12 A MULTI-AGENT MODEL INTEGRATING INVENTORY AND ROUTING PROCESSES

Daria Bernardi[1,2] , Giuseppe Confessore[1] , Giuseppe Stecca[1,2]
[1] Istituto di Tecnologie Industriali e Automazione - Sezione di Roma
Consiglio Nazionale delle Ricerche
Area della Ricerca Roma Tor Vergata, Via Fosso del Cavaliere, 100
–00133 Roma–ITALY. {d.bernardi g.confessore, g.stecca}@itia.cnr.it
[2] Dipartimento di Ingegneria dell 'Impresa
Università di Roma "Tor Vergata"
Via del Politecnico 1 – 00133 Roma – ITALY

The increasing changing rate of the marketplace forces the enterprise to face the complexity with new organizational paradigms like virtual enterprise or extended enterprise. These organizational paradigms bring in consideration coordination and integration issues of different DSS designed to solve different problems.
In this paper we analyze the problem of a logistics operator which need to route goods to customers. Customers have different preferences on the time of delivery based on their resource management policies. In our work we use a multi-agent model in which agents use classic techniques to solve single problems and through coordination try to optimize the global goal of minimization of logistic service operator and customer costs. In the architecture we designed, there is an agent that solves the Vehicle Routing Problem with Time Window constraints representing the interests of the logistic service operator. Another agent uses an algorithm to determine the cost function of goods picking at delivery point based on resource management policy of delivery point. A Third agent asks to the two agents for solving different instances of the single problems and tries to match solution using multi-criteria techniques. The model was implemented and tested on real case of an Italian logistic service operator. Some results and comparisons are presented.

1. INTRODUCTION

Factors such as cost reduction, flexibility and focus on core competencies are critical for the survival of companies. In recent years, outsourcing concepts evolved in Virtual Enterprise concepts. A Virtual Enterprise can be viewed as a temporary alliance of enterprises that share resources and skills, to better respond to business opportunity and that is supported by an appropriate IT infrastructure (Camarinha-Matos and Afsarmanesh, 1999). Many reference models has been proposed as

guidance to the realisation of Virtual Enterprises (Tølle, and Bernus (2003)); all these reference models bring in evidence the fact that in Virtual Enterprise and Virtual Organizations, more than one actor is involved in decisional process: indeed, distributed decision support tools are crucial in Virtual Enterprise environments.
In this paper we use a multi-agent model in way to design and develop a distributed decision support tool for distribution process. In particular, we study a capacitated vehicle routing problem with time windows as a multi-decision makers problem. In the considered scenario, there are three main actors involved in the distribution process, each one of these being a decision maker involved in a different phase of the process. The actors are the customers, the supplier, and a logistic operator to which the supplier outsource the distribution process.
The multi-agent view allows us to put in evidence the presence of more than one actor in the decisional process (Jennings et al., 1998; Shen et al., 2000). The main goals of the work are the utilisation of local DSSs for the process improvement and the involvement of the customer in the decisional process.

The paper is organized as follows. In Section 2, we describe the distribution process and its reengineering when a logistic service operator manage part of it; In section 3 we show the multi-agent model bringing in evidence the relationships between actors. In section 4 we deeply discuss the decisional tools used by agents. In section 5 we discuss test results and make some conclusions.

2. THE DISTRIBUTION PROCESS REENGINEERING

Distribution regards all the activities related to the provisioning of service to a set of customers by a set of vehicles located in one or more depots, operated by a set of drivers. Often in a supply chain, the depot is an inventory managed from a supplier who delivers goods to customers through a Logistic Operator. Customers place orders to the suppliers following proper inventory management policies and production plans. In our study the supplier out sources the product delivery to the logistic operator. In these settings, customers place orders to supplier who forwards delivery orders to logistic operator who generates the delivery plan using routes planner, and deliver the goods to customer.

2.1. The reengineering of the distribution process

The above descript distribution process has an important lack: there is no interaction between logistic operator and Customer needs. The logistics operator simply receives orders from suppliers and tries to optimize its resources in way to meet customer needs expressed in terms of delivery time and quantity to delivery. The goal is to reengineer the process in way to have a better interaction between customer and logistic operator. The customer costs strictly depend on the time in which the delivery occurs, so it can be very useful for it to participate in the route determination process. Orders placed from customers are the result of inventory management policies, and production planning. It is clearly inapplicable the comprehensive modeling and the integration of logistic operator and customers DSSs. On the other hand, an auction mechanism could help to reveal cost functions, but it is not applicable and not realistic in the case we want model a sort of cooperation between Logistic Operator and customers. In this paper, we follow a soft cooperation policy schema. The process is reengineered based on information communication between customer and logistic operator. More precisely, customer communicates to logistic operator some useful information about cost function and logistic operator proposes a choice being the trade off between delivery time (that represent a customer service level indicator) and routing costs. The logistic operator can highly reduce costs if it does not have hard constraints on delivery time windows. If customer communicates to Logistic Operator some information about costs the logistic operator can find the best trade off between customer service level and total costs. In the reengineered process there are the following basic steps:

1. Customers place orders to supplier;
2. Supplier forward delivery orders to the logistic operator;
3. The *route planner actor,* based on delivery orders, generates a set of vehicle routes using an optimization tool;
4. An *inventory cost actor* interacts with customers from which get inventory cost functions and, together with the customer, determines suitable delivery schedules for each customer.
5. A *mediator actor* determines a set of delivery plans based on the best trade off between vehicle routes and customer cost functions.

Steps 3 and 4 are repeated in way to improve the set of available plans. Routing costs are updated based on the different delivery times chosen to serve customers. This is an important difference in respect of situation in which customers simply select between a list of possible deliveries (such as, for instance, Amazon – like applications); in our proposed application, mediator actor always has visibility of routing costs.

In place of a single route planner, in the new designed process there are three interacting actors: one for vehicle routing optimization (the route planner), one who take care of customer needs (the inventory cost actor), and a third entity who try to meet the different goals (the mediator actor). The model is addressed for scenarios in which customers are companies having time dependent cost functions. Following in this paper we show the design and the implementation of the new process through a multi-agent model.

3. THE MULTI-AGENT MODEL

Multi-agent systems are widely studied in the literature for interoperability and manufacturing management at Virtual Enterprise level (inter-enterprise), enterprise level (intra-enterprise) and shop floor level (Hao et al, 2003). In this paper we use a multi-agent model mainly for inter-enterprise level with the main scope of developing a decentralized decision support system. The multi-agent model allows the integration of customer cost functions with transportation cost functions preserving actors' autonomy. Referring to the actors explained in previous section, the multi-agent model foresees three agents:

- The inventory cost agent who interacts with customers DSS in way to obtain cost functions.
- The Route planner agent who solve the vehicle routing problem with time windows constraints (VRPTW) and relative routing costs. The solving tool for VRPTW is explained in the next section.
- The mediator agent who determine the delivery plan using multi-criteria analysis in way to match customer needs and routing costs.

The figure 1 shows the multi agent model information flows, while figure 2 shows, through an UML (Unified Modeling Language) sequence diagram, the chronological sequence of interactions in the multi-agent model. Agents interact following these basic steps:

- Customers send orders to supplier;
- Supplier forward orders to Logistic Operator who activates the mediator agent.
- The mediator agent propose to the route planner to solve an instance of the VRPTW with some broad delivery time windows and then it performs the following steps:
- *F=0;*
- Loop until all delivery time windows are matched :
  1. Ask inventory customer function information to inventory cost agents;
  2. It does the multi-criteria analysis based on traveling cost and customer service level;
  3. Pick the best *S* solution;
  4. If there are more than *m* solution then discard the worst found
  5. let *F* to be the set of delivery time windows satisfied by *S;* it constructs a new instance of VRPTW with hard time windows: $F \cup [a_j, b_j]$ being *j* the client with most improvable service level;
  6. Ask to the route planner agent to solve the new VRPTW instance;
  7. $F \leftarrow F \cup [a_i, b_i]$;
- Propose the *m* routing plans to logistic operator.

The multi-agent system, based on schema in figure 1, has been implemented using the JADE (Java Development Framework) toolkit. Jade uses a FIPA compliant message format.

