A GENETIC APPROACH FOR TWO-ECHELON CAPACITATED VEHICLE ROUTING AND SCHEDULING PROBLEM WITH TIME WINDOWS

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PREFACE

This dissertation is submitted for the degree of Doctor of Philosophy at the Kyoto University. The research described herein was conducted under the supervision of Professor Taniguchi Eiichi in Department of Urban Management, Logistics Management System Laboratory, Kyoto, between October 2012 and September 2015.

Manuscript of this Ph.D. dissertation partly includes contents of the following conference papers.

Peer-Reviewed Conference Proceeding

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Conference Papers

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ABSTRACT

This study is the Two-Echelon Capacitated Vehicle Routing Problem with Time Windows (2E-CVRPTW) in the distribution system. The scope of the delivery model is planning delivering goods from a main depot to the customers through intermediate depots, which are called the satellites on specified time. This problem is motivated by city logistics planning related to legal restriction, environmental impact, confined space, and congested network. Due to these policies, it becomes infeasible to use large vehicles and/or construct a depot facility inside the center of large cities. The proposed method is based on a modification of the Multi-Depots Vehicle Routing Problem with Time Windows (MDVRPTW) solved by using a Genetic Algorithms (GA) in order to solve the whole processes.

There are several variants and classes of vehicle routing problem (VRP) as the capacitated (CVRP) with time windows (VRPTW). The most delivering model is based on the direct shipment. The single-echelon or direct shipment system operates only one layer of delivery activities meet the demands between a single depot. In many applications and real world situations, this model is not completed efficiency yet. Therefore, throughout decades, freight distribution and vehicle routing have been moved from a direct shipment in single layer delivery system to a multi-echelon distribution system. The advantage of usage of a multi-echelon and particular two-echelon delivery system can optimize several features as the transportation cost, loading factor, timing and the number of vehicles.

the multi-echelon delivery system, and the two-echelon system in particular, refer mainly to supply chain and inventory management problem These problems did not use an explicit vehicle routing problem approach for the multi-levels which concentrated more on the production and supply chain management issues. One of the first applications of the routing in two-echelon system was the problem of distributing newspapers via transfer points (Jacobsen and Madsen, 1980). The real application of two-echelon distribution network optimizing the global transportation costs is related to the city logistics. Additionally, this delivery system can be integrated to city logistics systems for the large cities, which usually are over-populated and have massive buildings for the commercial, administrative, and cultural activities. They served by a dense network of mostly narrow and generally congested streets Also, in particular parking areas with strict space regulations are implemented to limit

the vehicle sizes. Under the city logistics systems schematic, the controlled zones are relatively close to the outskirts of the city where the depots are located (Taniguchi, E.*et.al*, 1999). Therefore, it is more effective to arrange two-tiers distribution network as in the 2E-CVRP where a depot is located at the outskirts of the city. This delivery system is developed for a specific situation and a generalization of such a system has not already been formulated. The completed mathematic model of 2E-CVRP with the solutions of the sample test data in the classical approach has been proposed and complemented with the method for computing efficiency

Several classes of 2E-CVRP have been studied in the literature. Thought addressing different approaches for exact algorithms and heuristics, they all focus on 2E-CVRP formulation and the benchmarks test data are proposed to demonstrate their efficiency. In addition to the geographic component, more realistic routing problems include a time windows constraint by operating travel time between every pair of nodes, customer and satellite service time. The practical situations and routing problem with time windows for 2E-CVRP have not been attempted yet.

The new areas of 2E-CVRP distribution system much attends to improve the service quality by increasing customer satisfaction in particular time periods of delivery. This research idea is similar to the current VRPTW optimization models. The advantage of this research is a variety of practical applications. However, some practical issues have not been addressed yet. This research proposes simplified classical of 2E-CVRP-TW formulations to evaluate the efficiency of the freight transportation in the city. The scope of the model is developed for the vehicle fleets operations to ensure that the deliveries arrive at the satellite and the customers within specified time windows.

In the 2E-CVRP-TW, each customer (satellite) has a related time windows defined by the earliest and the latest time to start the service. The depot may also have a horizon time windows. Time windows can either be hard time or soft time windows. In the hard time windows case, if a vehicle arrives to the customer (satellite) too early, it is allowed to wait until the customer (satellite) windows is open. However, late delivery is not permitted. However, the soft time windows permits time windows violations at the extra charge for the penalty cost.

The main algorithm used in this research is a genetic algorithm that works on relaxation for 2E-CVRP-TW. The model is inspired by a genetic algorithm for the multi-depot vehicle routing problem with time windows (MDVRPTW). The GA consists of two phases; the first phase performs the calculations for the second echelon as the MDVRPTW. The MDVRPTW requires the capacitated vehicles to deliver goods to a set of customers from a set of satellites. The delivery has to be done within a customer time windows and vehicle needs to return to the same satellite. Each customer must be visited once. After that, the second phase is solved for obtaining an optimal- feasible solution for the first echelon. The procedure starts after the best solution of the second echelon is imported. A set of satellites are served by a depot within the required time windows. The objective is to minimize the total cost in both phases.

In this research evaluate the model of freight transport for two layers in Osaka network, where satellite platforms are used to transship goods from vehicles arriving from main depot to smaller, center-city-friendly vehicles. The problem concerned the selection of routes and the scheduling of departures for the vehicles of the two fleets involved, as well as the selection of the delivery routes for customer demands from the main-depot through satellites to the final customer. Strict coordination and time synchronization of the operations of the two fleets are central elements of the problem, which appears to belong to a new problem class that we denoted the two echelon vehicle routing problem with time windows (2E-CVRPTW)

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INTRODUCTION

1.1 General background

The transportation of goods is considered a key factor that allows for economic and social activities mainly occurred in urban areas. For the inhabitants of the city, it forms an important link with suppliers and customers Indeed, there are few activities that take place in the city that does not have at least some items were moved. (OECD, 2003).

But transport is also an important factor in the problems of city life. Cargo vehicles (freight transport) and private transport into the roads and arteries of the city have contributed significantly to congestion and environmental nuisances such as noise and emissions. A report from the Organization for Economic Cooperation and Development (OECD 2003), for example 43% of the sulfur dioxide and 61% of particulate emissions in London for freight while for nitrogen oxide emissions is 28% for London and 77% for Japan. This affects the lives of people as well as the production and associated supply chain

In many cases, urbanization is expected to lead in to further development of the metropolis such developments, coupled with the growth in the movement of traffic leads to traffic problems. For example, in central London, vehicles spend half of their time waiting in traffic jams (OECD 2003). The increase in the number of passenger vehicles and trucks has created a problem in terms of the environment, congestion and safety.

Current production and distribution practices based on low inventories and the timely delivery, growth of e-commerce business will cause significant growth in the number of vehicles to transport goods moving in urban areas.

For example, OECD report (2003) says "in the Netherlands, the number of cars has doubled in ten years (1991-2001) and up to 6.5 million the number of trucks has also increased in many countries due to the need for frequent deliveries and just-in-time and access restrictions for larger vehicles." Due to such increases in vehicles and other problems many projects have been implemented in recent years to resolve these issues to understand and control goods within the city limits.

The basic idea is to support initiatives to stop considering each company individually and transportation vehicles. However, one should consider whether the system components integrated logistics.

1.1.1 Trends in freight transport

The freight transportation is expected to increase in demand for freight in the US, the forecast growth of cargo (2000-2020) by 100-200% growth in the region from the south to the 79% growth in the Northeast (OECD 2003). In recent years the company has concentrated continued their capacity in fewer places and with expanded geographic scale of the supply and distribution of their operations.

Globalization also influences the form of freight transport in urban areas as shown in Figure 1.1.

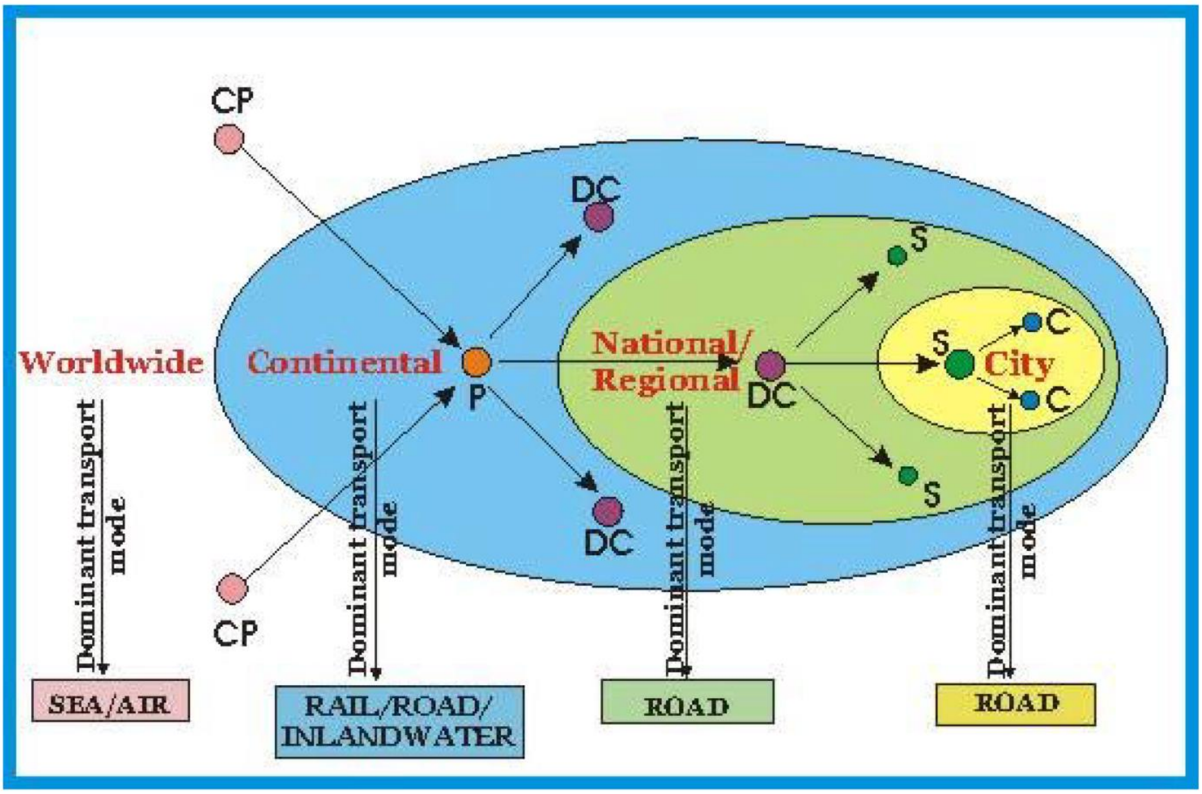


Figure 1.1 Example of a modern distribution pattern integrating the long haul transport chain with urban goods transport chain

(*Source*: OECD Working Group on Urban Goods Transport, 2003)

Table 1.1 shows the different types of vehicles are used for different purposes.

Table 1.1 Different categories of vehicle and their use in urban goods transport (as applied in the Netherlands) (*Source*: OECD Working Group on Urban Goods Transport, 2003)

Weight	Contents – length	Goods
Less than 3.5 tonnes	Maximum: $8m^3$ – 6 metres	Parcels Services B2B Independent retail
3.5 – 7.5 tonnes	Maximum: $23m^3$ – 7.5 metres	Lifestyle(clothes/shoes) Daily products(food) B2B Parcels
7.5 – 18 tonnes	Maximum: 40-$44m^3$, 10 metres	Bars/restaurants Lifestyle (clothes/shoes) Daily products (food) B2B
18 – 40 tonnes	Maximum: 34-$100m^3$, 19.3 metres	Department stores Daily products (food) Do-it-yourself
The production requirements for new vehicles are: less visual intrusion, increased safety, better working conditions, high capacity, light weight, and clean engine.		

