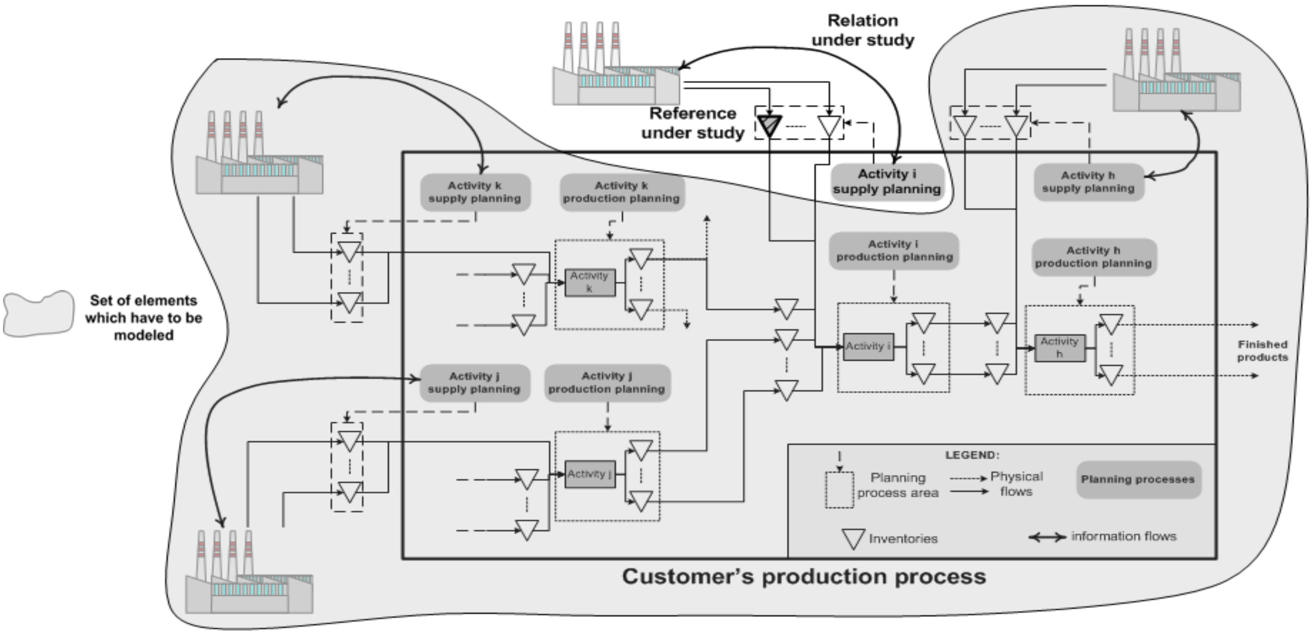


Figure 4: Scope of the study

4 AGGREGATE PLANNING PROCESS MODEL

4.1 Sources of disturbance of raw material GR

In order to build the aggregate model the first step is to identify processes and associated behaviors that can affect a raw material gross requirement plan. In the scope of this paper we have established a generic representation of the different planning processes for each SC actor processes as presented in Figure 5. According to the tactic/strategic granularity of our study, the temporal unity is the week. Figure 4 shows that all behaviors associated to the actor's planning processes and the market behavior represents potential sources of disturbance for the gross requirement plan.

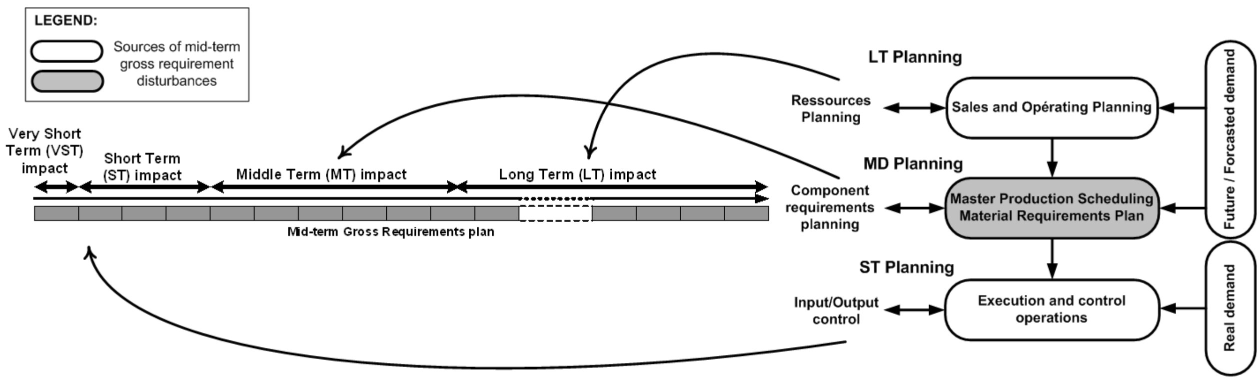
Four planning horizons have been differentiated. The first three are the classical Long (LT), Middle (MT) and Short (ST) terms issued from MRPII planning processes. Each one is associated to a specific level of the MRPII process: Sales and Operation Planning (LT), Master Production Scheduling (MT) and Execution and Control operations (ST).

