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ABSTRACT. *The improvement of the manufacturing productivity today is increasingly a result of cooperation between companies. Reflection on such industrial organization called "industrial architecture" aims at the development of a specific decision-making and control supports. The objective of our work is to propose a formalization of this cooperation by intending to coordinate the means used for consumer goods production. This formalization allows to establish an assistance tool for the distributed control of material and information flow between firms. Multi-criteria analysis is used to find the best balance between the delay and the cost in order negotiation.*

RÉSUMÉ. *Le gain en productivité passe aujourd'hui par une plus grande coopération entre les entreprises appelées à collaborer autour d'un même produit. La réflexion sur les organisations industrielles qui se constituent désormais en « Architectures Industrielles » conduit à la mise au point d'outils spécifiques d'aide à la décision et au pilotage. L'objet de cet article est d'apporter des éléments de réponse à ce nouveau besoin, en proposant une formalisation de la coopération basée sur la négociation de la commande à travers les délais de livraison et le prix.*

KEY WORDS: *decision-making, industrial architecture, cooperation, flows between firms, distributed control, Petri nets.*

MOTS-CLÉS : *aide à la décision, architecture industrielle, coopération, flux interentreprises, pilotage distribué, réseaux de Petri.*

1. Introduction

The Industrial Architecture (IA) notion was introduced for analyzing and controlling relationships between companies [HAU 99]. To generate a better productivity, these companies need the coordination of the actions which are distributed among autonomous partners [ALT 92], [KJE 98], [ROT 98]. Recent research shows a growing interest in studying cooperation relationships among the multiple actors of an industrial architecture [AXE 92], [RAP 87], [FER 01], [MON 01B].

Cooperation can take various forms. It can be defined as a collaboration between partners each having equivalent decisional capacity and acting together towards a common objective. One example of collaboration is the co-design in the automotive [WOM 92] or aeronautical sectors. Cooperation can also be defined as the coordination and synchronization of operations carried out by independent actors [MAL 94], [MON 01a]. Each partner has a limited decision power that corresponds to its action field [CAM 00], [CAM 97], [HUG 94].

To improve its reactivity and to better manage its costs, a company might consider subcontracting. It involves a "make or buy" decision. This may imply various time frames of decision: a long run decision defines for the company the whole of its external and internal nodes of production, distribution and supply [ARN 95]; a medium run specifies contracts (quantities, delays, prices…) that the company is likely to have with its internal and/or external providers in order to carry out a production program which reaches the best balance between cost and delay [DAM 95]; or a short run decision considers subcontracting simply for overload capacity in order to absorb the temporary fluctuation of demand [AHM 94].

In this paper, we are interested in the mechanism of order negotiation between a firm and its client and a firm and its providers. This mechanism's aim is optimize the balance between the respect of the delay and the cost. In order to be effective, a distributed decision must take into account at the same time the autonomy of each firm and the global coherence of this decision. The objective of our work is to propose a formalization of the cooperation which coordinates the means used for consumer goods production. This formalization aims to establish an assistance tool for the distributed command of flows between firms.

This work follows an analysis of machining companies (aluminum screw cutting) in the Arve valley of France. These companies commonly exchange among themselves a part or all their orders. This allows each to solve the reoccurring problem of internal production over-load.

First, the context of the decision is presented and how decision-making is distributed is developed. We detail our approach in the second part using three complementary analysis methods: respecting only the cost or only the delay, or searching for a hybrid scenario. And finally we present some conclusions and further research.

2. The distributed decision

2.1. *The centralized and hierarchical approaches*

Historically, control in a network of firms was centralized [GIA 88]. Companies tried to control all the material flow from the first provider to the last client through a vertical integration. In this architecture, all the decisions are made in a unique center. This centralization of the decision generates a centralization of the information system and an information bottleneck. To avoid this difficulty, the hierarchical approach was developed. In this structure, different centers are coordinated by an entity that is hierarchically higher. All decision-making for a given level are centralized by this center called "coordinator". The latter has all the necessary information which has been transmitted by the supervised centers (Figure 1).

A network with coordinators is representative of organizations where vertical integration is strongly present. The two aspects of this approach, hierarchical and centralized, allow better control of opportunist risks for each of partners.

This hierarchical dependence for decision ensures the coherence of choices. But with this approach, it is difficult to admit that decision-making is often distributed in an Industrial Architecture.
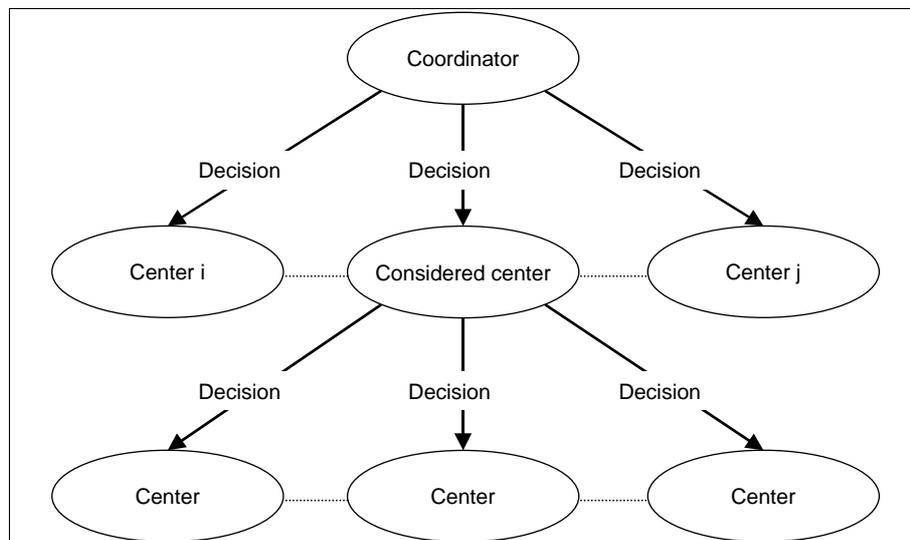

Figure 1. *Hierarchical allocation of decisions*

2.2. *An alternative for the centralized approach [JES 01]*

With the distributed approach, we are considering a network with autonomous decision centers. This network can be described with a graph whose nodes represent decision centers and arcs decision making actions (Figure 2). This approach makes it possible to take into account constraints that must be respected in a decision center. Such constraints are the result of upstream decision centers (i.e. providers) and can influence downstream centers (i.e. clients). If constraints applied to a center are too restrictive, the decision is impossible. This is called a lack of autonomy. In this case upstream centers will not be able to validate their decisions. Negotiation is launched to find a consensus.

