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A MULTI CRITERIA ALLOCATION MODEL FOR NETWORKS OF FIRMS

A. Hammami, P. Burlat, J. P. Campagne

Ecole Nationale Supérieure des Mines de Saint Etienne
158 cours Fauriel, F 42023 Saint Etienne Cedex

Abstract: This paper exposes an order allocation model for networks of firms. We assume that networks of firms need e-manufacturing tools to co-ordinate fairly their collaborative activities, and that these tools must both prevent opportunism and enable learning processes within networks. The tool we present aims to calculate satisfying routes for each order, according to antagonist criteria such as resource occupation and knowledge acquisition. *Copyright © 2002 IFAC*

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1. NETWORKS OF FIRMS

1.1 The emergence of networks.

In a context of deep transformation of the relations between firms, a new organizational form recently emerged : the network. We are interested here with "networks of firms", i.e. virtual industrial structures linked with horizontal agreements (unlike the "firm network" managed by a mainspring firm). Those networks are made of independent firms virtually linked together to achieve a goal. Different types of network can be identified according to the nature of the relations that federate their members, for example (Poulin et al., 1994) :

- Purchasing network: economies of scale for purchases and supplies,
- Production network: joint production,
- New market oriented network: sharing new business services to increase turn over,
- Quality certification network: sharing quality experts to obtain ISO 9000 certification,
- Data exchange standardization network: constructing and adopting common norms to exchange data.

It is noted that these types of network are not mutually exclusive. For example, a group may correspond at the same time to a production network and a purchasing network.

1.2 Co-ordination inside networks.

Inside networks, co-ordination is not carried out through a hierarchical organisation (as in the firm) or through price mechanism (as on the market), but through co-operation and interaction between firms within the network, and more exactly, by mutual adjustment and learning processes

In that context, our research specially addresses SME networks. SME networks are particular because the shareholder and the manager of a SME is often the same person. According to most studies, co-ordination is a relevant problem for SME networks, where each partner preserves its independence and often runs its own decision making processes among the network.

Furthermore, different kinds of opportunism may appear among business networks of SMEs, such as only apparent co-operation (limited effort, lower quality goods, service below standard, …), catch of an excessive share of joint profits (overvalued switching costs, overvaluation of the added value brought), excessive exploitation of a joint resource, or personal appropriation of the resources created in common or by others.

1.3 Learning processes within networks.

Meanwhile, investigations have shown that acquisition of know-how and experimentation constitutes the first goal (60%) of co-operation between manufacturers, before economies of scale (Hannoun and Guerrier, 1996). Our own observations and investigations about networking also led us to presume that knowledge exchanging is the main reason why independent firms join networks. In that context, we assume that networks of firms need e-manufacturing tools to co-ordinate fairly their collaborative activities, and that these tools must both prevent opportunism and enable learning processes within networks. We have developed in that way a tool to distribute customers orders among the partners of a network. This tool aims to calculate satisfying routes for each order, according to two kinds of criteria :

- Short term performance, such as activity level, resource occupation, quality, lead time.
- Long term performance based on learning processes.

We will now introduce a conceptual model for this tool (section 2), expose a data model (section 3), and then discuss about the criteria we use to guide the routing decision process (section 4). We will present methods to optimise dynamically the network configuration according to orders (section 5). Finally, we will propose further perspectives about this research (conclusion).

2. CONCEPTUAL MODEL

The conceptual model is based on four elementary entities : actor, resource, activity and competency.

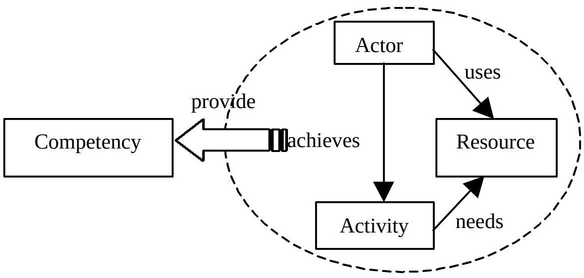

Fig. 1. The conceptual model.

Actor; an actor is a firm of the network. If necessary, the accuracy of the model can be improved : an actor will then be a service or even a person within a firm.