1.1.2 Environmental issues

Transport contributes to global greenhouse gas emissions and air pollution in the country reducing the quality of the environment in urban areas. Many trucks still use older technology(diesel)to become heavy polluters as shown in Figure 1.2thus improving the method to decrease emissions of its vehicles is an important issue

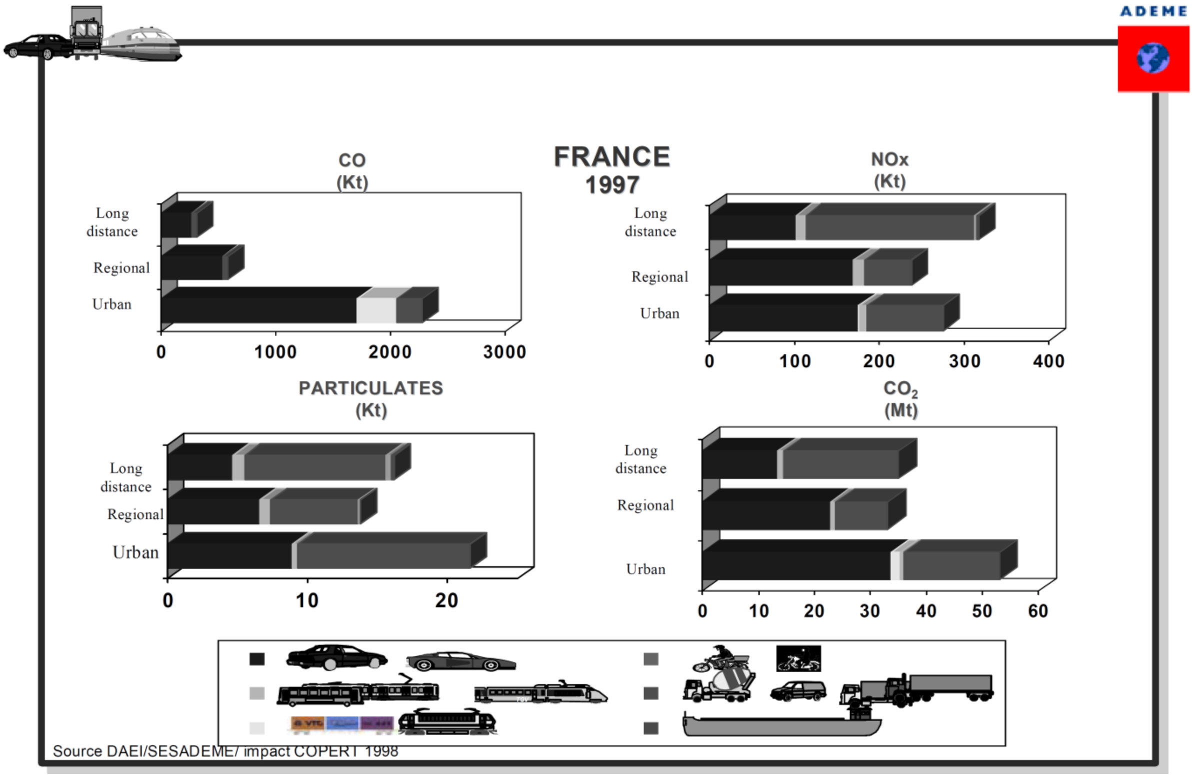


Figure 1.2 Urban transports share in environmental problems

(*Source*: OECD Working Group on Urban Goods Transport, 2003)

1.2 City Logistics scheme

To avoid the presence of heavy vehicles in the city first developments occurred mainly in countries of the European Union and Japan. City logistics projects were first conducted in Europe and Japan based on two echelon systems (Main depot and consolidation centers). Different business models and strategies were tested. (Taniguchi, et al, 2001)

"City Logistics" concepts developed in Netherlands used to load vehicles and license limits the total number of vehicles entering the city on any given day policies promoting the use of electric cars have also been used. Small and medium-sized cities were more successful in sustaining the city logistics projects (Dablanc 2007). In many big cities parking is at a premium and strict rules limit the size of the main bus depot directly with customers leading to more complex system of covering a number of sub-systems (satellites) close" to the city center using smaller vehicles suitable for the city center.

1.3 Motivation of research

City logistics challenges, city officials, business and public services to introduce new business models and operations based on public-private collaboration and cooperation. For the innovative research and scientific operations, transportation city logistics is considered both as challenge and an opportunity in terms of method development and social effects that actually occur. The review of existing literature, however, shows that. "Optimizing" components of the logistics have not yet been developed. This dissertation focuses our study on city logistics systems of two-echelon hierarchical structures with huge depot sited outside urban area and satellite locations adjacent to or within the city center. Planning challenges in the two-echelon system of logistics relates to short-term scheduling, integrated operations and resource management. The problem therefore involves multi depot on the two echelon problem with time windows (VRPTW).

1.4 Proposes and objective of research

The main contribution of this work is the introduction of the Two-Echelon Vehicle Routing problem with Time Windows, were the routing and the freight management are explicitly considered at the different levels. The transportation network is decomposed into two levels: the 1st level connecting the depot to intermediate depots and the 2nd one connecting the intermediate depots to the customers. The objective is the minimization of the total transportation cost of the vehicles involved at both levels. Delivery within a pre-specified time windows and capacity constraints of the vehicles and the satellites are considered.

1.5 Organization of the thesis

This PhD. Thesis is organized as follows. In chapter 1, the introduction about city logistics concepts and applications to the research will be presented, and, from these experiences, trends in freight transport, urban transport in the cities and environmental issues are described. Motivation of research and proposes and objective of research are presented.

The second chapter will be dedicated to literature reviews, give a general description of urban transport. Two-Echelon Vehicle Routing Problems, is the generalization to 2-echelon of the well-known Vehicle Routing Problem family. The reviews focus on two-echelon problems, and in give a general description of 2-Echelon Vehicle Routing Problems, presenting the main definitions and the most common variants that can be considered. Section 2.3 is dedicated to the introduction the Multi-Echelon Vehicle Routing Problems and present concepts and definitions, as well as multi-echelon distribution system. Section 2.4 presents Multi-Depot Vehicle Routing Problem with Time Windows (MDVRPTW). This section includes general concept and methodology

In order to evaluate the models, four sets of test instances for the 2E-CVRP are introduced in chapter 3, the proposed method is based on a modification of the Multi-Depots Vehicle Routing Problem (MDVRP) solved by using Hybrid Genetic Algorithms (HGAs) in order to enhance an initial solution. Results on 21 benchmark instances show that the algorithm performs effectively to solve 18 instances to the optimal solutions reported in previous studies using exact algorithms.

Chapter 4 introduces to propose an algorithm based on philosophy of the Genetic Algorithms (GAs) to solve the model of Two-Echelon Capacitated Vehicle Routing Problem with Time Windows (2E-CVRPTW). The study is proposed to determine the optimize travel costs of deliveries. The proposed method is based on a modification of the Multi-Depots Vehicle Routing Problem with Time Windows (MDVRPTW) to 2E-CVRPTW. The evaluating performance of proposed the algorithm, the benchmarks of MDVRPTW not only were solved, but new benchmarks of 2E-CVRPTW also was set to determine the best solution.

Chapter 5 applies the 2E-CVRPTW modeling with the real network in Osaka, Japan. The result will be discussed to evaluate city logistics.

Finally, conclusion and future research guidelines will be proposed in chapter 6. Moreover, the recommendation apply this concept in city logistics and development for further studies are also present

References

Dablanc, L. (2007) Goods Transport in Large European Cities: Difficult to Organize, Difficult to Modernize, *Transportation Research Part A*, 41, 280–285.

OECD (2003) Delivering the Goods, 21st Century Challenges to Urban Goods Transport, OECD Publishing.

Taniguchi, E., Thompson, R. G., Yamada, T., & Duin, R. V. (2001). City logistics: Network modeling and intelligent transport systems. Pergamon, Oxford.

2

LITERATURE REVIEW

2.1 General

Freight industry is a major source of employment and economic development of the country. The freight transport activity is disturbed due to congestion and environmental nuisances that affect quality of life, especially in urban areas.

Distributed systems are relatively frequent in the supply chain and logistics system. They are used by management in public transport and strategic planning, as well as visits to their companies to model their distribution systems. Most of the studies in the literature that addresses issues related to the movement of the entire system from their origin to their final destination. The latest trend is to focus on the management of vehicles needed to transport services among of different systems. Freight distribution strategy has two main ways direct shipping and multi echelon distribution. The direct delivery vehicles from the depot, transport their goods to the customer. In multi levels, the cargo is delivered to the customer from the satellite

The aim of this research was two echelon. Before introducing several families of the routing problem vehicles in a wide range comprehensive set it shipped from one depot and more satellites that are managed by the routing and freight consolidation at satellite. It is considered in detail the basic version of the multi-level vehicles routing problem, two-level capacitated vehicle routing problem VRP, which is an extension of the classic delivery in direct shipment.

2.2 Two-Echelon Capacitated Vehicle Routing Problem

Distribution and routing of freight vehicles played a key role in the past decade in the supply chain and production planning. They had leading role in many aspects of environmental and traffic problems. Routing vehicle has become a major issue in the field of logistics and freight transport. In some market sectors, transport costs as a percentage of value-added products. Thus, the method for transporting the computer can result in savings ranging from 5% to as much as 20% of the total cost. (Toth and Vigo, 2002).

The case modeled by the VRP, also known as Capacitated VRP (CVRP), considers a feet of identical vehicles. The objective is to reduce the cost of transportation within the limits of its capacity in the delivery of each vehicle. In real world applications, the problem is often different and many variants of VRP have been developed. The most well-known variants are VRP with time windows (VRP-TW), multi-depot VRP (MDVRP) and VRP with pickups and deliveries (VRP-PD) (Cordeau et al., 2007). Freight consolidation from shippers and different kinds of service providers related to the coordination of operations is one of the most important ways to achieve the rationalization of activities. Some distributors Intelligent Transport Systems and operations research methods to help optimize the design, planning, management and operation of City Logistics. (Taniguchi et al., 2001).

Consolidation activity occurs at the distribution center (DCS) when the DCS is smaller than main depot and can be stored for only a short time, they are called satellites. Shipping is included in the small vehicles which transport them to their final destinations. Apparently, a similar system could be set in the reverse flow is from its origin in the area to places outside.

As stated in the introduction, this research focuses on the expansion to the system of multi-echelon vehicle routing problem which has been poorly studied in the literature, the multi-echelon systems, and the two-echelon systems in particular, refer majorly to supply chain and inventory problems. These problems do not focus on paths at different level. Instead, focus on manufacturing and supply chain management issues. The research is the only difference from facilities that VRP satellite to be considered explicitly VRP with Satellite Facilities, (VRPSF) variable in network facilities, including the use of vehicles to fill in the path. When possible replenishment satellites allows drivers to carry out the delivery without the need to return to the depot. This situation occurs primarily in the distribution of fuel and some other retail programs; The satellite will not be used as a warehouse to reduce the cost of transportation (Crevier et al., 2007).

Jacobsen and Madsen, (1980) presented the first application of the distribution system two echelon with a clear reduction of the cost of transportation. A more recent real application of two-echelon distribution network is presented by Crainic et al. (2004). and is related to the freight distribution in a large city area (Crainic et al., 2004). The authors have developed a distribution system to transport two echelon for congested urban areas using a small depot, called satellite as a central point for the distribution of freight. Although many specific studies on strategic shipping directly (As a single), behavior analysis, have been developed for multi echelon. (such as Jacobsen and Madsen, 1980), but no extension of a general multi-echelon routing scheme has been developed.is the problem of less than truck loads serving multiple clients be used only in the second echelon, it is close to MDVRP but usually location-allocation of satellite and customers becomes important decisions leading to a Location Routing Problem (LRP). The unresolved problem with the two separate echelons has been determined as more complex problem (Prins et al., 2007).

The general version of Multi-Echelon Vehicle Routing Problem arising in practice is the Two-Echelon Vehicle Routing Problem. Basic points of Two-Echelon Capacitated Vehicle Routing system operates are described in the literature (Crainic et al., 2009) as follows:

- Freight arriving at a depot outside the zone, which will include a 1^{st} echelon vehicle. it is already implemented in full truck load;
- Each 1^{st} echelon vehicle travels to satellites and then it will return to the depot;
- At a satellite, freight is transferred from 1^{st} echelon vehicles to 2^{nd} echelon vehicles;
- Each 2^{nd} echelon vehicle performs a route to serve the customers, and then travels to a satellite. The 2^{nd} echelon vehicles return to their departure satellite.

References

Cordeau, J. F., Gaudioso, M., Laporte, G. and Moccia, L. (2007). The service allocation problem at the Gioia Tauro maritime terminal, *European Journal of Operational Research* 176: 1167–1184.

Crevier, B., Cordeau, J., & Laporte, G. (2007). The multi-depot vehicle routing problem with inter-depot routes. *European Journal of Operational Research,* 176(2), 756-773.

Crainic, T. G., N. Ricciardi, G. Storchi. (2004). Advanced freight transportation systems for congested urban areas. *Transportation Research Part C*, 119-137.

Crainic, T. G., N. Ricciardi, G. Storchi. (2009). Models for evaluating and planning city logistics systems. *Transportation Science*, 43 432–454.

Taniguchi, E., Thompson, R. G., Yamada, T., & Duin, R. V. (2001). City logistics: Network modeling and intelligent transport systems. Pergamon, Oxford.

Toth, P., Vigo, D. (2002). Models, relaxations and exact approaches for the capacitated vehicle routing problem. *Discrete Applied Mathematics* 123, 487–512.

Jacobsen, S., Madsen, O. (1980). A comparative study of heuristics for a two-level routinglocation problem. *European Journal of Operational Research,* Vol. 5, pp. 378–387.

Prins, C., C. Prodhon, A. Ruiz, P. Soriano, R. Wolfler Calvo. 2007. Solving the capacitated location-routing problem by a cooperative lagrangean relaxation - granular tabu search heuristic. *Transportation Science* 41 470–483.