Contrary to the centralized coordinated approach, this approach can, by definition, take into account the distributed nature of decisions. On the other hand, it needs to apply specific management methods to ensure both a control of opportunist behavior and a coherence of distributed choices throughout the IA. These methods will be developed in this paper.

The theory of decision distribution is currently a subject of much discussion. The LAMIH suggests a formal decentralized control system to help design a complex product (as applied to GEC-ALSTOM) [TRE 01]. The DIAM develops a method of decentralized control for client/provider relationship. In this method, all providers in relation with a given client are assimilated into a virtual enterprise whose members allocate production tasks using a set of proposals [OUN 01].

An additional advantage of the distributed approach is that a provider company (or client) is taken into account throughout the several IAs, while in centralized approach, all information must be grouped at one hierarchical level. This is difficult to obtain if a firm is active in several IAs where decision centers' constraints are superimposed and even are in competition with one another.
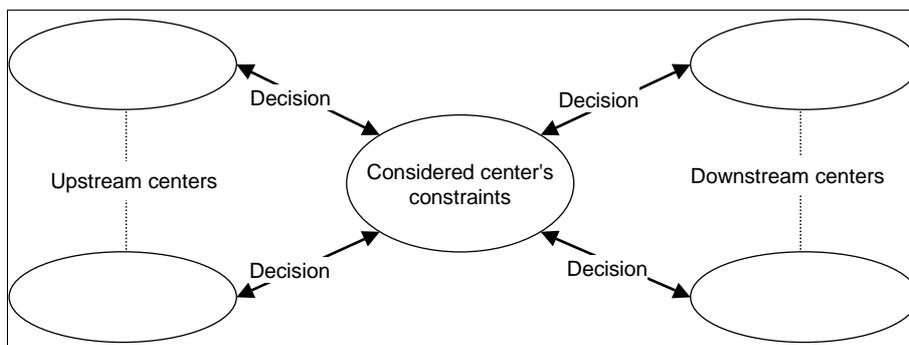

Figure 2. *Allocation of the distributed decisions* **[MON 01c]**

2.3. *Negotiation, a concerted decision making*

In a distributed decision-making structure, each member-company of the IA is considered an independent decision center and is therefore capable of modifying the details of the industrial process, which it has elected to include in its activity. In a cooperative context, a member-company's internal decisions have to be considered. Cooperation can be described as a will to act collectively towards a common goal. In the case of inter-firm industrial flow control, cooperation can be considered to be the coordination of the means of each company composing the IA, to produce goods that in the end, generally optimize an equilibrium among cost, quality and delay. This coordination allows the making of consistent individual decisions and aims at synchronizing them.

Decision-making becomes necessary when the environment changes. A change can be external to the member-company (direct decision maker's environment), as is the case of receiving an additional order from a client or when a problem occurs with a provider; or it can be the result of an internal evolution, when an unexpected event appears in the company itself. Here, cooperation promotes both collective and distributed decision-making, aiming to synchronize actions shared among the different partners. We are in a co-decision context which intends to coordinate individual actions.
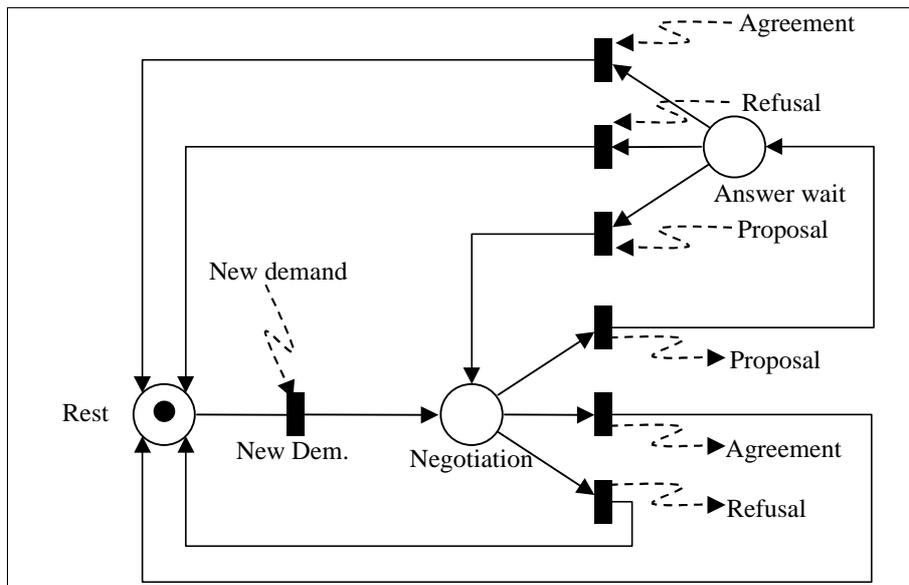

Figure 3. *Evolution of negotiation*

The Petri net (*Figure 3*) illustrates the mechanism of the decision making. When a demand is initially detected, the Rest token, which indicates there is no negotiation, is consumed. The negotiation phase creates three possibilities of firing.

Depending on a feasibility study, decision-makers can either further negotiation by replying with a proposal, or stop it by replying with an agreement or a refusal. If he receives a proposal, the second partner will determine his possibility of firing. Decision-making is interactive. When a company has to deal with situations beyond its control, conducting a feasibility study causes the company to make new demands on providers who will in their turn have to start negotiations [MON 00]. Decision-makers have to take partners' prerogatives into account during the decision making. By this process each partners' internal constraints have been propagated among the IA.

So, by this decisional mechanism which respects the propagation of constraints, we guarantee at the same time, center's autonomy of a decision and the coherence of decision making between centers [MON 01c]. A group of bilateral decisions acting in concert with two protagonists can guarantee general coherence in an IA having a treelike structure, as illustrated in *Figure 4*.
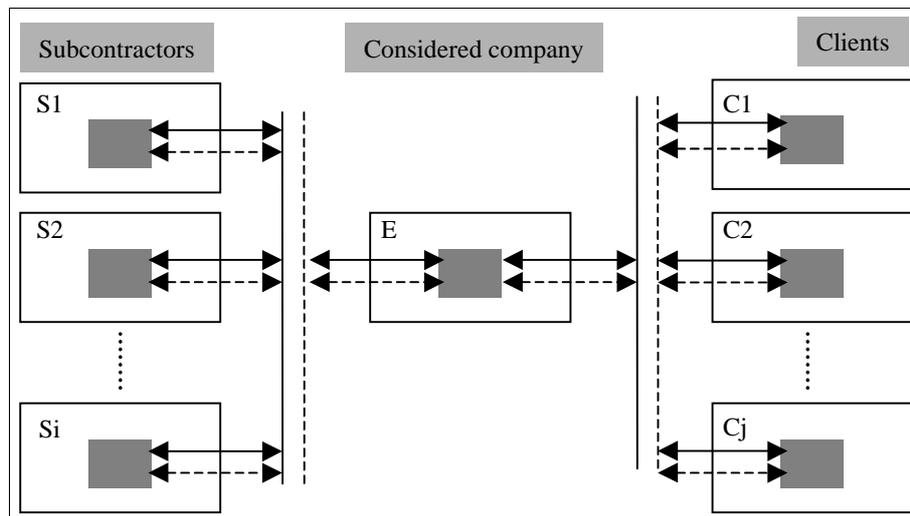

Figure 4. *Partial representation of an IA having a tree structure*

3. Our suggested approach

3.1. *Industrial Architecture modeling*

3.1.1. *A company in relation with its partners*

IA modeling needs to consider companies as independent and interrelated entities [BOU 97]. Our model will present an enterprise (E) in relation to providers (S) and clients (C).