Figure 5: impact planning processes on the mid-term gross requirements plan

The length of each horizon is function of the system characteristics. However we can say that it must cover a period at least equal to the time required to accomplish the plan. The fourth, the Very Short Term (VST) is linked to the granularity chosen: the week. The VST horizon allows production flows and events inside the week to be aggregated through a weekly flow assessment in order to know, for each week, what actor actually produced.

The main potential decisions and events which can impact mid-term gross requirement plans are listed. Disturbances associated to LT, MT and ST horizons are presented in Table 2 for , and VST in
Table 3.

The associated horizon is defined for each decision or event. Then the impact on gross requirements is described in two possible types GR changes: (1) "movements" in the time and (2) "modifications" of the quantity. They can be respectively detailed in term or "anticipation" or "putting back" and "increase" or "decrease". The distinction between push and pull production strategy can allow types of impact to be linked to particular production context. Attributes that characterized each type of impact are presented in the fifth column. Finally, a figure is given in order to illustrate each impact and its attributes.



From a long term point of view, if an actor decides to adapt its capacity ("**capacity adjustment**" or 'chasing') to the planned load, gross requirements are not impacted. However, if he decides to adapt the planned load, i.e. the requirement plan, to the capacity, different solutions appear:

- "**smoothing"** the planned load. It can be traduced in movements of requirement in LT planning horizon. Each movement can be characterized through three main attributes:
  - o the *direction* (anticipation or putting back),
  - o the number of weeks (*Nb_period*) over which the movement is done (*amplitude*)
  - o and the *quantity* of requirements that is smoothed;
- "**subcontracting**":
  - o the production and supply processes. The actor is not responsible of the raw material supplying. The requirement disappears;
  - o the production activity while keeping the raw material supplying responsibility. According to the deadline extension due to the production externalization, the supply process has to be anticipated. The impact is therefore a movement of requirement in the LT horizon similarly to the smoothing decision. However, direction is always anticipation.

From a middle-long term point of view, gross requirement plans can be affected by the demand behavior. Two types of "**future demand variations**" can be distinguished:

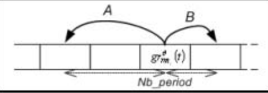
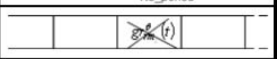
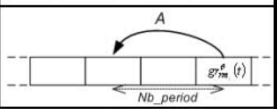
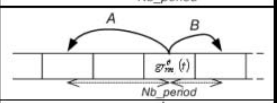
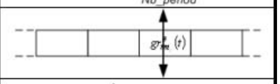
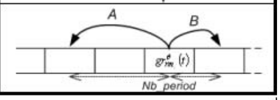
- a variation of the date of the demand. This variation implies a movement of requirement. The attributes are similar to the smoothing decision;
- a variation of the planned quantity. This variation implies a quantity modification of the requirement. The associated attributes are the *type* of modification (increase or decrease) and the *amplitude* of the modification.

From a short term point of view, with a push production strategy, "**detailed scheduling**" can affect the requirement plan through movements of production orders in the ST horizon. *Direction*, *amplitude* and *quantity* are the attributes that describe this movement. We consider here that detailed scheduling does not exist in pull production context.

