A Multi-agent Model for Distribution Problems in Logistics Systems

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1 Introduction

Logistics activities provide the bridge between production and market locations that are separated by time and distance (Ballou, 1998). Global competitiveness, in conjunction with advances in communications and transportation technologies, imposes cost reduction in logistics systems and, in particular, in the distribution phase when goods have to be shipped in right quantities, at the right locations, in the right time interval.

It is usual to represent distribution problems as vehicle routing problems, widely studied in literature (e.g., see Laporte et al., 2000; Toth and Vigo, 2000). Practical issues lead to model the problem by using a variant of this problem known as the capacitated vehicle routing problem with time windows (e.g., see Brysy and Gendreau, 2003a, 2003b; Tan et al., 2000).

In this paper, we study a capacitated vehicle routing problem with time windows as a multi-decision makers problem and represent it by a multi-agent model. The multi-agent view gives evidence to more than one actor in the decisional process (Jennings et al., 1998; Hao et al., 2003). In fact, due to out-sourcing practices, it is usual to find logistics processes managed by more than one organization.

In particular, in the considered scenario, there are many actors involved in the distribution process; these actors can be classified in three categories. The first one is the logistics operator who has the responsibility to deliver the goods from a single depot to customers; its task is to meet customer service level requirements. The second one is the truck operator who delivers the goods by using own vehicles; its goal is the minimization of the total traveled distance.

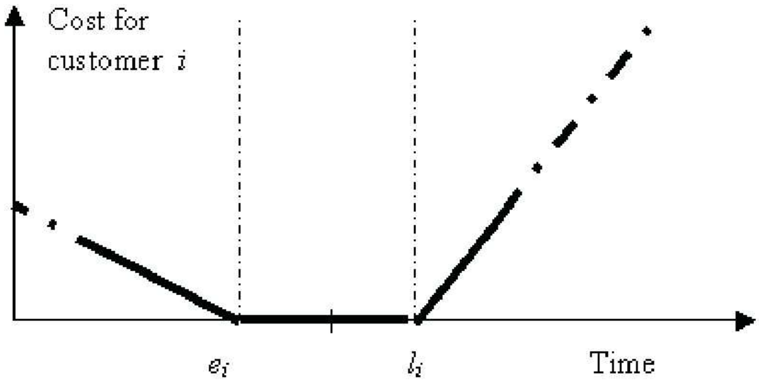

Figure 1: Example of penalty function

The last one is the customer that has to receive goods within the requested delivery time. In the proposed multi-agent model each agent represents an actor of the previous scenario.

We propose a multi-agent model for distribution problems represented as a multi-decision makers capacitated vehicle routing problem with time windows. In particular, we describe the architecture of the multi-agent model, the local optimization problems solved by each agent, the parameters negotiation between agents, and the issues related to the convergence toward a feasible solution. Moreover, we analyze the proposed architecture on a real Italian scenario.

2 The problem

The Vehicle Routing Problem with Time Windows (VRPTW) is a well known NP - hard in strong sense problem, and it is a generalization of the Capacitated Vehicle Routing Problem (CVRP). The CVRP consists of finding a collection of simple routes of minimum cost in a connected digraph (the objective function is defined as the sum of the costs of the arcs belonging to the routes) such that each customer is visited by a route, each route visits a depot center, and vehicle capacity constraints are respected. In the VRPTW additional constraints impose that each customer is associated with a time interval called a time window. A vehicle is permitted to arrive before the start of the time window, and wait at no cost until service becomes possible, but it is not permitted to arrive after the end of time window. Variation of the VRPTW considers the time window as a soft constraint; its violation is associated with a penalty function in the objective function (Ioannou et al., 2003). Such a function represents the cost for each customer if the arrival time is out of the time window (see Figure 1, where $[e_i, l_i]$ is a time window associated to customer i).

In order to introduce the studied problem, we briefly recall a classical formulation of the VRPTW where a single-decision maker has to find a feasible (optimal) solution. In particular, the decision maker has to minimize an objective function that can be represented as the sum of three terms:

$$\underbrace{\sum_{i=0}^{N}\sum_{j=0,j\neq i}^{N}\sum_{k=1}^{K} c_{ij}x_{ijk}}_{(1)} + \underbrace{\sum_{k=1}^{K} w_k z_k}_{(2)} + \underbrace{\sum_{i=1}^{N} p_i}_{(3)} \quad (*)$$

