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Constraint optimization as a tool for business process re-engineering

*Gérard Bel †, Karine Rota † ‡, Caroline Thierry † **
† ONERA Centre d'Etudes et de Recherches de Toulouse, Département d'Automatique, BP 4025
31055 Toulouse-Cedex
‡ Sup Aéro
∗ Université Toulouse II Le Mirail

Abstract
The purpose of this paper is to show that constraint optimization techniques are a convenient tool to model the problem and to help during the decision process in business re-engineering. Two different levels of the re-engineering process are studied. First we consider a strategic decision level in business process re-engineering which concerns the optimal location of production units and the corresponding tasks assignment to these units. A mixed integer programming method and genetic algorithms are used to solve this problem. Then a more tactical decision level is treated. At this level a coordination problem in a multi-site environment which consists in planning items production is solved using Simplex algorithm and CSP approach.

Keywords
Location, allocation, production coordination, constraint optimization.

1 DISTRIBUTED SYSTEMS AND VIRTUAL ENTERPRISE

Todays enterprise organization happens to be more and more distributed (Bel, 1995) :

- most of the production facilities of manufacturing companies are located in various sites in different countries. This comes from historic and economic reasons. Indeed, on the one hand, several companies merged into one company, and on the other hand, the enterprise needs to be close to the market in order to minimize production and logistic costs ;

G. Doumeingts et al. (eds.), *Modelling Techniques for Business Process Re-engineering and Benchmarking*

- the activities of large companies are more and more centered on integration of various components manufactured in a set of smaller or specialized companies ;
- companies try to focus on their own competence domain, in other words they use service outsourcing.

So production and service activities are realized by a set of agents which will act globally as a virtual enterprise. Furthermore, the different entities of the enterprise are more or less autonomous and are responsible for a part of the production or service activities. As far as re-engineering is concerned in such companies, three questions have to be solved :

- what is the best set of sites to locate production facilities ?
- what is the best allocation of activities to each production facility (sites or enterprises) ?
- how is it possible to coordinate the activities of these various sites in order to give a better service to the customer at lower total cost ?

This paper presents how constraint optimization approaches can be used to help decision making in such industrial problems.

2 OPTIMAL PRODUCTION FACILITIES LOCATION AND ACTIVITIES ALLOCATIONS

2.1 Problem

Here we consider the strategic decision level in business process re-engineering which concerns the optimal location of production units and the corresponding tasks assignment to these units (items they will produce). This problem has to be solved each time a new type of item is to be produced by a company, when a new workshop is to be build, or when major changes occur in production capacities.

The purpose is not to relocate all the existing facilities but to take into account existing locations and give information to the best target location and assignment for the new facilities. The optimality of such a location can drastically reduce costs (production and transportation) or simplify scheduling problems after the production lines have been built.

The objectives of such a re-engineering process are to be able to satisfy forecasted customer demands and to minimize production and transportation costs. On the other hand, these locations must remain quite optimal *w.r.t.* the imprecision of forecasted demands or costs. The three following parameters are considered to be imprecise : customer demand, transportation and production costs. It is necessary to determine locations which are the less sensitive to the modification of these values, *i.e.* to determine *robust locations.* Location robustness is here considered as the opposite of the over-cost induced by a given variation of one or the whole set of parameters for this given location.

2.2 Model and solving methods

The problem can be defined by :

- a set of customers located in various zones of the countries with their demands concerning the different types of items ;
- a given number of production lines with their individual global production capacity ;
- a set of possible locations for these production lines (existing factories or possible new ones), with a production cost to produce each type of item in each site and transportation costs to deliver each type of item from a production line located in a production site to the customer ;
- each production line can produce only a limited number of different types of items.

The problem to be solved is then :

- find the location of the production units and the types and quantities of items they will produce in order to get the best global cost (production cost and logistic cost) ;
- if possible, find the best trade-off between cost and robustness.

The cost optimization problem is a generalization of a classical Operations Research problem, known as the *warehouse location problem* for which only one type of item and so no allocation is taken into account and where the total number of warehouses is unknown.