Some events can disturb the production at the very short term between the end of the current week and the next simulated, i.e. between θ and θ+*fr*. In this case, it is not the planned requirements plan at θ that is affected but the real consumption of *rm* and/or the planned requirements plan at θ+*fr* (see Table 3):

- "**breakdowns**": breakdowns affect the capacity of the current time period (θ). In consequence, it exists a gap Δ between the planned requirements for the period ($gr_{rm}^{\theta}(t=1)$) and the real consumption. Then this quantity Δ has to be produced at the next production period (θ+*fr*). $gr_{rm}^{\theta+fr}(t=1)$ increases by the quantity Δ with the hypothesis that the capacity will be sufficient to absorb the increase. Otherwise, the increase will be spread out over different period ($gr_{rm}^{\theta+fr}(t=1)$, $gr_{rm}^{\theta+fr}(t=2)$, …
- "**scrap**": some production processes are affected by punctual scrap problems. In term of raw material consumption, it is traduced by an increase of the real consumption compare to the planned (by a quantity Δ). This additional requirement is often filled in by safety stocks. These stocks have therefore to be completed at the next production period ($gr_{rm}^{\theta+fr}(t=1)$ increases of Δ).
- "**urgent anticipation**": it is a variation of the date of the demand at a very short term. The totality or a part of the requirement planned at a time t ≥ 2 is anticipated to t = 1. It implies
  - o an increase of the real consumption com-

Table 2: LT, MT and ST gross requirement disturbances

Horizon	Decision / Events	Production strategy		Type of impact on $GR^{\theta}(rm)$	Impact characterization	Illustration
		Push	Pull			
LT	Capacity adjustment	×	×	No impact		
LT	Smoothing	×	×	**Movement** of $gr_{rm}^{\theta}(t)$ in the horizon	- *direction* of the movement: to anticipate (*A*) or to put back (*B*) - *amplitude* of the movement (*nb_period*) - *quantity* smoothed: $\alpha \times gr_{rm}^{\theta}(t)$ with $\alpha \in [0,1]$	
LT	Subcontracting production and supply	×	×	**Disappearance** of $gr_{rm}^{\theta}(t)$ in the horizon	- *quantity* subcontracted: $\alpha \times gr_{rm}^{\theta}(t)$ with $\alpha \in [0,1]$	
LT	Subcontracting production	×	×	**Anticipation** of $gr_{rm}^{\theta}(t)$ in the horizon	- *amplitude* of the movement (*nb_period*) - *quantity* subcontracted: $\alpha \times gr_{rm}^{\theta}(t)$ with $\alpha \in [0,1]$	
LT,MT	Future demand variation	×	×	**Movement** of $gr_{rm}^{\theta}(t)$ in the horizon	- *direction* of the movement: to anticipate (*A*) or to put back (*B*) - *amplitude* of the movement (*nb_period*) - *quantity* subcontracted: $\alpha \times gr_{rm}^{\theta}(t)$ with $\alpha \in [0,1]$	
		×	×	**Modification** of the quantity $gr_{rm}^{\theta}(t)$	- *type* of the modification: increase or decrease - *amplitude* of the modification	
ST	Detailed Scheduling	×		**Movement** of production orders $gr_{rm}^{\theta}(t)$ in the short term horizon	- *direction* of the movement: to anticipate (*A*) or to put back (*B*) - *amplitude* of the movement (*nb_period*) - *quantity* scheduled: $\alpha \times gr_{rm}^{\theta}(t)$ with α=1	

pared to the planned ($gr_{rm}^{\theta}(t=1)$)
- o and a decrease or a disappearance of a requirement in the next requirement plan ($GR^{\theta+fr}(rm)$).

- "**real demand different from planned**": this event can have two different impacts according to the type of production: push or pull. In a push situation, production order can not be changed, so real consumption is not impacted. Nevertheless, the gap between the real requirement issued from the real demand and the planned affects the future raw material requirements ($GR^{\theta+fr}(rm)$). For example, if the production order of 100 items has been decided. This order implies a requirement of 100 *rm*. Due to a late demand modification, the real demand is 80. The production order is not changed but the next production planning process will take into account this gap (decrease in the example). With the pull strategy, it is an opposite situation. The real consumption is adapted and the planning process is not affected. In the two cases, the modification is characterized by:
  - o a *type* (increase or decrease)
  - o and the amplitude of the *modification*.

4.2 The model

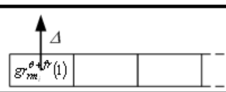
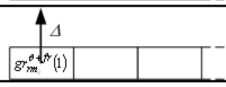
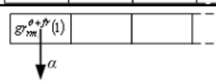
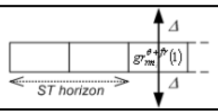
In order to integrate all these potential movements and quantities modifications, we propose an aggregated model that is based on the discrete event simulation. According to the classification presented in part 2, the proposed model is based on three common abstraction methods:

- **the aggregation mechanism** since all production activities and associated planning processes are combined into a single entity;
- **the omission** since we focus only on a reduced set of raw material;
- **from determinist to stochastic replacement** since the model does not represent in detail the planning processes that are the cause of movement and quantities modifications of requirement. They are replaced by some probability functions.

