An Integrated Approach for Production Planning and Distribution to Handling Exceptions

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ABSTRACT

In an international competitive environment, where companies can sell their products all over the world, collaboration with other companies is of utmost importance, as a means to obtain an optimal utilization of their own resources and a competitive advantage over other supply chains. Nevertheless, in real world, most businesses are reluctant to share demand information or future plans with others, even if they belong to the same supply chain, the reason being that most of them see any other company as a potential competitor. This paper describes the architecture of a collaboration system between three different echelons in a supply chain; i.e. a company, its suppliers and customers. This system tries to provide solutions to improve the supply chain by identifying the information that must be exchanged between nodes and developing methodologies for production and distribution planning and scheduling in a coordinated manner. Moreover, a number of exceptions have been considered, both in production and distribution, to make the model as realistic as possible. With regard to the production stage, this paper attempts to solve the problem of dynamic production scheduling with multiple plants. As regards the distribution stage, the paper presents the problem as a Dynamic Vehicle Routing Problem with time windows and backhauls. Apart from this, we also present some meta-heuristics, which will be used to address the problems. Finally, we expose the progress made so far, introduce several conclusions and provide some future research related to the topic. This research is part of the PRODIS project (Grant PI2011-58, funded by the Basque Government in Spain).

1. INTRODUCTION

Traditionally, companies have focused their interest on their own assets but over the last years they have started to broaden their scope to include other companies, since competition no longer applies to individual companies but to supply chains. A supply chain is a network of companies which performs the functions of procurement of raw materials, transformation of these raw materials into intermediate and finished products, and distribution of these products to customers. Until recently, each company focused on its own business without considering the benefits that could arise from the collaboration with other companies of the same supply chain. But in global markets, where competition is fierce, it is more necessary than ever to promote the collaboration of the different echelons of a supply chain in order to optimize the utilization of resources or obtain a competitive advantage over other companies. However, in practice, the companies do not collaborate with each other for fear of revealing or sharing their private information, among other things.

2. PROBLEM SCOPE

This article describes the architecture of a collaboration system in a supply chain consisting of 3 levels, i.e. suppliers, company and customers. This system tries to provide solutions that benefit the supply chain as a whole by identifying the information that should be exchanged between the different nodes and developing methodologies for production scheduling and distribution planning in a coordinated manner. In this respect, this article contributes to manage not only the value chain of each individual company, but also the value chain of the extended company, because it studies in depth the implications of a change in the supply chain for other related entities. Thus, the aim is to connect the production scheduling and distribution planning of the different entities of the supply chain in order to obtain a better global solution.

As far as production scheduling is concerned, each company has traditionally generated their own production schedules statically and independently. But supply chains are subject to the so-called bullwhip effect, where unplanned demand variations tend to increase the further they are from the ultimate customer. Equally, as regards the distribution of orders to customers, the so-called vehicle routing problem (VRP) has extensively been analyzed. But both dynamic production and distribution problems are gradually attracting more interest, due to its closeness to real-life situations and potential benefits for companies. The integration of production-distribution problems has scarcely been studied in the literature [1], [2], [3]. In general terms, these models use some simple assumptions and work only statically, which means they are neither realistic nor useful for companies.

This research proposes an approach for production planning and distribution with the following objectives:

- Identification of the information to be exchanged between different echelons in the chain.
- Coordination with suppliers and customers to ensure availability of raw materials and adjust unexpected production needs and untoward distribution needs.
- Exception handling in real time.

3. General Framework of the System

Demand variations and possible supply problems are inevitable, so it is necessary to ensure that the supply chain is responsive and flexible. Therefore, a fluent information exchange between different members of the supply chain is highly desirable. The different components of the supply chain need to cooperate with each other so as to exchange information. This research is part of the PRODIS project (Grant PI2011-58, funded by the Basque Government in Spain). The company that has been selected for this project has multiple plants that operate autonomously and independently, but are also able to share information and work together if unexpected events occur that requires it. In addition, the enterprise has multiple independent and autonomous local depots, which also share information with each other and can work together if it is necessary.

The general communication framework of this system is shown below (see fig. 1).

