ANTS COLONY SYSTEM FOR SUPPLY CHAIN ROUTES OPTIMIZATION

G. De Sensi, F. Longo, G. Mirabelli, E. Papoff
University of Calabria
Via Pietro Bucci, Cube 46C, 87036 Arcavacata di Rende, Italy
{g.desensi, f.longo, g.mirabelli, e.papoff}@unical.it
URL http://www.ingegenria.unical.it/impiantiindustriali

KEYWORDS
Modeling, Simulation, Ants Colony System, Optimization

ABSTRACT

The research work proposes a hybrid simulation based approach for efficiency enhancement of a supply chain operating in Calabria (Italy) in the field of pharmaceutical business retail. The supply chain is made up by several and different actors: suppliers, distribution centers, and pharmacies so the optimal supply chain organization is a critical factor for improving systems efficiency and performances.
The attention has been focalized on routes optimization, in other words the supply chain has been analyzed in terms Traveling Salesman Problem (TSP).

INTRODUCTION

As well known from literature the TSP aims to find the shortest tour in a set of given cities. Such kind of problem is a remarkable issue in several and different sectors and fields not only in logistics and transportation. The TSP problem is a correct representation of many real problems:

- machines scheduling;
- clustering of data arrays;
- warehouse material handling;
- analysis of crystals structures;
- gas turbine engines overhauls.

Such kinds of problems require a combinatorial approach for finding optimal solutions. In most of the cases the critical issue is the time for testing all the variables combinations: the higher is the number of variables the longer is the time for combinatorial calculations (as can be happen in supply chains, consider, for instance, the higher number of orders, items, information flows, finances flows and so on).
The problem of long times for combinatorial approach can be faced following two different ways:

- splitting it in easier problems;
- testing only the best variables combinations.

The next paragraphs propose a hybrid simulation based approach for solving the TSP problem (routes optimization) and enhancing supply chain efficiency. The hybrid approach contemporarily uses Modeling & Simulation and Artificial Intelligence techniques. In particular a supply chain simulation model has been used together with Ants Colony System (ACS) for obtaining both routes optimization and short evaluation time (high computational efficiency).
The ACS approach learns from experience and previous experiments and appears more flexible in comparison of traditional algorithms of operational research. Inspired by natural systems the algorithm recreates ants' behavior. Ants questing for food go out from the nest and explore neighborhood randomly depositing on the ground pheromones showing to other ants the best way for reaching food sources.
The optimization algorithm in combination with the supply chain simulation model allows to minimize the logistic costs by means of deliveries optimal scheduling and guaranteeing on time products delivery as well.

SUPPLY CHAIN DESCRIPTION

Italian pharmaceutical distribution is regulated by many government laws and standards which impose peremptory time of delivery, special conditions for stocking, high volumes of transition and items deliveries within two hours from pharmacies purchase orders emission. Each pharmacy can place orders to different distribution centers as well as the distribution centers receive items by different suppliers.
The supply chain analyzed in this research study is made up by 4 suppliers, 1 distribution center, 127 pharmacies (located in the province of Cosenza, Italy) and two distribution companies that respectively guarantee items transportations from suppliers to distribution centers and from distribution centers to

pharmacies. In figure 1 is shown a schematic representation of the supply chain.
Due to the low number of suppliers and taken into consideration that suppliers shipments are not scheduled with daily frequency as well as provide a huge amount of items the authors decided to focalize on customers shipments (twice per day, anti-meridian and post-meridian deliveries). Different trucks perform deliveries following different routes. Each route defines a geographic area (as reported in table 1) and each area is characterized by an identifying number.

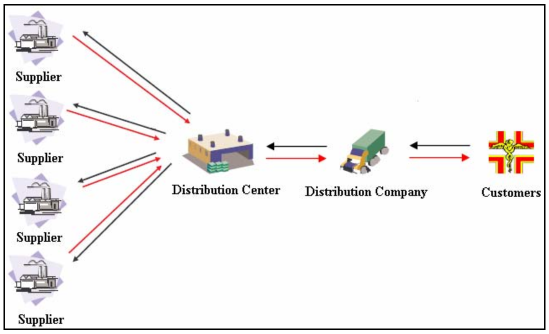

Figure 1: Supply chain scenario

As before mentioned deliveries to customers are performed twice per day, the customers' purchase orders are respectively placed before 1:30 PM for postmeridian delivery and before 7:30 PM for antemeridian delivery (the morning after).
The distribution center sets items for the shipment. Trucks loading schedule depends on the localities that have to be reached: the greater is the distance the greater is the priority in the loading schedule.