This representation of an enterprise (*Figure 5*), member of an IA, is based on two flow types: information flows (dotted lines) and material flows (continuous lines). These two flow types are oriented and controlled by a fundamental function of flow control (GF). On the other hand, to illustrate the transformation process of material flow, it is important to show the internal processing system (in gray).
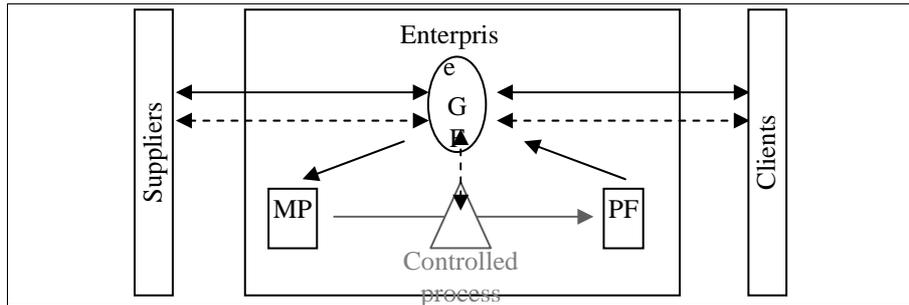

Figure 5. *General structure of an enterprise in relation with its partners*

This internal processing system is considered as a controlled process which consumes raw materials (MP) and creates manufactured products (PF).

This enterprise model has a real sense only in relation with its S and its C. The enterprise can be interpreted as a S or as a C depending on the point of view.

3.1.2. *Flows related to operational control of inter-firm relationships*

These flows are divided into two categories:
−   Information flows, necessary for IA management,
−   Material flows, comprising physical inter-firm trade.

Our goal is to model, in a single formalism, all these flows. This is why we have chosen to use an aggregate structure allowing us to avoid, owing to encapsulation of data, increasing the size of the model, in spite of the numerous types of flows. Moreover, this approach permits us to easily take into account a new type of flow.

3.1.2.1. *Information flows*

We are particularly interested in the information flows necessary for operational control. Also, these information exchanges are the main basis for the inter-firm cooperation.

An information flow in a commercial relationship is, in part, characterized by a sender/recipient pair constituted by C and S. Inter-firm exchange is essentially based on an order and its evolution. We define an order as a flow of information between two companies which contains following data:
−   The product concerned by the exchange,

- The quality needed,
- The delivery deadline.

This order follows an evolution in two phases: in the first one, the order is generated. At this stage, companies search together to define the specifications (product, quality, delay) of the order. The second phase is more operational, and aims to control the flow of material through the IA. This is characterized by the attribute "qualifier" of the aggregate "information flow" which can be: (numbers pertain to *Figure 6*):

- New client's demand (1),
- Client's proposal (2),
- Client's estimated order,
- Client's definite order,
- New enterprise's demand (3),
- Enterprise's proposal (4),
- Enterprise's estimated order,
- Enterprise's definite order,
- Provider's proposal (5).

As illustrated in Figure 6, the state of negotiation between sender and recipient of a flow is denoted by the attribute "status" of this aggregate. This state is represented by two fields illustrating the points of view of the two companies in negotiation, one square represents the client's position (C) and the other the provider's position (S) for the product concerned.

First, a proposal has to be validated (AV) by the second partner, who will accept it (A), or refuse it (R), or make a counterproposal (AV). Negotiation will finish on a common agreement (status <A, A>) or on one partner's refusal (status <A, R> or status <R, A>). With this process, we are able to follow the evolution of an order during its "life cycle". The *Figure 6* illustrates a possible evolution of an order, from the "new demand" to the "final agreement". In this figure, a mutual agreement is found after four successive proposals were sent and negotiated. It shows the order's generation process based on negotiation that we will develop in detail below. The example showed here illustrates how the "status" attribute changes over the order generation phase (first phase), but this attribute is also used during the material flow control phase, to denote, for example, of the final state of an order (Accepted or Refused).

For this flow, we will use notation as follows:

- Information flow < qualifier, product, quantity, delay, status, sender, recipient >

The "Product" aggregate included in information flow, but also in material flow, identifies the product concerned by the exchange. It is described by its designation, the required quality and its price.
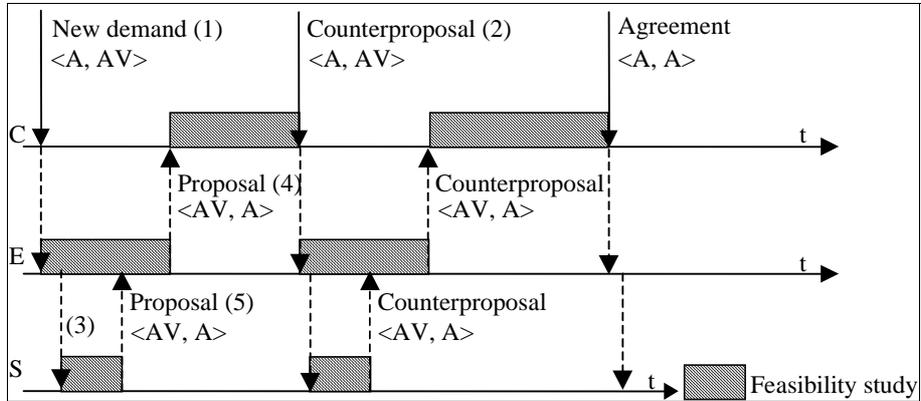
Figure 6. *An example of order generation*

3.1.2.2. *Material flows*

Material flows include materials (MP) (materials from S and supplies from C), or manufactured products (PF), as well as billing flow (bill) or payment flow (payment). The attributes – product, quantity, sender, and recipient – are the same as those concerned in information flows. The "transportation time" is necessary for the feasibility study of a demand. For this flow, we will use the following notation:

    –   Material flow <sender, recipient, transportation time, product, quantity>

Thus, through this formalism based on aggregate structure, we are able to represent whole flows circulating in an IA. ***Figure 7*** illustrates the structures of these inter-firm flows.

