LOGISTIC MODEL FOR THE DISTRIBUTION OF GOODS IN THE E-GROCERY INDUSTRY: A NEW ADAPTATION OF THE VEHICLE ROUTING PROBLEM

García Jiménez, Beatriz[(a)], Gómez González, Fernando[(b)]

[(a)]Senior Manager Client Solutions - Iberia Client Solutions
UTi, Madrid , SPAIN
[(b)]Profesor del Departamento de Sistemas Informáticos
Escuela Técnca Superior de Ingeniería ICAI
Universidad Pontificia Comillas de Madrid
Madrid, Spain

[(a)]bgarcia@go2uti.com [(b)] fgomez@dsi.icai.upcomillas.es

ABSTRACT

The increasing use of internet and the growing penetration of e-commerce in households have brought the need to redefine the business models and supply chains to achieve profitability in a sector in which logistics costs rises to 10-15%. The grocery industry is considered pioneer in home delivery service. Nevertheless, e-grocers haven't been still able to find the model of success that ensures profitability to their businesses.

This paper deals with the problem of distribution of goods in the grocery retail industry associated with e-commerce.

The problem has three main components that make the cost optimization difficult: the decisions about order filling (whether the picking should be made in stores closest to customers or in warehouses, and the definition of the level of automation in picking in warehouses), as well as the Vehicle Routing Problem with Time Windows, referred to as VRPTW.

The paper examines the solutions being adopted by companies in this sector, identifying best practices, deciding on the variables on which to act and making a proposal for the mathematical model to describe the problem.

Keywords: Logistics, e-commerce, e-grocery, supply chain, VRPTW, routing, MDVRP.

1. INTRODUCTION

During the last few years, and especially after the financial crisis, e-commerce has emerged and grown significantly. The speed of this growth together with the fact that the cost of logistic operations to sell products over the Internet to the final consumer (Business to Consumer industry, also called B2C) can reach 10-15% of total revenues, justify the efforts made in reducing logistic costs associated with the delivery of purchases through the network and consequently, in optimizing the supply chain that manages the flow of materials and information for the B2C business.

For year 2011, an increase of 18.9% is expected. This will mean an income of 680,000 million dollars in the world (Schonjeld 2010).

In 2009, the number of internet users grew from 58.3% up to 64% and the number of shoppers in the network was increased from 40.3% to 41.5% in Spain. That means 10.4 million of shoppers on line in 2009 and 7,760 million euro in sales over the internet in 2010.

In 2000, within the e-commerce, grocery retailing industry expected to have the highest growth rate (Rowlands, 2001). Then, the growth in food sales over the Internet generated great incomes. In the United Kingdom for example, this sector experienced a growth of 75%.

In Spain, e-grocery represents 10.5% of total e-commerce industry, which in 2010 was estimated at 7,760 million euro. According to this information, the sales volume of e-grocer sector in Spain stands between 81,5 and 122 million euro.

However, the problems associated with the logistics involved in selling this type of product through the Internet have not been surpassed yet, and the appropriate supply chain model still has not been found. Herefore, the real growth is far from expectations and there have been cases such as that of Streamline in the U.S., which after being launched in 1993 as the second on-line shop for food, had to close.

Compared to the traditional grocery retail sector, the Internet retail sector (e-grocery) requires new models of supply chain in order to be profitable.

In the supply chain for traditional business, the goods are sent to the shops where customers make their orders by themselves, picking for delivery to their homes. Nevertheless, in the e-commerce business, and specifically in e-grocery, the higher costs come from labor of picking and final delivery to the consumer (Lewis 2001). Defining an efficient supply chain model that minimizes costs and provides greater convenience to clients is the challenge to be met in this study.

Despite the strong interest generated by electronic commerce in food, very few research studies can be found in the area of logistics in the e-grocery (Auramo Aminoff and Punakivi 2002).

2. BACKGROUND

2.1. Home Delivery

According to Taniguchi and Van Der Heijden, from a logistical point of view, the existing operational models can be classified into four main combinations (Tanskanen 2000).

- Attended reception and order picking in central warehouse.
- Attended reception and order picking in store.
- Unattended reception and order picking in central warehouse.
- Unattended reception and order picking in store.