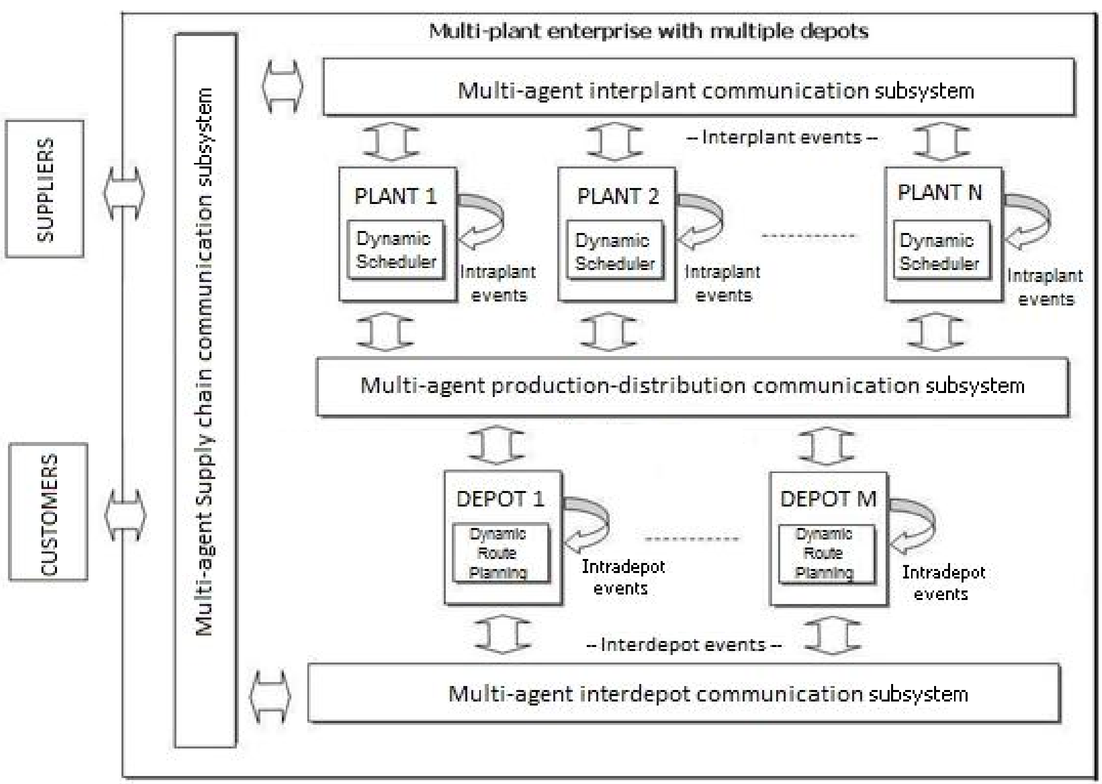

Figure 1: Multi-plant enterprise with multiple local depots.

The communication subsystems that have been identified in this framework are the following:

- The intraplant communication subsystem, in which unexpected events that can cause partial or complete production schedule reprogramming are handled. In the same manner, the intradepot communication subsystem, in which unexpected events that can cause partial or complete distribution schedule re-planning are managed.

- The multi-agent interplant communication subsystem, where unexpected events occurred in a plant that can affect other plants are handled. In the same manner, the multi-agent interdepot communication subsystem, in which unexpected events produced in a depot can affect other depots are managed.

- The multi-agent production-distribution communication subsystem, where unexpected events occurred in plants that may affect depots, or unexpected events arisen in depots that may affect plants are handled.

- The multi-agent supply chain communication subsystem, in which unexpected events arisen in a plant and/or warehouse that may affect suppliers and/or customers are handled.

4. EXCEPTIONS

One of the main points of the proposed framework is that it provides exception handling in real time, giving an almost immediate response to any unexpected event. Exceptions have been divided into two groups, namely internal and external exceptions. Internal exceptions are related to the company and may have their origin in production or distribution. Otherwise, external exceptions are not related to the company and may have their origin in events created by suppliers or customers.

Table 1. Types of exceptions

Internal exceptions		External exceptions	
Production-related	Distribution-related	Suppliers-related	Customers-related
Machine breakdown	Vehicle breakdown	Returned material	Increase of order quantity
Missing operator	Missing driver	Partial delivery	New rush order
Unavailable auxiliary resource	Unavailable customer	Delayed delivery	Decrease of order quantity
Suspended order	Traffic delays	Faulty delivery	Changed due date
Repetition of faulty items	Damaged order	Canceled delivery	

4.1. EXCEPTION HANDLING

At this point, a brief explanation about how an unexpected event is handled by the system will be provided.