Resource; a resource is an entity used to transform material or information, like machines or computers. We usually focus on bottleneck resources.

Activity; an activity is any action described by a verb. A chain of activities is made of several co-ordinated activities aiming to a goal.

Competency; a competency is provided by an actor using a resource to achieve an activity. A competency will exist only through the (actor, resource, activity) trio (see figure 1).

3. DATA MODEL

As indicated in section 2, a competency is associated to each actor for the achievement of an activity on a given type of resource. A physical resource belongs to an actor (undertaken particular or service common to several companies). Each competency is labelled with a qualification level between 1 (the lowest) and 4 (the highest). This qualification level will be used as a criterion to select routes according to learning goals. As indicated in section 3, the performance when realising an activity is contextual, i.e. it depends not only on the qualification level of the actor processing this activity with the resource, but also on the instantaneous load of this resource.

So to qualify the impact of this load in term of cost, quality or lead time, it is necessary to express this load, for a same resource, into different units : manpower hours, machine hours, number of operations.

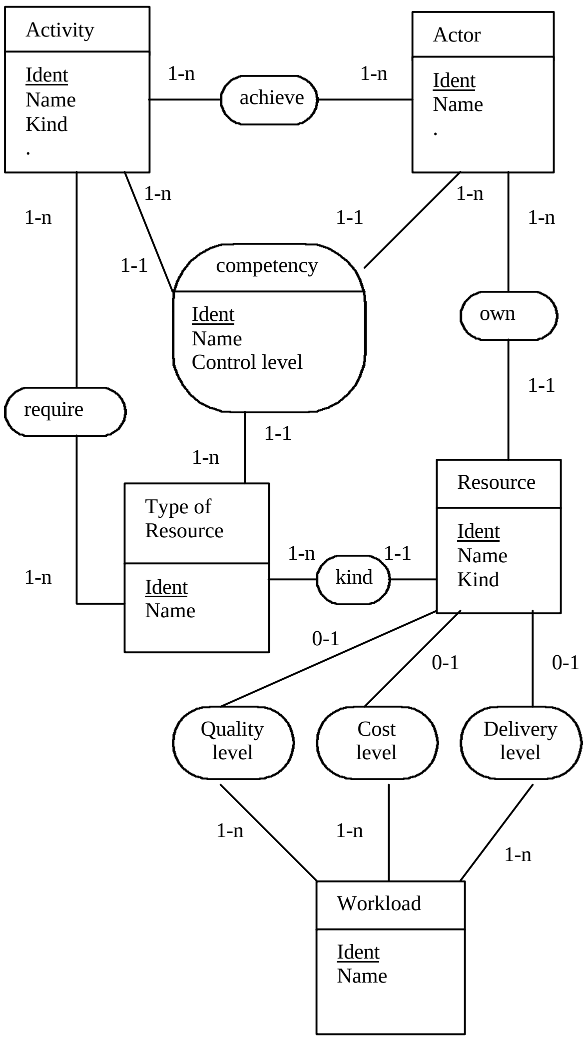

Fig. 2a. The data model.

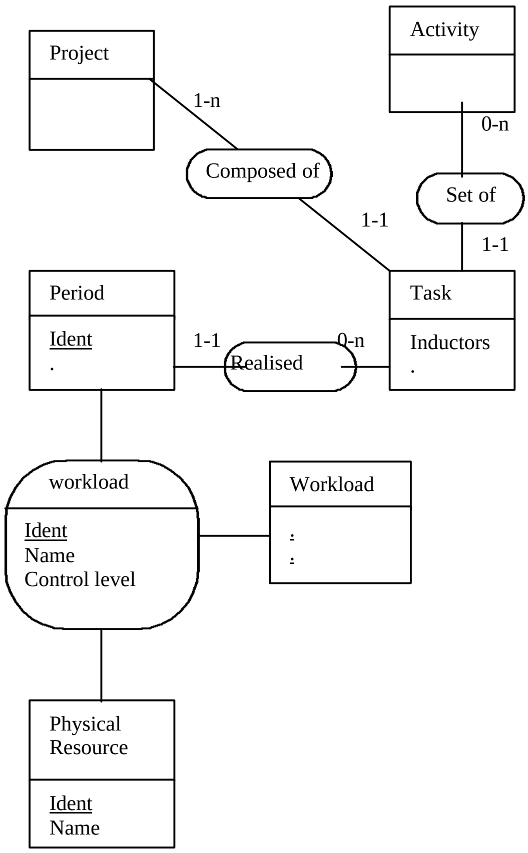

Fig. 2b. The data model.