All periodic events are characterized by the frequency at which the event appears and a frozen horizon over which disturbances are impossible (decisions have no impact or is impossible). Furthermore, it is possible to established groups based on the horizon over which they affect the requirement plan: LT, MT, ST and VST. In the model occurrences of these disturbances are not due to determinist and detailed planning processes. Disturbance appearance is modeled thanks to probability. Each requirement of a plan (from t = 1 to t = card (*PH*)) is submitted to different probability functions that decide if a change (modification or movement) appears and characterizes this change. Five types of events are introduced from this observation. The first ones is an event dedicated to the market structure generation. The four others are periodic and allow dynamics of the plans to be controlled through the different movements and quantities modifications. The five types of event are:

- "**market generation**": unique event that occurs at the beginning of the simulation (θ = 0). It is responsible of the demand generation for all periods of the simulation time;
- "**long term planning process**": periodic event that is responsible of the long term decisions. When this event occurs, LT decision making or not is a result of a succession of probability laws. For each requirement of the long term horizon the questions are:
  - o Is it a smoothing decision ? (yes-no),
  - o Which *type*? (anticipation or putting back),
  - o Which *amplitude* in weeks of the movement, *quantity* smoothed, then is it a subcontract ? (yes-no),…
- "**middle term planning process**": periodic event that is responsible of the representation of the market behavior. Existence of future demand variation and its characterization is the result of a probability laws succession:
  - o Is it a quantity modification due to future demand variation? yes-no,
  - o Which *type*? increase or decrease,
  - o Which *amplitude* of the modification,
  - o Is it a movement of requirement due to future demand variation? yes-no, *direction*, *amplitude*, *quantity*,…

Table 3: VST gross requirement disturbances

Horizon	Decision / Events	Production strategy: Push	Production strategy: Pull	Type of impact on $GR^{\theta+fr}(rm)$ and the real consumption	Impact characterization	Illustration
VST	Breakdown	×	×	**Decrease** of the real consumption **Increase** of the quantity $gr_{rm}^{\theta+fr}(t=1)$	- *amplitude* of the decrease: real consumption = $gr_{rm}^{\theta}(t=1)$ - Δ - *amplitude* of the increase : Δ	
VST	Scrap	×	×	**Increase** of the real consumption **Increase** of the quantity $gr_{rm}^{\theta+fr}(t=1)$	- *amplitude* of the increase: real consumption = $gr_{rm}^{\theta}(t=1)+\Delta$ - *amplitude* of the increase: Δ	
VST, ST	Urgent anticipation	×	×	**Increase** of the real consumption **Decrease** of $gr_{rm}^{\theta+fr}(t-fr)$	- *amplitude* of the increase: real consumption = $gr_{rm}^{\theta}(t=1)$ +Movement of $\overline{gr_{rm}^{\theta}(t)}$ from $t \in PH \backslash 1$ to $t = 1$) - *amplitude* of the decrease: $\alpha \times gr_{rm}^{\theta+fr}(t)$	
VST	Real demand different from planned	×		**Modification** of the quantity $gr_{rm}^{\theta+fr}(t)$	- *type* of the modification: increase or decrease - *amplitude* of the modification: $gr_{rm}^{\theta+fr}(t) = gr_{rm}^{\theta}(t-fr)+\Delta$ with $\Delta \in \overline{\Re}$	
			×	**Modification** of the real consumption No impact on $GR^{\theta+fr}(rm)$	- *type* of the modification: increase or decrease - *amplitude* of the modification: real consumption = $gr_{rm}^{\theta}(t=1)$ + Δ with $\Delta \in \overline{\Re}$	

- "**short term planning process**": periodic event that is responsible of the detailed scheduling consequences representation. The questions are:
  - Is it a movement of production order ? yes-no,
  - *direction*, *amplitude*, *quantity*,…
- "**very short term planning process**": periodic event that is responsible to translate consequences of real production events on the requirement plans. The questions are:
  - Is it breakdowns ? yes-no,
  - *Amplitude* of the gap between real and planned,
  - Is it scrap ? yes-no, *amplitude*…

The market generation is always the first event that occurs. It creates the demand for all periods of the simulation times. A first part of these quantities is used to build the requirement plan at $\theta = 0$. Others will be used to integrate new demand in the rolling horizon at each period. Then, the requirement plan is disturbed (or not) by each successive event at each simulated period.