However, after 10 years of experience since that publication, there have been new intermediate models. Currently, these are the main existing methods of picking preparation:

- Order picking in central distribution center.
- Order picking in specially designed storage areas for typical e-grocer orders (orders characterized by having a lot of lines per order and few articles per line)
- Order picking in shops.

While 10 years ago delivery was only classified as attended (home delivery) or unattended (reception boxes), we now find a new model already in operation. It consists of giving the client the choice of collecting his order in the supermarkets. According to this, the main existing methods of delivery are shown as follows:

- Home delivery.
- Reception boxes.
- Collection at supermarkets.

Despite the logistical alternatives studied, the winning combination has not been found yet (Punakivi, 2003). However, the knowledge of how to implement the logistic model of an e-grocer is a critical factor to achieve profitability.

2.2. Best Practices

From the traditional perspective of supply chain, there are two possible general models for e-grocery (Kamarainen, y Punakivi 2001).

From the traditional perspective of supply chain, there are two possible general models for e-grocery (Kamarainen and Punakivi 2001). Traditionally, those stores which have physical presence and have started to take part in the e-commerce have used their shops to attend their customers. The customers are attended to from their nearby shops. This is the most common model today, and up to now, it has also been successful as an added-value service offered by typical supermarkets, (Kämäräinen, Saranen, and Holmström 20001). However, the shops have been bound to seek for much more efficient solutions with the growing of the sector and the increase of the number of users of this service. Let us take Caprabo, they traditionally supplied their customers from their 325 shops, but their e-business already means more than 1% of their income, and they have had to redefine their strategy, and combine their current service with order picking preparation in their warehouse in Sant Boi de Llobregat.

The decentralizing setting of the orders seems to be the model adopted by the most successful businesses on the net.

On the other hand, other players directly started the e-commerce without having a real network of shops supporting them and they decided to set up big automated warehouses from the beginning. In this model the preparation of the orders is far more efficient. The organization of the layout of the warehouse and the processes depending on the kind of order provides speed to the picking. However, it also implies high investments (Holmström, Tanskanen and Kämäräinen 1999).

But this preparation of orders from centralized warehouses is frequently seen as a synonym of failure when experiences such as the one of Streamline are remembered.

In the US, purely virtual players started the e-grocery industry. However, in Europe the e-commerce was started by big brick-and-mortar grocery stores (Lewis and Allen 2000).

A lot of American e-grocers have failed, but some Europeans, thanks to their physical network, were able to gradually start in the sector. They have even invested in the USA in order to grow their .com business.

Today, Ahold, the traditional Dutch store, owns Peapod, one of the pioneers in the pure virtual e-grocer, and Tesco, the European grocery chain, bought Groceryworks in 2001 for the sum of 22 million dollars (Prior 2001).

Peapod has already experienced all the models in use. At the beginning, they used to buy the products in supermarkets which already existed, later they opened their own warehouse and they distributed the products which they bought from suppliers in the areas with a high demand. Finally it was bought by Royal Ahold, and they improved their demand, and went on with their supply chain strategy, which consisted on working simultaneously from warehouses and stores belonging to the new company (Royal Ahold).

Nevertheless, Tesco has chosen to supply their customers from their stores. It is not the most efficient model, but they take fewer risks in terms of investment. In 2006, Tesco had to start to operate from a central warehouse, as their shops were not ready to satisfy the demand. Now they keep a mixed model, but with special attention to picking in their shops. For Tesco, the biggest success comes from the fact that they have been able to integrate their data into the web. This way their customers may have information about their shopping on line (Rowland 2001).

The Streamline experience is different. It is the story of failure with a very simple explanation; high investment in automated central warehouses, in a business which is still immature.

Nowadays, the demand is high enough to offer good results in businesses based on working through central warehouses. What is more, it seems to be the natural tendency; even if they have physical shops, they are not able to meet their customers' demand.

In Spain the tendency has followed the same process as in the rest of Europe. At first, when the market leaders started the web business, they used their shops to get their orders ready. However, they have grown and matured, which has lead to different strategies of supply chain.

Carrefour has all the order picking preparation organized in two main platforms. From Guadalix, 10,000 sqm, it supplies more than 10,000 order lines to their customers on line. And from L'Hospitalet de Llobregat, it meets the demand in Cataluña

Condisline has centralized the preparation of their customer orders from Cataluña area in their warehouse in Pallejá (3,000 sqm). Nevertheless, in Madrid, they supply their orders from their shops.