Status	Information flow	Product	Material flow
Client	Qualifier	Designation	Sender
Supplier	Quantity	Quality	Recipient
	Delay	Price	Transport. time
	Sender		Quantity
	Recipient		Product
	Product		
	Status		

Figure 7. *Aggregates illustrating inter-firm flows*

3.2. *Negotiation mechanism*

3.2.1. *New demand feasibility*

When a company receives a new demand from a client, it has a choice among three complementary decisions. This choice is based on estimating the constraints induced by this new demand. The company:

−   can totally accept this demand respecting all constraints (Agreement),
−   can propose constraints modifications (Proposal),
−   or can refuse this demand from the client (Refusal).

These three choices have been studied at the one company's center of decision in light of that center's degree of autonomy [CAM 97]. Autonomy is satisfied if adding new an order does not generate incompatibility with constraints already present in the center. If autonomy is satisfied, the center can make a decision respecting all constraints (decision under constraints). On the other hand, if a lack of autonomy is detected, the center is able to propose constraints modifications to satisfy its own autonomy (decision on constraints).

The choice is based on an algorithm for new demand estimation. The goal is to decide, using knowledge of the systems current state, if a company β can accept or not a new demand from its client α. This decision is based on the evaluation of the load on a production center. To determine rapidly in what conditions the company is able to manufacture the new order, a comparison is made between the added load induced by this new manufacturing demand and the idle (unused production capacity) of each planning period (*Figure 8*). This analysis is done by focusing on the bottleneck activity[1] of the internal production system.

This estimation is divided into two phases. The first detects a lack of autonomy or not, and starts negotiation with providers if necessary. The second phase determines how the order has to be modified to respect the whole set of time constraints in the IA.
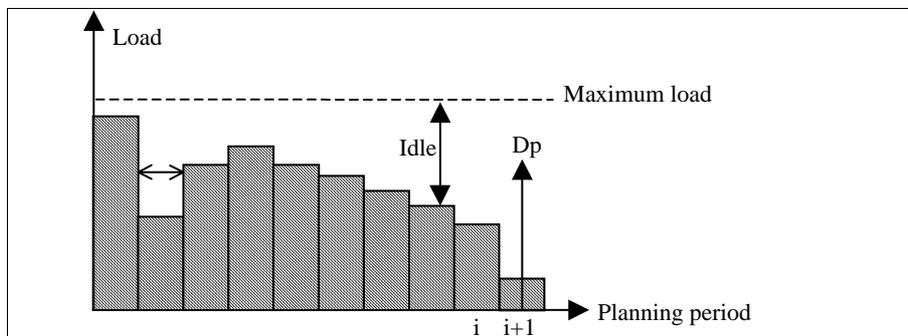
Figure 8. *Load of a production center*

We have decided that cooperation would be based on negotiation of delivery deadlines which is a very important criterion in the IA control. Currently, supply chain management tools aim mainly at optimizing the reduction of "logistic fat" which consists of the time wasted by a bad coordination.

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[1] We call bottleneck activity, activity which most restrains the load in the internal production process.

The feasibility study of a new order tries to determine if introducing an additional load is possible given the state of the system of production. If all constraints exerted on the company cannot be respected, estimation mechanisms will try to relax a part of these constraints in order to satisfy decision center autonomy. Before presenting the principle of evaluation, we would like to define a typology of constraints influencing order feasibility.

We can distribute the different constraints into two distinct categories (*Figure 9*):

–   internal constraints which are within the company considered,

–   external constraints which follow either from the other companies in the IA, or from the external environment (i.e. not from IA).

Here is a typology of various constraints influencing decision-making.
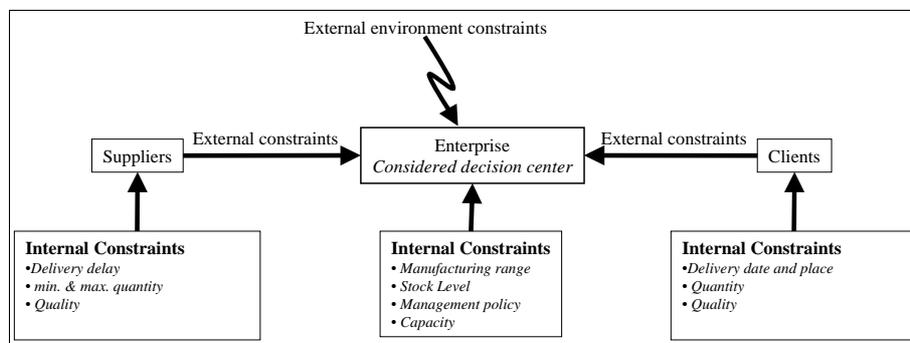
Figure 9. *Constraints influencing a decision center*

3.2.1.1. *Internal constraints influencing the order feasibility*

They are of two types,

–   time constraints:

–   the unit production processing time,

–   the production set up time.

The unit production processing time refers to the time necessary to manufacture one batch of the product required. The production set up time corresponds to the necessary delay to reconfigure manufacture resources (tools changes, adjusting of machines…)

–   physical constraints:

–   the quantity of products in inventory (raw materials and manufactured products),

–   the batch size,

–   the maximum production capacity.

The quantity of raw materials and manufactured products in inventory is a strong physical constraint. In reality, these determine interactions with providers (for the raw materials) and with clients (for the manufactured products). The batch

size is used to determine the number of batches to be launch. Finally, production capacity refers to the maximum load allowable in a planning period.

3.2.1.2. *External constraints influencing the order feasibility*

These follow from other IA-member companies directly connected to the company (direct partners): clients and providers.

−   **Clients**: Clients are demand initiators. They create external time constraints or physical constraints.

Their time constraints are related to the requested delivery date (deadline). This delivery date is a constraint date, it indicates the latest date when the last internal manufacture activity has to finish.

Physical constraints are related to the delivery quantity, to the quality and to the price. These physical constraints determine attributes that the outgoing physical flow has to respect. Here, we can recognize the cost/quality/delay triptych.

−   **Providers**: Providers supply raw materials or services. Their external constraints are also time or physical constraints.

Time constraints are related to the possible delivery date (release). This delivery date of raw materials is a constraint date. It indicates the soonest date for starting an internal manufacturing activity using these raw materials.

Physical constraints are related to the batch delivery size. These depend on raw materials packages, which could be different from the company's needs.

3.2.1.3. *Constraints from the external environment:*

It is important to take the environment into account. In France, for example, legislation limits the decision framework. Consequently, working time and the flow of material are limited (35-hour work week law, trucking traffic limitation on week-ends …).

