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Cooperative subcontracting relationship within a project supply chain: A simulation approach

Nicolas Parrod [a,b,e], Caroline Thierry [a,c,*], Hélène Fargier [d], Jean Bernard Cavaille [a,b]

[a] ONERA-DCSD, 2 Av. Edouard Belin, BP 4025, 31055 Toulouse Cedex 04, France
[b] ENSAE, 10 Av. Edouard Belin, BP 4032, 31055 Toulouse Cedex 04, France
[c] Université Toulouse II Le Mirail, Département de mathématiques et informatique, 5 allées Antonio Machado, 31058 Toulouse Cedex, France
[d] IRIT, 118 route de Narbonne, 31062 Toulouse Cedex 4, France
[e] Clairis technologie, 7 avenue Albert Durand, 31703 BLAGNAC, France

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Abstract

The management of supply chains is of the highest interest from both the industrial and the academic point of view since several years. The emerging notion of ''Project supply chain'' is less studied but also very appealing. In this paper, we study the interaction of different agents within this kind of supply chain. The major issue of such an interaction is the degree of cooperation between the agent and the capacity of each of them to forecast the impact of their behaviour. A simulation tool which studies the relationship between a principal contractor (in charge of project management) and a subcontractor (dealing with the management of a scarce resource) is proposed here, that aim at enabling both actors to understand the impact of their behaviour on risks and delivery dates.

Keywords: Performance measurement; Co-operative process; Project scheduling; Supply chain management; Externalisation of activity

1. Introduction

It is more and more common for industry to adopt project-based organisation, beginning right at production level. Facing a highly competitive market-place, companies must focus on and be specialists in their core business. Therefore, the number of suppliers and subcontractors is increasing and the realisation of some strategic tasks can be under the responsibility of specialised subcontractors. The project management thus has to face an increasing number of upstream and downstream constraints, which can be compared to the problem of integration in a supply chain – making the notion of the ''project supply chain'' a particularly promising one.

* Corresponding author. Address: Université Toulouse II Le Mirail, Département de mathématiques et informatique, 5 allées Antonio Machado, 31058 Toulouse Cedex, France.
E-mail address: thierry@univ-tlse2.fr (C. Thierry).

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The actors in the supply chain, and more particularly the project managers, must therefore aim at creating reliable partnerships, ideally within a strongly co-operative relationship. Suppliers and subcontractors should then be motivated by a mutual interest in such a co-operative attitude. Unfortunately, the project decision makers often lack tangible arguments. Our proposition is to build a simulator specifically designed for the testing and evaluation of different decision-making strategies within the project supply chain – and especially of co-operative ones.

Our case study contains several engineering projects in aeronautics. As such, they rely on the construction and testing of models. The test protocols are carried out in an external wind tunnel that usually caters for several customers. The quality and the flexibility of the relationship between the principal contractor entity (the project management) and the subcontractor is thus crucial both for the project and the resource. The key point of this relationship is the reservation of the resource. The goal of the subcontractor is to optimise the occupation of the resource. On the other hand, the principal (project) entity cannot start the strategic task before the end of the preceding ones – the problem being that projects are often not so precise in terms of deadlines and can accumulate delays. The reservation of the resource is thus a dynamic process in which the provisional plan for both the resource and the project is subject to changes.

In the present paper, we focus on a particular part of a project supply chain, namely the relationship between the principal contractor entity and one of its subcontractors. Once again, the idea is to simulate and measure the performances of more and less co-operative strategies of the two actors. The next section proposes a brief ''state of the art'' and analyses the worth of the different propositions to address our problem. Afterwards, we present the guidelines of our approach (Section 3) and we detail the process under study (Section 4). Section 5 is then devoted to the simulator that has been built. An example that highlights the potential of this tool is presented in Section 6.

2. State of the art

The literature on the management of product-oriented (as opposed to project-oriented) supply chains is plethoric. Surveys include [6,29,17,7,5] for general surveys; see [2,13,10] for surveys on the measurement of performance in product-oriented supply chains. The reader interested in the co-operative processes within a product supply chain should also consult [31,12]. Game theory and reinforcement learning also provide new but appealing paradigms that apply as soon as the performance of the chain is precise enough to be characterized in terms of payoffs. It is namely the case for the optimisation of individual trading policies of agents, as shown by recent TAC-SMC trading agent competitions[1] [1]. Game theory moreover provides the foundations of rigorous analysis of the global supply chains for the search for optimal equilibrium [3].

The project supply chain has not been widely studied in project management except in the sector of construction. For instance, [32] analyses the construction supply chain as a make-to-order (product) supply chain. They also show that the project supply chains are very particular: their characteristic is to be temporary. As a matter of fact, the one of the most often referred definition for the term ''project'' is the following one by the Project Management Institute: ''A project is a temporary endeavour undertaken to create a unique product or service'' [25]. Due to complexity, most construction research have used qualitative analysis based on quantitative models and concepts drawn from manufacturing management and operation management literature. For instance [20,21,32,23] devote their studies to the qualitative modelling of construction supply chains. [20,22] are also interested in the information flow within the supply chain – and more particularly in the automatic protocol of data transmission. As far as the product-oriented supply chain is concerned (i.e. [12]), ''integration of the supply chain, and thus, collaboration within the supply chain, has been one of the main focus areas in Supply Chain Management (SCM) literature'' [26]. Integration and collaboration is obviously also crucial in project supply chains.