Finally, a gross requirement plan and a real consumption are built each week for each analyzed product (*rm*). They will be used by the customer's supply planning process in order to establish the link with the associated supplier (part out of the scope of the study). However, it could be interesting to study the dynamics of the plan in order to analyze the impact of the different decision and event. In the next part we propose a set of indicators that allow dynamics of a plan to be emphasized.

5 CHARACTERIZATION OF THE DYNAMICS OF A PLAN

Dynamic of plans has been analyzed in the literature through terms as robustness or stability (Van Landeghem and Vanmaele 2002, Genin *et al.* 2008). Robustness of a plan can be characterized as the capacity of a plan to reduce the number of changes to the plan, while keeping the key performance measures fixed at their target level. In this part, we propose a set of indicators used to analyze requirement plan and more particularly the dynamics of these plans through the evaluation of changes (number, sense of the change, amplitude). Let:

- PH be the set of periods of the Planning Horizon for a given plan;
- T be the set of time θ at which the plan is produced;
- T^* be the set of $\theta \in T$ that define a period of analysis ($T^* \subseteq T$);
- $gr_{rm}^{\theta}(t)$ be the application that associates to a period $t \in PH$ of the plan $GR^{\theta}(rm)$ the value of the associated requirement.

This plan can be analyzed according two different points of views: static or dynamic. The former is interested in the structure of the plan at each $\theta \in T$. The latter allows the evolution of the plan during.

For example, let be $T = \{0, 1, 2, 3\}$ and $GR^{\theta}(rm)$ a plan defined at each $\theta \in T$ with five periods ($PH = 5$) such that: $GR^0(rm) = \{10;0;10;0;12\}$, $GR^1(rm) = \{0;10;5;10;0\}$, $GR^2(rm) = \{10;5;10;2;10\}$ and $GR^3(rm) = \{5;10;5;10;0\}$. The Table 4 summarizes these plans. Here, $T^* = T$

	$t=0$	$t=1$	$t=2$	$t=3$	$t=4$
$\theta = 0$	10	0	10	0	12
$\theta = 1$	0	10	5	10	0
$\theta = 2$	10	5	10	2	10
$\theta = 3$	5	0	5	10	0

Table 4: Example of plan

The horizontal (or static) and vertical (or dynamic) analysis consist in a two steps approach:

- The structure is firstly analyzed at each time $\theta \in T^*$ (static) and each $t \in PH$ (dynamic).
- Secondly, an aggregation is made to characterize the structure of the plan over the analysis period.

5.1 Horizontal analysis

The horizontal (or static) analysis consists in expressing the "typical" or "average" plan for a given *rm*. At each $\theta \in T^*$, the structure can be observed according to different temporal horizons. The plan can be analyzed globally, e.g. over all the periods, or partially, e.g. over different parts of the horizon. For example, the horizon can be cut into tree parts: ST periods, MT and LT. These different cuttings of the temporal horizon can be used to analyze the impact of decisions and events.

Three operators are proposed to describe the structure of a requirement plan at each time $\theta \in T^*$ and each cut horizon h = [a;b] (with $a, b \in PH$ and $a < b$):

- the average value of the requirement when it is defined (e.g. $gr_{rm}^{\theta}(t) > 0$) over a given horizon: $mean_{rm}^{h}(\theta) = \underset{t \in h}{mean}\left(gr_{rm}^{\theta}(t) / gr_{rm}^{\theta}(t) > 0\right)$;
- the standard deviation of the requirement when it is defined (e.g. $gr_{rm}^{\theta}(t) > 0$) over a given horizon h: $stdev_{rm}^{h}(\theta)$. This measure has sense if there are two or more requirements defined;
- the average period at which requirements appear: $freq_{rm}^{h}(\theta) = \dfrac{\underset{t \in h}{count}\left(gr_{rm}^{\theta}(t) / gr_{rm}^{\theta}(t) > 0\right)}{b - a}$;

The aggregation operator is an average over T^* in order to have a representation of the static dimension of the plan for this period. The Table 5 below gives the result for the example. On the left, measures related to each θ, on the right the global view for *T**.