Table 1: Routes description in terms of geographic areas and pharmacies

Geographic Area	Identifying number	Pharmacies in the area
Zona-Rossano	1	19
Alto-Tirreno	2	11
Basso-Tirreno	3	13
Pre-Sila	4	7
Dintorni-Cs	5	8
Alto-Ionio	6	13
Cosenza	7	21
Zona-Acri	8	13
Zona-Fagnano	9	22

The supply chain, as previously mentioned, is devoted to support pharmaceutical business retail; the priority tasks are:

- distribution efficiency enhancement providing to customers higher service levels;
- manpower utilization high levels for reducing as much as possible logistic costs.

In order to reach such objectives a supply chain simulation model has been implemented together with interface tools and optimization tools based on ACS. The proposed approach (better explained in the next paragraphs) reduces the logistic costs and increases transportation efficiency guarantying on time deliveries.

THE HYBRID SIMULATION MODEL

In a supply chain the main variables describing the system behavior can be considered as stochastic; an analytic approach for studying supply chain problems (very often characterized by restrictive assumptions) allows gaining knowledge about the system but, very often, it doesn't allow results transfer on the real system. In other words it becomes quite difficult to develop analytical models without restrictive assumptions, involving all variables and keeping into consideration the stochastic nature of the system.
The authors propose a simulation model implemented using the discrete event simulation package eM-Plant (by Tecnomatix Technologies). The modeling phase doesn't keep under consideration the traditional approach suggested by software's developers. The library objects provided by the software such as resources and entities cause two different types of problems:

- the higher number of entities flowing in the model the higher time required for executing a simulation run (consider that in a supply chain there are thousands of entities flowing in the model such as purchase orders and items) so the simulator becomes quickly inefficient from a computational point of view;
- even though the library objects provide different features for modeling system characteristics sometimes it becomes difficult to recreate, with an acceptable degree of precision, the real system.

The simulator has been implemented using an advanced modeling approach. Simple++ simulation language (provided by the software) is used for modeling, by means of code, suppliers, distribution centers and pharmacies as well as for implementing the rules and the policies governing the supply chain. The flow of entities is substituted by flows of information opportunely recorded in tables whilst the time advancing is scheduled by event generators.

The modeling approach proposed allows a remarkable time reduction for executing simulation runs guarantying high modeling flexibility as well (the code can be later accessed and modified for implementing new supply chain features).
In addition the simulation model presents a graphic users interface (see figure 2) for planning simulation experiments and supporting real time distribution operations. Input information as antemeridian or postmeridian deliveries, routes and customers to be served can be easily inserted and the simulation run is controlled by means of reset – start – stop buttons. Simulation results as trip times, unloading times, logistic costs, profits and service level for each pharmacy can be visualized using ad hoc buttons (see fig.2).

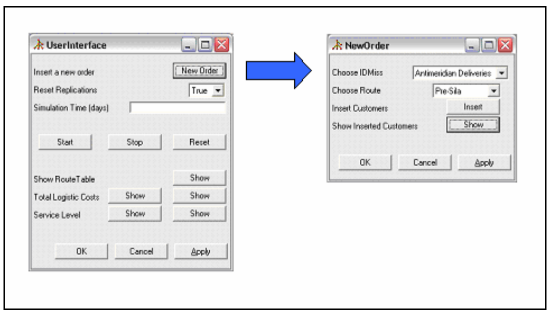

Figure 2: Graphic User Interface

To optimize the scheduling of the deliveries it has been implemented an algorithm that is based on the Ants Colony System behavior. It's well known that ants are social insects living in a colony that are capable to solve complex problems without use visual cues but only by means of a particular form of indirect communication called stigmergy.
By exploiting stigmergy the ants are able to find the shortest path between the food source and their nest. The ants deposit along the path chemical substances called pheromones. Other ants follow pheromone trails with the same probability, in particular higher is the amount of pheromone on the path more number of ants will move along it (this mechanism is called positive feedback). As the time goes by pheromone trails evaporate but other ants crossing the path reinforce it, this explains how ants are capable of finding the shortest path.
Thanks to stigmergy ants adapt their behavior to environment changes and they are always successful in finding a new shortest path once the old one is no more available [6].
As shown in figure 3 when ants have to decide between two paths after a transitory phase they will choose the shortest one. Suppose to consider ants colony walking along path (1) (in this case the shortest one) which connects food source with nest, once an obstacle appears the initial path is no longer available (2).