Mixed integer programming

The cost minimization problem can be formalized as a mixed integer linear programming problem, with 0-1 and continuous variables :

- 0-1 variables y_i model the fact that a production facility will or will not be located in location i ;
- continuous variables $qp_{k,i}$ model the quantities of item k produced by production facilities located in site i ;
- a set of linear constraints model the following features of the problem :
  - global and per type of items capacities of each production lines ;
  - customer demand satisfaction in each zone and for each type of items ;
  - limitation of the different items produced in a given production facility ;
  - limitation of the number of different production facilities where the same item will be produced ;
  - limitation of the total number of production facilities ;
  - prohibition or preferences for some locations for some production facilities.

The use of recent theoretical results in mixed integer programming (Savelsberg, 1994) allows a redundant and very efficient modeling of industrial problem. So an optimal location can be obtained efficiently. Linear programming gives objectives and right hand size sensitivity ranges for a given location (a given value of integer variables). From these sensitivity ranges it is possible to calculate over-costs and robustness in a limited range for a given cost optimal solution. But this robustness, computed for a solution, cannot be used as an optimization criteria in the linear programming approach.

So the cost/robustness optimal trade-off problem cannot be solved using integer linear programming, and another technique has to be used.

Genetic algorithms

New methods named as *stochastic optimization* propose a new approach to solve constraint optimization problems. With these approaches, criteria and constraints have not to be expressed with a relation between the problem variables but have only to be evaluated for a given solution. In this class of methods, we chose Genetic Algorithms, in order to test their capability to solve the trade-off cost-robustness problem.

Genetic Algorithms (GAs) (Goldberg, 1989) are general-purpose optimization procedures based on the mechanics of natural selection and natural genetics. GAs use a 3 steps process : generating solutions, evaluating different criteria for a each given solution, and improving the set of solutions, in order to converge to better solutions. GAs have been applied successfully in various domains of search and optimization, because this technique requires a little problem-specific knowledge differing from fitness or energy information.

Furthermore, GAs can find optimal trade-off solutions if many criteria have to be optimized. In multi-objective optimization, the notion of optimality is not at all obvious. Here we refused to interrelate the relative values of the different criteria, and so we came up with a different definition of optimality, one that respects the integrity of each of our separate criteria.

For facility location problem, we have implemented a Pareto domination tournaments, and a domination relation which establishes a partial order on the set of criteria. In the in-process set of solutions, GAs peak up two solutions and compare their own criteria, one by one with those of the other one (as a scalar comparison). Then :

- if all its criteria are better than the other ones, we consider this solution as dominant (*i.e.* the best solution or winner) ;
- if neither or both are dominant, then we must use other methods (such as sharing) to choose a winner.

Finally the winner is compared with another solution.

2.3 Example and industrial applications

We compare mixed integer linear programming method and GAs on a real-world application, defined as follows : three production units have to be located in order to get the best solution in respect with a predefined criterium (cost, robustness or trade-off cost/robustness), knowing :

- a set of 41 customers, with their demands concerning two types of items ;
- a given number of production lines with their individual global production capacity ;
- a set of 41 possible locations for these production lines (existing factories or possible new ones), with a production cost to produce each type of item in each site and transportation costs to deliver each type of item from a production line located in a production site to the customer ;
- each production line can produce both types of items.

Table 1 Cost criteria

	MILP	GA
Solution	8,31,39	8,31,39

Table 2 Robustness criteria

	MILP	GA
Solution	not possible	9,13,39

Table 3 Trade-off cost/robustness criteria

	MILP	G A	
Solution	not possible	8,31,39	9,39,41
		9,39,40	9,38,39

Tables 1, 2 and 3 represent the test results obtained by mixed integer linear programming method (*MILP*) and GAs (Rota, 1995) for each criterium to optimize.

GAs give the best economic cost solution (which has been checked as being the same as the solution obtained by mixed integer linear programming method), the best robust solution and the best trade-off between these two criteria. GAs are all the more powerful than the optimal solution is found whatever the criterium is, whereas the mixed integer linear programming method only finds the optimal cost solution.

A set of real sized cases has been solved for Renault with up to 10 types of items, 42 possibles locations which induce 17 220 real and 462 integer variables. This set has been efficiently solved with mixed integer programming and compared with GA's approach when possible.

3 MULTI-SITE, MULTI-ENTERPRISE PRODUCTION COORDINATION

3.1 Problem

Let's consider a more tactical decision level : in order to improve the business process, distributed enterprises must use, in a better way, synergy between the different production and services agents.