θ	h	mean	stdev	freq
0	tot	10,7	1,15	0,6
0	[1;2]	10	-	0,5
0	[3;5]	11	1,41	0,67
1	tot	8,33	2,89	0,6
1	[1;2]	10	-	0,5
1	[3;5]	7,5	3,54	0,67
2	tot	7,4	3,71	1
2	[1;2]	7,5	3,54	1
2	[3;5]	7,33	4,62	1
3	tot	6,67	2,89	0,6
3	[1;2]	5	-	0,5
3	[3;5]	7,5	3,54	0,67

Aggregation over T*

h	mean	stdev	freq
tot	8,27	2,66	0,7
[1;2]	8,13	-	0,63
[3;5]	8,33	3,28	0,75

Table 5 : example of static analysis

In the example, the "typical" quantity of a gross requirement over *T** is 8,27 and these quantities appear between each week and each two weeks (horizon analyzed in totality: tot = [1;5] = *PH*). The different parts in the horizon ([1;2] and [3;5]) shows that the appearance period is smaller at the beginning than at the end of *PH*.

5.2 Vertical analysis

The vertical or dynamic analysis consists in describing the typical evolution of a given *rm* from one week to the other. A plan build at $\theta \in T^*$, have a given quantity of periods in common, called PH^* (card (PH^*) = card(*PH)* – 1) with the precedent plan (made at θ *-1*). For each of these shared periods (each $t \in PH^*$), the target is to characterize the evolution between the two plans. In other terms, we build a view of the dynamics of the plan between θ and θ *-1* (see Figure 6)

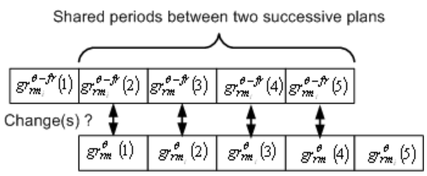


Figure 6: dynamics between two successive plans

Four types of measures can be taken for each period:

- the number of change ($n \in [0;1]$);
- the sense of the change (decrease, no change or increase respectively associated to –1, 0 and 1): $s \in [-1;0;1]$;
- the amplitude of the increased change: $q^+ \in \mathbb{Z}^+$;
- the amplitude of the decreased change: $q\text{-} \in \mathbb{Z}^-$.

After computing these four measures for each $t \in PH^*$ at each θ ∈ *T** (except θ = 0), an aggregation is made thanks to the average over *T**. The Figure 7 below summarizes measures for the example.

	Aggregated Measures			
t	n	q-	q+	s
1	0	0	0	0
2	0,33	-10	0	-1
3	0,67	0	4	1
4	0,33	-2	0	-1

Figure 7: example of dynamic measures

This table can be translated into a graph (see Figure 8). The periods of the plan are on the abscissa. Measures *n* and *s* are linked to the left vertical axis. Measures *q+* and *q-* are linked to the right vertical axis.

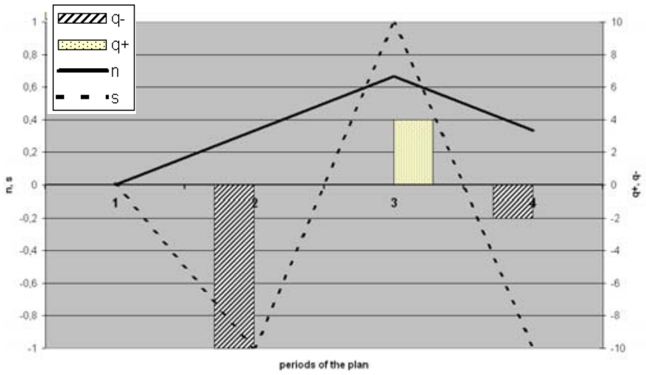


Figure 8: graphic representation of the dynamics of a plan

Thanks to these measures, we can conclude about the general dynamics of a plan over a period *T**. In the example, no change appears in the first period. However, several changes appear in period 2, 3 and 4 (see *n* evolution). We can add that the quantity modification is always a decrease in periods 2 and 4 and always an increase in period 3. *q+* and *q-* inform us about the average quantity about this modification when it occurs (increase and decrease respectively).

6 CASE STUDY

A case study has been developed in cooperation with pharmaceutics partners in order to illustrate the research project from which the elements presented in this paper are extracted. Pierre Fabre Dermo-Cosmétique (PFDC) is a branch of an international firm founded in France in 1961. Pierre Fabre Laboratories plays a leadership role among healthcare professionals in key business lines such as drugs, family medication and dermo-cosmetics.