Damaged order

This event occurs when part of one or more orders are partially or completely damaged on the way from the warehouse to the customer. This may happen when the customer or the truck driver realizes that the order has been damaged during transportation.

Depending on the percentage of the damaged order and the possibility of reaching an agreement with the customer, the system considers several cases:

a) Only the undamaged part of the order is delivered and the rest of the order will be either re-delivered as a new rush order or canceled, depending on the customer decision.

b) The entire order is delivered as a new rush order.

c) The customer decides to cancel the entire order.

If there is not enough stock in the depot to cover the damaged units, this will be communicated to production through the multi-agent production-distribution communication subsystem so as to plan the production order and calculate the new delivery date to be proposed to the customer. This involves a new customer-related exception that is called “new rush order”. In either of the above cases, the distribution plan will be modified in order to pick up the damaged order and inform the affected customers about the updated distribution plan.

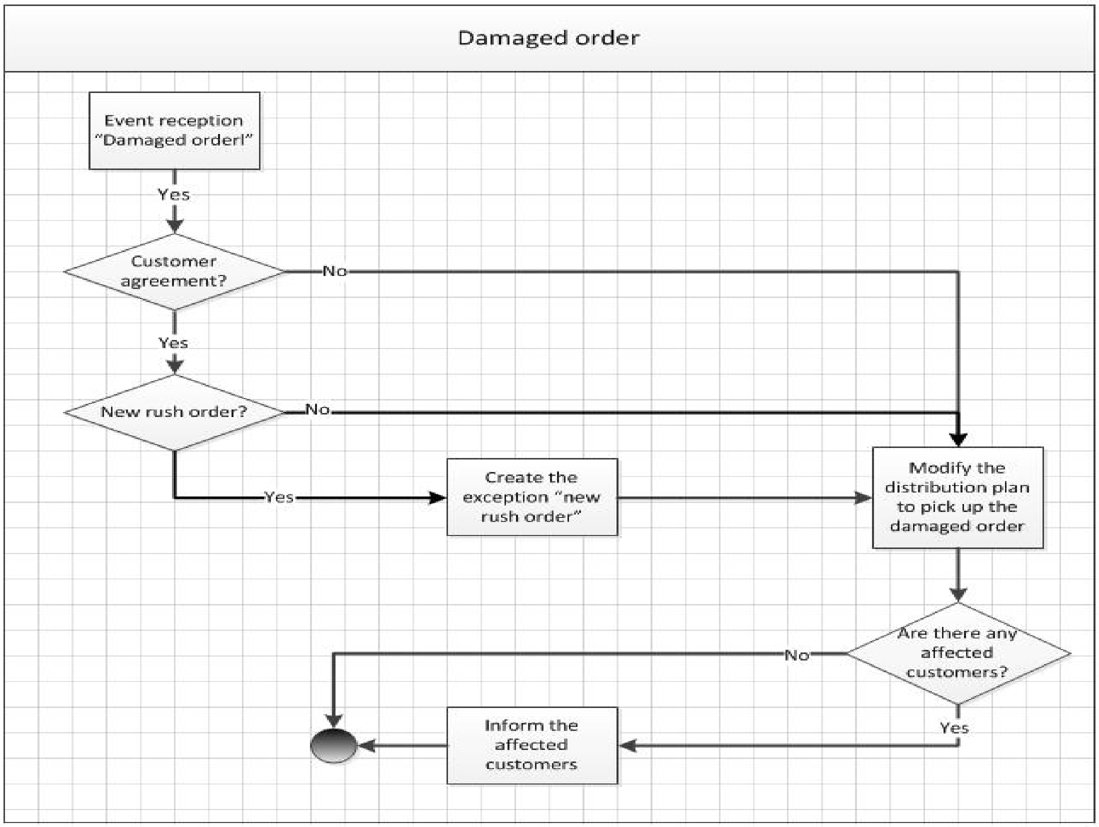

Figure 2: Flowchart of a “damaged order” exception

5. DISTRIBUTION

This section will discuss how to address the problem of distribution in this project.

5.1. THE DISTRIBUTION PROBLEM

As already explained above, in this project there are two phases, the first one is referred to production, and the second one is about distribution. The latter is responsible for delivering products to customers and it is the one that has been selected to be explained in more detail in this paper.