The other domains of research related to our study include project planning and scheduling: project scheduling in make-to-order organisations, deterministic scheduling with resource constraints, Resource Constrained Project Scheduling Problem (RCPSP), etc. Numerous methods have been proposed – the reader

[1] See also http://www.sics.se/tac.

should refer to surveys and books of reference, e.g. [33,15,14,19]). The latter reference proposes a state of the art on project scheduling with time windows and scarce resources, including exact methods, heuristic methods and optimisation criteria drawn from real applications.

Furthermore, [11] shows that the stability and strength of a solution are central to project scheduling: attention has been drawn to a recent reference that has set the dynamic of a rolling horizon as a central problem. Numerous approaches which have been proposed in particular for project scheduling under uncertainty have been also studied: probabilistic PERT [28], probabilistic GERT [18], fuzzy PERT [27,9,8].

The literature on project scheduling under resource constraint, and especially the papers devoted to the management of critical resources are thus very relevant for our concerns. On the other hand, the problem of co-operation in the project supply chain appears as one of the most important factors on the chain influencing performance – but is, paradoxically, seldom studied.

3. A new approach for co-operation analysis in project supply chain

The concept of supply chain has received a lot of attention from both practitioners and academics. Widely used, it may concern the product as well as the company itself. However it has seldom been applied to project management – as shown in Section 2, the "project supply chain" is an emerging concept (see Fig. 1).

The notion of project supply chain has been defined by [26] as " the global network used to deliver a project from raw materials to the final project customer through an engineered flow of information and physical distribution". A project supply chain thus involves the principal contractor who is in charge of the management of the project, the clients and their own clients, the suppliers and their own suppliers and subcontractors, the subcontractor and their own subcontractors (cf. Fig. 1).

In this study we focus on a subcontracting relationship between a principal in charge of a project and a subcontractor handling a strategic specialised resource. The resource is also used by other clients and thus belongs to several supply chains. As a consequence, the subcontractor manages several significant relationships (cf. Fig. 2).

In this paper, we are interested in providing a decision support tool for the design of co-operative policies between two actors of a project supply chain, the notion of policy of cooperation encompassing:

- the content of the exchange or the sharing between the actors: data, data processing,
- the process used by the decision-makers to do the data processing,
- the process used by the decision-makers to exchange and share the data: occasional exchange, permanent sharing, or sequenced and formalised exchange.

The targeted users of the tool are a project manager and a decision maker in charge of the subcontractor resource. The aim of this tool is to enable a better communication and thus cooperation between these two

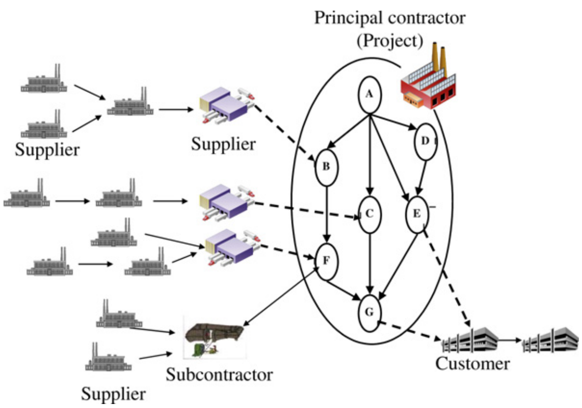

Fig. 1. The project supply chain.

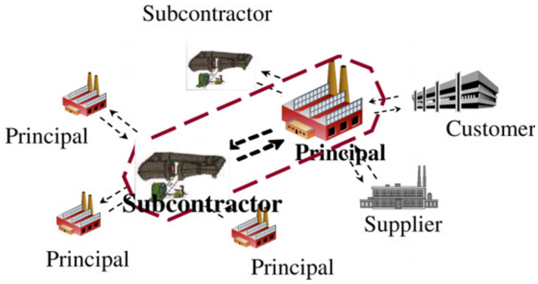

Fig. 2. The principal/subcontractor relationship and the external actors.

actors of the principal/subcontractor relationship when conjointly working in a cooperative process. In practice, the process we focus on is the planning and the updating of time window on the strategic resource.

In Supply Chain Management, we distinguish different types of approaches. On the one hand, analytic and generative approaches that aim at automatically determining the (optimal) values of decision variables. This class includes constraint-based and/or game theoretical approaches – see e.g. [34]. The system then aims at providing the users with a solution that should be immediately operational. On the other hand, evaluative approaches rather propose an evaluation of the different pro and cons of solutions designed by the decision makers themselves – the role of the machine is to help them evaluate their performances.

In this study, we are interested in enhancing the policies of co-operation of the two actors of a supplier/customer relationship. As said previously, the task we are focusing on is a time window reservation process, which is dynamic in essence. The difficulty with this kind of process is that its quality cannot be entirely modelled in terms of additive payoffs or quantifiable performance indicators: for instance the trace of the reservation process itself is an information of high interest for the actors. The evaluation should also include the development of indicators that figure the risk factor encountered by the different strategies (e.g. the stability of the reservation). In this kind of application, the indicators are temporal rather than monetary. Moreover, they should be measured not only at the end of the initial reservation process but also after each update of the plans.

Hence, the policies cannot be automatically generated from a model of the relationships. This would presuppose the definition of an explicit criterion of optimisation that would govern the relationship. Since the evaluation criteria are difficult to define *a priori* for the decision makers, we prefer to propose, in a first step, an approach by simulation that evaluates the performance of the strategies of co-operation chosen by the actors of the principal/subcontractor relationship. One of the main advantages of an approach by simulation is that it keeps track of the successive plans. Together with performance indicators, these plans form a base of convincing examples for discussion between the partners.