3

HYBRID GENETIC ALGORITHMS FOR TWO–ECHELON CAPACITATED VEHICLE ROUTING PROBLEM

3.1 General

There are two main strategies of freight transportation: direct shipment system and multi-echelon distribution system (Perboli et al., 2001). The single-echelon or direct shipment system operates only one layer of delivery activities meet the demands between a single depot and customers while the multi-echelon distribution system consists of delivering goods from one or more depots to the customers through intermediate depots, which are called satellites. Throughout decades, freight distribution and vehicle routing have been moved from a direct shipment in single layer delivery system to a multi-echelon distribution system (Perboli et al., 2001; Ho et al., 2008; Crainic et al., 2009; Meihua et al., 2011; Jepsen et al., 2012).

Additionally, this approach can be integrated to city logistics systems for large cities, which usually are over-populated and have massive buildings for commercial, administrative, and cultural activities, served by a dense network of mostly narrow and generally congested streets (Crainic et al., 2004). Also, in particular parking areas strict space regulations are implemented to limit the vehicle sizes. Under city logistics systems schematic, the controlled zones are relatively close to the outskirts of the city where the depots are located. Therefore, it is more effective to arrange two-tier distribution network as in the 2E-CVRP where a depot is located at the outskirts of the city. Figure 3.1 illustrates an example of a 2E-CVRP distribution system with two satellites and nine customers (see Figure 1). The customers are represented by circles, the satellites by triangles, and the depot by a square. First and second echelon vehicle routes are represented by bold lines and thin lines, respectively.

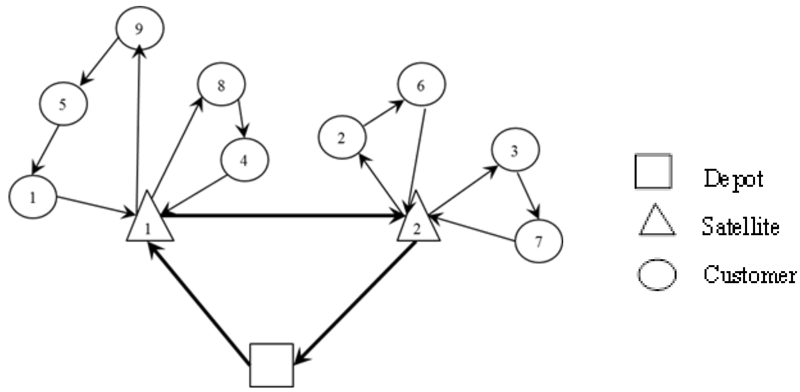


Figure 3.1 2E-CVRP distribution problem

In this study, the 2E-CVRP is studied which extends from the classical CVRP, and includes two layers of delivery systems. The problem consists of a depot, a set of satellites, and a set of customers with demand (Jepsen et al., 2012). A direct depot-to-satellites distribution mode operates for long distances, offering a large capacity vehicle type (first echelon vehicles). The distribution between satellite and customers is yielded for the city center traffic by using a small capacity vehicle type (second echelon vehicles).

The main algorithm used in this research is a hybrid genetic algorithm that works on relaxation for 2E-CVRP. The model is inspired by a hybrid genetic algorithm for the multi-depot vehicle routing problem (MDVRP) (Ho et al., 2008). The GA has two phases; the first phase performs calculations for the second echelon. A hybrid algorithm consists of a genetic algorithm and k-means clustering is used to provide feasible solution for MDVRP. After that the second phase is solved for obtaining an optimal- feasible solution of the first echelon. The procedure starts after the best solution of the second echelon is imported. The objective is to minimize the total vehicle travel cost in both of the phases. Since the constraints on the maximum capacity of vehicles and the satellites are considered, this study, therefore, solves 2E-CVRP by using hybrid genetic algorithms method.

3.2 Problem description

This study decomposed 2E-CVRP into two phases. The first phase (the second echelon) is solved by using a classical MDVRP, in which a hybrid algorithms is used for preparing feasible solution. The second phase (the first echelon) is independently solved by using the similar procedure of the previous phase. Each satellite must be served by large vehicles based at the central depot.

The MDVRP approach is implemented at the second level routing as satellites represent multi-depots. The solutions of the multi-depot are initially compared with lower bounds in literature to ensure the accuracy before the next step. However, in order to solve the problem to the optimality, while the obtained results is still a local lower bound, it is important to determine a feasible solution for the second level shortly after the feasible solution of the first level can be generated. In this way, the feasible global solution can be considered as an upper bound (Contrado at al., 2008).

As mentioned in the introduction, the delivery from the depot to customers, in multi-echelon VRP is allowed through different intermediated satellites. The process aims to ensure an effective and low-cost operation of the system, where the freight is delivered so that the travel cost on the whole transportation network is minimized. The focus of 2E-CVRP, in particular, is only one intermediate level of satellites connected with the depot and customers. The load must be delivered to customers, and meet customer's demand d_i. Each demand load cannot be split among different vehicles or multiple routes. We defined in the first echelon, a route that transports demands by a large vehicle $\bar{k}$ with capacity $Q_{\bar{k}}$ that starts from the depot, service one or more satellites and ends at the depot while in the second echelon, a route run by small vehicle k with capacity $Q_K$that starts from satellite, serves one or more customers, and ends at the same satellite.

The simplest version of 2E-CVRP is used with no time dependence (Perboli et al, 2001; Ho et al., 2008; Crainic et al., 2009; Meihua et al., 2011; Jepsen et al., 2012). At each level, all vehicles are in the service have fixed capacity. The fleet size of each level is fixed, while the number of vehicles assigned to each satellite is not known in advance and need to be optimized. The objective is to deliver loads to the customers by minimizing the total travel cost, satisfying the capacity constraints of the vehicles. There is a single depot and fixed number of capacitated satellites. All customer demands are fixed, known in advance, and must be compulsorily satisfied. The demand of both levels must less than vehicle's capacity.

3.3 Hybrid genetic algorithms

Genetic Algorithms (GA) was firstly developed as a stochastic optimization technique (Ho et al., 2008). Likewise, the other artificial intelligence heuristics such as the Simulated Annealing (SA) and the Tabu Search (TS), GA can avoid getting trapped in a local optimum by the assistance of one of the genetic operations called mutation. The fundamental idea of GA is to preserve a population of candidate solutions that evolves under selection procedure and survival of the fittest. Hence, it can be illustrated as a class of local search algorithms based on a solution generation mechanism operating on characteristics of a set of solutions rather than of a single solution, which is commonly called the move-generation mechanism of the local search methods, such as SA and TS (Osman and Kelly, 2008). In recent years, GA has been adopted successfully to a wide variety of NP-hard optimization problems, such as the traveling salesman problem (TSP) and the quadratic assignment problem (Gen and Cheng, 1997; Goldberg, 1989). The success is principally due to its clarity, easy operation, and greater flexibility. These are the major reasons why GA is implemented as an optimization tool in this paper also.

This study applies the integration of three relatively hard optimization problems of grouping, routing, and scheduling problems. Each individual problem, mentioned-above, is already complex and difficult to solve. A simple GA may not perform well in the proposed MDVRP, which is a combination of the stated three hard optimization problems. The application of GA is therefore, hybridized to improve the solution further, and to deal with the problem effectively. Therefore, a Hybrid Genetic Algorithms (HGAs) is developed in this paper.

Many researchers have worked with HGAs for solving hard optimization problem in last decade. The procedure of the proposed HGA is explained as follows: the GA parameters are decided first, including population size, the crossover rate, mutation rate and the iteration number. After that the initial chromosomes are generated. The initial solution is improved by grouping, based on k-means clustering heuristics, and with routing, based on Clark and Wright (1964) saving method. Finally, scheduling is improved with the Nearest Neighbor Heuristics (NNH) (Reinelt, 1994). The whole processes must satisfy the given constraints. The chromosomes contain nodes of customers, and link between them that can represent together the delivery sequences of the vehicles. The HGA iteration is started by randomly selecting some chromosomes for the genetic operations. It consists of uniform crossover and a single point mutation heuristics. All improved chromosomes are evaluated by the objective function. After all new chromosomes have been generated; each of them is assigned to the nearest depot. The iteration is repeated in order to improve predominated chromosomes, until the stopping criterion is met.

Above mentioned process gives the solution procedure of the MDVRP that is generated in the second echelon. The first echelon is similarly solved by using the proposed HGA, on a network with depot and satellites. In section 3.3.1 we have further defined steps adopted for improved initial solution. The iterative HGA procedure, comprising of selection, crossover operator and mutation operator is described in section 3.3.2

3.3.1 Improved Initialization Solution

In the decision making procedure, at the grouping step, the initial solution is improved by the *k*-means algorithm. Briefly, the *k*-means clustering algorithm classifies or partitions off the customers into *k* clusters, in which each customer belong to the cluster with the nearest mean. The *k* is the number of available vehicles set in the second level, and it is set to a positive integer number. The number of available vehicles is specified early before calculation. It has an advantage to set the number of *k* clusters. The Euclidean distance is used for checking the selection of the customers within cluster.

The grouping procedure is composed of the following steps: after the number of *k* has been decided, *k* clusters are randomly defined by the cluster centers. Then each customer is assign to the nearest cluster center, which is then recalculated to the new position of *k* centroids. This procedure is repeated until the convergence criterion is met, and the centroids are no longer moved. Figure 3.2 illustrates the clustered customers after the *k*-means clustering has been applied (see Figure 3.2).

- ***K* mean clustering**

K- means (MacQueen, 1967) is one of the easiest ways to learn closer to solving the problems of the well-known group. The next step is a simple and easy way to identify information that has been set up through a number of the group (assuming the group *k*) to edit. The main idea is to set one for each group centroids *k* centroids should these are in place, how cunning because different cause such a difference. So a good alternative is to give them as much as possible away from each other. The next step is to take each point of the data sets are received and linked to the nearest centroid. At any point during the first phase, which was completed in early age and do at this point, we have to calculate *k* new centroids are centers group resulting from the previous step. After we have these new *k* centroids are binding action between the same data set and the nearest new centroid. He has been building As a result of this band, we may notice that the centroids *k* process of changing their positions by step until there are no more changes will be made, in other words centroids not move any more. The algorithm is composed of the following steps:

- Place *K* points into the space represented by the objects that are being clustered. These points represent initial group centroids.
- Assign each object to the group that has the closest centroid.
- When all objects have been assigned, recalculate the positions of the *K* centroids.
- Repeat Steps 2 and 3 until the centroids no longer move. This produces a separation of the objects into groups from which the metric to be minimized can be calculated.

Although it can be proved that the procedure is canceled algorithm *k*, no need to find an optimal configuration that corresponds to the minimum objective function worldwide. The algorithm is also significantly important to start randomly selected group center. The *k*-means algorithm can be run multiple times to reduce this effect.

The routing procedure is then performed. The customers in the same cluster are assigned to a route that is to be served by the small vehicle. A saving matrix is constructed for every two customers in the same path based on Clark and Wright (1964) saving method.

Finally, in the third step of improving procedure the scheduling problem is solved by NNH. There are two steps for scheduling; starting randomly with a customer in a path, obtained in the routing step. After that, the next nearest customer is selected from those unselected customers to the delivered sequence until all customers are selected to compute the shortest path between two customers. Finally, the arrangement of each path will be determined better solution.

From these three hard optimization processes, the initial solution is prepared to give the chromosomes of the initial population to be used in the next HGA procedure. Thus, to obtain the best solution, the initial solutions have been modified for GA, as compared to a random initialization.

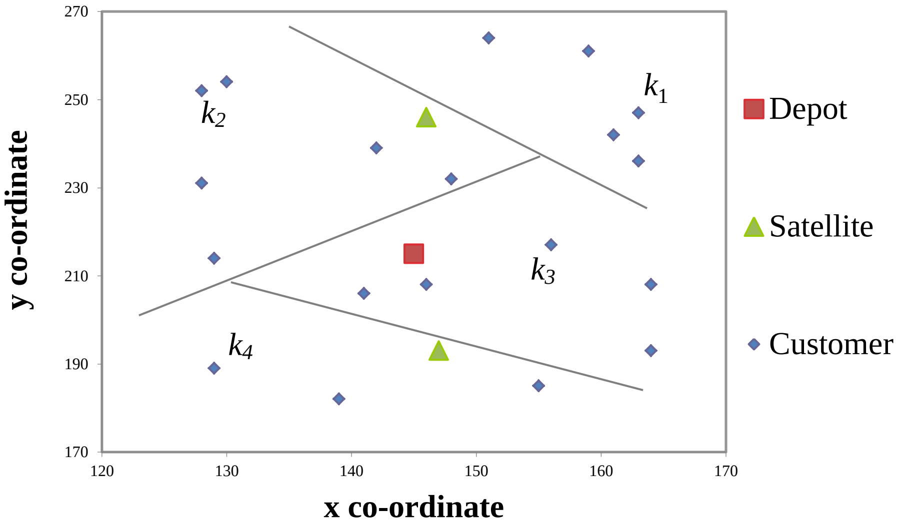


Figure 3.2 The clustered customers after *k*-means clustering

3.3.2 Genetic Algorithms

The GA gradually selects few parent chromosomes and generates children chromosomes until enough children chromosomes have been created to replace the old population. To breed, the programming begins with an empty population of children chromosomes. Then, two parent chromosomes are selected from the initial population. Copy and cross them over with one another, and finally mutate the results. This gives two children chromosomes, which are added to child population chromosomes. The process is repeated until the child population is entirely filled. The three steps of the algorithm are further defined as follow:

The grouping procedure is composed of the following steps: after the number of k has been decided, *k* clusters are randomly defined by the cluster centers. Then each customer is assign to the nearest cluster center, which is then recalculated to the new position of k centroids.