These should be considered as absolute constraints: they are fully external to the Industrial Architecture. By definition, these constraints are not negotiable.

3.2.2. *Mono-criterion negotiation: delay*

3.2.2.1. *Mainspring of the estimation*

Given the following new demand of product P:
Information flow <New_demand, product_p, Q_p, D_p, <A, AV>, α, β>
Where:
− Q_p is the quantity of product p to be delivered;
− D_p is the required delivery time;
− α et β are respectively the client and the "provider" company;
−   product_p is composed by: <P, quality_p, C_p>;
  −   P is the product designation;
  −   quality_p is the required product quality;

     – C_p is the price.

The internal constraints of the company (E):

– I_p is the quantity of product p in inventory ;

– L_p is the batch size of the product p;

– F_p is the time to manufacture a batch of product p;

– R_p is the time necessary for the change of production towards the product p.

NOTE. – In order to simplify this presentation, we have chosen to merge the required delivery time D_p and the bottleneck activity deadline.

The feasibility study of a new command will use the three complementary channels showed in the Table 1, and involving more and more resources.

Realization mode \ Involvement	Sales service	Manufact.	Purchasing service
Delivery with manufactured product in inventory	✔		
Manufacture using raw materials in inventory	✔	✔	
Manufacture using raw materials supplying	✔	✔	✔

Table 1. Resources used for an order

Therefore, firstly we determine if the demand can be satisfied with manufactured product inventory. This is the shortest channel for the feasibility study. If manufactured product inventory is insufficient, the production function will be involved. Finally, and if the raw materials inventories are insufficient, the purchasing service will be involved requiring eventual exchanges with providers. Thus it is necessary to follow the third channel, which is the longest because it can generate negotiations with providers. Internal decision-making will require waiting for answers from several partners.

We strive to reduce the time necessary for the feasibility study by formalizing this decision-making and the negotiations ensuing from it. The feasibility study successively follows these three channels, checking in each stage that constraints are respected. The diagram of the *Figure 10* illustrates the stages followed according to the different decision channels.
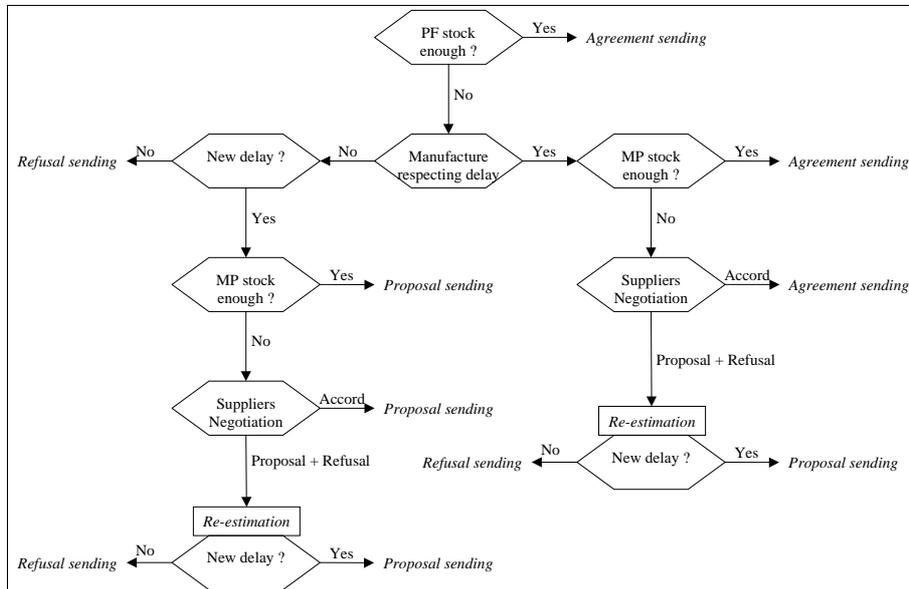
Figure 10. *Decision progress*

3.2.2.2. *Algorithm of new demand estimation:*

The following algorithm uses two sub-functions that, respectively, either allow making a decision under constraints (search for an insertion abiding by the delay), or allow making a decision on the constraints (search for a realizable insertion). A complementary re-estimation procedure is necessary when one of the answers given by the providers is not according to the initial need. This procedure assumes changes can be propagated to the client.

This algorithm explores the three decision channels. It will be based on the two other procedures for the "decision under constraints" and for the "decision on the constraints". Dmax is the real bottleneck deadline (at the beginning, Dmax = D_p).

If [Qp − Sp ≤ 0] then   **## Manufactured product inventory comparison**
  Answer sending = agreement   **## Inventory is sufficient**
Else

$$Nd = round\_up\left\lceil \frac{(Qp - Sp)}{Lp} \right\rceil$$ **## Number of batch to launch**

  $CHp = Np \times Fp + Rp$ **## Induced load on the center**
  Search for an insertion abiding by the delay   **## Estimation under constraints**
  If insertion is possible, then
    Comparison with the raw materials inventory
    If inventory is sufficient, then answer sending = agreement
    Else
      Suppliers new demands sending
      If answer is agreement, then answer sending = agreement
      If answer is proposal or refusal, then re-estimation
  Else
    Search for the shortest delay   **## Estimation on the constraints**
  If insertion is possible, then
    Comparison with the raw materials inventory
    If inventory is sufficient, then answer sending = proposal
    Else
      Suppliers new demands sending
      If answer is agreement, then answer sending = proposal
      If answer is proposal or refusal, then re-estimation
    Else answer sending = refusal

Figure 11. *Algorithm of new demand estimation*

3.2.2.3. *Search for an insertion abiding by the delay (decision under constraints)*

The goal of this algorithm is to determine the existence of an insertion respecting the deadline. This insertion will not have to exceed the manufacturing center's load limit. This algorithm allows to know the latest raw materials needs date for potential negotiations with providers. We have chosen to insert this new command using the latest production policy. So the induced load (CHp) will be inserted as close as possible before the bottleneck deadline D_p. The insertion could be made under a maximum of two planning periods. We suppose the planning period is longer than the industrial cycle.

i+1 is the planning period that contains the bottleneck deadline D_p
Insertion = false, Stop = false
While (Insertion = false and Stop = false) do
  ε = idle(i) – CHp
 If $\varepsilon \geq 0$ then
  Insertion = true
  idle(i) = idle(i) – ε
  start production period = i   **## need for the entering products date**
  end production period = i+1 **## availability of the outgoing products date**
 Else
  If (idle(i – 1) + $\varepsilon \geq 0$) then
   Insertion = true
   idle(i) = 0
   idle(i – 1) = idle(i – 1) + ε
  start production period = i-1 **## need for the entering products date**
  end production period = i+1 **## availability of the outgoing products date**
  Else
   i = i-1
   If (i = stop_min_date[2]) then Stop = true

Figure 12. *Decision under constraints algorithm*

3.2.2.4. *Search of the shortest delay (decision on the constraints)*

When a lack of autonomy is detected, it is important to determine how constraints have to be changed to be able to satisfy an order. The goal of this algorithm is to define a possible insertion date minimizing the change. As the previous algorithm, this new delay will be a framework for potential negotiations with providers. Here we will try to find the earliest insertion after the bottleneck deadline D_p.