That is why a tool that simulates the dynamics of the relationship between a project and a subcontractor (resource) entity has been specified and implemented. The prototype is based on a discrete event simulation. The idea is to track the evolution of the principal/subcontractor relationship over a given horizon. This tool provides both actors with a means of testing their policies of co-operation in the context of the time window reservation process. The first prototype was principally aimed at testing the feasibility of the approach. That is why it relies on algorithms that are very close to the one used by project managers when using MS-project and similar tools (see [30] for more details). The prototype should then integrate better methods of planning and more advanced models of behaviour.

Before entering the details of the simulator in Sections 5 and 6, let us first present in more details an analysis of the reservation process targeted by our study.

4. The process of time window reservation

The main activity of the principal/subcontractor relationship being studied is the reservation of the resource and more precisely the definition and the updating of the time window during which the principal will use the resource. The following characterization of the process is based on an analysis of different industrials cases in the field of aeronautics and space involving companies like Airbus or ONERA – see [24] for more details.

4.1. The process of resource reservation – initial phase

When planning a testing task, the project manager mainly rely on the current state of the activities of the project, and especially on the current plan. He specifies the demand of the project on this basis before contacting the subcontractor. A more or less formalised dialogue is then initiated between the two actors. Each of them has some knowledge of the needs, capabilities and communication strategies of the partner. The process is eventually concluded by the reservation of a time window on one of the subcontractor's resources. Each agent then integrates the time window in his own plan, which is modified accordingly.

Fig. 3 depicts this initial reservation process. P^i_{t-} denotes the plan of agent i valid just before the date of the negotiation (say, date t). A time window is conjointly chosen by the two agents, on the basis of their own needs and capacities (typically the P^i_{t-}). Each agent then updates his own plan so as to take this time window into account, thus creating a plan P^i_{t+}.

4.2. The updating process

In this kind of medium-term project, the reservation is only provisional and set far before the actual realisation of the task (several months before). During this period, perturbations occur that can have a severe impact on the activities of the actors and that can invalidate the time window originally planned. The time window should then be brought up to date through a process of updating that runs until the final execution of the task (cf. Fig. 4): both actors interact during this period in order to maintain a valid time window. If needed, the reservation can be updated and the plan is modified accordingly.

The updating process can be viewed as a series of reservation processes. The maintaining of the time window takes place periodically (depending on the re-planning period of the actors) or on demand, when significant factors impact the resource or on the project.

4.3. Impact of the degree of cooperation

Our study of the different processes (time window reservation and updating) has highlighted the strategic importance of the definition of the time window. The impact is obvious for the principal: the satisfaction of the due date directly depends on the availability of the resource. For the subcontractor, the performance of these processes is determined by two antagonistic factors: the occupation of the resource and obviously the satisfaction of the customers. As noticed by [16], the degree of co-operation in the principal/subcontractor relationship is directly related to the quality of the information transmitted by the actors, and obviously depends on how that information is used on both sides. For example, in one of the instances of our case study, the project was accumulating so much lateness due to unavailability of the resource that an external institutional actor was called in to impose a solution. The subcontractor was then forced to provide the time window necessary

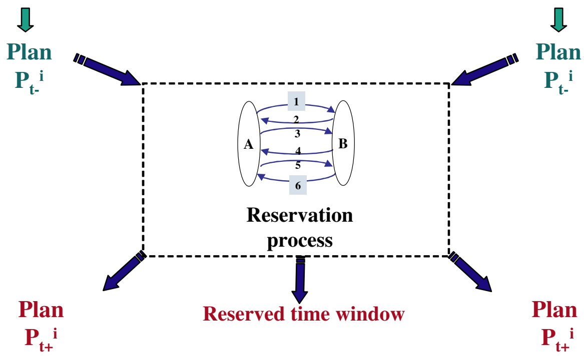

Fig. 3. The time window reservation process.

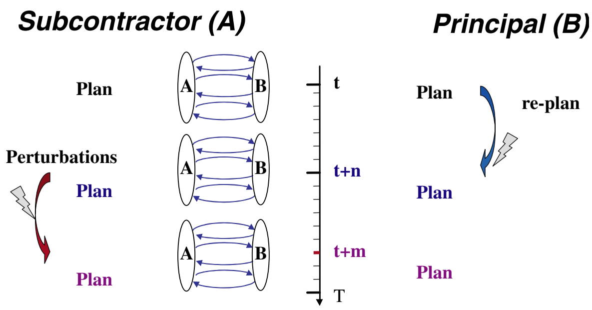

Fig. 4. The updating process.

to the project, thus penalising other clients. A more co-operative behaviour from the resource management would have led to a much better solution for all the customers.

5. The simulation tool

The simulation tool is based on a discrete event simulation. The idea is to track the evolution of the principal/subcontractor relationship over a given horizon. The tool is mainly designed for a project manager (of the principal) who wants to convince one of the suppliers of the project to adopt co-operative behaviour. The tool thus provides the pair of actors with a means of jointly testing their policies of co-operation. It relies on a triple model: a model of the principal (project), a model of the subcontractor (resource) and a model of the relationship that frames their interaction – namely, a model of the reservation and the updating processes (cf. Fig. 5). The parameters of each of the three components are to be set by the user (the project manager) and drive the simulation.

Since the project manager does generally not have a precise information about the subcontractor, most of the time for confidentiality reasons, a detailed model of this actor is thus unfeasible. That is why the system requires only a macroscopic model of the subcontractor. Concerning the second component, the principal, a more detailed model is required. Let us now present the three components in more detail.

5.1. The relationship model (principal (project)/subcontractor (resource) relationship)

This model formalises the initial reservation process and the dynamic process of maintaining the time window. It is characterised by the balance of power between the two actors.

