CHEMICAL ENGINEERING TRANSACTIONS Volume 18, 2009
Editor Jiří Klemeš

DOI: 10.3303/CET0918051

Optimization of logistics in industrial districts through creation of a community of agents

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The aim of this paper is to find an optimal solution for freight transportation in an industrial district taking into account the point of view both of agents and customers, and trying to reduce the environmental pollution. We propose a system architecture that drives agents to cooperate in minimizing costs, and environmental negative impacts. The idea is to achieve an optimization of logistics by setting up a community made of district enterprises. We address the situation in which a virtual coordinator helps the agents to reach an agreement among each other. The objectives are: maximizing customers satisfaction, and minimizing the number of trucks needed. A fuzzy clustering, a fuzzy/genetic system and a greedy algorithm are thus proposed to achieve these objectives, and eventually an algorithm to solve the Travelling Salesman Problem.

1. Introduction

Nowadays, logistics management is becoming a more and more competitive factor among industrial firms, since its aim is to produce value for customers by improving services and lowering costs. In this paper we have analyzed logistic processes within territorial agglomerations of firms, so-called "Industrial districts" (Pyke and Sengenberger, 1992). The atmosphere of districts allows agents creating an integrated system in which performance, potential competitive advantages and economies of scale can be increased as much as the network is efficiently organized (Krugman, 1991). Inside districts any innovation or optimization process achieved by an agent of district becomes an external economy (Marshall, 1925) or rather a district's asset, shared or sharable by other district's agents (Foss, 1996). However, the increase of road transportation demand causes several negative impacts related to current transportation systems, like road congestion, accidents increase, acoustic and environmental pollution. Several attempts have been made in order to eliminate, or at least reduce, the environmental impact of transportation systems. They were directed in improving technological characters (for example, using less polluting fuels), and in any case take the risk of being compromised by a fast growth of transportation demand. Then, the strategies for a more sustainable transport must be directed both in reducing the transportation demand, and in building a transportation system integrating economical effectiveness and environmental purposes. To this aim, rationalization of goods flows,

Please cite this article as: Dell'Orco M., Sassanelli D. and Tiso A., (2009), Optimization of logistics in industrial districts through creation of a community of agents, Chemical Engineering Transactions, 18, 321-326 DOI: 10.3303/CET0918051

obtained through an integrated logistics that coordinates different operations of the logistic chain, has been addressed.
A key tool to optimize logistic services without increasing costs, and to reduce environmental negative impact, is represented by “interaction” (Handfield and Nichols, 1999). It allows a group of agents to handle logistics through information exchange and negotiation, and to reach mutual agreement among agents about belief, goals or plans. According to this we propose an architecture that push for cooperation and coordination among the district agents in logistic field. This framework is a tool, able to create a community that allows users – sharing the same interests – communicating among each other, and thus able to optimize the logistics management.

2. Optimization of logistics in industrial districts

The aim of this work is to find an optimal solution, from the point of view both of agents and customers, for operational planning of freight transportation in an industrial district. More specifically, we consider the problem of minimizing total transportation and environmental costs to match a specific demand, coming from companies in an industrial district, and characterized by quantity of products, origins, destinations, shipping dates, and so on. To this purpose, we propose the formation of a network among logistic services customers, which we shall call “agents”. Usually, in industrial districts there is a lack of inter-firm relationships (Carbonara et al., 2002). The companies often don’t know each other, so they behave like individual agents. As for freight transportation, they contact individually transportation services providers, just when they need to deliver their products. In other words, small and medium firms in an industrial district generally require “spot” transportation services. However, vehicles often are not filled up, since a single company could be not enough to fill a truck. As a consequence, transportation costs and external diseconomies such as accidents, pollution and traffic congestion increase. Therefore, in this paper we have studied a model in which firms belonging to the same industrial district, for example, can agree upon delivery dates, quantity of product to deliver, or destinations. In this way, more companies can use together the same vehicle, and consequently reduce the number of vehicles used for shipment. Thus, the filling rate of vehicle increases. The system aims to facilitate contacts and negotiation processes among agents that start acting, in this way, like a *community of agents* in the district. Although every agent in an industrial district has its own interests, goals and tasks (Shehory and Kraus, 1998), a community of agent is advisable when single agents’ demands cannot be fulfilled individually in an economical way. In fact, it could be beneficial in case group performance is more efficient than performance of singles (Shehory et al., 1998). In this paper we formalize the idea of *communityware*. It is defined as an electronic medium that facilitates contacts among agents who have similar interests and preferences, but possibly don’t know each other. According to this, the proposed methodology allows improving cooperation and coordination among the agent in a quick way.