This procedure is repeated until the convergence criterion is met, and the centroids are no longer moved. Figure 3.2 illustrates the clustered customers after the k-means clustering has been applied (see Figure 3.2).

- **Selection**

  Two individuals of the initial population are selected randomly.

- **Crossover**

  The child chromosomes treat all genes fairly with respect to linkage by crossing over each point independently of one another, using Uniform crossover (see Figure 3.3). Each gene is defined by the randomly crossover rate. If that rate met the criterion of crossover, then they are able to swap independently to one another.

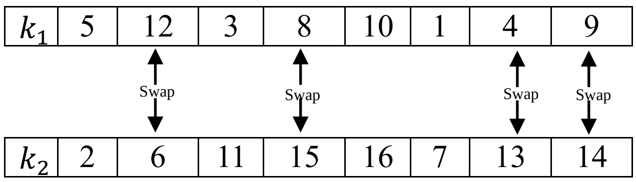


Figure 3.3 Uniform crossover

- **Mutation**

  The mutation operation is performed with one chromosome only. The gene is selected in order to mutate by using the mutation operation rate. Figure 4 illustrates the gens 3 and 15 which are exchanged together (see Figure 3.4). The advantage of mutation operator is to preferable increase in the diversity of population than the quality of the population.

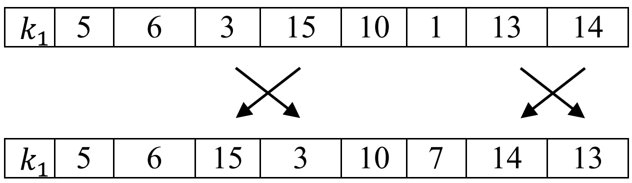


Figure 3.4 Mutation

Each path obtained in the child population is assigned to the nearest satellites. The calculation is based on the travel cost matrix between the satellites node and the customer's nodes. After the path is assigned to the nearest satellite, it is evaluated for the travel cost. The worst solution path is replaced in the new population. The whole process of HGA is repeated until the stopping criterion of iteration is satisfied.

3.4 Computational results

In this section, the computational results of the proposed algorithm are shown in term of effectiveness and efficiency comparing it with exact solution method in the litterers (Perboli et al., 2010; Jepson et al., 2012).

3.4.1 Performances of the Developed Solution Approaches over Instance Sets

The performance is evaluated by using instances sets for the 2E-CVRP. These have been modified from the existing instances for CVRP by Christofides and Eilon (1969) namely E-n13-k4, E-n22-k4, E-n33-k4, and E-n51-k522. All instances can be downloaded at the OR-Library website by Beasley, J. E. (1990). In this paper we define some benchmark to test and verify the effectiveness of the algorithm. Through a large number of experiments, the genetic parameters are set as iteration = 10,000, crossover rate = 0.8 and mutation rate = 0.15. All of instance tests were performed on a 2.21 GhZ AMD Athlon™ 64 X2 Dual Core Processor 4200 PC with 2 Gb of Ram. The codes of the model were implemented in MATLAB (R2012a version) programming.

Table 3.1 Summary of instances tests

Instance Set	Class	Satellites	No. of Instances
Set 2	E-n22-k4	2	6
	E-n33-k4	2	6
	E-n51-k5	4	3
Set 3	E-n22-k4	2	6

Table 3.2 Results on tested instances

Instance	Satellites	Literature [1, 4]	Tested Results	Gap (%)
		Best bound		
E-n22-k4	6, 17	417.07	417.07	0.00
	8, 14	384.96	384.96	0.00
	9, 19	470.60	470.60	0.00
	10, 14	371.50	371.50	0.00
	11, 12	427.22	427.22	0.00
	12, 16	392.78	392.78	0.00
E-n22-k4	13, 14	526.15	526.15	0.00
	13, 16	521.09	521.09	0.00
	13, 17	496.38	496.38	0.00
	14, 19	498.80	498.80	0.00
	17, 19	512.80	512.80	0.00
	21, 19	520.42	520.42	0.00
E-n33-k4	1, 9	730.16	730.16	0.00
	2, 13	714.63	714.63	0.00
	3, 17	707.48	707.48	0.00
	4, 5	778.74	778.74	0.00
	7, 25	756.85	756.85	0.00
	14, 22	779.05	779.05	0.00
E-n51-k5	2, 4, 17, 46	530.76	548.41	3.33
	6, 12, 32, 37	531.92	546.33	2.71
	11, 19, 27, 47	527.63	577.25	9.40

In this study, test results are presented for set 2 and set 3 of benchmark 2E-CVRP instances (Perboli et al., 2001). The study used class of instance E-n22-k4 in both set 2 and set 3, which have different location of satellites. For instances E-n22-k4 and E-n33-k4, 2 satellites have been adapted. For instances E-n51-k5, 4 satellites are selected. Table 1 summarizes of number of solved instances.

The performance of the algorithm is compared with other literatures using an exact solution method. The proposed heuristics algorithm gives 18 out of the best solutions and three close to optimal solutions for E-n51-k5, while computational time is less than 1000 second as shown in Table 2. The first column reports name of the class instances, while the name of satellites node is shown in Column 2. Column 3 and 4 contain the previous best solution from literature and our best solution, respectively. The last column shows percent gap of that solution.

3.5 Summary

The 2E-CVRP associated with the application of city logistics schemes, is a challenging problem and only few researches have been developed in this topic. The uniqueness of this 2E-CVRP is two layers of delivery system; a direct depot-to-satellites and a satellite-to-customers. Both stages must be optimized to satisfy transportation choice.

The 2E-CVRP model is solved using the developed HGA. The grouping procedure of initial solution of the HGAs is developed on an optimization technique in order to efficiently solve the MDVRP problem in the second echelon. The 2E-CVRP benchmarks were tested for evaluation the algorithm. However, the MDVRP benchmarks proposed for future testing after the improvement of algorithm because they are the large-scale problems. The algorithm shows the effectiveness and efficiency, as based on the 21 instances tested in this study, it seems that the algorithm is working efficiently and it can be implemented to large-scale real word problems.

Future research will concentrate on real-world situation of the city network. It deals with an evaluation of environmental impact and delivery on congested network.

References

Beasley, J. E. (1990) OR-Library: Distribution test problems by electronic mail, *Operation Research*, Vol., 41, 1069-1072.

Contardo, C., Cordeau, J.F. and Gendron, B. (2008). A branch-and-cut algorithm for the capacitated location routing problem, *Optimization Days*.

Christifides, N., S. Eilon., (1969). An algorithm for the vehicle dispatching problem, *Operation Research*, Vol. 20, 309-318.

Clarke, G., Wright, J.W.,(1964) Scheduling of vehicles from a central depot to a number of delivery points, *Operations Research*, Vol. 12**,** 568–581.

Crainic, T. G., N. Ricciardi, G. Storchi., (2004). Advanced freight transportation systems for congested urban areas, *Transportation Research Part C*, 119-137.

Crainic, T. G., Ricciardi, N., and Storchi, G. (2009). Models for Evaluating and planning city logistics, *Transportation Science,* Vol. 43, 432-454.

Gen, M., Cheng, R.,(1997). Genetic Algorithms and Engineering Design,Wiley.

Goldberg, D.E.,(1989) Genetic Algorithms in Search, Optimization and Machine, Learning. Addison-Wesley.

Ho, W., Ho, G. T.S., and Lau, H.C.W. (2008). A hybrid genetic algorithm for the multi-depot vehicle routing problem, *Engineering Application of Artificial Intelligence,* 548-557.

Jepsen, M., Spoorendonk, S. and Ropke, S. (2012). A branch-and-cut algorithm for the symmetric two-echelon capacitated vehicle routing problem, *Transportation Science*, 432-454.

MacQueen, J. B. (1967) "Some Methods for classification and Analysis of Multivariate Observations, *Proceedings of 5-th Berkeley Symposium on Mathematical Statistics and Probability"*, Berkeley, University of California Press, 1:281-297

Meihua, W., Xuhong,T. Shan, C., Shumin, W. (2011). Hybrid ant colony optimization algorithm for two echelon vehicle routing problem, Procedia Engineering: *Advanced in Control Engineering and Information Science*, 3361-3365.

Osman, I.H., Kelly, J.P.: Meta-heuristics. (1996). Theory and Applications, Kluwer Academic Publishers.

Perboli, G., Tadei, R. and Vigo, D. J. W. (2001). The two-echelon capacitated vehicle routing problem: Models and Math-Based Heuristics, *Transportation Science*, Vol. 45, No. 3, 364-380.

Perboli, G., Tadei, R. Masoero, F. (2010). New family of valid inequalities for the two-echelon vehicle routing problem., *Electronic Notes in Discrete Math*, 639–646.

Reinelt, G. (1994). The Traveling Salesman: Computational Solutions for TSP, *Applications Springer.*

4

A GENETIC APPROACH FOR TWO-ECHELON CAPACITATED VEHICLE ROUTING PROBLEM WITH TIME WINDOWS

4.1 General

The modelling for 2E-CVRPTW is motivated by city logistics issue. The problems of city logistics associated with the logistics activities by freight transportation as well as social problems including environment, congestion and energy savings in urban areas (Taniguchi et al., 2001). There are many modelling for evaluating the city logistics. Therefore, challenging city logistics planning issue aims to optimize such advanced urban transportation (Cranic, 2008). The application model 2E-CVRPTW for evaluating city logistics problem has been proposed. The 2E-CVRPTW is a new route optimization technique employed in city logistics. City logistics focuses on practical logistics problems, which are specified time windows and environmental-friendly vehicles; this scenario is modelled using 2E-CVRPTW.

The modelling 2E-CVRPTW is an application of VRPTW and MDVRPTW model. There are several variants and classes of vehicle routing problem (VRP) as the capacitated (CVRP) with time windows (VRPTW). Most delivering models are based on the direct shipment. The single-echelon or direct shipment system operates only one layer of delivery activities meet the demands between a single depot. In many applications and real world situations, this model is not completely efficient. Therefore, throughout decades, freight distribution and vehicle routing have moved from a direct shipment in single layer delivery system to a multi-echelon distribution system. The advantage of usage of a multi-echelon and particular two-echelon delivery system is that it can optimize several features as the transportation cost, loading factor, timing and the number of vehicles as figure 4.1.

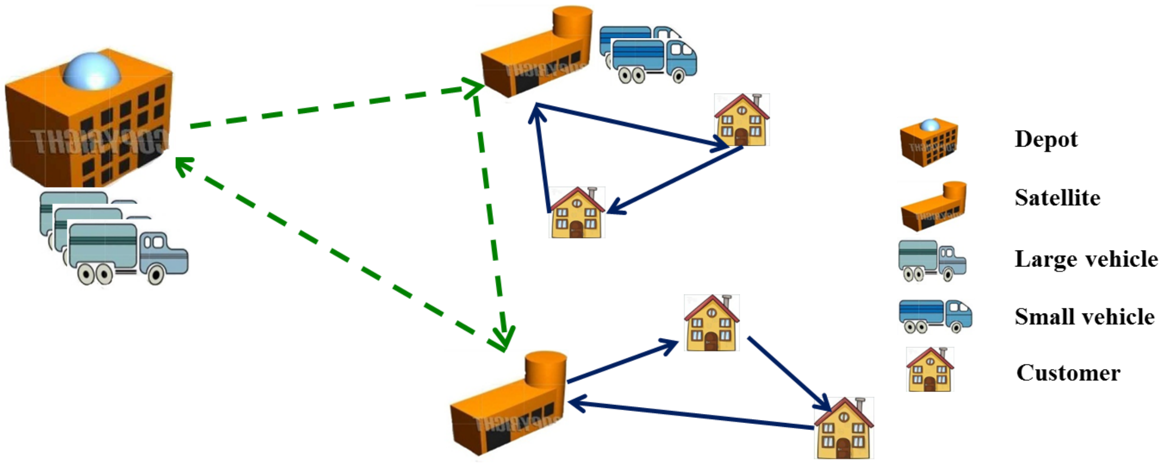


Figure 4.1 Two-echelon distribution system

Several classes of 2E-CVRP have been studied in the literature. There are different approaches including exact algorithms and heuristics, but they all focus on 2E-CVRP formulation and the benchmarks test data are proposed to demonstrate their efficiency. In addition to the geographic component, more realistic routing problems include a time windows constraint by operating travel time between every pair of nodes, customer and satellite service time. The practical situations and routing problem with time window for 2E-CVRP have not been attempted yet.