In this problem we have defined a distribution network composed of multiple warehouses or depots. These depots serve previously assigned clients, based on several factors e.g. proximity. This means that a customer will only be served by vehicles belonging to a single depot. Fig. 3 shows an example of a possible environment comprising several depots and customers.

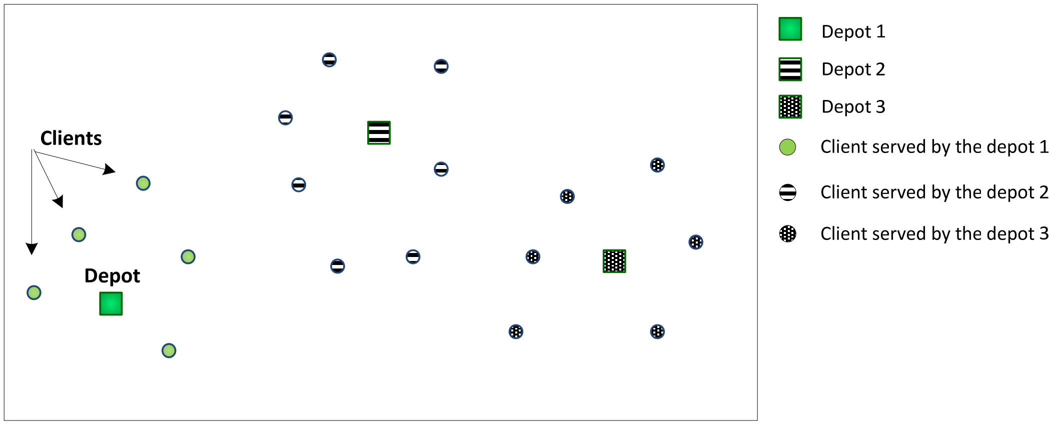

Figure 3: Multi-depot environment

5.2. Specification of the Problem and Review of the Literature

The problem to be tackled is the so-called Dynamic Vehicle Routing Problem with Backhauls and Time Windows, which is a hybrid of three different problems of routing vehicles. Below are described several features of the problem, i.e. backhauls, time windows and dynamism.

Backhauls

Backhauls is a feature that allows customers to request either delivery or pick-up of materials [5], so that truck capacity becomes an extremely important factor. In recent years it has been shown that much money can be saved if we combine the two services, i.e. visiting both suppliers and consumers within the same route. The Interstate Commerce Commission estimated that, with the introduction of backhauling, savings in the US grocery industry had reached 160 million of dollars [6].

In this case, customers can order pick-up or delivery, but not both things simultaneously. In addition, deliveries are done first, and then pick-up. This is so because, otherwise, a rearrangement of materials within the truck could be necessary. This may happen for example if we put materials at the front of the truck when there are some goods that still have to be delivered at the back. In our problem, reverse logistics could be necessary when a customer is not satisfied with the order received, either because it is defective or because a delivery error has arisen.

Time Windows

This feature allows each client to have a time window associated $[e_i, l_j]$. This time range has a lower limit and an upper limit that trucks must respect. This means that vehicles have to meet customer demand within that time window. Therefore a route will not be feasible if a vehicle arrives to any customer after the upper limit or before the lower limit.

This problem has been studied extensively throughout the history [7], [8]. One reason why it is so interesting is its dual nature. It might be considered as a problem of two phases, the first concerning the vehicle routing and the second concerning the planning phase or customer scheduling. Another reason is its easy adaptation to real world, because in the great majority of distribution chains, customers have strong temporal constraints that have to be fulfilled.

Dynamism

Dynamism in vehicle routing problems is a relatively new field which many researchers have been studying in recent years [9], [10]. Dynamism can force to update previously planned routes. This fact can be caused either by possible disruptions or the arrival of some information that was not available at the beginning. In our case dynamism is due to unexpected events, several of which have already been explained in the previous section.

Once one of these events occurs, distribution must decide whether to reschedule some of the routes, or accept some delays in customer deliveries. In order to take this decision the potential costs of each of the options are calculated, so that the least expensive option is chosen.

5.3. OBJECTIVE FUNCTION

According to the previous concepts, we have defined a problem where customers can request either delivery or pick-up of materials, within certain time windows. Apart from this, it covers the dynamism coming from untoward events which may affect the feasibility of the distribution plan.