3. Creation of a community of agents

The agents’ community is created through an algorithm that achieves the logistic optimization. In the proposed model, agents log in the system through the web, and provide, by the users interface, the demand attributes as destinations, quantities of product to be delivered, and possible ranges of delivery dates. All these data are then stored into the demand database. A kind of virtual coordinator of the agents' coalition (Shehory and Kraus, 1998), undertaking the initiative of forming the coalition among interested agents, is then created (fig. 1). It helps the agents to reach an agreement, while preserving a satisfactory level of system efficiency and fairness.

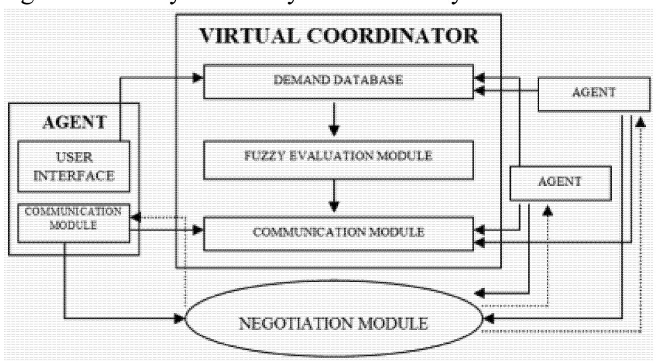


Figure 1. System Architecture

Agents iteratively submit shipment demands to the coordinator. Afterwards, coordinator starts to browse the database, picking out and clustering "similar" demands, on the basis of closeness of destinations and *similarity* of delivery dates entered by agents. The system sets up the agents' community, using a fuzzy algorithm (Bezdek, 1987). The use of *Fuzzy Clustering C-means* (FCM) algorithm proposed in this paper essentially deals with the task of partitioning a set of agents into a number of homogeneous classes (clusters) with respect to a suitable similarity measure. The agents belonging to anyone of the clusters are similar to each other (*intra-class similarity*), and as dissimilar as possible to agents belonging to different clusters. Afterwards, the system calculates the number of trucks T having capacity C (usually 25 tonnes), needed to satisfy shipment demands Q_i (i = 1,...n), with the hypotheses that :

i. capacity C is constant for every truck,
ii. there are no constrains about the number of available trucks.

According to this, the relevant equation is:

$$T = \sum_i \left(\text{minimum integer} \geq Q_i/C\right) \tag{1}$$

Of course, when the number of clusters increases, the degree of *inadequacy* of partitions decreases, but the number of trucks needed to fulfil the transportation demand increases. To find the optimal solution, we have proposed, along with the FCM algorithm, a Fuzzy/Genetic (F/G) algorithm. After FCM clustering, though selection, crossover and mutation among cluster's members, and their shipment demands attribute, this algorithm finds the *nearest optimal* solution. In this application to logistic systems, the population is initialized as random binary strings. Selection of individuals to be replaced is done according to "elitism method" in which worst individuals are replaced by the best individual. In fig. 2 the relevant pseudo-code is reported.

```
BEGIN
        Create initial population
        Calculate individual fitness
        WHILE NOT finished DO BEGIN
                BEGIN
                        Select new population (elitism)
                        Crossover between two individuals
                        Mutation of single individuals
                        Calculate the descendants' fitness
                END
                IF stop condition is satisfied THEN
                        finished:= TRUE
                END
        END
END
```

Figure 2. Pseudo-code for the Fuzzy/Genetic algorithm

The "best individual" is found by two Fuzzy Inference Systems. The first one finds, through a set of fuzzy rules, the agents' satisfaction according to the range of dates they entered, through the following set of fuzzy rules:

1. **If** date is *not preferred* (right) **then** satisfaction is *low*
2. **If** date is *preferred* then satisfaction is *high*
3. **If** date is *not preferred* (left) **then** satisfaction is *low*

The second one calculates the "goodness" of solution based on the maximization of agents' satisfaction, and minimization of the number of trucks needed, through the following set of fuzzy rules:

1. **If** trucks are *many* **then** solution is *bad*
2. **If** trucks are few **then** solution is *the best*
3. **If** satisfaction is *low* **then** solution is *bad*
4. **If** satisfaction is *high* **then** solution is *the best*

Mutation and crossover processes start from a situation in which all the individuals are the same. The procedure restarts iteratively, until the best value of fitness function is found, or the number of iterations exceeds a fixed threshold. Afterwards, the system optimizes truck loading through a greedy algorithm. The greedy value is given by (2):

$$r = (\text{availability to load})/\ \text{max capacity} \qquad (2)$$

The algorithm loads the trucks so that the load split for each agent is as small as possible. Finally, the proposed system solves a Travelling Salesman Problem to minimize delivery route. In this way, the system finds out the possible members of the coalition among agents with similar transportation demand.