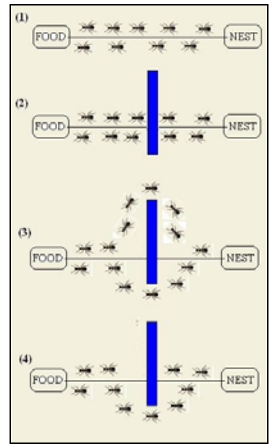

Figure 3: Ants finding the shortest path

The ants cannot proceed so they have to decide whether turn left or right, since they don't know the shortest path, it can suppose that half ants will turn left and the other half turn right (3). The ants that have chosen the best path will reconstitute pheromone trail more rapidly than the others and they will deposit on the ground a more amount of pheromone per time unit. Thus very fast all ants will choose the shortest path (4). The behavior of real ants has inspired a class of algorithms called ants algorithms in which artificial ants cooperate to find good solutions by means artificial pheromones.

OPTIMIZATION ALGORITHM

For a better understanding of the simulation results this paragraphs reports some reminds on optimization algorithms based on Ants Colony System for solving the Traveling Salesman Problem (TSP). For a more detailed explanation of ACS please refer to [7]-[10]. Given a set of cities the TSP aims to find the shortest closed tour which allows to visit each city only once.
In this algorithm the cities are represented by the vertices of a graph and the links between the cities are the edges of the graph. On each edge of the graph is deposited an artificial pheromone $\tau_{(r,\ s)}$ and a cost function $\delta_{(r,\ s)}$ which assign to the path from the node r to the node s the necessary cost to walk the edge. In the initial phase (at the iteration $t=0$) we have on each edge of the graph a certain quantity of pheromone which is used by the ants to build tours. This amount of

pheromone will be reinforced every time an ant crosses the edge. In particular, once the ant *k* has completed a tour P_k at the iteration *t* will deposit on each edge of the tour an amount of pheromone $\Delta\tau_{rs}^{k}(t)$. The quantity $\Delta\tau_{rs}^{k}(t)$ is a function of the length of the tour P_k as follows in equation 1:

$$\Delta\tau_{rs}^{k}(t) = \begin{cases} Q / L_k & \text{if edge } (r,s) \in P_k(t) \\ 0 & \text{if edge } (r,s) \notin P_k(t) \end{cases} \tag{1}$$

where *Q* is a parameter that defines the unit of pheromone. An ant chooses the next city to visit according to a probabilistic state transition rule. Such rule gives the probability with which an ant *k* in the city *r* chooses the next city *s* to move to. The probability $p_{rs}^{k}(t)$ has been defined as follows (equation 2):

$$p_{rs}^{k}(t) = \begin{cases} \dfrac{[\tau_{rs}(t)]^{\alpha}[\eta_{rs}]^{\beta}}{\sum_{c \in I_k(r)}[\tau_{ic}(t)]^{\alpha}[\eta_{rc}]^{\beta}} & \text{if } s \in I_k(r) \\ 0 & \text{if } s \notin I_k(r) \end{cases} \tag{2}$$

where $p_{rs}^{k}(t)$ is the probability with which the ant *k* chooses the next city *s*, $\tau_{(r,s)}$ is the amount of pheromone on the edge (r, s), $\eta_{(r,s)}$ is an heuristic measure of the desirability of the considered edge, α and β are two parameter which weigh the importance of the pheromone and the heuristic, $I_k(r)$ represents all the cities that the ant *k*, when it is in the city *r*, has to visit. It is also necessary to introduce a mechanism of pheromone evaporation which allows to make less attractive the worst tours. Pheromone evaporation on each edge has obtained by a coefficient of evaporation $\rho \in [0,1]$. On the edge (r, s) at iteration t+1 the amount of pheromone will be (equation 3):