At this level :

- each facility or each agent is located in a site (see section above) and has production capacities and capability profile (tasks allocation or items they can produce : see section above) ;
- items can be processed or bought in various sites or companies ;

- customers set on demands concerning finished products (cars, TV sets, aircraft,..) manufactured with a set of components ;
- agents can manufacture several items either finished products or components and a single item can be manufactured by several agents ;
- moreover, different components of a given finished product can be manufactured by different agents.

The problem is :

- to know if it is possible to coordinate the various production activities of these distributed agents according to their capacities in order to better satisfy customer demand (parts, quantities, due-date) ;
- to evaluate what will be the benefit and drawback of such a coordination taking into account the existing autonomy of agents and the existing management tools on each site or company ;
- then to decide the degree of autonomy given to each agent and choose the corresponding coordination process.

The coordination problem to be solved is to plan items production. So the question is : how much, where and when to produce and transport the different items. This multi-site coordination problem includes :

- the management of production alternatives ;
- the coordination between agents in charge of components production of a single finish product.

3.2 Model and solving methods

This problem is naturally distributed. Different kinds of model and resolution approaches can be used which are more or less distributed. The chosen approach is a semi-centralized one in which :

- some items (*critical items*) are planned by a *centralizing agent* (for instance the logistic department of the company) which realizes the coordination and sends to each agent a production plan for these items ;
- others are managed by the local planning and control systems of the different agents ;
- in order to make this semi-centralized approach feasible a process of capacity reservation for *non-critical items* in each site is triggered.

This approach allows to take into account the fact that in big multi-site companies each agent very often has its own planning control system for most items.

The plan concerning multi-site and critical items is made once a week (or a month) to exchange informations between the different agents.

This problem can be modeled and solved by constraint optimization (linear programming or constraint satisfaction problem : CSP) :

- time is divided in a set of time-periods of various sizes (days for the first ones, weeks for the following ones and months for the last ones) ;
- variables are :

  - quantities $qp_{p,k,i}$ and $qs_{p,k,i}$ of an item k produced and stocked on each site i for each time period p ;
  - quantities $qt_{p,k,i,j}$ of an item k transported each time period p between each couple (i,j) of production units ;

- constraints represent :

  - production units capacity limitations ;
  - sequencing due to the bill of material since the assembly process has obviously to be taken into account in this problem ;
  - due dates for customer demands.

- criteria is to satisfy customer demands at the lowest price.

Making some simplifications this problem can be modeled as a linear one having been solved with Simplex algorithm. The optimal solution is given very efficiently. But, if there is a set of equivalent solutions the user cannot take into account criteria other than cost.

The CSP approach is different : it uses constraints to prune the search space and heuristics procedures afterwards to find quickly a solution (Alliot, 1993). This approach can use *variables and values ordering procedures* which enable to give a plan which respects constraints and takes into account the industrial preferences as well (Bel, 1993).

3.3 Example and industrial applications

Example

Let's consider an example with :

- 2 Customers Units : $CU1$ and $CU2$;
- 4 Production Units : $PU1$, $PU2$, $PU3$ and $PU4$;
- 2 final products : i_1 ans i_2 with the following bill of material (figure 1).

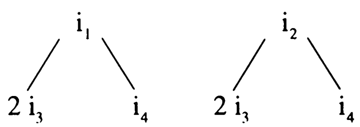

Figure 1 Bill of material of i_1 and i_2

Table 4 Customer demands in Customer Unit 1

	Item	i_1						
Period	3	4	5	6	7	8	9	10
Demand	100	50	50	210	240	300	100	100

Table 5 Customer demands in Customer Unit 2

	Item	i_2					
Period	4	5	6	7	8	9	10
Demand	50	120	120	200	100	110	150

Figure 2 represents the multi-site enterprise structure considered, and Tables 4 and 5 give the customers demands.