The objective function is to minimize the total cost incurred. This cost has several components that are evaluated as follows:

$\sum_{k\epsilon M} F_k \sum_{j\epsilon V'} x_{0j}^k$	**Cost of vehicle utilization**. For each vehicle that is used, the fixed cost of this is added to the function. The variable F_k is the fixed cost of each vehicle, which are grouped in M. x^k_{ij} is a binary variable which indicates whether the vehicle k has traveled between customer i and customer j. All the nodes are grouped in V.
$\sum_{k\epsilon M} C_k \sum_{i,j\epsilon V} d_{ij}^k x_{ij}^k$	**Cost of distance traveled**. This cost is equal to the total distance traveled by each of the routes, multiplied by the variable cost of the vehicle used for each path. The variable C_k indicates the variable cost of a vehicle while d^k_{ij} is the distance between customers i and j.
$\sum_{k\epsilon M} PC_k$	**Penalty for underuse of vehicles**. For every vehicle, the load it carries is examined, and a penalty is imposed if it is underused. This penalty applies to vehicles that are loaded below 75% of its capacity.
$\sum_{i,j\epsilon V} PCNS\, x_{ij}$	**Penalty for unfulfilled due date**. In the case that, for any reason, a vehicle cannot supply a client, a penalty on the objective function is imposed. In this case, the penalty will vary depending on the importance of the customer and the amount of goods that have not been served.
$\sum_{k\epsilon M} HE_k$	**Overtime cost.** This cost appears if the route exceeds the capacity of the driver in regular time and it is decided to apply overtime. To do this, the excess of hours is multiplied by the cost of each extra hour.

The objective function that has been proposed for this D-VRPBTW (Dynamic Vehicle Routing Problem with Backhauls and Time Windows) is the sum of all the aforementioned costs and is given by:

$$\sum_{k\in M} F_k \sum_{j\in V'} x_{0j}^k + \sum_{k\in M} c_k \sum_{i,j\in V} d_{ij}^k x_{ij}^k + \sum_{k\in M} PC_k + \sum_{i,j\in V} PCNS\, x_{ij} + \sum_{k\in M} HE_k$$

5.4. PROPOSED SOLVING TECHNIQUES

For solving the aforementioned problem the use of three different meta-heuristics has been proposed. Two of them are some of the most used techniques for combinatorial optimization problems throughout history. The third, in contrast, is a novel meta-heuristic proposed as an alternative to the previous two.

The first two techniques are the tabu search [11] and the genetic algorithm [12]. The third technique, as already mentioned, is a new population based meta-heuristic for solving combinatorial optimization problems. This new meta-heuristic prioritizes individual improvement of each i, making crossovers between players only when it is necessary and when it is known that it is going to be beneficial for the results.

5.5. WORK MADE SO FAR

Up to now, some tests with several vehicle routing problems have been made, applying two of the techniques that we have been proposed to address the problem that arises for this project. The techniques that have been implemented and tested so far are the genetic algorithm and the new meta-heuristic. The problems studied are the Traveling Salesman Problem, the Capacitated Vehicle Routing Problem and the Vehicle Routing Problem with Backhauls. These problems are similar to the problem that we must tackle in our research, especially the last one. The following table shows the results obtained for the Vehicle Routing Problem with Backhauls, using multiple modified instances of the Solomon Benchmark [13]. Beside the name of each instance appears the number of nodes it has. The table displays the results of both algorithms with the execution of 20 runs per instance. The objective function for each of the problems is the sum of the distances traveled by all routes.

Vehicle Routing Problem with Backhauls

New Meta-Heuristic	C101 (75n)	C201 (58)	R101 (75n)	R201(100n)	RC101 (40n)	RC201(100n)
Average	648,73	616,31	865,39	1008,43	552,05	1106,15
Best Result	562,03	583,43	835,88	962,95	516,83	1062,46
Worst Result	663,95	647,91	902,62	1049,47	585,19	1128,29
Time	33,50	15,00	33,70	69,50	12,00	71,90

Table 1: Results of the new meta-heuristic for the VRPB.