The new areas of 2E-CVRP distribution system attend to improve the service quality by increasing customer satisfaction in particular time periods of delivery. This research idea is similar to the current VRPTW optimization models. The advantage of this research is usefulness in variety of practical applications. However, some practical issues have not been addressed yet. This research proposes simplified classical of 2E-CVRPTW formulations to evaluate the efficiency of the freight transportation in the city. The scope of the model is developed for the vehicle fleets operations to ensure that the deliveries arrive at the satellite and the customers within specified time windows. In the 2E-CVRPTW, each customer (satellite) has a related time windows defined by the earliest and the latest time to start the service. The depot may also have a horizon time windows. Time windows can either be hard time or soft time windows. This paper tests benchmarks with the hard time windows case, if a vehicle arrives to the customer (satellite) too early, it is allowed to wait at no cost until the customer (satellite) window is open. However, late delivery is not permitted.

This study presents an algorithm based on philosophy of the GA to solve the model of 2E-CVRPTW. The proposed method is based on a modification of the MDVRPTW to 2E-CVRPTW. The evaluate performance of proposed algorithm, the benchmarks of MDVRPTW were solved, as well as new benchmarks of 2E-CVRPTW also ware set to determine the best solutions.

The study decomposed 2E-CVRPTW into two phases. The first phase (the second echelon) is solved by using a classical MDVRPTW, in which a genetic algorithm is used for preparing feasible solution and optimal solution. The customer is visited by environmental-friendly vehicle exactly once. The second phase (the first echelon) is independently solved by using the similar procedure of the previous phase. Each satellite must be served by large vehicles based at the central depot. The objective is to minimize the total distance travelled by all vehicles.

The basic VRP and basically all of its variants are a part of the class of NP-hard problems (Garey and Johnson, 1979). There are many exact algorithms, as described in Kohl et al. (1999) and Laporte and Nobert (1987), which take large computation time as soon as problem instances size increases. Therefore, for large scale problem instances as real network applications finding an optimal solution is not practicable. Nowadays, researchers interest different types of heuristics or meta-heuristics, preparing route construction and route improvement which quickly produces solution of reasonable quality.

In the literature of the multi-echelon delivery system, and the two-echelon system in particular, refer mainly to supply chain and inventory management problem. One of the first application of the routing in two-echelon system was the problem of distributing newspapers via transfer points (Jacobsen and Madsen, 1980). This delivery system can be integrated to city logistics systems for the large cities, which usually are over-populated and have massive buildings for commercial, administrative, and cultural activities. They served by a dense network of mostly narrow and generally congested streets (Crainic et al., 2004). Also, in particular parking areas with strict space regulations are implemented to limit the vehicle sizes. Under the city logistics systems schematic, the controlled zones are relatively close to the outskirts of the city where the depots are located (Taniguchi, E.et.al, 1999). Therefore, it is more effective to arrange two-tier distribution network as in the 2E-CVRP where a depot is located at the outskirts of the city. This delivery system is developed for a specific situation and a generalization of such a system has not already been formulated. The completed mathematic model of 2E-CVRP with the solutions of the sample test data in the classical approach has been proposed and complemented with the method for computing efficiency (Perboli, G., et al., 2010. Cranic et al, 2009) proposed a formulation for the time-dependent version with fleet synchronization and customer time windows, namely two echelon, synchronized, scheduled, multi depot, multiple-tour, heterogeneous VRPTW (2SS-MDMT-VRPTW).

The MDVRPTW is a generalization of the VRPTW and is thus NP hard. Cordeau et al, (2001) described the application of an adapt Tabu Search (TS) algorithm, which had previously been applied to the MDVRP and Periodic VRP. The simple neighbourhood method was main features, a move of one customer from one route to another, and the infeasible solutions are allowed during the search. The results are presented for the Periodic VRPTW, the MDVRPTW and the VRPTW. The VNS based meta-heuristics was implemented to solve MDVRPTW in another papers (Polacek M et al, 2004). The main characteristics of this algorithm are a simple and flexible Local Search as well as an acceptance criterion for neighbouring solutions inspired by Threshold Accepting.

In computational study, the MDVRPTW is proposed to model the second echelon; the best known solutions are compared the best known solution found by Polacek M et al., (2004) for validating model. The new benchmarks for 2E-CVRPTW are created to test model efficiency. This research proposes an algorithm based on philosophy of the Genetic Algorithm (GA) to solve 2E-CVRPTW. GA was firstly developed as a stochastic optimization technique (Ho et al., 2008). Likewise, the other artificial intelligence heuristics such as the Simulated

Annealing (SA) and the Tabu Search (TS), GA can avoid local optimum by the assistance of one of the genetic operations called mutation. The fundamental idea of GA is based on a population that evolves and survival of the fittest. Hence, it is local search algorithm on characteristics of a set of solutions rather than of a single solution, which is commonly called the move-generation mechanism of the local search methods (Osman and Kelly, 1996). In recent years, GA has been adopted successfully to a wide variety of NP-hard optimization problems (Gen and Cheng, 1997; Goldberg, 1989). The major reasons why GA is implemented as an optimization tool in this paper also is principally due to its clarity, easy operation, and greater flexibility..

4.2 Problem description

This study decomposed 2E-CVRPTW into two phases. The first phase (the second echelon) is solved by using a classical MDVRPTW, in which a GA is used for preparing feasible solution. The second phase (the first echelon) is independently solved by using the similar procedure of the previous phase. Each satellite must be served by large vehicles based at the central depot.

The MDVRPTW approach is implemented at the second level routing as satellites represent multi-depots. It is important to determine a feasible solution for the first echelon shortly after the feasible solution of the second echelon can be generated. In this way, the feasible global solution can be considered as an upper bound (Contrado at al., 2008).

As mentioned in the introduction, the delivery from the depot to customers, in multi-echelon VRPTW is allowed through different intermediated satellites. The process aims to ensure an effective and low-cost operation of the system, where the freight is delivered so that the travel cost on the whole transportation network is minimized. The focus of 2E-CVRPTW, in particular, is only one intermediate level of satellites connected with the depot and customers. The load must be delivered to customers, and meet customer's demand d_i. Each demand load cannot be split among different vehicles or multiple routes. We defined in the first echelon, a route that transports demands by a large vehicle $\bar{k}$ with capacity $q_{\bar{k}}$ that starts from the depot, service one or more satellites and ends at the depot while in the second echelon, a route run by small vehicle k with capacity q_k that starts from satellite, serves one or more customers, and ends at the same satellite.

The simplest version of 2E-CVRPTW is used with time dependence. At each level, all vehicles are in the service have fixed capacity. The fleet size of each level is fixed, while the number of vehicles assigned to each satellite is not known in advance and need to be optimized. The objective is to deliver loads to the customers by minimizing the total travel cost, satisfying the capacity constraints of the vehicles. There is a single depot and fixed number of capacitated satellites. All customer demands are fixed, known in advance, and must be compulsorily satisfied. The demand of both levels must less than vehicle's capacity.

This study incorporate the hard time windows, represented by notation a_i and b_i. For improving the service quality, the delivery service must be satisfied by customer's required period (Taniguchi, et at., 2001)

4.3 Formulation for 2E-CVRPTW

Given a set of depot $V_0 = \{0\}$, a set of satellite $V_s = \{s_1, s, \dots, s_n\}$, and set K_0 of homogeneous 1st echelon vehicle, which belong to the depot. Also, given a set of satellite $V_s = \{s_1, s, \dots, s_n\}$, a set of customer $V_c = \{c_1, c_2, \dots, c_n\}$, and set K_s homogeneous 2nd echelon, which belong to satellite. The 2E-CVRPTW can be defined in the graph $G = (V, A)$ where V consist of set V_0, V_s and V_c while A is the set of all arcs (i, j), $i, j \in V$. Let us define the set of all 1st echelon vehicle as $K = K_0$ and for 2nd echelon vehicle as $K = \cup_{s \in S} K_s$.

Q_s is capacity of satellite. For each customer d_i and each satellite d_s is customer and satellite demand with time windows $[a_i, b_i]$. Each vehicle $k \in K_0$ for 1st echelon and $\bar{k} \in K_s$ for 2nd echelon has a capacity q and $\bar{q}$, respectively. c_{ij} is the operating cost matrix between depot and satellite as well as satellite and customer.

The model to minimize the total cost of the two echelon may be formulated as follows:

Formulation for 1st echelon;

$$\min \quad \sum_{k\in K}\sum_{(i,j)\in A} c_{ij}x_{ijk} \tag{1}$$

subject to

$$\sum_{k\in K}\sum_{j\in V_s\cup V_0} x_{ijk} = 1 \qquad \forall j\in V_s \tag{2}$$

$$\sum_{j\in V_s\cup V_0} x_{0jk} = 1 \qquad \forall k\in K_0 \tag{3}$$

$$\sum_{i\in V_s} x_{i0k} = 1 \qquad \forall k\in K_0 \tag{4}$$

$$\sum_{i\in V_s\cup V_0} x_{ihk} - \sum_{j\in V_s\cup V_0} x_{hjk} = 0 \qquad \forall h\in V_s, \forall k\in K \tag{5}$$

$$\sum_{i\in V_s} d_i \sum_{j\in V_s\cup V_0} x_{ijk} \le q \qquad \forall k\in K \tag{6}$$

$$s_{ik} + t_{ij} - s_{jk} \le M(1-x_{ijk}) \qquad \forall (i,j)\in A, \forall k\in K_0 \tag{7}$$

$$a_i \le s_{ik} \le b_i \qquad \forall i\in V, \forall k\in K_0 \tag{8}$$

$$x_{ijk}\in\{0,1\} \qquad \forall (i,j)\in A,\ \forall k\in K_0 \tag{9}$$

Formulation for 2nd echelon;

$$\min \quad \sum_{i\in V_s\cup V_c}\ \sum_{j\in V_s\cup V_c}\ \sum_{\bar{k}\in K} c_{ij}x_{ij\bar{k}} \tag{10}$$

subject to

$$\sum_{s\in V_s}\sum_{\bar{k}\in K}\sum_{j\in V_c\cup V_s} x_{ijk} = 1 \qquad \forall i\in V_c \tag{11}$$

$$\sum_{j\in V_c\cup V_s} x_{sj\bar{k}} = 1 \qquad \forall s\in V_s, \forall \bar{k}\in K_s \tag{12}$$

$$\sum_{i\in V_c\cup V_s} x_{is\bar{k}} = 1 \qquad \forall s\in V_s, \forall \bar{k}\in K_s \tag{13}$$

$$\sum_{i\in V_c\cup V_s} x_{ih\bar{k}} - \sum_{j\in V_c\cup V_s} x_{hj\bar{k}} = 0 \qquad \forall h\in V_c, \forall \bar{k}\in K \tag{14}$$

$$\sum_{i\in V_c} d_i \sum_{j\in V_c\cup V_s} x_{ij\bar{k}} \le \bar{q} \qquad \forall \bar{k}\in K \tag{15}$$

$$d_s = \sum_{\bar{k}\in K_s}\left[\sum_{i\in V_c} d_i \sum_{j\in V_c\cup V_s} x_{ij\bar{k}}\right] \qquad \forall \bar{k}\in K_s \tag{16}$$

$$d_s \le Q_s \qquad \forall s\in V_s \tag{17}$$

$$s_{i\bar{k}} + t_{ij} - s_{j\bar{k}} \le M(1-x_{ij\bar{k}}) \qquad \forall (i,j)\in A, \forall \bar{k}\in K_s \tag{18}$$

$$a_i \le s_{i\bar{k}} \le b_i \qquad \forall i\in V_c\cup V_s,\ \forall \bar{k}\in K_s \tag{19}$$

$$x_{ij\bar{k}}\in\{0,1\} \qquad \forall (i,j)\in A, \forall \bar{k}\in K_s \tag{20}$$

Objective function is equation (1) and (10). Equation (1) is minimize transportation cost of 1st echelon and equation (9) is minimize travel cost of small vehicle in 2nd echelon. Therefore, total transportation of this research is sum of travel cost of both echelon. Constraint (2) and (11) are assignment constraints ensure that every customers/ satellites must be serviced once. Constraint (3), (4) and (5) are flow conservation of 1st echelon constraint, if the 1st vehicle start from the depot, it must return to the depot, also constraint (12), (13) and (14) are flow conservation of 2nd echelon. Every vehicle $\bar{k}$ must start and end the same satellite and the vehicle to leave the customer h if it visit the customer h. Capacity constraint is equation (6) for 1st echelon and (15) for 2nd echelon. Constraint (17) is total demand of customer must be less than capacity of the satellite. Constraint (7) and (8) is time windows constraint indicating that if the vehicle goes from i to j, it must serve customer i before j within its time windows for 1st echelon, in constraint (18) and (19) for 2nd echelon. Constraints (9) and (20) is equal 1 if arc (i,j) is used by vehicle k , $\bar{k}$ for 1st echelon and 2nd echelon, respectively and 0 otherwise. The variable s_{ik} and $s_{i\bar{k}}$ imply the time when k or $\bar{k}$ start to service customer i.