PFDC production process is composed of two main activities: bulk production of skins and packaging of the finished products. It is a push production process. In the scope of this project, we are interested in the collaboration support of a particular set of 1st tier supplier of PFDC: the packaging components suppliers. To day, PFDC has established two different protocols for its set of packaging elements suppliers. They seek to know "which protocol for which supplier". The choice is function of the supplier's characteristics and behaviors and of the requirements associated to the item(s) supplied. The construction of a complete model is impossible according to the quantity of references (> 3000) manipulated.

Here, we present the analysis focused on four particular products in order to illustrate the use of our model and of the indicators presented in the previous part. Two types of information are available:

- global information from managers' interviews (expert). This is a priori information about the localization of the impact of the different processes;
- real requirement plan weekly extracted from the information system of the industrial (13 weeks collected).

In addition to these planning processes information, we have collected from expert data about market behavior and translation in terms of raw material requirements.

6.1.1 Dynamic parameters of the model

Table 6 below summarizes the kinds of impacts that will be simulated. An expert interview has allowed to identified which processes are used in the PFDC case.

Horizon	Decision / Events	Production strategy		Type of impact on $GR^{\theta}(rm_i)$	PFDC model
		Push	Pull		
LT	Capacity adjustment	×	×	No impact	no
LT	Smoothing	×	×	**Movement** of $gr^{\theta}_{rm_i}(t)$ in the horizon	yes
LT	Subcontracting production and supply	×	×	**Disappearance** of $gr^{\theta}_{rm_i}(t)$ in the horizon	no
LT	Subcontracting production	×	×	**Anticipation** of $gr^{\theta}_{rm_i}(t)$ in the horizon	yes
LT,MT	Future demand variation	×	×	**Movement** of $gr^{\theta}_{rm_i}(t)$ in the horizon	yes
		×	×	**Modification** of the quantity $gr^{\theta}_{rm_i}(t)$	yes
ST	Detailed Scheduling	×		**Movement** of production orders $gr^{\theta}_{rm_i}(t)$ in the short term horizon	yes
VST	Breakdown	×	×	**Decrease** of the real consumption **Increase** of the quantity $gr^{\theta+fr}_{rm_i}(t=1)$	no
VST	Scrap	×	×	**Increase** of the real consumption **Increase** of the quantity $gr^{\theta+fr}_{rm_i}(t=1)$	no
VST, ST	Urgent anticipation	×	×	**Increase** of the real consumption **Decrease** of $gr^{\theta+fr}_{rm_i}(t-fr)$	yes
VST	Real demand different from planned	×		**Modification** of the quantity $gr^{\theta+fr}_{rm_i}(t)$	yes
			×	**Modification** of the real consumption No impact on $GR^{\theta+fr}(rm_i)$	no

Table 6: dynamic parameters for the PFDC model

Subcontracting is a solution adopted by PFDC to adapt the planned load to the capacity. However, only the packaging activity is subcontracted. Packaging elements are still supplied by PFDC.

From a very short term point of view, the packaging activity is a very mastered process with negligible breakdown and gasp rates. As a push production, production orders are not affected by the real demand variation at the very short term.

This study focuses on a reference which is "statically" characterized by the following values for the horizontal analysis (see Table 7). Here, T^* = [0,…,13] and PH = 24:

	Horizons				
	PH	**[0;7]**	**[8;11]**	**[12;19]**	**[20;23]**
Average requirement	17 307	19 990	12 663	15 935	7 878
Average period	5	5	3	6	2
Requirement / Period	3 616	4 432	4 842	2 774	4 268
Average sdt deviation	10 610	12 069	532	2 271	1 168

Table 7: horizontal analysis of real data

The ratio Requirement / Period shows that LT ([20;23]) planning is quite good while problems appear in MT horizon ([12;19]). High standard deviations are due to lot sizing decision and the lack of data to a statistical analysis (only 13 weeks).

Figure 9 below illustrates the application of the indicator used to evaluate the dynamics of a plan.

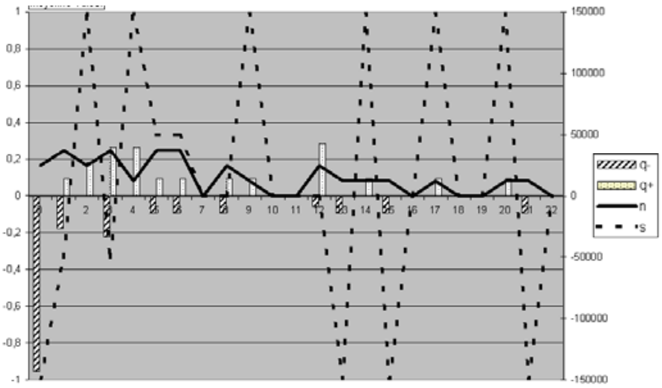


Figure 9: Dynamics of real plan (over 13 weeks)

From experts interviews, we know that punctual changes at t = 0 are linked to urgent anticipation (VST). Little waves from t = 1 to t = 7 are due to production orders movements. Furthermore, this reference is not much affected by long term decisions (smoothing and subcontracting) and market variation.