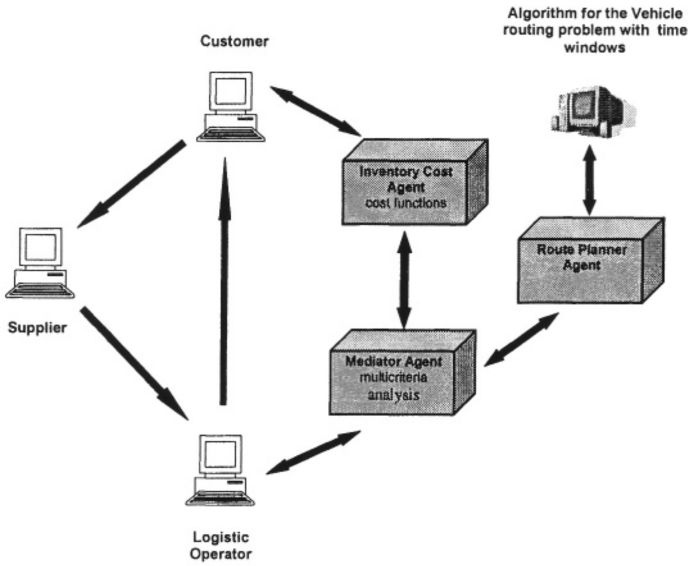

Figure 1 – information flow of the multi-agent model

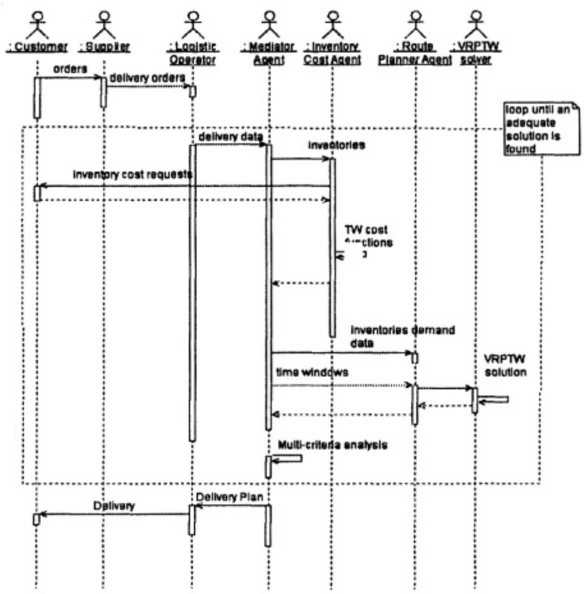

Figure 2 – UML sequence diagram of the system

4. THE OPTIMIZATION TOOLS USED BY AGENTS

In this section we explain more deeply tools used by agents. At the end of the loop in Figure 2 the mediator agent propose to logistic operator a set of routing plans ranked in ascendant way. The logistics operator chooses one of these routing plans based on its strategy. This set of routing plan come from the interaction of the three agents that use tools and techniques explained in the following.

4.1 The VRPTW solving tool

The Vehicle Routing Problem (VRP) calls for the determination of the optimal set of routes to be performed by a fleet of vehicles to serve a given set of customers, and it is one of the most important, and studied, combinatorial optimization problem. In particular, the VRP with Time windows (VRPTW) is the extension of the Capacitated VRP where the service at each customer must start within an associated time window (Toth & Vigo 2000). The optimization tool used in this project is written in the java language and solves the VRPTW using a Simulated Annealing metaheuristics. Simulated Annealing is not the most performing technique for VRPTW but it gives good solution in short time (Tan et al, 2001). Each time the mediator agent wants to evaluate a routing plan, it asks to route planner agent to solve the VRPTW problem. The route planner calculate the cost of to serve customer requested quantity and delivery time through the VRPTW.

4.2 Inventory cost functions

The customer service level highly depends on the time in which the customer receives goods. Indeed, if delivery occurs at time a_j, customer j sustains a cost $c^j(a_j)$. The inventory cost agent asks to customer to communicate information about the values c_{min}, h_{min}, c_{max}, h_{max}, c_{med}, and $h_{med} = (h_{min} + h_{max})/2$. It also computes the weight of each inventory in terms of sensibility of cost function to delivery changes.

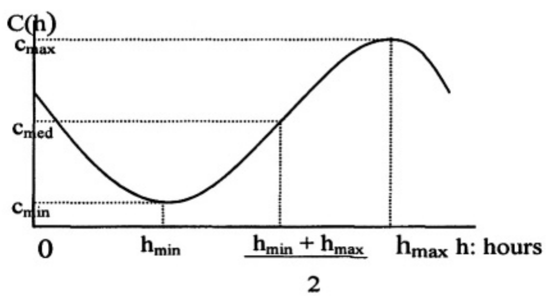

Figure 3 – Customer cost function

4.3 Multi-criteria analysis

Multi-Criteria Decision Making (MCDM) models, rather than compute an optimal solution try to determine via various ranking procedures a classification of the relevant actions (decision alternatives) that is "optimal" with respect to several criteria (Triantaphyllou, 2000). The Mediator agent uses Multi-Criteria Decision Making (MCDM) in way to help the logistic operator to find the best match between the customer service level and the transportation costs. In particular, an alternative *k* is a routing plan. Criteria are the performance of alternative on each customer inventory plus the performance of such alternative on transportation costs. If *n* is the number of customer to serve, the MCDM problem can be expressed as a $(m \, X \, (n+1))$ matrix B where element $[b_{ij}]$ denotes the performance that routing plan *i* has on criteria *j*. Indeed, mediator agent has to evaluate plans based on $n + 1$ criteria. The performances are expressed, for the first *n* columns, by formula (1), where c^j is the cost function computed by inventory cost agent and it is evaluated at arrival time a_{ij}, h_{min}, and h_{max}

$$i_{rj} = 1 - \frac{c^j(a_{ij}) - c^j(h_{min})}{c^j(h_{max}) - c^j(h_{min})} \quad (1)$$

Each element $[b_{i\ (n+1)}]$ of matrix B represent the ratio between the cost of routing plan *i* and the minimum cost found of routing plans. The routing plans are ranked based on weighted sum model (WSM) method; according to this method, the different criteria have a relative weight. In particular there is a weight for customer criteria w_c and a weight for transportation cost w_t and $w_c = 1 - w_t$. The different tunings of these two weights effect on the determination of the relative importance of transportation costs and customer service level.