El Corte Inglés warehouse is in Valdemoro. This platform supplies mass market and the goods which go to their shops daily. It is the regional warehouse which gets the goods from their suppliers and sends them to their own shops (Hipercor, El Corte Inglés, Opencor, Supercor…). The orders on line are provided from their shops.

Mercadona also used their shops to supply the orders on line. However, Caprabo, which started on Internet using only their shops, and delivering its orders in 40 regions in Spain, has had to open a new warehouse to be able to meet the growing demand. From Baix Llobregat they prepare the orders from Cataluña.

The success and failure mentioned above give evidence to the theory that the mixed model is the one which must be chosen to ensure profitability.

The model we propose in this paper is the one used by Peapod or Royal Ahold, the biggest chain in the U.S. today, or by Tesco, Caprabo or Condis, which are mixed models that work from their warehouses and stores at the same time seeking the most successful solution.

2.3. The Vehicle Routing Problem

Transport and distribution of goods can be addressed in the simplest model like the VRPTW. Nevertheless, the supply chain issues associated with electronic commerce in the retailing grocery industry increase the difficulty of the problem.

Decisions must be taken about the size and degree of warehouse automation, sites to prepare orders and position from which to make distribution to customers.

If a mixed model of combined distribution from the stores and warehouses is applied, the problem turns to a multi-depot VRP. In the event that customers are pre-assigned and grouped around each depot, the problem is simplified because it is divided into several VRPs. Yet, the flexibility required in the real world due to rapidly-changing demands and intermixing of customers and deposits, doesn't favor pre-allocation of depots to achieve better results. In this case the problem is highly complex, resulting in the vehicle routing problem with multiple depots (Multi-Depot Vehicle Routing Problem, or MDVRP).

If this problem is well suited to the particularities of the e-grocer, the result is a new and highly complex model.

The literature on this type of problems is quite sparse. This approach has led the authors to the definition of the problem as e-MDVRPTW, vehicle routing problem with time windows associated to e-commerce business and specifically to the grocery industry.

3. HYPOTHESIS

Hypothesis 1

The mixed solution, which consists of the combination of distribution centres and stores to prepare the orders, is more effective than the only use of warehouses. It provides flexibility and allows a greater performance; up to 90-100% with less investment.

Hypothesis 2

The decision of assignment of the orders to a warehouse or store should not be considered a static decision, in which we assign a customer to a warehouse only because of its proximity, but a dynamic decision which must be introduced in the optimization model on the premises of getting the best solution.

Hypothesis 3

Level of automation of warehouses for picking fulfillment should be considered medium-low in order to give the necessary flexibility and to assure the ROI (Return On Investment).

Hypothesizes 1 and 2 of this paper have been proved thanks to the e-grocers examples, success and failure stories.

The proposed mixed model is related to the successful models of Peapod/Royal Ahold, Tesco, Caprabo or Condis, which work simultaneously in stores and warehouses in order to keep flexibility, find high profitability in places with a dense population, and consequently a high demand, and at the same time, to be able to get to more areas of actuation, through the preparation of the orders in the stores in case of immature demand areas.

The continuous geographic change of customers and orders makes it difficult to find a balance between cost and efficiency when delivering the goods. Besides, the changing tendency and the quick evolution show that the perfect model of delivering goods is the one which may offer profitability today, and allow an easy growth tomorrow The multidepot model that we propose, adapts to this condition when we consider the choice of the place from which we attend to the customer as an operative variable.

Hypothesis 3 is also justified in this paper through the study of the existing models. The automated warehouses are only convenient to great demands in mature markets. Webvan, for example, made a mistake when they lost flexibility on devoting big investment to the design of the warehouses. Since, today, it is impossible to find a country which has a homogeneous demand, the right solution consist on a mixture of low – medium automatic warehouses together with stores to be able to get to all the customers efficiently.