Market structure has been defined to generate requirements closed to data presented in Table 7. From a dynamic point of view:

- few urgent anticipation (VST);
- few production orders movements (ST);
- very few market variation (MT);
- very few smoothing and subcontracting (LT).

This model has been simulated during 208 weeks. Presently, we are confronted to several validation difficulties due to the little quantity of real data (only 13 weeks). Consequently, among the 208 plans, we have extracted data from θ = 190 to θ = 206 in order to take a scale similar to the scale used to analyze real data. Table 8 and Figure 10 present the results obtained for the simulated plans from a static and a dynamic point of view.

Model and reality are very closed from a quantity of the requirements and a dynamic points of view. Bad results in terms of period and standard deviation have two main explanations: on the one hand, parameters of the market structure would be more precise, on the other hand the referential is altered by the lack of real data. However, the dynamics analysis allows hypothesis expressed by the experts about planning processes and their impact to be "validated" (with a degree limited because of the size of the population studied: one reference).

	Horizons				
Average requirement	*PH*	[0;7]	[8;11]	[12;19]	[20;23]
Real	17307,2011	19989,82	12662,61	15935,3	7878,3461
Simulated	17460,1143	18751,5429	1962,9714	3254,4	7748,57
Gap	1%	-6%	-84%	-80%	-2%

	Horizons				
Average period	*PH*	[0;7]	[8;11]	[12;19]	[20;23]
Real	4,7868	4,51	2,6153	5,7435	1,8461
Simulated	11,88	6,28	0,6195	1,7142	2,8571
Gap	148%	39%	-76%	-70%	55%

	Horizons				
Average sdt deviation	*PH*	[0;7]	[8;11]	[12;19]	[20;23]
Real	10609,72	12068,662	531,85	2270,6	1168,3
Simulated	4918,64	1534,13	178,94	219,16	0
Gap	-54%	-87%	-66%	-90%	-100%

Table 8: Simulated data static analysis compared to real

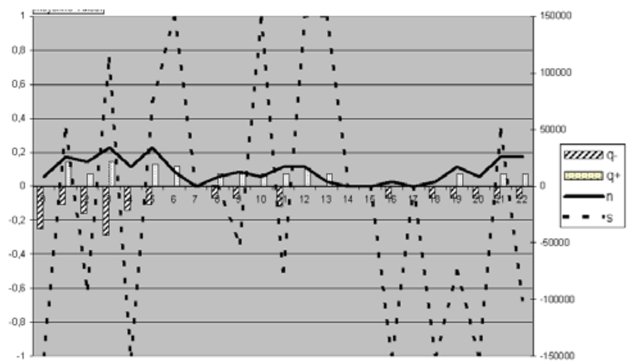


Figure 10: dynamics of the simulated plans

7 CONCLUSION AND PERSPECTIVES

In a supply chain, collaboration performance could be affected by several parameters: the actors' internal behaviors, the collaboration protocols instituted between them and the market behaviors. In this study, we are interested in the customer's and market behavior modeling. Their effects are materialized by the raw material gross requirement plan generated by the customer. According to the complexity of several supply chain context and associated detailed modeling difficulty, the objective was to propose an aggregated model of actor's planning and market behaviors.

To achieve this goal, we have formalized the different disturbances sources of a gross requirement plan through a list of decisions and events with their associated impact. Each type of impact has been characterized. Then, a model has been defined based on three abstraction techniques: aggregation, omission and model form transformation (from determinist to stochastic). The first results on an industrial case show that the proposed model is able to reflect several dimensions of the reality. In order to demonstrate this point, a set of indicators have been built that evaluate static aspect and mainly dynamics of requirement plans. However, at this state of development, the validation process of our model is beginning. The calibration of the model is a cyclic process review where we confront model output with real data extracted from industrial partners' information system. Today, the database is new and the accuracy of the model setting will increase with it.

In the future the target is to build a more significant real data base. The sensitivity of each parameter of the model has to be deeply analyzed. Then we aim to build a typology of product based on the associated actor's and market behaviours.

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