---

[2] That date represents the most acceptable lead time following the first deadline.

```
i is the planning period that contains the bottleneck deadline Dp
Insertion = false, Stop = false
While (Insertion = false and Stop = false) do
   ε = idle(i) – CHp
  If  ε ≥ 0 then
    Insertion = true
    idle(i) = idle(i) – ε
    start production period = i      ## need for the entering products date
    end production period = i+1   ## availability of the outgoing products date
    Dmaxp = i + 1
  Else
    If ( idle(i + 1) + ε ≥ 0 ) then
      Insertion = true
      idle(i) = 0
      idle(i + 1) = idle(i + 1) + ε
    start production period = i      ## need for the entering products date
    end production period = i+2   ## availability of the outgoing products date
    Dmaxp = i + 2
    Else
      i = i+1
      If (i = stop_max_date) then Stop = true
```

Figure 13. *New deadline Dmax$_p$ research (decision on the constraints algorithm)*

3.2.2.5. *Re-estimation*

This complementary procedure is necessary when providers' answers do not respect all the internal constraints. It is a matter of the re-estimating insertion possibility respecting the raw materials delivery lead times given by providers (release). This procedure is very close to the search for the shortest delay, on the other hand the search is executed not after Dmax, but after the most restricting date between Dmax and the raw materials delivery dates DL(MP).

Here, external constraints from providers are known in advance. So the result of this re-estimation is sure to respect external constraints from providers. It will not be necessary to negotiate with these partners.

In this case, i is the planning period that contains the most restricting date between Dmax and the raw materials delivery dates DL(MP) (see Figure 13).

3.2.3. *Multi-criteria negotiation: cost / delay*

3.2.3.1. *Global decision structure and decision under constraints*

The feasibility analysis is made under the constraints already presented in the chapter 3.2.1

We will use the p product's order which is defined by the following attributes: $<Q_p, D_p, C_p>$. We also take into account the maximum production capacity per period, as well as the already existing load on each period. This load comes from the rest of the company's customers.

First, the new order $<Q_p, D_p, C_p>$ of P product is compared to the inventory level. If $[Qp - Ip \leq 0]$ then it's possible to deliver this order only with the inventory P product. Else, $Qp - Ip$ defines the need of p to be produced.

The second stage consists in inserting this new production in the planning.
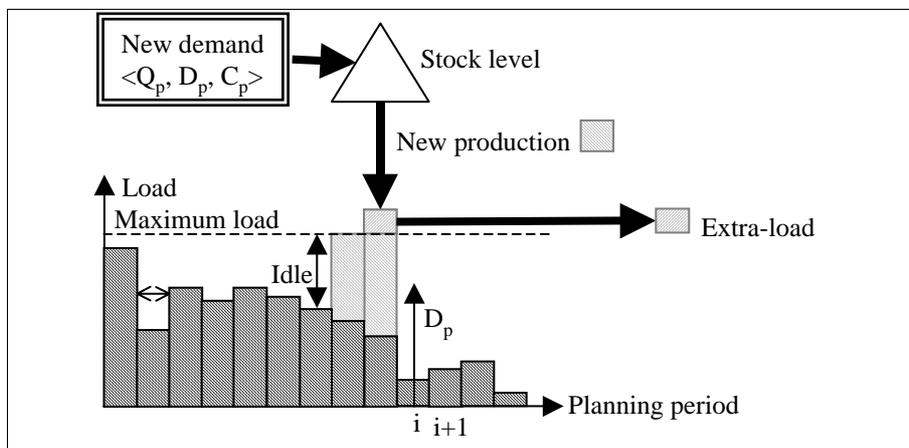
Figure 14. *Decision under constraints*

$$CHp = round\_up\left[\frac{(Qp - Ip)}{Lp}\right] \times Fp + Rp \qquad [1.]$$

To respect all constraints, CH_p should be inserted before the deadline D_p. We have chosen to insert this new command using the latest production policy. If the insertion is possible, the company can respect all the described constraints and deliver the product P. Else, it is possible to relax some of the constraints. The company may:

- Modify the deadline D_p and propose a later one D'_p,
- Employ subcontractors and/or overtimes which increase the cost C_p,
- Use a hybrid solution by slightly modifying D_p and C_p.
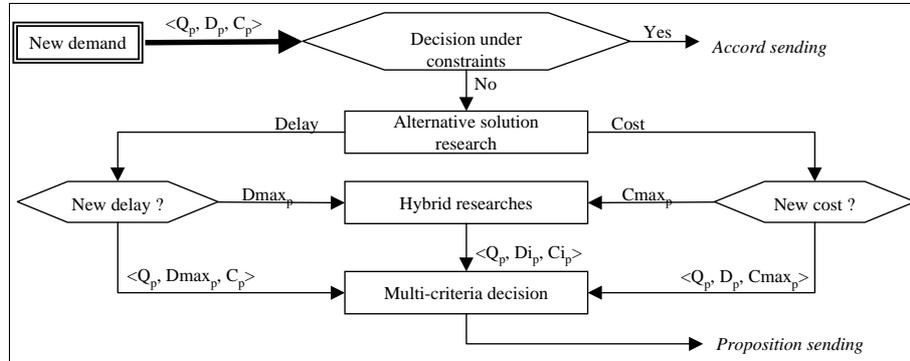
Figure 15. *Structure for multi-criteria cost / delay decision*

This decision structure is described in the ***Figure 15***. If the decision under constraints is not possible, an alternative solution research is launched. This stage contains the three analyses mentioned above. First, an analysis with respect to the cost gives a maximum modified deadline called $Dmax_p$. At the same time, an analysis with respect to the delay gives a maximum modified cost called $Cmax_p$. This cost includes the overtimes and subcontractors' to be used. With these two data, $Dmax_p$ and $Cmax_p$, a hybrid solution is constructed. This analysis uses $Dmax_p$ and $Cmax_p$ to limit the research area.

A multi-criteria decision compares the different scenarios. A proposal corresponding to the best arrangement between cost and delay is sent to the client.