3.1.Example.

Let us consider that a product is achieved trough two consecutive activities of machining and assembly.
The activity of machining requires a versatile manpower as well as a specific machine. The cost of achievement will depend on the total manpower load of this workshop:

Table 1 Cost and load level

Load level	$< n_1$	$n_1<A<n_2$	$>n_2$
Cost coefficient	1	1.25	1.4

The lead time will depend on the load on the bottleneck machine:

Table 2 Lead time and load level

Activity level	$<q_1$	$q_1<A<q_2$	$q_2<A<q_3$	$>q_3$
Lead time	1 day	2 days	3 days	4 days

On the other hand, the quality on this station will be independent of the load, because it is ensured by the machine (capable machine).

The activity of assembly does not require a specific machine and the capacity can be increased from level n_1 to level n_2 by using overtime. Beyond this level, we have to call to additional personnel.
The adjustment of the capacities makes it possible to do not affect the lead time. However, quality, equal up to the level n'_2, then degrades because of the call to unskilled manpower.
The tables translate the impact of the activity on the performance. They refer both with the same measuring unit and are as follows:

Table 3 Cost, quality and load level

Load level	$< n'_1$	$n'_1<A<n'_2$	$>n'_2$
Cost Coefficient	1	1.25	1.4
Quality level	Q_1	Q_1	Q_2

As indicated in section 3, a qualification level is associated to each actor for the achievement of an activity on a given type of resource. Any physical resource is the property of an actor. The performance in the achievement of an activity is contextual, i.e. that it can depend not only on the qualification level of the actor carrying out this activity on the resource chosen, but also on the instantaneous load of this resource.

To qualify the impact of this load in term of cost, quality or time, it is necessary to express this load, for a same resource, into different units – hours labour, hours machine, number of operations –

4. CRITERIA FOR DECISION MAKING

The criteria we use to guide the decision process will be decomposed into two kinds: short term performance and long term performance.

4.1. Short term performance in the network.

In the model, this performance is based on three classical criteria : cost, quality and lead time.

Cost; The cost of an activity is evaluated through an Activity Based Costing (ABC) method (Brimson, 1991). This approach considers that products do not consume costs but activities, and that those activities do consume costs. Accordingly, the aim of this method is to gather consumed activities according to an economic chain of the cause-and-effect type tied to the raison d'être of the network. For example, among the joint inter-enterprise supplies activity in the case of a purchasing network, the cost of the search for new suppliers could be charge according to the number of non-standard new components added to new products by the Research Unit or Engineering Department of each enterprise. This allocation system differs from the work unit concept because the grouping keys are essentially selected in order to locate the source of the cost (in this example, one of the Research Units, introducing many new components, will be the source of a significant part of purchasing costs). This type of model has the strong advantage of giving explanations for the total cost of an order allocation route through the network, thereby facilitating realistic and efficient joint cost-reduction processes.

Quality; The quality level of an activity is given by a table based on observations and depends on the activity level (we can admit that over-activity may decrease the quality level).

Lead time; Lead times for activities are evaluated with average numbers and statistical fluctuations. In the case of a bottleneck resource, the lead time is calculated dynamically according to the capacity of the resource and to the work in process queue.

4.2. Long term performance.

Assuming that skills exchange is one of the main long term reasons for networking, the model will focus onto learning processes within the network. For each competency Ck, the policy of each firm Fi in the network is analysed as below :

Table 4 Competencies analysis

Ck competency	F_1	F_2	F_3
Acquire	1	0	0
Develop	0	1	0
Share	1	0	0
Externalise	0	0	1
Abandon	0	0	0

This table gives criteria to select orders routes according to learning objectives : an order needing the activation of the Ck competency will be routed through the F2 firm so that this firm may develop this competency. By the way, it can also reveal difficulties among the network : in this example, F1 wants to acquire a competency that F2 does not want to share.