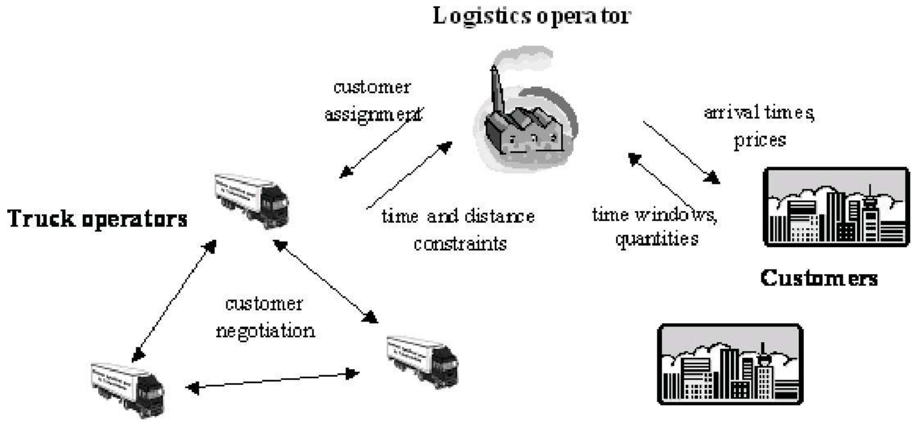

Figure 2: Decision makers in the studied problem

where a digraph $G = (V, A)$ with $|V| = N + 1$ nodes is considered (node 0 is the depot center node), and:

- K is an upper bound on the vehicles number to be used;
- $x_{ijk} \in \{0, 1\}$ is equal to 1 if $arc(i, j) \in A$ is traversed by vehicle k, 0 otherwise; $i, j = 0, 1, \ldots, N$;
- c_{ij} is the cost to travel the $arc(i, j) \in A; i, j = 0, 1, \ldots, N$;
- $z_k, \in \{0, 1\}$ is equal to 1 if the vehicle k is activated, 0 otherwise, $k = 0, \ldots, K$;
- w_k is the cost for vehicle activation, $k = 0, \ldots, K$;
- p_i is the penalty function associated to each one of N customers, $i = 1, 2, \ldots, N$.

Moreover, in order to find a feasible solution, the following constraints have to be satisfied, i.e.:

a) every route must starts and ends at a central depot;

b) every customer must be visited by one vehicle;

c) there is a capacity constraints for each vehicle;

d) there is a maximum travel time or distance for each vehicle.

As said before, in this paper we study a multi-decision makers version of the VRPTW. We consider the presence of three categories of decision makers (or actors) involved in the distribution process (see Figure 2): logistics operators, truck operators and customers.

In our scenario, we consider one Logistics Operator (LO), a set of K vehicles each one considers as a Truck Operator ($TO_j, j = 1, 2, \ldots, K$), and, a set of N Customers ($C_i, i = 1, 2, \ldots, N$). For each decision maker we can define a (local) optimization problem. In particular, the

LO ships goods to each customer C_i using the minimum number of TOs assuring that each customer is served. Then, the LO has to minimize the second term of equation $(*)$ satisfying the constraint *b)*. Each TO_j selected from LO has to minimize the cost of serving assigned customers (the first term of equation $(*)$) assuring feasibility of constraints *a)*, *c)*, and *d)*. Each customer C_i has to minimize its cost (the third term of equation $(*)$). Then, each decision maker has to find a feasible solution for its optimization problem by considering that, due to the information exchange between decision makers, as we show in the next section, the parameters of each local optimization problem could be changed. That is, a convergence problem toward a feasible solution must be studied.

3 The multi-agent model

We model the multi-decision makers version of the VRPTW by a multi-agent system, that is, a system composed by a set of self-contained problem-solving entities (e.g., see Jennings and Wooldridge, 1995; Jeong and Leon, 2002) called agents. Each agent operates by collecting data from the environment, elaborating them, and applying strategies in order to achieve its goal. Moreover, each agent has incomplete information, there is not a centralized system control, the computation is asynchronous, and data are decentralized. In fact, in a multi-agent system we could have logically and geographically spread information. Two key issues in a multi-agents system are the classes of agents, and the communication protocol, that is the set of rules used to exchange messages. Each message is information that the agents use to pursue their goal. In particular, we consider a coordinator agent, the LO, which is responsible for the shipments of goods to customers, and, an agent for each TO_j and for each customer C_i. The architecture of the multi-agent model is based on the schema of Figure 2, in which the arrows show the information exchange. A possible set of rules used to exchange messages could be defined as follows:

1. Each customer C_i send requests for goods to the *LO*. The generic request is a couple (quantity q_i, time window $[e_i, l_i]$).

2. The *LO* assigns customers to the TOs. Then, communicates arrival times and prices to customers.

3. Each *TO* exchange customers trying to improve their solutions. *LO* has a supervisor role in order to assure that each customer is served.

4. The *LO* send to customers new price and negotiate with them new time windows.

5. Steps 2, 3, and 4 are repeated until a stop criteria defined by *LO* is reached.

The described multi-agent model will be tested on a real Italian scenario. The possibility to improve the logistics process by using a particular set of rules to exchange messages among actors will be investigated.

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