The virtual system coordinator submits to agents the set of clusters having the best performance in terms of number of trucks needed and agents' satisfaction, a near-optimal solution for the logistic problem. On their turn, the agents can accept the proposed solution or, through a *negotiation module*, can change the demand attributes. The system shows to agents the negotiation chances, and any agent could decide individually to change his tolerance about delivery date, fulfilling a not completely full truck and thus reducing the shipment costs. Otherwise, they could reduce or increase load amount, and thus agree with another cluster member having same shipment destinations, to takes advantage in using a truck completely full. In this case, the procedure restarts with formation of new clusters. In fig. 3, an example of results of the algorithm is depicted.

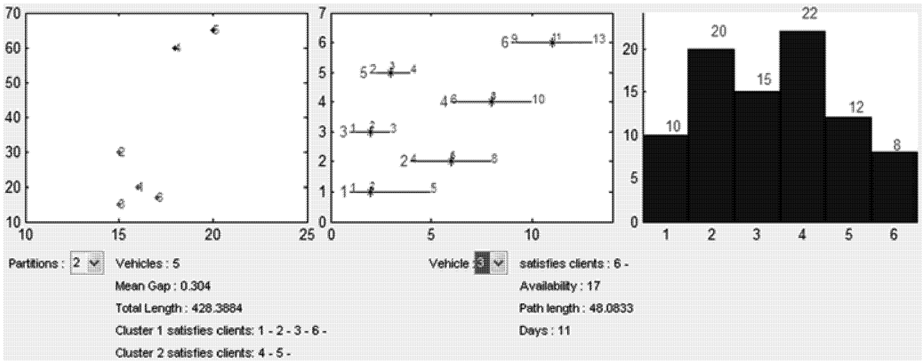


Figure 3. Example of results of the algorithm shown by the system

4. Numerical example

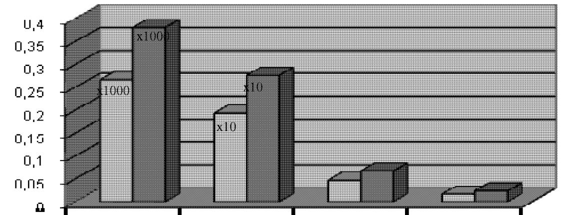
The proposed model allows reducing pollutions through the reduction of truck used, due to the agreement between district agents. We have compared the emissions in case each agent delivers his load separately, with the case in which the agents agree to optimize the truck load. There are several emission models in specific literature (see for example Horowitz, 1982; Joumard et al., 1995), to calculate the emissions of polluting gases from vehicles through the assessment of speed and acceleration in standardized urban driving cycles. In particular, the MODEM model proposed by Joumard et al. provides, for classes of speed and speed by acceleration, emissions of four of the most widespread pollutants (CO, HC, NO_x and CO_2). Other models consider the basic components of vehicle movements (Crauser et al., 1989), in order to characterize the emission (André et al., 1995; André, 1996). Another model is the "Comprehensive Modal Emission Model" (CMEM), which takes into account the fluctuations of speed and allows the calculation of instantaneous emissions, developed by the University of California, Riverside (An et al.,1997). Pollutants usually considered, because of their potential impact on health, are nitrogen oxides (NO_x), volatile organic compounds (VOCs), carbon dioxide (CO_2) and fine particulate matter (PM).
The emission model used in this study is derived from that proposed by Int Panis et al. (2006), and is expressed by the equation (3):

$$E_{t,tot} = N_t \cdot \left(f_{k,1} + f_{k,2} \cdot v_m + f_{k,3} \cdot v_m^2 + f_{k,4} \cdot a_m + f_{k,5} \cdot a_m^2 + f_{k,6} \cdot v_m \cdot a_m\right) \qquad (3)$$

where:

$E_{t,tot}$ = total instantaneous emission (g/s) at the time t;
N_t = total truck number on at the time t;
v_m = average speed of trucks (m/s);
a_m = average acceleration of trucks (m/s^2);
$f_{k,1}, \ldots f_{k,6}$ = specific emission coefficients of pollutants (NO_x, VOC, CO_2, PM), k=1,...4.

We have hypothesized a case in which five agents have to deliver 164 tons of goods (6,6,27,105,20 respectively). In case they don't agree, the number of trucks needed is ten (Q_i/C). Indeed, they can achieve an agreement and, using the proposed method, minimize the number of trucks. In this case, the resulting number of trucks needed is seven. Accordingly, the emission of pollutants reduces as the following table shows (fig. 4):



	CO_2	NO_x	VOC	PM
7	0,265914796	0,192922716	0,0467227	0,01664978
10	0,37907020	0,27660300	0,06674672	0,0237064

Figure 4. Emission of pollutants

5. Conclusions and future developments

The framework proposed could be useful to streamline the flow of goods in industrial district. Indeed it makes easier an agreement among district firms, and therefore reduces the number of vehicles used. The proposed system is able to create an electronic community, where the agent can meet, exchange information and knowledge, and possibly negotiate a compromise among themselves. It appears that this framework may be used to provide real time solutions to complex practical logistics and negative environmental problems. Future research will focus on the negotiation phase.

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