4.4 Genetic algorithms (GAs) heuristics

In this study, as an application, a simple GA (Qureshi e al, 2010) is used to evaluate and calculate the heuristics 2E-CVRPTW solutions and computation time.

- **Chromosome representative and population**

The population is composed of 1000 integer valued individuals or chromosomes, each representing a complete feasible VRPTW solution. A greedy look-ahead insertion heuristic based on time windows matching is used to generate a feasible solution. Half of the initial population is obtained by randomly swapping one to four customers in this feasible solution, while the remaining half is generated randomly. Figure 4.2 shows a chromosome for a nine customer instance and its interpretation in the sample GA for new vehicles due to the presence of a depot gene or due to the violation of capacity or time windows constraints. Two continuous variables ($qsum_0 = 0$ and $twroute_0$) for each vehicle are initiated (as per equation (21)) and updated every time that vehicle travels from i to j according to the equation (22) and equation (23).

$$twroute_0 = max\ [a_0, a_i - t_{0i}] \tag{21}$$

$$qsum_j = qsum_i + d_j \tag{22}$$

$$twroute_j = twroute_i + t_{ij} \tag{23}$$

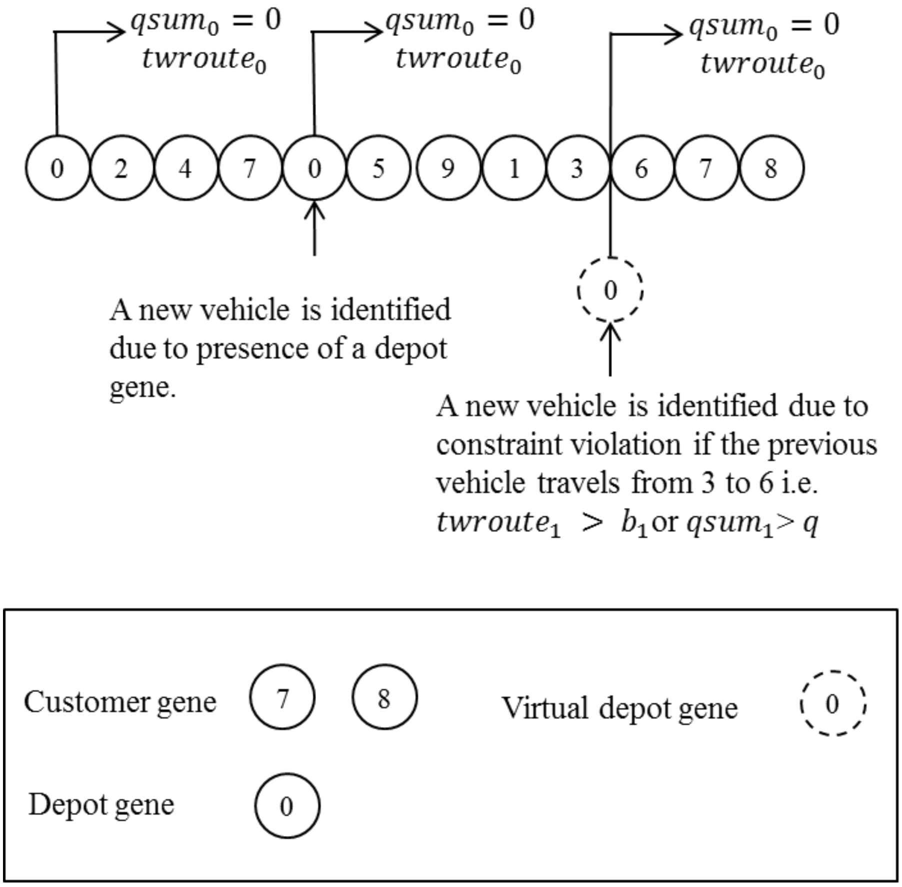


Figure 4.2 VRPTW chromosomes coding in GA-2

The sample GA was improved by the Stochastic Push Forward Insertion Heuristics (SPFIH) (Alvarenga et al., 2007) method for obtaining the entire chromosome. It was modified to incorporate with time window. Let $i_0, i_1, i_2, \ldots, i_m$) be a partial route in the SPIFH that start and ends at the depot (i.e. $i_0 = i_m = 0$). Insertion of a customer vertex u between i_{p-1} and $i_p$causes a push forward (PF_{i_p}) in a schedule at the customersi_p. Similar to Solomon (1987), the best feasible insertion place is determined using equation (24) for each un-routed customer u in order to find the insertion cost (equation (25)) of each un-routed customer u. Finally, the best customer $u^*$to be inserted in the route is obtained using equation (26)

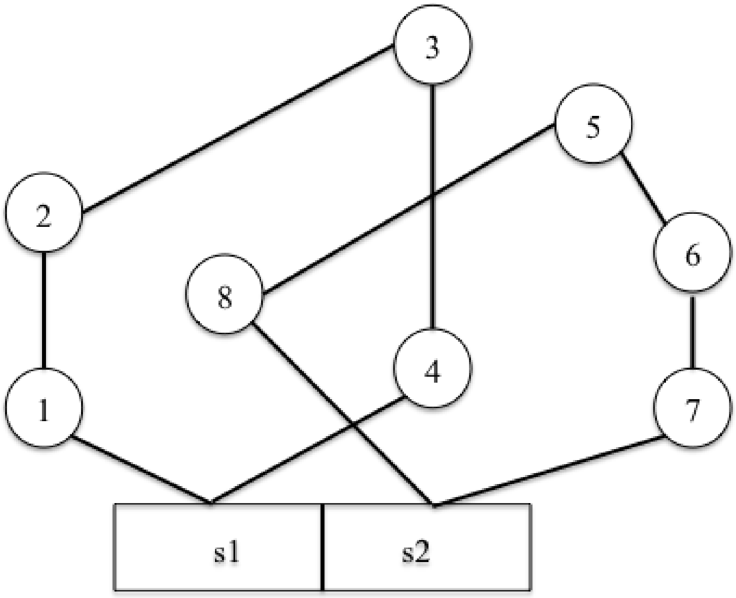
$$c_1(i(u), u, j(u)) = \min[c_1(i_{p-1}, u, i_p)], p = 1, \dots, m \quad (24)$$

$$c_1\left(i_{p-1}, u, i_p\right) = c_{i_{p-1},u} + c_{u,i_p} - c_{i_{p-1},i_p} \quad (25)$$

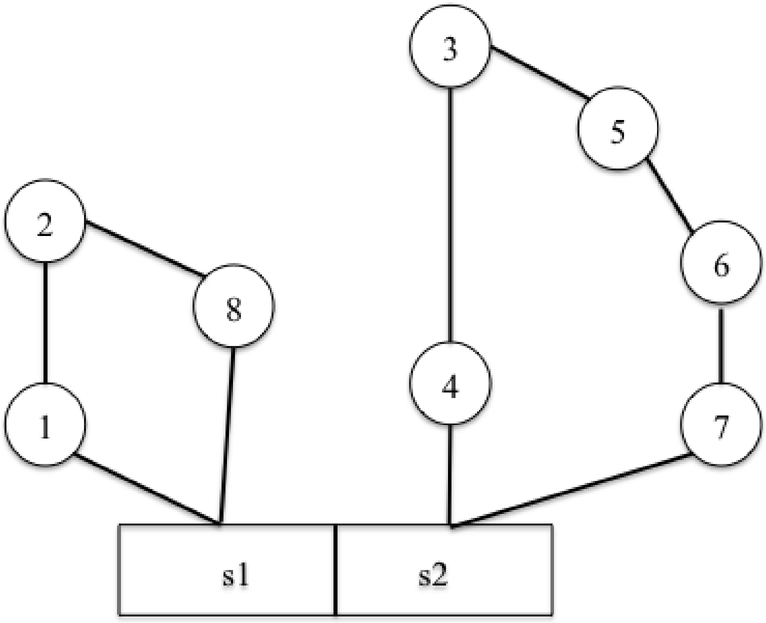
$$c_1\left(i(u^*), u^*, j(u^*)\right) = \min_u[c_1(i(u), u, j(u))] \quad (26)$$

- **Crossover, mutation and elitsm**

To generate the population chromosomes for the next generation, individuals from the present population are selected using the Stochastic Universal Selection (SUS) method (Chipperfield et al., 1994) based on their fitness value. To maintain the feasibility of the chromosomes, i.e., to avoid duplication of the same customer gene, an ordered-based two-point crossover is used with a crossover rate of 98%. A simple swap mutation is used to stirrup the search pattern at a mutation rate of 10%. To ensure that each iterations of the GAs always finds a new or maintains the best solution found so far, elitism is adopted thereby keeping the best 2% individuals of the current population in the population of the next generation. GA-2 was implemented and modified from VRPTW to MDVRPTW. Therefore, each path obtained in the child population is assigned to the nearest satellites. The calculation is based on the travel cost c_{ij} matrix between the satellites node and the customer's nodes. After the path is assigned to the nearest satellite, it is evaluated for the travel cost. The worst solution path is replaced in the new population. Figure 4.3 shows chromosome representative of satellite 1 and satellite 2 before crossover (Figure 4.3a) and after applying the crossover then it creates new chromosome representative of satellite 1 and satellite2.



(a) Chromosomes representative



(b) Chromosome representative after crossover

Figure 4.3 MDVRPTW Chromosome representatives

4.5 Computational results

In this section, the computational results of the proposed algorithm are shown in term of effectiveness and efficiency comparing it with best known solution (heuristics method) for MDVRPTW to evaluate the performance of GA-2 method in the literature (Polacek et al., 2004).

- **Performances of the developed solution approaches over instance sets**

In this section the GA-2 implementation proposed above will be analysed and its performance will be compare to the result of Variable Neighborhood Search (VNS) specified in Polacek et al (2004). The GA-2 was implemented in MATLAB and experiments were performed on AMD Phemom™ X6 1100T Proceeor 3.30 GHz.

The problem instances used for analysis originate from Cordeau, Laporte, and Mwecier (2001) and are available on the internet at http:// ww.hec.ca/chairedistributique/data. The data set consist of 20 instances with differ with respect to their size as well as their time window tightness. Table 4.1 provides some information about the problem instances and best known solution by VNS. Problem size 1-100 customers, 101-200 customers, 201-300 customers, computation time are 1.97 hrs., 2.53 hrs. and 2.68 hrs., respectively (Polacek et al., 2004). The algorithm are tested the performance with MDVRPTW instance, and then 2E-CVRPTW instance are generated and tested to evaluate the model application of 2E-CVRP for city logistics.

More precisely, the column head with *n*, *s*, and *k* are representing the number of customers, the number of depots (satellites), and number of available vehicles at each depot (satellite), respectively.

Table 4.1 Comparison of instances MDVRPTW and its results

No.	*n*	*s*	*k*	VNS	GA-2	Gap %	Time (min)
01	48	4	2	1074.12	1074.12	0.00	9.24
02	96	4	3	1762.21	1762.21	0.00	23.10
03	144	4	4	2373.65	2388.50	0.63	32.30
04	192	4	5	2815.48	2896.25	2.87	40.10
05	240	4	6	2993.94	3075.19	2.71	47.56
06	288	4	7	3629.72	3816.14	5.14	50.25
07	72	6	2	1418.22	1423.29	0.36	17.21
08	144	6	3	2096.73	2112.45	0.75	30.12
09	216	6	4	2730.54	2799.92	2.54	42.54
10	288	6	5	3499.56	3608.18	3.10	55.37
11	48	4	1	1005.73	1005.73	0.00	8.24
12	96	4	2	1472.76	1472.76	0.00	19.65
13	144	4	3	2001.83	2030.45	1.43	27.54
14	192	4	4	2215.51	2258.61	1.95	34.74
15	240	4	5	2465.25	2523.42	2.36	45.26
16	288	4	6	2896.03	2951.31	1.91	45.62
17	72	6	1	1236.24	1236.24	0.00	11.09
18	144	6	2	1796.21	1828.50	1.80	28.95
19	216	6	3	2292.45	2334.51	1.83	42.38
20	288	6	4	3076.37	3115.97	1.29	53.24

The performance of GA-2 algorithms for testing MDVRPTW is shown in the table. The results of five instances were similar to best known solution of VNS heuristics. It indicates that the second echelon can be solved by this algorithm. Moreover, there are 1.53% gap between best known solution and the new GA-2 algorithm. All GA-2 algorithm presented the best known solution are based on run 10^4 iterations. Maximum computation time for large problem size is less than 60 min.