5. RESOLUTION METHODS

The order allocation problem was treated according to the main steps suggested by the decision theory.

Step1: settle the set of partners,
Step2: determine the selection criteria,
Step3: evaluate each partner according to each criterion,
Step4: propose a resolution method,
Step5: select the partner(s).

The order allocation problem is very complex: first, the selection decision are complicated by the fact that various criteria must be considered in the decision making process. Second, there is a very large number of options. Third, in multi-criteria order allocation problem, there is generally no combination of partners with the best performance on all criteria. Finally, partners performance on relevant criteria may change.

To study the order allocation problem, we were inspired by research works on the vendor selection problem because of the similarities of both problems. Moreover, the vendor selection problem is widely studied , hence, the scientific literature is rich in works not only about selection criteria but also about selection methods, their application environment, their advantages, limitations, solutions sets,…

This section begins with a state of the art about the vendor selection problem. We then explain the extension of the vendor selection problem to the order allocation problem. Finally, we propose an algorithm to choose the selection method for the order allocation problem.

5.1 The vendor selection problem.

Several selection criteria and methods have been developed in the literature on supplier selection. (Dickson 1966) surveyed 273 purchasing manager who identified 23 selection criteria. (Weber & al 1991)reviewed 74 articles: 47 of the articles address multiple criteria. The most mentioned criteria in both studies are: price, delivery, quality, facilities and capacity, geographic location and technical capability.

Different analytical methods were used in the vendor selection process: the categorical method, the cost ratio method, weighted point method (Timmerman 1986), Analytic Hierarchy Process (Narasimhan 1983), (Nydick & al 1992), (Barbarosoglu & al 1997), (Phuong Ta & al 2000), Principal Component Analysis (Petroni & al 2000), goal Programming (Buffa & al 1983), (Chaudhry & al 1991), (Hajidimitriou & al 2000), mixed integer optimization programming (Bender & al 1985), (Narasimhan & al 1986), (Current & al 1994), Multi-objective programming(Weber & al 1993; Weber 1996; Weber & al 1996; Weber 1998; Weber 2000; Weber & al 2000), Activity Based Costing (ABC) approach (Roodhooft & al 1996), (Degraeve & al 1998), Total Cost of Ownership (Ellram 1995), (Degraeve & al 2000), Imterpretive Structural Modelling (ISM) (Mandal & al 1994) human judgments models (Patton 1996), statistical analysis (Mummalaneni & al 1996), neurones networks (Siying & al 1997), Discrete Choice Analysis Experiment (Verma & al 1998)…

5.2 The order allocation problem.

The order allocation problem deals with distribution of customers orders among the partners of a network. It differs from a vendor selection problem by the presence of dependant activities linked up by anteriority constraints.

The algorithm described below (fig. 3) helps the decision maker to choose a mathematical programming method for modelling the order allocation problem. The choice of a method depends on the way the criteria are evaluated, the expression of criteria priorities and the objective to optimise. For example, when weights are assigned to criteria, and when the decision maker wants to minimise the gap between an ideal solution, he should opt for Compromise Programming.

allocation problem. We have then discussed about different kinds of performance indicators for networks of firms. Finally, we have surveyed selection methods and we have proposed an algorithm for the decision maker to choose a mathematic method to model the order allocation problem. The authors are currently examining a two layer methodology to solve the order allocation problem. The first layer consists in generating a set of non inferior solutions, using the multi-objective programming. In the second layer, we use multi-attribute decision methods to select the solution that translates the best compromise between objectives.