$$\tau_{rs}(t+1) = (1-\rho)\,\tau_{rs}(t) + \Delta\tau_{rs}(t) \tag{3}$$

where $\Delta\tau_{rs}(t) = \sum_{k=1}^{m}\Delta\tau_{rs}^{k}(t)$ and *m* is the number of ants. After ants have completed its tour the shortest path will have more amount of pheromone while, since pheromone evaporation, longest tours will have less. When each individual of the artificial colony has completed a tour, the ants will be reactivated to find a new route and appealed by the pheromones previously deposited on the edges they will attain better solutions.
In the algorithm the exploitation of a tour marked with pheromone (experience already acquired) and the research of new tour (learning of new knowledge) depends on a parameter $v_0 \in [0,1]$. Each ant has a casual number v, if this value is less than v_0 the ant will choose a path already marked otherwise will prefer a new path. The parameter v_0 allows to study the whole space of solutions. The number of the ants used in the algorithm (*m*) is a constant and it can be considered as priority parameter. In fact a low number of ants negatively act on the stigmergic communication that cannot take place, instead an high number of ants cause inefficiency from a computational point of view. It has been assumed for *m* a value equals to the number of the cities. In addition it has been chose α = 1, β = 2, ρ =0.5 and *Q* = 50; these values allows to obtain an efficient algorithm for solving the problem in a short period of time.

SIMULATION RESULTS

The ants algorithm implemented in the model represents an important support decision tool to optimize the distribution system. In particular the algorithm allows to optimize the delivery routes toward pharmacies and to schedule products deliveries.
By means of the simulation model the optimization algorithm has been applied to the supply chain focalizing on items distributions to pharmacies.
Each route has been optimized reducing the total amount of kilometers as shown in figure 4. Some routes as Rossano and Alto-Tirreno shows a remarkable decrease of the total kilometers.

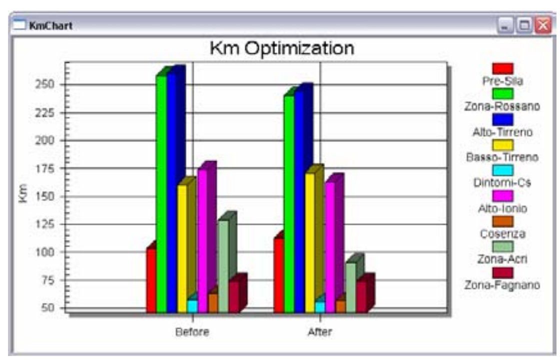

Figure 4: Comparison between Km driven before and after the optimization

If we consider the service level provided to customers we can assert that in the case of pharmacies the service level is function of delivery time starting from the antemeridian or postmeridian business hours. Reducing the total amount of kilometers per routes means faster deliveries or, in other words, anticipated deliveries

(respect to the non-optimal configuration) so, as consequence, the service level provided to each customer has been increased.
In addition to the previous analysis the actual logistic scenario has been compared with the optimal one (obtained using the ant algorithm) in terms of logistic costs. Figures 5 and 6 show costs reduction on weekly and monthly basis. In the first case the gain is about 200 euros per week whilst in the second case is 800 euros per month.

Figure 5: Comparison between weekly costs

Figure 6: Comparison between monthly costs

Even tough the costs reduction is small it is however challenging and important at the same time to obtain such reduction because each route is driven twice per day and 365 days per year (because the pharmaceutical deliveries are performed every day).
The total cost reduction per year (or profits increment) is about 8000 euros (see figure 7).
For a better understanding of the presented results consider that 8000 euros per year can be used for covering an half of the trucks insurance expenses or almost the gasoline of all the trucks for two months.