- **New instance set for 2E-CVRPTW**

The generation of problem instances set for 2E-CVRPTW is based on problem set of MDVRPTW. This problem is a single depot. Time windows are determined at each customers (2^{nd}TW) and satellites (1^{st}TW). The data set consist of 15 instances with differ with respect to their size as well as their time window tightness. Table 4.2 show for each instance set of 2E-CVRPTW. In column 2 and 3 show number of customers and satellites. *c1* and *c2* are capacity of each vehicle size, they are located at satellites and the depot and they have a fixed cost *fc1*and *fc2*. The available of vehicle at a satellite and the depot, *k2* and *k1* respectively. This study is solved by GA-2 algorithms for both levels.

Table 4.2 2E-CVRPTW instances set

No.	***n***	***s***	***c1***	***c2***	***fc1***	***fc2***	***k1***	***k2***	**1st-TW**	**2nd-TW**
2E-01-1	25	2	450	200	750	500	1	2	✓	✓
2E-01-2	19	2	450	200	750	500	1	2	✓	✓
2E-01	48	4	450	200	750	500	2	2	✓	✓
2E-02-1	48	2	700	195	750	500	2	3	✓	✓
2E-02-2	48	2	700	195	750	500	2	3	✓	✓
2E-02	96	4	700	195	750	500	2	3	✓	✓
2E-03-1	70	2	900	190	750	500	2	4	✓	✓
2E-03-2	74	2	900	190	750	500	2	4	✓	✓
2E-03	144	4	900	190	750	500	3	4	✓	✓
2E-07-1	26	2	600	200	750	500	1	2	✓	✓
2E-07-2	46	4	600	200	750	500	1	2	✓	✓
2E-07	72	6	600	200	750	500	2	4	✓	✓
2E-08-1	76	3	900	190	750	500	2	3	✓	✓
2E-08-2	68	3	900	190	750	500	2	3	✓	✓
2E08	144	6	900	190	750	500	3	3	✓	✓

The result in table 4.3 clearly shows the strong performance of GA-2 algorithms. *k1'*and *k2'* represent number of vehicle that visit the customers at both level. The results are not guaranteed to be the best solution. However, the GA-2 algorithm was tested for checking the performance with MDVRTW instance set as discussed above. The result shows optimum solutions not only for small size problem but for large size problem also. The time windows are determined strictly for service satisfied customers and the satellite. The last vehicle must return to the satellite within time period of each satellite too.

This study shows the results that calculate by the new proposed algorithm for evaluate the problem of 2E-CVRPTW. This is the new model to be application in city logistics scheme in the next research.

Table 4.3 The result of 2E-CVRRP instances set

No.	GA-2	*k1'*	*k2'*	Time (min)
2E-01-1	2873.00	1	3	1.21
2E-01-2	3008.00	1	3	0.87
2E-01	5881.00	2	6	11.50
2E-02-1	4534.00	1	5	2.32
2E-02-2	4259.00	1	5	2.29
2E-02	8793.00	2	10	25.80
2E-03-1	5320.47	1	6	15.90
2E-03-2	7289.91	2	8	16.50
2E-03	12610.39	3	14	30.20
2E-07-1	2912.62	1	3	0.74
2E-07-2	4890.25	1	6	1.22
2E-07	7802.87	2	9	14.10
2E-08-1	6947.71	2	8	15.10
2E-08-2	5596.93	1	7	13.20
2E08	12544.65	3	15	38.30

4.6 Summary

The 2E-CVRPTW associated with the application of city logistics schemes, is a challenging problem and only few researches have been developed in this topic. The uniqueness of this 2E-CVRPTW is two layers of delivery system; a direct depot-to-satellites and a satellite-to-customers. Both stages must be optimized to satisfy transportation choice and customer are served within time windows.

The 2E-CVRPTW model is solved using the developed GAs. The crossover procedure for preparing the chromosome representative solution is developed on an optimization technique in order to efficiently solve the MDVRPTW problem in the second echelon. The new 2E-CVRPTW instances set were tested for evaluation the algorithm. Also, MDVRPTW benchmarks proposed for testing after the improvement of GA-2 algorithm. The algorithm shows the effectiveness and efficiency, as based on the 20 instances tested in this study, it seems that the algorithm is working efficiently and it can be implemented to large-scale real word problems.

References

Alvarenga, G. B., Mateus, G. R., & Tomi, G. de. (2007). A genetic and set partitioning two-phased approach for the vehicle routing problem with time windows. *Computers & Operations Research*, 34, 1561-1584.

Chipperfield, A., Fleming, P., Pohlhiem, H., & Fnoseca, C. (1994). User guide: Genetic algorithm toolbox for use with MATLAB. Department of Automatic Control and Systems Engineering, University of Sheffield. Availableat

Contardo, C., J.F. Cordeau, and B. Gendron. (2008). A branch-and-cut algorithm for the capacitated location routing problem. *Optimization Days*.

Cordeau, J.F., G. Laporte, and A. Mercier. (2001). A unified tabu search heuristic for vehicle routing problems with time windows. *Journal of the Operational Research Society* 52, 928–936.

Crainic, T. G., N. Ricciardi, G. Storchi. (2004). Advanced freight transportation systems for congested urban areas. *Transportation Research Part C*, 119-137.

Crainic, T. G., S. Mancini, G. Perboli, R. Tadei. (2008). Clustering based heuristics for the two-echelon vehicle routing problem. Technical report CIRRELT-46.

Crainic T. G., N. Ricciardi, and G. Storchi. (2009). Models for evaluating and planning city logistics. *Transportation Science*, Vol. 43, 432-454.

Gen, M., Cheng, R. (1997). Genetic Algorithms and Engineering Design,Wiley.

Goldberg, D.E. (1989). Genetic algorithms in search, optimization and machine. Learning. Addison-Wesley.

Garey, M.R. and D.S. Johnson. (1979). Computers and Intractability: A guide to the theory of np completeness. New York: W.H. Freeman & Co.

Ho, W., Ho, G. T.S. and Lau , H.C.W. (2008). A hybrid genetic algorithm for the multi-depot vehicle routing problem. *Engineering Application of Artificial Intelligence,* 548-557.

Jacobsen S, Madsen O. (1980). A Comparative study of heuristics for a two-level routing-lacation problem. *European Journal of Operation Research* , 378-387

Kohl, N., J. Desrosiers, O.B. Madsen, M.M. Solomon, and F. Soumis. (1999). 2-path cuts for the vehicle routing problem with time windows. *Transportation Science* 33, 101–116.

Laporte, G. and Y. Nobert. (1987). Exact algorithms for the vehicle routing problem. *Annals of Discrete Mathematics* 31, 147–184.

Osman, I.H., Kelly, J.P.: Meta-heuristics. (1996). Theory and Applications. *Kluwer Academic Publishers*.

Perboli,G R. Tadei, F. Masoero. (2010). New family of valid inequalities for the two-echelon vehicle routing problem. *Electronic Notes in Discrete Math*, 639–646.

Polacek M., R.F. Hartl and K. Doerner (2004). A variable neighborhood search for the multi depot vehicle routing problem with time windows. *Journal of Heuristics*, 10: 613-627

Qureshi, A. G., Taniguchi, E., & Yamada, T. (2010). Exact solution for the vehicle routing problem with semi soft time windows and its application. *Procedia Social and Behavioral Science* 2, 5931-5943

Solomon, M. M. (1987). Algorithms for the vehicle routing and scheduling problem with time windows constraints. *Operations Research*, 35, 254-265.

Taniguchi, E., Noritake, Yamada, T., & Izumitani T. (1999). Optimal size and location plannong of public logistics terminals. *Transportation Research Part E* ,35(3). 207-222.

Taniguchi, E., Thompson, R. G., Yamada, T., & Duin, R. V. (2001). City logistics: Network modeling and intelligent transport systems. Pergamon, Oxford.

5

APPLICATION FOR OSAKA NETWORK

5.1 General

Osaka has served as the capital of Japan, and for centuries been a port of entry for international exchange. In more modern times, it has been a bastion of trade and finance and plays a major role in the economic and industrial development of Japan. This metro area, centered on the city of Osaka is home to many businesses operating in a variety of disciplines and business hub is a very active market. The Osaka market is large and growing with the economy. Many researchers are very interested in testing the model of economic development to the network Osaka. Transportation to the city is attracting more and more attention in many parts of the world due to the greater mobility of the population and increasingly related urban, social and environmental problems. Therefore, the government must continue to deal with problems in urban areas. Creation of transportation in a city that offers higher efficiency and lower costs and to make sure environment, community safety and well-being of the people. Osaka is the second urban area with. "International Strategic Comprehensive Special Zone" started by the national government as a strategic growth market and the strong growth in Asia.

Figure 5.1 Highway network around Osaka bay

(*Source*: Kinki Regional Development Bureau, Ministry of Land, Infrastructure. Transportation and Tourism)

City logistics challenges, city officials, business and public services in relation to transport their products and introduce new business models and operations requires an understanding of public-private collaboration and cooperation. For the innovative research and scientific operations, transportation city logistics is considered both a challenge and an opportunity in terms of method development and social effects that actually occur. The review of existing literature, however, shows that. "Optimizing" components of the logistics have not yet been developed. The concept and major studies are carried out. But very few published version and how it is dedicated to the design, evaluation, planning, management and control.

This research evaluates the model of freight transport for two layers in Osaka network, where satellite platforms are used to transship goods from vehicles arriving from main depot to smaller, center-city-friendly vehicles. The problem selects the routes and the scheduling of departures for the vehicles of both fleets. Strict coordination and time synchronization of the operations of the two fleets are central elements of the two echelon vehicle routing problem with time windows (2E-CVRPTW). The problem will be solved using the same methodology as described in the previous chapter.

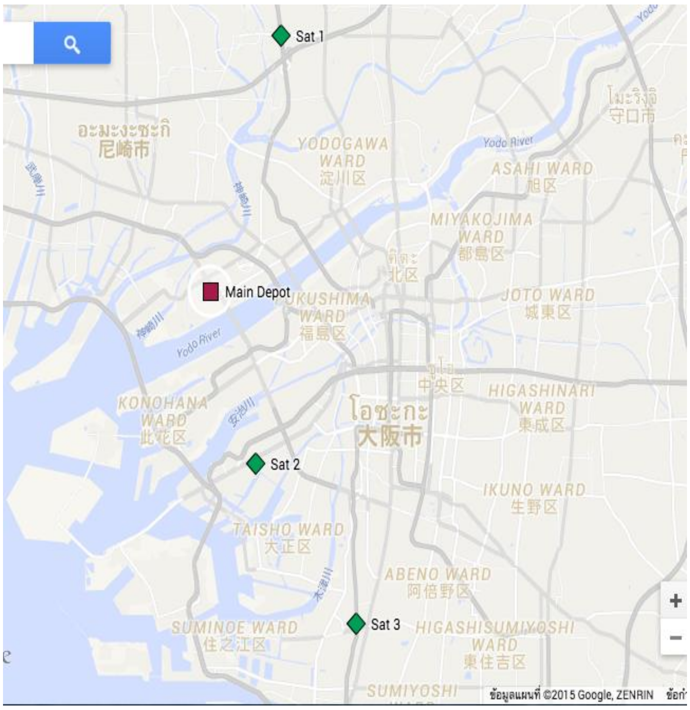


Figure 5.2 Location of Main depot and satellites in Osaka network' instances

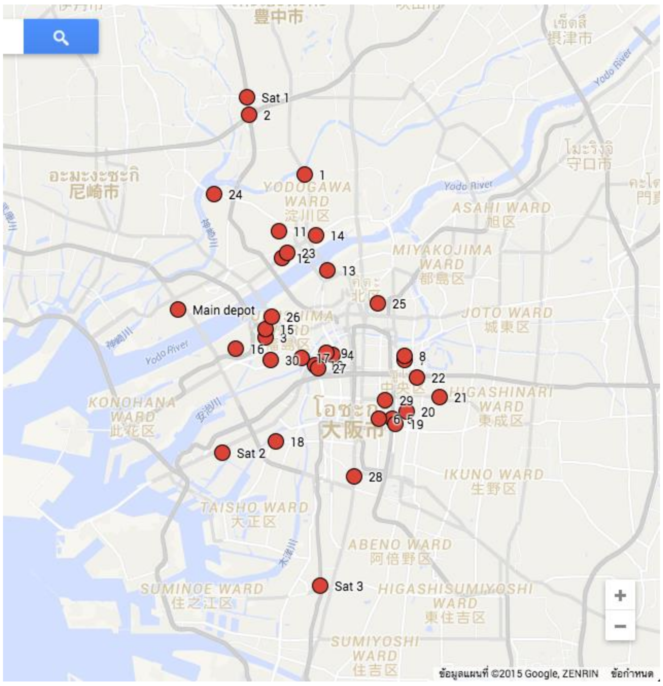


Figure 5.3 Location of customers in Osaka network' instances

5.2 Osaka network test instances

The generation of problem instances set for 2E-CVRPTW is based on problem set of Osaka network instance. There are 6 scenarios (Table 5.1). The first to third scenario includes one depot with 3 satellites, 2 satellites and only one satellite respectively. With each scenario, 1st level vehicles have the same depot cost, capacity and fixed vehicle cost. Also, in the 2nd level vehicle of first to third scenario are tested in the same depot cost, capacity and fixed vehicle cost. The data set consist of 30 instances which differ with respect to their size as well as their time windows tightness. Table 5.2 shows for each instance satellites and customers' demand and time windows. In column 1 shows number of customers and satellites. The demand of each customer is shown in column 2. Time windows are determined at each customer and satellites are shown in column 3 and 4. Service time of customers and satellites is in the column 5.