3.2.3.2. *Analysis with respect to the cost*

The goal of this analysis is to determine a new deadline $Dmax_p$ that respects the load of the company. The algorithm is detailed in the ***Figure 12***. The method is very similar to insertion with respect to the delay, but the research starts at the deadline D_p and move forwards trying to find the earliest idle. This analysis is also used in the hybrid research to determine, for each planning period, the "extra-load", which has to be done by subcontractors or by overtimes. In this case, for each period i, the overload ε_p is produced with these two extra-resources.

$$\varepsilon_p = \text{round\_up}\left[\frac{\varepsilon}{Fp}\right] \times Lp \qquad [2.]$$

3.2.3.3. *Analysis with respect to the delay*

A company may be unable to fill an order within the required delay D_p given by the client due to insufficient capacities. In this case, the company may investigate whether:

–   to subcontract a part or the entire overload using providers ("extra-load"),
–   to plan overtime for the in-house increase of its capacities.

A mathematical model is established in order to simulate these strategies [BOU 01]. The model gives the quantities of each product be produced in-house and/or to be bought from providers for minimizing the cost in each scenario. In our case study, the constraints to be satisfied are related to: the internal capacities, the order, the transport capacities, the inventory status, and the delays.

Each scenario may have a different cost and the one with the lowest cost will be chosen.

3.2.3.3.1. *Indices, sets and data*

The following notations are considered:
– $p \in \{1 \ldots P\}$: a product type,
– $f_p \in \{1 \ldots F_p\}$: index relating to each potential provider of the product p.

The following data are also considered for our model:
– ε_p: demand for each product p which corresponds to the overload to be subcontracted and/or done in-house using overtime.
– $CAPMin_p$: minimum capacity of the in-house production of the product p
– $CAPMax_p$: maximum capacity of the in-house production of the product p
– $CAPtranMin_{fp}$: minimum capacity of product p transport, if the potential provider f_p is used.
– $CAPtranMax_{fp}$: maximum capacity of product p transport, if the potential provider f_P is used.
– I_p: inventory level of product p at the end of the period considered by the command.
– $Cvar_p$: variable cost for the product p in-house production. This will include the extra cost that corresponds to overtime in case where this scenario is considered.
– $Cfix_p$: fixed cost for the product p in-house production.
– $Cach_{fp}$: unit price of purchasing from the provider f_p.
– $Ctransp_{fp}$: unit cost of transport from the provider f_p.
– $Cfix_{fp}$: fixed cost of purchasing from the provider f_p.
– h_p: holding cost per unit of inventory.
– F_p: in-house manufacturing lead time of a product p batch.
– L_p: in-house production batch size of the product p.
– $F_{p,fp}$: procurement lead time of a product p batch from provider f_p.
– $L_{p,fp}$: procurement batch size of product p from provider f_p.
– D_p: delay to be respected for product p (given by customer order).

3.2.3.3.2. *Decision variables*

$$Z_p, f_p = \begin{cases} 1 \text{ if provider } f_p \text{ is used to produce } p \\ \\ 0 \text{ if not} \end{cases} \qquad [3.]$$

X_p, f_p : quantity of product p provided from f_p.

$$Z_{p,i} = \begin{cases} 1 \text{ if product } p \text{ is made in-house (i)} \\ \\ 0 \text{ if not} \end{cases} \qquad [4.]$$

$X_{p,i}$: quantity of product p manufactured in-house (i) using internal resources.

3.2.3.3.3. Objective function

The considered objective is to minimize the costs (fixed and variable) related to the option "make", to the option "buy", as well as to minimize the storage cost which is common to both options.

The objective function is then written as follows:

$$\underset{p}{\text{Min}} \Big\{ \sum_p \Big\{ \Big[(C \, var_p \times X_{p,i} + Cfix_p \times Zp, i) \Big] + \Big[\sum_{f_p} (Cacha_{f_p} + Ctransp_{f_p}) Xp, f_p + \sum_{f_p} Cfix_{f_p} Zp, f_p \Big] + h_p I_p \Big\} \Big\} \qquad [5.]$$

3.2.3.3.4. Constraints

– Internal capacity:

$$CAPMin_p \, Z_{p,i} \leq X_{p,i} \leq CAPMax_p \, Z_{p,i} \qquad \forall \, p \qquad [6.]$$

Each time one chooses to make ε_p in-house ($Z\,p,i = 1$), the quantity to be produced is limited by a minimum capacity related to the economy of scale and a maximum capacity related to the capacity of the production means and available resources. This is true for each product of the current period of planning. Through this constraint, we will be able to check also that if $Zp,i = 0$ (one decides not to make in-house), then $Xp,i = 0$.

– Demand:

$$X_{p,i} + \sum_{f_p} Xp, f_p \leq \varepsilon_p \qquad \forall \, p, f_p \qquad [7.]$$

This constraint makes it possible to express that the in-house and outside produced quantities are limited by the estimated request for each product for the current period of planning.

−   Transport capacity:

$$CAPtranMin_{fp}\ Z_{p,fp} \le X_{p,\ fp} \le CAPtranMax_{fp}\ Z_{p,\ fp} \qquad\qquad \forall p, f_p \qquad [8.]$$

The bought quantities for each product (p) are limited by the maximum capacities of transport related to the corresponding provider (capacities of the transport means). This constraint implies also that if one decides not to buy from f_p ($Z_{p,f_P} = 0$), then $X_{p,f_P} = 0$.

−   Inventory level:

$$I_p = I_{p,0} + X_{p,i} + \sum_{f_p} Xp,f_p - \varepsilon_p \qquad\qquad \forall p \qquad [9.]$$

This constraint may be used to express the fact that inventory at the end of the current planning period is a function of the quantity in inventory at the beginning of the period ($I_{p,0}$), the in-house produced quantities, the bought quantities and, for each product, this is decreased by the request planned over the considered period.