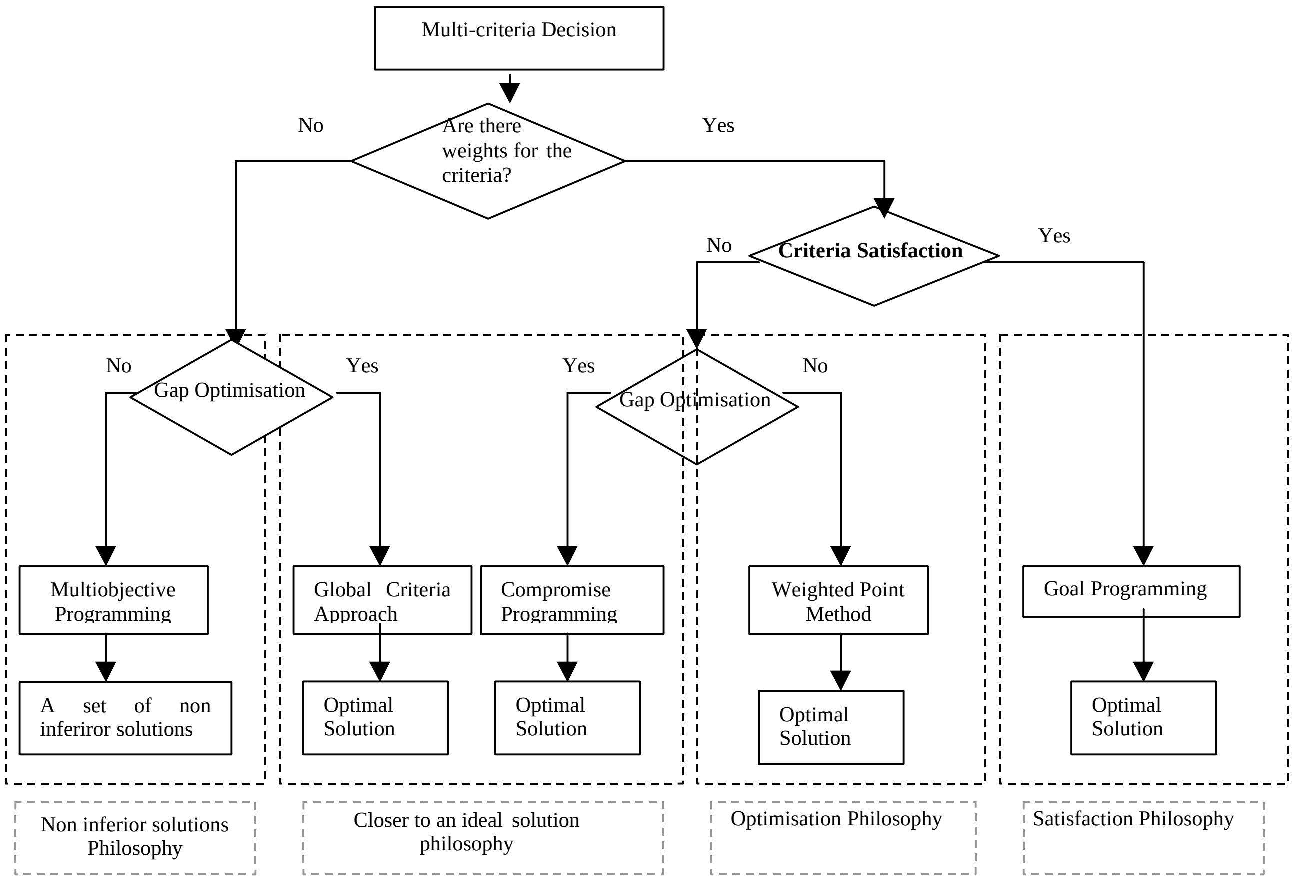

Fig. 3. Algorithm to select a mathematical method for the order allocation problem

Many other methods can be used to model the order allocation problem such as multi-attribute decision methods (Electre, Promethee, Topsis, Evamix, SMART,AHP…) which provide the decision maker with a classification of solutions. However, these methods are very efficient only if there is no constraint in the problem formulation. Besides, different techniques yield different results when applied to the same problem, apparently under the same assumption and by the same decision maker.

6. CONCLUSION.

In this paper, we have illustrated the importance of co-ordination and learning mechanisms within networks of firms. We have proposed a conceptual model and a data model to formulate the order

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