Table 5.1 Parameters used in each scenario

Scenario	**Depot**	**Satellite**	**Depot Cost**	**Satellite Cost**	**1st level Vehicle**		**2nd level Vehicle**	
					Capacity	**Cost**	**Capacity**	**Cost**
1	1	1	68,403	22,801	3,000	10,418	1,340	5,209
		2		14,334				
		3		21,357				
2	1	1	68,403	22,801	3,000	10,418	1,340	5,209
		2		14,334				
3	1	1	68,403	14,334	3,000	10,418	1,340	5,209
4	1	-	68,403	-	3,000	10,418	-	-
5	1	-	68,403	-	2,000	7,441	-	-
6	1	-	68,403	-	1,340	5,209	-	-

Table 5.2 Satellites and Customers' demand and times windows

Customer	Demand	Time Windows		Service Time
		a_i	b_i	
Satellite 1	calculated by programing	15	117	20
Satellite 2	calculated by programing	8	170	20
Satellite 3	calculated by programing	23	110	20
1	175	399	525	2
2	250	121	299	7
3	270	389	483	21
4	290	204	304	24
5	120	317	458	1
6	185	160	257	17
7	310	170	287	6
8	325	215	321	5
9	260	80	233	7
10	165	90	206	1
11	310	397	525	4
12	225	271	420	10
13	152	108	266	2
14	372	340	462	16
15	190	226	377	23
16	220	446	604	18
17	350	444	566	3
18	320	434	557	15
19	145	319	460	13
20	162	192	312	10
21	110	414	572	4
22	130	371	462	23
23	153	378	472	20
24	256	308	477	10
25	335	329	444	4
26	165	269	377	2
27	145	398	494	23
28	185	257	416	6
29	145	198	294	8
30	150	375	467	10

5.3 Computational results

In Osaka network instances test separate to six scenarios. The first to third scenario was tested by 2E-CVRPTW model. For forth to sixth scenario is traditional VRP which was tested by CVRPTW. The table 5.3 in last column illustrates total route cost for the 2E-CVRP model and CVRP model. Costs are always higher for 2E-CVRPTW model and advantage appears to increase with the number of satellites, see Figure 5.3. For example, route cost of scenario 1 is lower than route cost of scenario 3. Route cost of the CVRTW model will be increased when using a large vehicle, see Figure 5.4.

The discussion between 2E-CVRPTW model and traditional CVRP model is the route cost. It seems that the route cost of scenario 1, 2 and 3 that was tested by 2E-CVRPTW model are higher than the scenario 4, 5 and 6 that was tested by classical CVRPTW because this study considered only distribution cost and vehicle fixed cost. However, if the study consider total costs include environmental cost and facilities cost, the total costs of 2E-CVRPTW model trend to be lower than traditional CVRPTW model. Customers are satisfied the delivering goods with in the right time which is advantage of 2E-CVRPT model because satellite can be served the goods with in time windows, due to the location of the satellite is closed to customers. The delivery goods from main the depot that was located at outside the city may miss the delivery within time windows, they will re-deliver. Therefore, the total costs CVRPTW model may higher than 2E-CVRPTW model.

Table 5.3 Osaka network' instances test results

Scenario	Depot	Satellite	Depot Cost	Satellite Cost	1st level Vehicle		2nd level Vehicle		Route Cost	Total Cost
					Capacity	Cost	Capacity	Cost		
1	1	1	68,403	22,801	3,000	10,418	1,340	5,209	62,809	189,704
		2		14,334						
		3		21,357						
2	1	1	68,403	22,801	3,000	10,418	1,340	5,209	64,513	170,358
		2		14,334						
3	1	1	68,403	14,334	3,000	10,418	1,340	5,209	65,820	148,557
4	1	-	68,403	-	3,000	10,418	-	-	31,450	99,853
5	1	-	68,403	-	2,000	7,441	-	-	29,971	98,374
6	1	-	68,403	-	1,340	5,209	-	-	26,283	94,686

Total cost of traditional CVRPTW model shows lower cost than model of 2E-CVRPTW. Total cost of 2E-CVRP is higher because Two echelon model has more construction cost, vehicle cost etc. The CVRPTW model has one depot, located at outskirt, far from location of customers. The delivery may miss time windows, customer can reject goods, in particular newspaper industry or fresh foods industry. If there are many vehicle approach to the city, then they will face traffic congestion, difficult to find parking area. The transportation may be delayed, it will effect satisfying of customer. 2E-CVRPTW model proposed for solve that problem, in particular city areas. If it shows higher cost, many industry trend to change for sustainable freight transportation.

5.4 Summary

The 2E-CVRPTW model is solved using the developed GAs. The Osaka network instances were tested for evaluation of the routing cost. It seems that the algorithm is working efficiently and it can be implemented to large-scale real word problems. In this research evaluate the model of freight transport for two layers in Osaka network, where satellite platforms are used to transship goods from vehicles arriving from main depot to smaller, center-city-friendly vehicles. It seems that the model 2E-CVRPTW can solve the Osaka network' instances

References

Kinki Regional Development Bureau, Ministry of Land, Infrastructure. Transportation and Tourism (2002)

6

CONCLUSION AND FUTURE RESEARCH

6.1 Conclusion

In this thesis, the importance of two-echelon distribution in real transport applications, and more specifically in City Logistics, have been presented. Nowadays, many combinatorial optimization problems deal with freight distribution, but no general methods which consider the entire system without separating it in a number of independent smaller problems have been presented. It's why I introduced a new family of combinatorial optimization problems, the two-echelon VRP.

This dissertation focus our study on city logistics systems where merger activity and coordination to implement the facility is a two-echelon hierarchical structure with huge on depot sited urban and satellite locations adjacent to or within the city center. Vehicles, especially dedicated to each class load transfer system operated satellites. The two systems are offering more levels for major cities with serious problems related to transportation. But the method has not been proposed to assist the planning process involved. Challenge, especially in planning the two-echelon system of logistics related to short-term scheduling, integrated operations and resource management. The problem is that the choice of routes and the timings of departure for vehicles, as well as choosing the preferred route from the main depot via satellite to final customers. To coordinate and synchronize the operation of vehicles is a key element of the problem and the proposed formula. The new issue will therefore multi depot on the two echelon problem with time windows (VRPTW).

After defining a general two-echelon distribution system and giving a synthetic survey con two-echelon systems and route optimization problems, I have presented the new family of decision problems known as two-Echelon VRP, giving their generalities and main complex aspects, which are in general found at the connection constraints between levels. Then, we focused on the two-echelon capacitated VRP, which have been defined in detail, and HGAs have been developed. The model derives from the classical vehicle flow formulation for the VRP, which is based on TSP concepts and uses sub tour elimination constraints (which number depends exponentially from the number of satellites and customers).

The model have been tested on new benchmarks derived from the CVRP instances of the literature, showing a good behavior of the model for small and medium sized instances. Moreover, a first attempt to find a priori conditions on the solution quality of 2E-CVRP has been performed, enabling the introduction of a classification of the instances according to the combination of easy-to-compute instance parameters, such as satellite accessibility and mean transportation cost.

The 2E-CVRP associated with the application of city logistics schemes, is a challenging problem and only few researches have been developed in this topic. The uniqueness of this 2E-CVRP is two layers of delivery system; a direct depot-to-satellites and a satellite-to-customers. Both stages must be optimized to satisfy transportation choice.

The 2E-CVRP model is solved using the developed HGA. The grouping procedure of initial solution of the HGAs is developed on an optimization technique in order to efficiently solve the MDVRP problem in the second echelon. The 2E-CVRP benchmarks were tested for evaluation the algorithm. However, the MDVRP benchmarks proposed for future testing after the improvement of algorithm because they are the large-scale problems. The algorithm shows the effectiveness and efficiency, as based on the 21 instances tested in this study, it seems that the algorithm is working efficiently and it can be implemented to large-scale real word problems.

New model of 2E-CVRP is applied to 2E-CVRPTW. Both stages must be optimized to satisfy transportation choice and customer server within time windows. The 2E-CVRPTW model is solved using the developed GAs by application of GA-2. The crossover procedure for preparing the chromosome representative solution is developed on an optimization technique in order to efficiently solve the MDVRPTW problem in the second echelon. The new 2E-CVRPTW instances set were tested for evaluation the algorithm. Also, MDVRPTW benchmarks proposed for testing after the improvement of GA-2 algorithm. The algorithm shows the effectiveness and efficiency, as based on the 20 instances tested in this study, it seems that the algorithm is working efficiently and it can be implemented to large-scale real word problems.

City logistics ideas, projects, and initiatives appear to hold one of the keys to achieving a more balanced distribution of the benefits of moving freight in and out of the city and the environmental, social, and economical nuisance and cost associated to freight transportation, particularly in large and congested urban zones. The core operation is the coordinated delivery of freight of many different shipper-carrier-consignee commercial relations through consolidation facilities such as satellites. City logistics explicitly refers to the optimization of such advanced urban freight transportation systems.

In this research evaluate the model of freight transport for two layers in Osaka network, where satellite platforms are used to transship goods from vehicles arriving from main depot to smaller, center-city-friendly vehicles. The problem concerned the selection of routes and the scheduling of departures for the vehicles of the two fleets involved, as well as the selection of the delivery routes for customer demands from the main-depot through satellites to the final customer. Strict coordination and time synchronization of the operations of the two fleets are central elements of the problem, which appears to belong to a new problem class that we denoted the two echelon vehicle routing problem with time windows (2E-CVRPTW)

6.2 Future research

In a first time the research was defined a basic city logistics system based using a hub and spoke strategy (based on UDCs are called satellites) on an urban context, by observing the existing experiences in this domain. In some cities, this approach can be and in fact is used, but other important aspects have to be considered, as the economic, environment (pollution and sound) and social costs, which are difficult to model in a mathematical way. Also the diseases produced by freight transportation have to be considered.

The model limitations are evident, and for real applications (large-scale instances), only a quick and simple heuristic should be the best solution, due to the number of customers involved in these kind of even if the number of satellites will not be in general greater than 5 for city logistics applications. However, in other distribution applications the number of satellites and customers can increase. In some applications, meta-heuristics can be used. To test these future heuristic methods, it is important to obtain exact solutions for the proposed instances of 2E-CVRPTW. In order to build an exact method obtains the best solution. In order to deal with this aspect, another method, which considers a mega-route containing the routes of the first and the second levels, is proposed, but has not yet been tested.

The new area is focused on heuristic methods. In a fist time, it seems more interesting for real applications to focus on quick local search heuristics for different reasons. The first of them is that they are more flexible than meta-heuristics, and even if the results they obtain are worse than those obtained with meta-heuristics, they can be applied to large-scale problems, and then can be adapted easily to deal with real time applications where the calculation times are more important than to obtain a near-optimal solution (to obtain a quite good solution is enough in these cases). Such heuristics can also be used in a second time to give initial solutions for exact and meta-heuristic methods.

APPENDIX A

LIST OF ABBREVIATIONS

Abbreviation	**Full Expression**
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CVRP	Capacitated Vehicle Routing Problem
DCVRP	Distance Constrained Capacitated Vehicle Routing Problem
GAs	Genetic Algorithms
HGAs	Hybrid Genetic Algorithms
LTL	Less-Than-Truckload
LRP	Location Routing Problems
VRP	Vehicle Routing Problem
MDVRP	Multi-Depots Vehicle Routing Problem
MDVRPTW	Multi-Depot Vehicle Routing Problem With Time Windows
MILP	Mixed-Integer Linear Programming
NE-LRP	N-Echelon Location Routing Problem
NO_x	Nitrogen Oxides
NE-VRPCD	N-Echelon Multi-Item Vehicle Routing and Scheduling Problem with Cross-Docking
SO_x	Sulphur Oxides
SPM	Suspended Particulate Matter
TL	Truck Load
UTSA	Unified Tabu Search Algorithm
UDC	Urban Freight Distribution Centers
VOCs	Volatile Organic Compounds
VRP-PD	VRP With Pickups and Deliveries
VRPSF	VRP with Satellites Facilities
2E-CVRP	Two-Echelon Capacitated Vehicle Routing Problem
2E-CVRPTW	Two-Echelon Capacitated Vehicle Routing Problem With Time Windows
2E-VRP-SS	Two-Echelon VRP with Satellites Synchronization