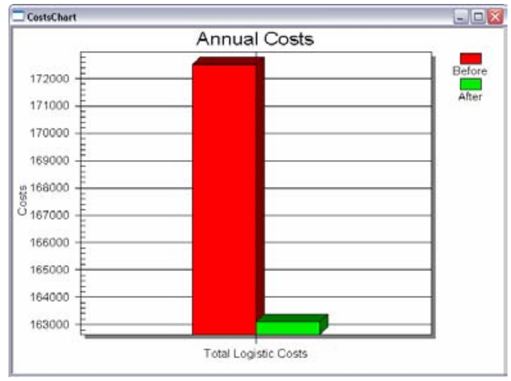

Figure 7: Comparison of logistic costs on yearly basis before and after the optimization

CONCLUSIONS

The simulation model can be considered as a support tool for supply chain management in the field of pharmaceutical distribution. The advanced approach used in the modelling phase guarantees high modelling flexibility (also in terms of future changes or new implementations) and short time for performing simulation runs as well. The graphic interface allows the user to easily test different distribution scenarios and carry out logistic costs and service level analyses.
The implementation of the ants colony system based algorithm assures better results (from a computational point of view) than the traditional techniques of operational research. The ants algorithms are characterized by versatility (they can be adapted to similar problems), robustness (they allow to find solution even though some ants of the colony fail), and decentralization (no one organises activities), which allows them to solve particularly complex problems.
Thanks to the hybrid simulation model it is possible to obtain routes optimization and a remarkable reduction of the total logistic costs as well. Further researches are still on going for studying the distribution center inventory management.

REFERENCES

[1] Banks J., “Handbook of simulation”, Wiley Interscience.
[2] F. Longo, G. Mirabelli, E. Papoff, “Modeling Analysis and Simulation of a supply chain devoted to support pharmaceutical business retail”, Proceeding of ICPR 18, July 31 – August 4 2005, Salerno (SA) (Italy).

[3] C. Briano, A. G. Bruzzone, F. Longo, E. Papoff, S. Viazzo, “Simulation and virtual reality applied to modelling retail and store facilities”, Proceedings of Summer Computer Simulation Conference, July 25 – 29 2004, S. Jose, California
[4] G. Bruzzone, S. Viazzo, F. Longo, G. Mirabelli, E. Papoff, C. Briano, M. Massei, “Discrete event simulation applied to modelling and analysis of a supply chain”, Proc. of MAS 2004, Bergeggi (Ge) 28-30 October.
[5] Ballou R. “Business Logistics/Supply Chain Management", 2003, Prentice Hall, Readings.
[6] S. Goss, S. Aron, J.L. Deneubourg, J.M. Pasteels, “Self organized shortcuts in the Argentine ant”, 1989.
[7] L.M. Gambardella, M. Dorigo, “Solving symmetric and asymmetric TSPs by ant colonies”, Proceedings of the IEEE Conference on Evolutionary Computation, New York, 1996.
[8] Marco Dorigo, Eric Bonabeau, Guy Theraulaz, “Ant algorithm and stigmergy”, Future Generation Computer Systems, 2000.
[9] J.-L. Deneubourg, S. Goss, Collective patterns and decision making, Ethol. Ecol. Evol. 1, 1989.
[10] M. Dorigo, L.M. Gambardella, “Ant colony system: a cooperative learning approach to the traveling salesman problem”, IEEE Trans. Evol. Comput. 1, 1997.
[11] Sanjay Jain, “Supply chain management tradeoffs analysis”, Proceedings of Winter Simulation Conference 2004, Washington, 1358-1364.
[12] Zandin K. B., Maynard’s “Industrial Engineering Handbook”, McGraw-Hill, NYC.
[13] MontGomery D.C., Runger G.C., “Applied statistics and probability for engineers”, 2003 Third Edition.
[14] Monks J.G."Operations Management", 1996 McGraw Hill, NYC.
[15] Roberson J.F "Logistics Handbook", 1994 Free Press.
[16] Banner D.K. "Designing Effective Organizations: Traditional and Transformational views", 1994 Sage Thousand Oaks.
[17] Birkin M. Clarke G, Clarke M.P, "Retail Intelligence and Network Planning", 2002 J.Wiley, NYC.
Blackwell R.D. "From Mind to Market", 1997 Harper-Collins Publisher, NYC.
[18] Bolstorff P., Rosenbaum R. "Supply Chain Excellence: SCOR Model", 2003 Amacom.
[19] Seifert D, Marzian R, McLaughlin J. "Collaborative Planning, Forecasting, and Replenishment: How to Create a Supply Chain Advantage", 2003 Amacom.
[20] David Simchi-Levi, Philip Kaminsky, Edith Simchi-Levi: "Designig and Managing the Supply Chain", McGraw-Hill.