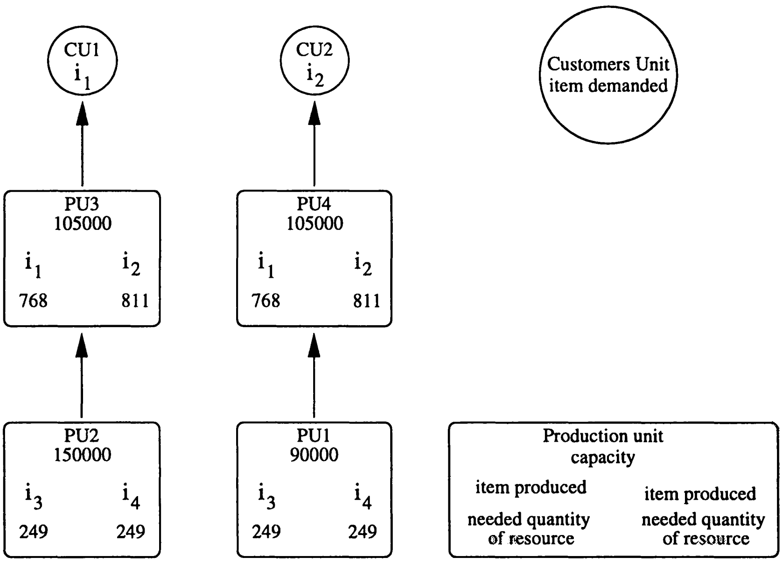

Figure 2 Example structure

Our model and solving method show that there is no possible plan for this problem. Indeed, $PU1$ cannot afford i_4 production to respect the customers demand of i_1 and i_2 on critical periods 1,2 and 3.

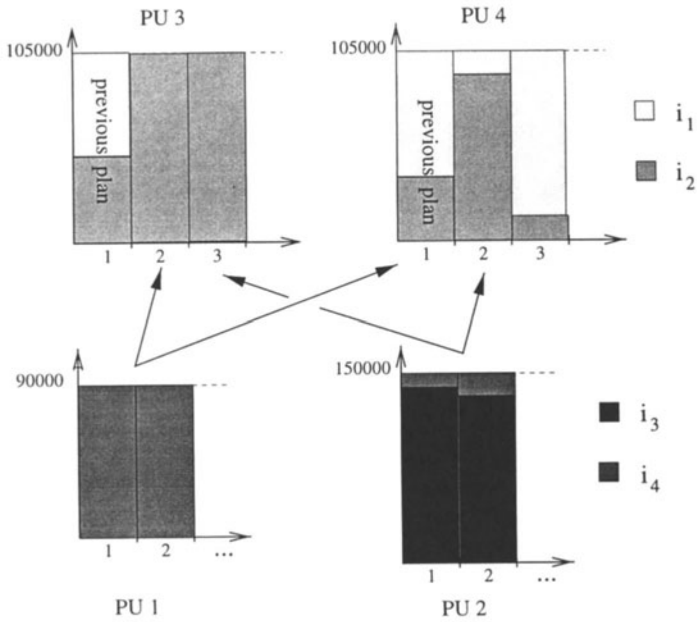

Figure 3 New solution obtained

Then, a reorganization of the company has to be tested to improve its efficiency. Let's then add transportation pathes between $PU1$ and $PU3$, and between $PU2$ and $PU4$. The following plan (Figure 3) is obtained for the critical periods which demonstrates that maybe a better use of existing synergies between sites removes the use of subcontractors to increase $PU1$ capacity (Thierry, 1994).

Industrial application

A multi-site planning system has been developed in the Esprit project DISCO (Distributed Management and Coordination of Scheduling Systems in a Multi-site Production Environment) with the following partners Magneti-Marelli, AEG, Bull, IAO, ISA, Promip (Disco, 1993). This system has shown that a better coordination between sites is possible (even with big number of items : 75 000 final products to be produced) in a re-engineering situation. It has been shown how a better use of existing synergy between sites makes feasible schedules satisfying customers' due dates (which was not possible without coordination).

4 CONCLUSION

In this paper it has been stated that there is a set of constraint optimization techniques that can be, and has been, used to help business process re-engineering.

The use of such techniques :

- offers a quantitative modeling frame which is a strong support for analyzing re-engineering problems ;
- allows the partial use of structured user's knowledge. By this way the user's experiences and preferences can be employed in order to take into account constraints and criteria which cannot be modeled directly in the constraint optimization frame ;
- allows an exploration of the *feasible*. They take into account the quantitative constraints and use efficient algorithms which solve the combinatorial part of the problem the human cannot manage.

So all these techniques can be used as efficient decision-aid in the global decision process :

- decision-maker has to be supported in some part of his decision making (quantitative part of the problem) but he is the only one who can manage all the non-quantitative parameters of the re-engineering problem ;
- when a set of the decision makers collaborate to a global process these methods allow a better coordination of this multi-agent process.

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