5.1.1. The reservation process

Understood as a function, the model inputs time windows (the propositions made by the two actors) and outputs a final time window or "reserved window". Firstly, each actor provides the other with initial information:

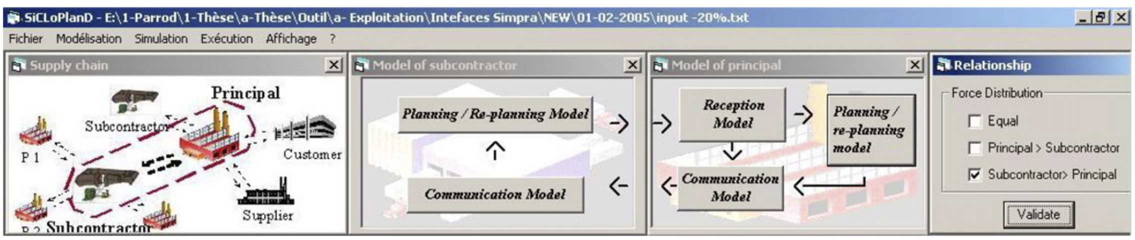

Fig. 5. The main organisation scheme of the tool.

– the subcontractor provides the free time windows for the resource,
– the project entity provides either a date of earliest starting time, or the direct proposition of a time window.

A time window is then sought, which is in accordance with these initial requirements (cf. Sections 5.2 and 5.3). If the requirements are incompatible, each actor will then apply his (more or less) co-operative behaviour, in order to make a new and more permissible proposition (for instance, the actors relax some of their constraints). Thus the new time window(s) is (are) transmitted. The compatibility of the new propositions is then checked for (cf. Section 4.2 and Section 5.3.1). If no admissible solution is reached, the model of the balance of power is used: it designates the dominant actor and the last proposition of this actor is selected. This rule thus enforces the decision, as would the dominant actor do in reality. The decision is obviously made according to the propositions brought forward at the second step (the more flexible ones). This rule of conclusion ensures the convergence of the reservation process on a "joint time window" which is more or less satisfying for the actors (i.e. the resource can be considered free at infinite time and the due date constraint can be relaxed). The degree of satisfaction of an actor depends on his relative position in the balance of power.

5.1.2. The dynamic process (updating the time window)

Through a dynamic process, we designate the joint action for both parts that ensures the maintaining of the reserved time window from the end of the phase of reservation to the actual execution of the task on the resource. It ensures the concordance between different activities of the actors and the time window. Technically, this process is a series of small reservation processes. The simulator executes the series following a next event method.

The different types of events that can be posted on the list are:

– The joint checking of the reservation on a periodical basis: the actors have conjointly defined a list of precise dates. When such an event occurs, the actors must check that the reserved time window is not in conflict with other constraints of their project/resource. This type of synchronisation corresponds to a classical method of project maintenance. This process concludes by the confirmation of the time window, or by its invalidation.
– The periodic checking of the project: the periodicity to be followed for the revision of the project.
– The periodic checking of the resource: the periodicity to be followed for the revision of the resource plan.
– External event: the simulator allows for the possible occurrence of major hazardous events impacting on the project plan or the resource plan (see Section 5.1.3).

The user should set the three checking periods (joint checking, project checking, resource checking) and define the values of the parameters of the generator of hazardous events as well. The treatment of any of these events can lead to a new project plan or a new resource plan, and possibly make the current joint time window inadequate. If this is the case, a process of time window reservation is ran as described in Section 5.1.1. A series of reservation processes is thus executed over the simulation horizon.

5.1.3. Modelling hazardous events

Hazardous events are randomly generated by the system, depending on parameters fixed by the user of the simulator. Four kinds of hazardous events can affect the data pertaining to the current plan of the project, namely:

– modification of the duration of some tasks (shortened or lengthened),
– modification of some due date tasks (shortened or lengthened),
– modification of some release date tasks (shortened or lengthened),
– modification of the starting time of other tasks, other than the one planned on the resources.

The selection of data that will by modified by a hazardous event is done randomly (based on a uniform distribution). Once the data is chosen, the amplitude of the modification is computed. It depends on the distance between the instant of occurrence (of the event) and the starting time of the task impacted by the event. The closer the task, the less important the modification of its data is. This approach suits the modelling of absorption of uncertainties that occurs when the ending time of a task draws closer.

5.2. The model of the project entity

The model of the project entity relies (for the principal) on three sub models (cf. Fig. 6):

– The project planning/re-planning model.
– The model of information reception (interpretation of the information provided by the subcontractor entity).
– The communication model.

5.2.1. The planning/re-planning model

The project manager's task is very close to the problem of *Project Scheduling With Time Windows* ([4,30]). The project is defined by I tasks. Each task i is characterized by a starting time t_i, a duration d_i, and a release date α_i. Parameter ω_i corresponds to the time that must elapse between the beginning of T_j and the beginning of T_i. It can also have a due date: its ending time must occur before a date β_i. If no actual due date exists, let us set $\beta_i = +\infty$. The planning activity consists of a choice of a value for each t_i. It must meet some constraints, namely: precedence constraints (1), release date constraints (2), due date constraints (3) and resource constraints (4) requiring that the entire execution of some tasks take place within predefined time intervals (the possible free time windows). Let m be the number of possible free time windows $y[Ep_y^t, Ep_y^t]$ computed at time t. Each time window is characterised by its beginning denoted Ep_x^t and its end denoted Sp_x^t:

$$\begin{cases} t_i - t_j \geqslant \omega_{ji} & \text{(a)} \\ t_i \geqslant \alpha_i & \text{(b)} \\ t_i + d_i \leqslant \beta_i & \text{(c)} \\ t_i \in \bigcup_{y\in[1;m]} [Ep_y^t; Sp_y^t - d_i] \text{ if } i \text{ is performed on the subcontractor resource} & \text{(d)} \end{cases} \quad (1)$$

$\forall$i,j $\in$ (1, ..., I)

Two different planning policies can be used for the setting of t_i:

– earliest starting time,
– latest starting time.