−   Delay respect:

$$\text{Max}\ \left\{ F_p\ \frac{X_{p,i}}{L_p}, F_{p,fp}\ \frac{X_{p,f_p}}{L_{p,f_p}} \right\} \le Dp \qquad\qquad \forall p \qquad [10.]$$

This constraint allows the respect of the times imposed by the received order, if one decides to make in-house by considering additional overtime, or to use external providers, without however excluding the two options at the same time. In any case, the time needed to fill the order is the maximum between the in-house completion dates and the lead times of external providers. Indeed, if one chooses the external supply the time required to fill the order corresponds to the provider who has the longest deadlines. In the same way and if one selects the two options at the same time, the time will correspond to the maximum between the internal times and the times corresponding to the external chosen providers. This time must be lower or at least equal to that required by the customer (D_p). For the solution of the model and in order to express the constraints in a linear way, so that they can be solved using linear programming software (such as LINDO), this constraint is expressed as following:

$$F_p \frac{X_{p,i}}{L_p} \leq D_p \qquad\qquad \forall\, p \qquad [11.]$$

$$F_{p,fp} \frac{X_{p,f_p}}{L_{p,f_p}} \leq D_p \qquad\qquad \forall\, p, f_p \qquad [12.]$$

$$X_{p,i} \geq 0 \,;\, X_{p,fp} \geq 0 \,;\, I_p \geq 0 \qquad\qquad \forall\, p,\, f_p \qquad [13.]$$

This constraint expresses the sign of the decision variables. The quantities to be produced in-house or to be possibly bought outside must be positive.

$$Z_{p,i} \,;\, Z_{p,fp} \;\in\; \{\, 0,1 \,\} \qquad\qquad \forall\, p,\, f_p \qquad [14.]$$

These binary variables are related to the choice "make or buy". The possibility of choosing the two options at the same time (to make together) is not excluded.

3.2.3.4. *Multi-criteria decision*

In response to the order (represented by C (D_p , C_p) on the fig. 6) and if the client is unable to give satisfactory constraints for the costs and the deadlines at the same time, several cases can be considered:

– to respect the deadline (D_p) while considering either additional overtime or subcontracting the internal overload capacity. A (D_p, $Cmax_p$) corresponds to this case. $Cmax_p$ is given by the first two terms of the objective function which correspond to the cost of making in-house by considering additional overtime and/or buying cost when considering external providers (linear program),

– to respect the cost (C_p) given by the order, while seeking for an insertion date according to the internal production load (algorithm *Figure 13*). This case is represented by B ($Dmax_p$, C_p),

– to look for a compromise between cost and delay, A and B limit a zone that represents a set of possible scenarios (M_i).

These scenarios (M_i) could answer the customer's order in the case where neither cost, nor deadline given by the order are considered as constraints. Indeed, by regarding deadline as major constraint, this will increase costs considerably and vice versa. Hence it will be possible to seek and to find the scenario which satisfies as well as possible both costs and deadlines.
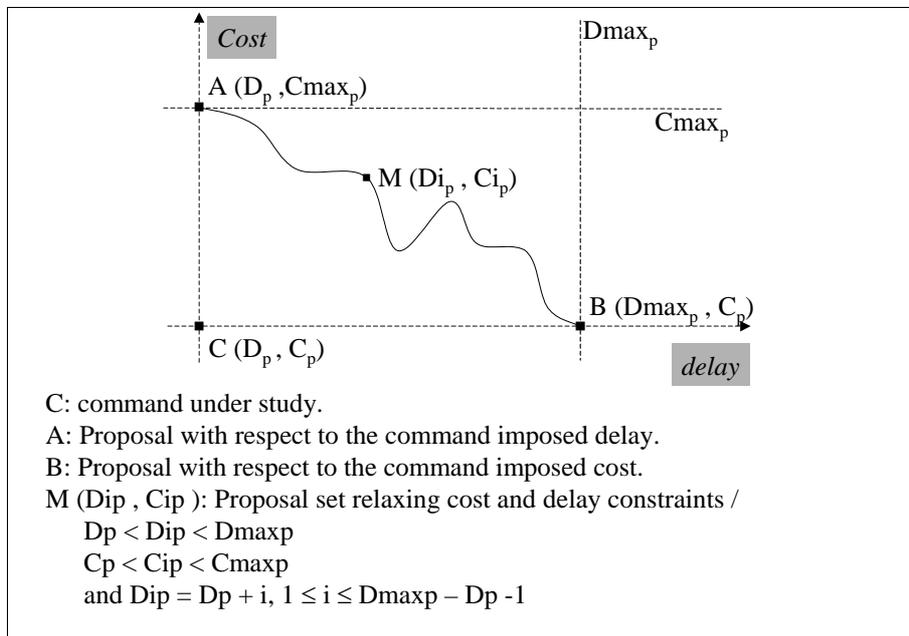
C: command under study.
A: Proposal with respect to the command imposed delay.
B: Proposal with respect to the command imposed cost.
M (Di_p , Ci_p): Proposal set relaxing cost and delay constraints /
    $Dp < Dip < Dmaxp$
    $Cp < Cip < Cmaxp$
    and $Dip = Dp + i$, $1 \le i \le Dmaxp – Dp -1$

Figure 16. *hybrid scenarios generation*

Consider a new delay to be proposed (Di_p) ranging between D_p and $Dmax_p$ incremented by subsequent periods. To define M_i , the corresponding cost (Ci_p) will be deduced considering either to make in-house, or to buy the overload observed capacity for the new delay (linear program).

For scenario evaluation, the following method chooses the best scenario which answers as well as possible both cost and delay criteria :

−   compute the percentage of margin between the order and the cost and delays established for each scenario (A, B, Mi).

−   weigh these deviations according to cost and delay by a coefficient which represents the relative importance of each criterion in negotiation. This depends on the type of relationship between the client and the provider and the client's priorities. Hence, a new set of points (A′, B′, M′i) with these new coordinates is attributed to each scenario.

−   calculate the norm of the vector given by each new point A′, B′, M′i representing the balanced variation compared to the order. The scenarios which make it possible to have the lowest distance compared to the origin correspond to those which can be proposed to the client in response to his order.

$$A' = \left(0, c_2 \times \frac{C max_p - C_p}{C_p} \right)$$
[15.]

$$B' = \left(c_1 \times \frac{D\max_p - D_p}{D_p}, 0 \right) \qquad [16.]$$

$$M_i' = \left(c_1 \times \frac{Di_p - D_p}{D_p}, c_2 \times \frac{Ci_p - C_p}{C_p} \right) \qquad [17.]$$

4. Conclusion and future research

New Industrial Architecture organization based on cooperation highlight the problem of flow control and management by independent decision centers. Decision distribution along the supply chain needs coherence between partners in order to achieve better productivity and greater reactivity.

In this article, we have studied order negotiation between a client-manufacturer and its providers. In the case where the provider is unable to satisfy all the constraints of an order, each member of the IA should use its own external subcontractors or propose a modification of the delivery delay. Hence, different scenarios could be considered by relaxing some order constraints. Such an analysis will define new cost and delay to be used in a new proposal. A method based on multi-criteria analysis has been proposed to evaluate the best scenario.

In further research, we will introduce the quantity as a decision criterion. Indeed, a company can supply a part of the command in time and deliver the rest later. Other criteria, related to the level of quality to be respected by subcontractors, should also be considered in the decision.

Moreover, we will develop an algorithm taking into account several parallel negotiations with several clients. This is important to be able to apply our methods in a real industrial environment.

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