Genetic Algorithm	C101 (75n)	C201 (58)	R101 (75n)	R201(100n)	RC101 (40n)	RC201(100n)
Average	671,10	739,09	899,35	1093,17	594,49	1184,45
Best Result	594,28	567,17	862,43	1005,35	554,17	1108,63
Worst Result	728,42	964,10	947,79	1219,29	658,00	1268,71
Time	61,80	37,40	60,50	59,40	32,50	60,50

Table 2: Results obtained by the Genetic Algorithm for the VRPB

Focusing on the results obtained by the two meta-heuristics and the difference in results obtained, it can be concluded that the new meta-heuristic proves to be better than the genetic algorithm. It is much better in terms of quality and runtime. Apart from this, the solutions are more regular, since the difference between the best and worst solution is not very large. This feature gives robustness and security to the algorithm. The genetic algorithm, however, does not show this characteristic.

6. Conclusions

In this paper, an approach for integrated planning and distribution has been proposed in a supply chain consisting of three levels, i.e. suppliers, company and customers. The approach tries to provide solutions for exception handling that benefit the supply chain by identifying the information that should be exchanged between the different nodes and developing methodologies for production scheduling and distribution planning in a coordinated way.

Furthermore, a communication framework that links the different entities has been defined that consider several communication subsystems at the intraplant, interplant, intradepot and interdepot levels. The possible exceptions have also been categorized into four groups depending on whether they come from production or distribution, customers or suppliers. Then, an example of an exception handling has been described that includes several possible courses of action.

Finally, the distribution problem has been defined including an objective function. For this problem, we have implemented two metaheuristics for solving some similar problems. After several tests, we can say that the selected metaheuristics have obtained good results, so we can conclude that we are on the right path.

7. References

[1] Park, Y. and Hong, S.: "Integrated production and distribution, planning for single-period inventory products". International Journal of Computer, Integrated Manufacturing, Vol. 22, No. 5, 443–457, 2009.

[2] Safaei, A.S., Moattar Husseini, S.M., Farahani, R.Z., Jolai, F. and Ghodsypour, S.H.:, "Integrated multi-site production-distribution chain by hybrid modeling". International Journal of Production Research, Vol.48, No. 14, 4043–4069, 2010.

[3] Bilgen, B. and Günther, H.O.: "Integrated production and distribution planning in the fast moving consumer goods industry: a block planning application", OR Spectrum, 2010.

[4] *Álvarez, Esther and Fernando Díaz, A Web-based Approach for Exceptions Management in the Supply Chain, Robotics and Computer Integrated Manufacturing, Vol. 27, No. 4, pp. 681-686, 2011, Elsevier, The Netherlands.*

[5] *Toth P. and Vigo D.: "VRP with backhauls." Monographs on Discrete Mathematics and Applications. In Toth P. and Vigo D. The Vehicle Routing Problem. SIAM: 195-224. 2000.*

[6] *Golden B.L., Baker E., Alfaro J., Schaffer J.: "The vehicle routing problem with backhauling: two approaches." In R. Hammesfahr, Proceedings of the XXI Annual Meeting of S.F. TIMS, Myrtle Beach, SC. 90-92. 1985.*

[7] *Bräysy O. and Gendreau M.: "Tabu Search Heuristic for the Vehicle Routing Problem with Time Windows." An Official Journal of the Spanish Society of Statistics and Operations Research, 10: 211-237. 2002.*

[8] *Condeau F., Desaulniers G., Desrosiers J., Solomon M. and Soumis F.: "The VRP with time windows." Technical Report Cahiers du GERAD G-99-13, École des Hautes Études Commerciales de Montréal. 1999.*

[9] *Pillac V., Gendreau M., Guéret C. and Medaglia A.L.: "A review of Dynamic Vehicle Routing Problem." Industrial Engineering: 0-28. 2011.*

[10] *Beaundry A., Laporte G., Melo T. and Nickel S.: "Dynamic transportation of patients in hospitals." OR Spectrum, 32: 77-107. 2010.*

[11] *Basu S. and Ghosh D.: "A review of the tabu search literature on traveling salesman problem." IIMA Working Papers 2008. Indian Institute of Management Ahmedabad. 1-16.2008.*

[12] *Holland J.H.: "Adaptation in natural and artificial systems: an introductory analiysis with applications to biology, control, and artificial intelligence." Oxford, England: University of Michigan Press. 1975.*

[13] *Solomon, M.M.: "Vehicle Routing Problem with Time Windows Benchmark Problems." http://web.cba.neu.edu/~msolomon/problems.htm. 2005.*