If a plan satisfying all the constraints exists, say a plan P_t^-, a time window CDO_i^t is computed (functions g and g') that corresponds to the occupation of the resource by task i of the project in that plan t. This time window is characterised by its beginning denoted EDO_i^t and its end denoted $SDO_i^t (CDO_i^t = [EDO_i^t, SDO_i^t])$:

$$EDO_i^{t_{n+1}} = g(t_i, \{[Ep_y, Sp_y]\}_{y\in[1,m]}) \quad \text{and} \quad SDO_i^{t_{n+1}} = g'(t_i, \{[Ep_y, Sp_y^- d_i]\}_{y\in[1,m]})$$

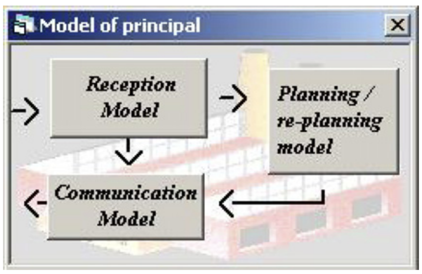

Fig. 6. The principal contractor (project) entity model.

If no satisfying plan exists (all constraints cannot be met simultaneously), different scenarios of constraint relaxation or "relaxation strategies" can be simulated [30]. A relaxation strategy is a list that indicates how the constraints pertaining to the project should be relaxed: the strategy ranks the constraints from the least important to the most important (these should not be relaxed until all other relaxation has been tried). Typically, the project manager can shorten a duration, postpone a due date or obtain earliest release dates; the model excludes the relaxation of the resource constraints (type (4)).

5.2.2. The reception model

When receiving new information, typically the proposing of time windows (transmitted time windows), the project manager does not accept it as such – the information is usually interpreted. For instance, when the subcontractor is known to accumulate important slacks, the manager systematically extrapolates larger free time windows than the one provided. That is why a reception model has been defined, that formalises how the project manager transforms the data (namely, the free time windows) transmitted by the subcontractor entity. The transformation depends on the knowledge the project manager has on the subcontractor behaviour.

Let n be the number of different free time windows $x[A_x^t, B_x^t]$ transmitted by the subcontractor entity at time t. Each time window is characterised by its beginning denoted A_x^t and its end denoted B_x^t. The raw information received by the project is a disjunction of intervals (of free time windows): $C^t = \bigcup_{x\in[1,n]}[A_x^t, B_x^t]$.

The ≪ possible time windows ≫ Cp_i^t which are considered for the planning process are computed (functions f and f') at time t according to the transmitted time windows by the subcontractor. Let m be the number of possible free time windows $y[Ep_y^t, Ep_y^t]$ computed at time t. Each possible time window is characterised by its beginning denoted Ep_x^t and its end denoted Sp_x^t.

$$Cp^t = \bigcup_y \in [1,m][Ep_y^t, Sp_y^t] \text{ with :}$$
$$Ep_y^t = f(A_1^t, \ldots, A_n^t, B_1^t, \ldots, B_n^t)$$
$$Sp_y^t = f'(A_1^t, \ldots, A_n^t, B_1^t, \ldots, B_n^t)$$

The reception policy is then characterised by a ratio that defines the free time windows enlargement (or reduction). If there are some windows overlaps after the enlargement, they are grouped together. For instance, a project manager who thinks that the subcontractor is pessimistic will systematically enlarge the free time windows. On the contrary, if the subcontractor is generally too optimistic, they will be reduced.

5.2.3. The communication model

At the end of the planning process, a time window (or "planned window") is planned for the execution of the task on the subcontracted resource– it forms the basis of the proposition transmitted by the project entity to the subcontractor entity. However, the project manager does not necessarily transmit the planned window as such. For instance, the window is often enlarged in order to create room for negotiation. The importance of the changes can often depend on the trust accorded to the subcontractor entity by the project entity. The project entity thus computes (functions h and h') a "required window" on the basis of the planned window and transmits it to the other entity.

$$Ed_i^t = h(EDO_i^t) \quad \text{and} \quad Sd_i^t = h'(SDO_i^t).$$

Like the reception policy, the communication policy is characterised by a ratio that defines how the planned time window is modified before its transmission as a required planned window.

5.3. The subcontractor (resource) entity model

The model of the subcontractor is established by the main user of the system, typically the project manager. Since the principal entity has only a macroscopic knowledge of the subcontractor entity, the model of the latter entity is less detailed (cf. Fig. 7). It consists of three sub models:

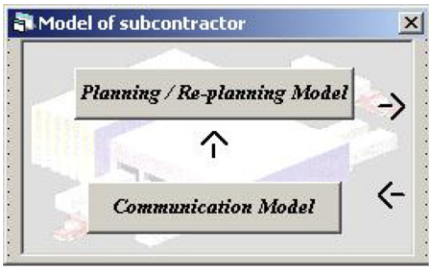

Fig. 7. The subcontractor entity model.

– The macroscopic model of the resource planning (essentially, the free time windows and the relaxation strategies of the subcontractor).
– A model of communication.
– A model of the hazardous events.

5.3.1. The model of the resource planning process

Contrarily to the planning process of the project, that one of the resource is beyond the focus of the simulator. The user simply defines a list of time windows in which the resource is supposed to be reserved by other clients – i.e. he defines the initial plan of the resource.