The mediator agent iteratively tries to improve the set of *m* routing plan that it proposes to logistic operator. At each step it request to route planner agent to solve an instance of the VRPTW with different time windows. The worst plan based on MCDM ranking is replaced with the new routing plan.

5. EXPERIMENTAL RESULTS AND CONCLUSIONS

The implemented multi-agent model has been tested and compared with a not distributed solution. Confrontation terms are the customer service level for each routing plan *j* (csl_j) defined in formula (2), and transportation costs.

$$csl_j = \sum_{j=1}^{n} w_j i_{rj} \quad (2)$$

We made test varying different problem data; in particular, we change the number of customer (from 3 to 20) and for each instance we made 200 tests.

We tested 2 different scenario representing two different policies:

- *Scenario 1:* at the beginning state the logistic operator does not consider the time window constraints. It obtains the minimum transportation cost. We want evaluate how much the multi-agent system can increase customer service level;
- *Scenario 2:* at the beginning state, the logistic operator meets all time windows. We want evaluate how much the multi-agent system can reduce the transportation costs.

In Table 1 we report some relevant test results: for each scenario we report the increment or the reduction of customer service level, and transportation costs (minumim, medium, and maximum values in percentage) obtainded with the multi-agent system with the respect of the centralized solution.

Table 1 – Sample table

Scenario 1			Scenario 2		
Increment of c. service level (%)			Reduction of c. service level (%)		
Min	Medium	Max	Min	Medium	Max
87.1	**118.01**	181.8	0.09	**0.72**	2.27
Increment of Transportation costs (%)			Reduction of Transportation costs		
Min	Medium	Max	Min	Medium	Max
21.88	**33.77**	57.99	0	**23.12**	63.45

As shown in Table 1, in scenario 1 there is a radical growth of customer service level; in scenario 2 there is a low reduction of customer service level but a high reduction of transportation costs. Confrontations with a centralized solution could be made referring to one global objective function expressing the sum of routing costs and penalty functions (The VRP with Soft Time Windows constraints). Other then these numerical data, it is important to notice as, in our work, we implemented a multi-agent model able to use local DSSs for the process improvement and the participation of the customer in the decisional process. Another important point to notice is the fact that, at the end of the optimization process, the mediator agent propose to the logistic operator not a single routing plan but a set of routing plans ranked with the criteria stated in section 4.3.
The multi-agent system is going to be implemented in a distributed infrastructure where tools can be accessed by agents as services. Major improvements are foreseen for inventory cost agent who will be able to adopt inventory management policies.

6. REFERENCES

1. Camarinha-Matos, L.M. and Afsarmanesh, H. "The virtual enterprise concept", in Proceedings of PRO-VE'99, Infrastructures for Virtual Enterprises, Kluwer Academic Publishers, ISBN 0-7923-8639-6, pp. 3-14 (1999).
2. Hao Q., W. Shen, G. Stecca, L. Wang. "Towards An Internet Enabled Cooperative Manufacturing Management Framework", in Proceedings of PRO-VE'03, pp. 191-200, (2003).
3. Jennings N.R, K.Sycara, M.Wooldridge. "A Roadmap of Agent Research and Development". Autonomous Agents and Multi-Agent Systems 1,275-306, (1998).
4. Shen W., R.Kremer, D.H.Norrie. "Internet-enabled collaborative agent-based supply chains". Proceedings of the SPIE International Conference on Network Intelligence: Internet Based Manufacturing. Boston, MA, (2000).
5. JADE Java Agent Development Framework http://sharon.cselt.it/projects/jade/index.html
6. Tan K.C., L.H. Lee, Q.L. Zhu, K. Ou, "Heuristic methods for vehicle routing problem with time windows", Artificial Intelligence in Engineering 15,281-295, (2001).
7. Tølle M., and P. Bernus. "Reference models supporting enterprise networks and virtual enterprises", International Journal of Networking and Virtual Organizations, Vol 2, No. 1, (2003).
8. Toth P., D.Vigo. "The Vehicle Routing Problem". SIAM monographs on Discrete Mathematics and Applications (2000).
9. Triantaphyllou E. "Multi-Criteria Decision Making Methods: A Comparative Study". Kluwer Academic Publishers (2000).