When the simulation begins, free time windows are computed on the basis of this initial resource occupation plan. Small windows are merged (an action commonly carried out by resource managers in order to protect the confidentiality of the other clients). Depending on the proposition made by the principal, the subcontractor entity then selects some free time windows that are in accordance with that proposition – this forms the basis of the information that will be transmitted to the project entity.

Several predefined planning policies have been implemented for the subcontractor component. The so-called optimistic behaviour leads to a shrinkage of the free time windows, whereas the pessimistic behaviour results in an enlargement of these time windows. The planning policies can thus be characterised by a percentage of reduction (or enlargement) of the time windows. This reduction (or augmentation) is spread over the simulation horizon in such a way that the closer the execution of the subcontracted activity, the less important the modification.

If no solution is found after this first exchange of information, the relaxation strategy of the subcontractor is to be applied: it also consists of an enlargement through the addition of some time windows and the broadening of the existing one. Once again, the ratio of relaxation is determined by the user of the simulator when setting the parameters of the model.

5.3.2. The communication model

The duration of the window transmitted by the subcontractor entity does not necessarily exactly match that of the window computed by the planning model. The duration of the window transmitted to the other entity can be shortened or lengthened, depending on the degree of trust that the subcontractor entity has in the principal. We suppose here that the behaviour of the subcontractor does not change over time i.e. that the windows transmitted to the project entity are systematically shortened, or systematically lengthened, or are never changed. The parameterisation of the communication policy thus consists in setting this degree of modification.

5.3.3. The model of the hazardous event

The last parameters that the user should set are those associated with the hazardous event that can impact the tasks that other customers are executing on the resource (typically, the tardiness accumulated by another customer). The occurrence of such an event leads to a modification of the free time windows: they can disappear or appear, their duration can be modified (shortened or lengthened), their starting time can be postponed

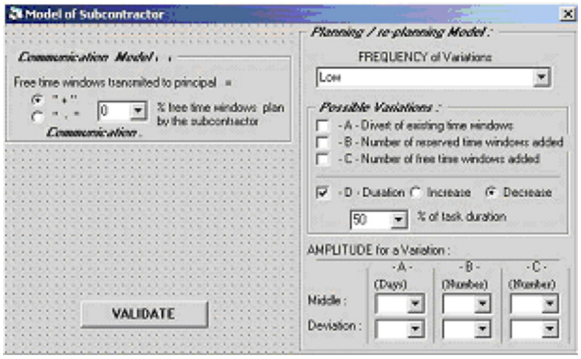

Fig. 8. Setting the parameters of the model of the subcontractor entity model.

or moved forward. These modifications are determined by random modules that select them from a predefined list. The type and amplitude of the possible modifications is defined before beginning the simulation, as shown in Fig. 8.

6. An illustration of the use of the simulator

As a case study, we have studied industrial processes involving a resource centre specialised in aerodynamics: ONERA-Fauga is a specialised centre in aerodynamic testing facilities; the central resource is a compressed air system and an array of industrial wind tunnels. Different projects plan their aerodynamic tests in this centre each year. Many principals are using this strategic resource in their projects for test and validation of aerodynamic models. The principal project analysed for the case study is a research project in charge of the design of a wire-driven manipulator. This case study is characterised by a very unbalanced principal/subcontractor relationship (characterised by the subcontractor's strong domination).

Let us now illustrate how a decision maker (in charge of a project belonging to the principal) can use this tool – for instance, to convince the resource manager that the modifications of the reserved window impact not only on the project but also on the performance of the resource management.

6.1. The situation

In the situation being considered, the project entity has a very collaborative behaviour: the tasks are planned at their earliest starting time and no uncertain event impacts the reservation process.

The project entity uses the earliest starting time planning policy; it is supposed to trust the subcontractor entity and does not modify the information received in any way.

The relaxation strategies of this entity which have been considered are as follows:

Policy 1

– The resource constraints are never relaxed.

– The duration of the task which is performed on the subcontracted resource is first reduced (the amount of the reduction depends on the type of the activity and is given *a priori*).

– Then, if no solution is found, the release dates are put forward (the amount of the reduction depends on the possible opening of negotiations with the suppliers and on the date at which the planning process is run.

– Finally the due date constraint can be postponed (the amount of the postponement depends on the possible opening of negotiations with the customer and on the date of the planning process).

Policy 2

– The resource constraints are never relaxed.
– The release dates are first put forward (the amount of the reduction depends on the possible opening of negotiations with the suppliers and on the date of the planning process).
– Then if no solution is found, the duration of the task which is performed on the subcontracted resource is reduced (the amount of the reduction depends on the type of the activity and is given *a priori*).
– Finally the due date constraint can be postponed (the amount of the postponement depends on the possible opening of negotiations with the customer and on the date of the planning process).

It is considered that the subcontractor entity displays optimistic behaviour: the duration of the tasks present on the resource plan are thus sub-estimated. The aim of the simulation is to check whether this optimism is a good strategy in light of the very co-operative behaviour of the principal. So, over time, the free time windows that are transmitted to the project entity are narrower than the ones initially presented (Fig. 9). This is due to the fact that the actual execution of the tasks on the resource needs more time than initially planned by the subcontractor entity

On the other hand, the subcontractor entity does not modify the available information when transmitting it to the project entity (the free time windows of the resource are transmitted without any modifications).

Finally, the relationship is characterised by the dominant position of the subcontractor.

6.2. Simulations

The simulations are performed from 1 year before the planned starting time of the task which uses the resource of the subcontractor. The duration of the project is 120 days at the beginning of the simulation process. Moreover, two time periods are defined for the relaxation strategies: during period P1 constraint relaxation is easier than during period P2.

More or less optimistic behaviours of the subcontractor entity have been tested (the duration of the tasks planned on the resource by other customers are shortened in a proportion that varies from −20% to −60%).

The project characteristics are depicted in Table 1.

The resource characteristics as known from project point of view are depicted in Table 2.

The results are depicted in Table 3. The performance indicators provided by the system are the tardiness of the project (customer satisfaction), the effort made by the project entity when relaxing some release or due

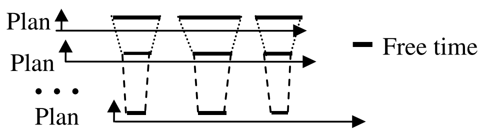

Fig. 9. The dynamics of the resource plans over time: the free time windows are diminishing.

Table 1
Project characteristics

Project duration (months)	Slack of the project[a]	Number of release dates	Number of due dates
27	9	2	1

[a] Minimum free slack of the project tasks (considering the due date of the last task of the project).

Table 2
Resources characteristics

Number of free time windows	Maximum hardness[a] of a resource at the beginning of the simulation
4	0.9 (−20%); 0.6 (−50%); 0.5 (−60%)

[a] Quantity (expressed as a duration) of the resource needed by the project, divided by the resource freedom during the project duration (time windows).

Table 3
The performance indicators: Policy 1

	20%	50%	60%
Stability			
# of modifications to the reservation	3	5	5
Amplitude of the modification (in days)	1	79	78
(max, average, min)	0	16	16
	1	1	1
# of days without modification (max, average, min)	180	215	215
	124	136	136
	89	60	60
Delay (due date violation)			
Tardiness of the project (in days)	–36	46	45
Effort			
Maximum effort (in days)	0	5	5

dates (customer satisfaction), and the stability of the reservation (since it influences the subcontractor resource planning process).

The evaluation of the performance indicators shows that the hazardous have a severe impact on the principal/subcontractor relationship when the subcontractor entity has an over-optimistic behaviour.

The graphical interface of the system (Figs. 10–13) can provides the user with a more detailed description of the situation that the global stability indicator (e.g. the evolution of the free time windows and the evolution of the reservation). It is for instance possible for the user to follow the evolution of the transmitted and reserved time windows over the time.

In the same context (that of an over-optimistic subcontractor in the dominant position), the project manager can also test and evaluate the possible behaviours of its own entity, e.g. its relaxation strategy. For instance, Policy 2 has been simulated as a possible improvement in the (−50%) and (−60%) cases (see the results on Table 4).

As a result, Policy 2 solves the problem of delay in the (−50%) and (−60%) cases; nevertheless, the effort (release date relaxation) is very high compared to the (−20%) case with Policy 1. Moreover, this policy does not lead to satisfactory results in the (−20%) case.

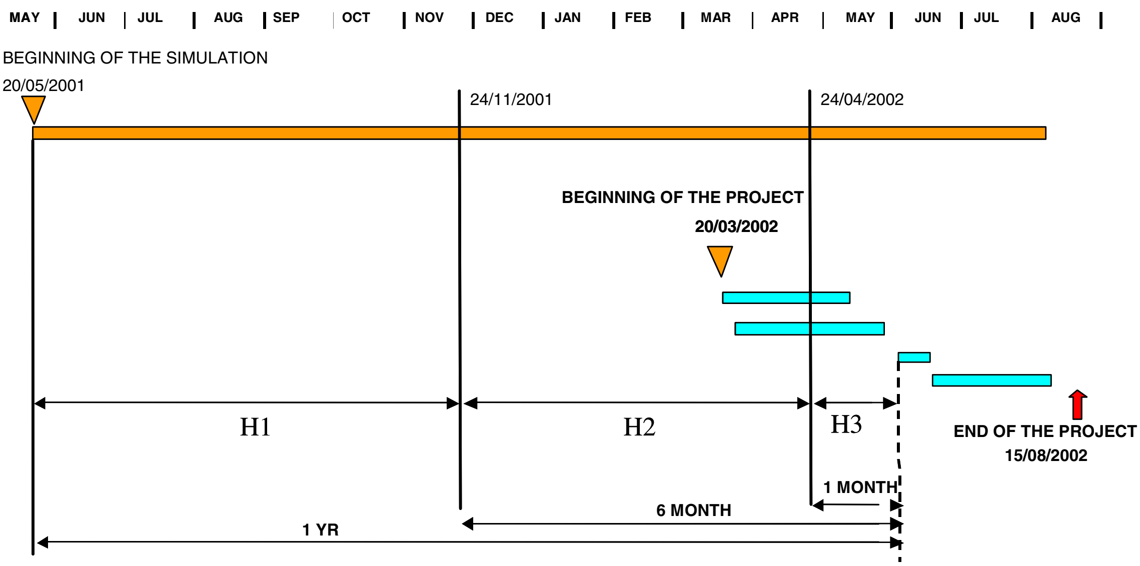

Fig. 10. Simulation and project durations.

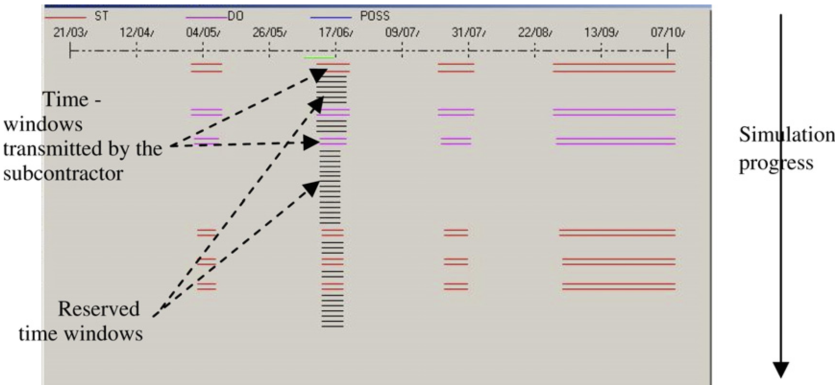

Fig. 11. Impact of the degree of optimism of the subcontractor entity on the reservation (20%).

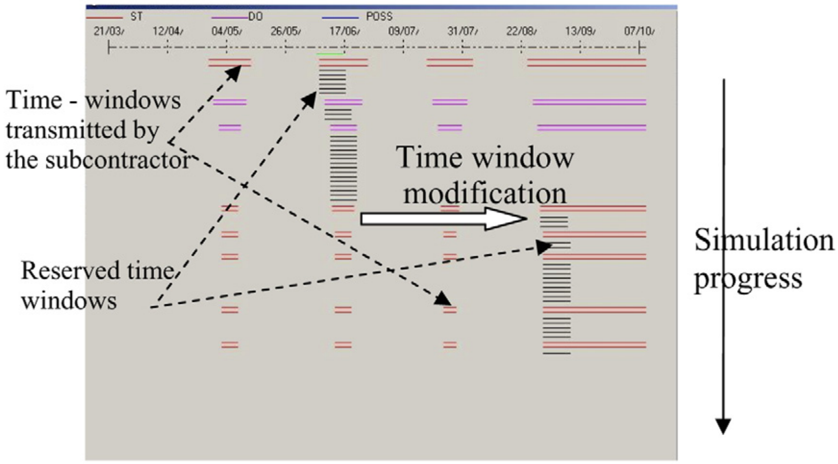

Fig. 12. Impact of the degree of optimism of the subcontractor entity on the reservation (60%).

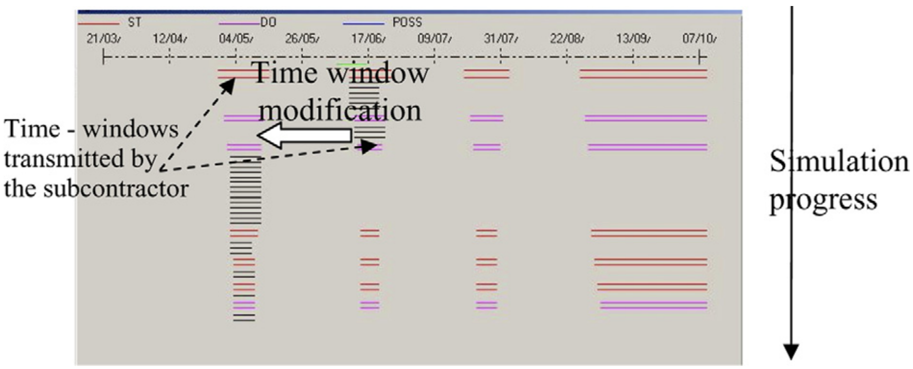

Fig. 13. Impact of the degree of optimism of the subcontractor entity on the reservation (50%).

The efficiency of the relaxation strategy of the principal is very dependent on the behaviour of the subcontractor. The simulation shows that if the principal contractor expects an optimistic behaviour from the subcontractor, he will use a given fitted relaxation strategy. However this choice will be very disadvantageous if the subcontractor information is reliable. But the principal can rely on the simulation to convince the subcon-

Table 4
The performance indicators: Policy 2

	−20%	−50%	−60%
Stability			
# of modifications of the reservation	3	4	4
Amplitude of the changes (in days) (max, average, min)	40	39	41
	13	10	11
	1	1	1
# of days without changes (max, average, min)	180	120	120
	138	94	61
	82	60	30
Delay			
Tardiness of the project (in days)	−79	−76	−76
Effort			
Maximum effort (in days)	36	35	36

tractor that an improvement in the process performance requires co-operation within the principal/subcontractor relationship on the processing (behaviour) themselves. Indeed, in this case, local improvements in the behaviours of the project and the resource are not sufficient, neither are extra-exchanges of data.

7. Conclusion

Although the policies of co-operation within the principal/subcontractor relationship have been identified as a crucial parameter in the performance of project supply chains, they are seldom studied. In this paper, the analysis of a case study has allowed the identification of the main industrial requirements, and highlighted the interest of tools capable of evaluating the impact of different co-operative behaviours, namely in a principal/subcontractor relationship involving a principal (project) entity and a subcontractor managing a strategic resource.

Our idea was to provide the project manager with a simulator enabling the test of different policies of co-operation. We have thus presented the models on which the simulator is based (the model of the principal entity, the model of the subcontractor entity and the model of the relationship). Finally, we have shown how the system can be used by a project manager in order to convince a strategic subcontractor of the worth of adopting co-operative processes is terms of exchanges on the processing themselves.

The current simulator is restricted to the most standard planning policies used in project management. Further enhancements include the development of more sophisticated policies (cf. [19] for instance). In the same way, the transmission model should allow the use of flexible time windows (the project could then transmit different required time windows together with preferences).

Nowadays, the subcontractor model is simplified. When the subcontractor is convinced of the interest of such a simulation tool to design co-operation policies, he will be part of the modelling process itself and the model will thus be improved.

Finally, we aim at equipping the prototype with a complete methodological kit, including a full base of scenarios and experimental plans.

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