Hypothesis 4

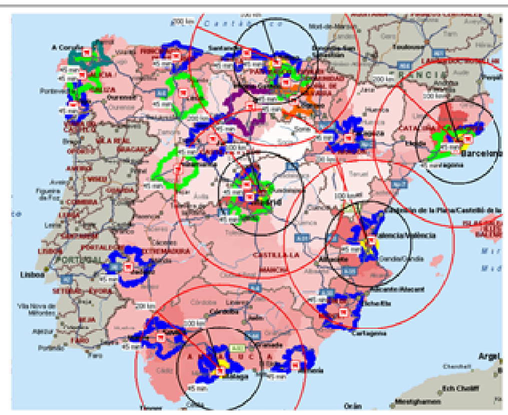
The traditional VRP is not good to this paper research and it has been formulated again to adapt it to the real model as it is proposed with its constraints and peculiarities of e-grocer. It will be called e-MDVRPTW. It has been proposed by the authors, and it appears in bibliography for the first time through this paper.

4. NETWORK DESIGN ADAPTED TO REALITY

The proposed network adapts to the sector needs and has the following characteristics:

- It is highly flexible and scalable because of the dynamic assignment of the clients to depots which can function on different levels of activity.
- With the designed network it is possible to cover almost the entire population of Spain or, at least, the most densely populated areas or those where the internet activity is higher. Apart from that, it is the same customer service in all the geographic locations, which contributes to the maximum level of customer satisfaction.
- It ensures the achievement of compromise between the efficiency and ROI, and work on a mixed solution where the proper stores are involved as network depots and the warehouses have low or medium level of automation. This contributes to the achievement of profitability in a market still immature and changing.
- Latest technology is also to be integrated in the solution, so the model has a higher level of adaption to reality.

The designed network covers the demand in Spain for the size of an e-grocer leader which annual turnover from grocery sales in internet is about 60 million euro.



Fuentes: Informe Anual de Sociedad de la Información en España 2008 [U08] y MapPoint

Figure 1: Network Design in Spain.

After analyzing the best experiences there was chosen a mixed model, which works like a chain formed of small and medium warehouses with medium level of automation and stores suitable for the order preparation and distribution to customers.

In order to be efficient, it is estimated that one store can serve up to 2 million euro. Considering that the average order value is 118,56 euro and that each order has about 45 lines, it corresponds to 2.875 lines a day. With productivity of 1,22 in-store orders per hour, there would be necessary 6,97 persons to meet this demand. It is understood that more people working in online order shop would be inconvenient for the daily progress of the other activities in the store.

The store which is capable to prepare orders and then deliver them to customer from the same establishment is called e-fit. Those are the shops with clear cost advantages because of their geographical location, annual turnover, space, service capacity and lay out. These stores also could make cross docking orders, once prepared in the warehouse, they would be sent to a store at night for further distributing along with the other orders during the following day.

The more stores are considered e-fit, the more freedom will be given to the execution process and therefore better solutions could be found.

Speaking about the distribution centers in order to guarantee ROI, the stores will have to work at least with 50% of their capacity (400 orders/day), which means preparing daily at least 200 orders and 2.376.000 lines per year. Each store would be designed for a maximum of 400 orders a day.

These data were obtained from the simulation of store performance at different levels of possible activity and the calculation of Net Present Value savings from the preparation of orders in warehouse over store preparation, subtracting the investment which is necessary to install the warehouse. On the other hand, these savings come from improved productivity in preparing orders in the warehouse.

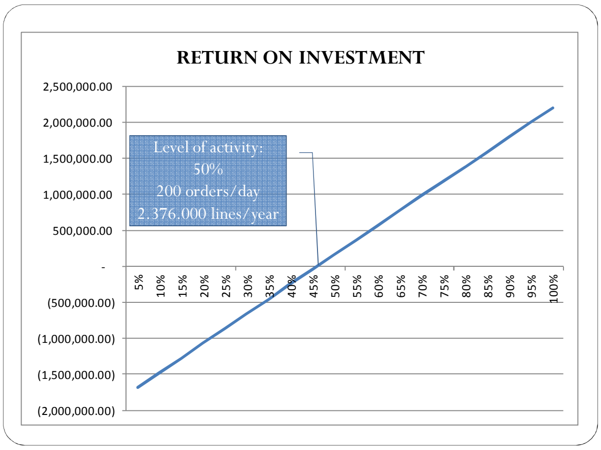


Figure 2. Breakeven point in the activity level of the warehouse with medium/low automation.

If 5 warehouses are installed in the most mature areas with high density of demand, the minimum demand of 31,3 million euro should be covered by these centers (considering the minimum order value is 118,56euro/order). In addition there should be 14 stores more to meet the demand.

The designed network aims to reach almost entire Spanish territory and make the search for the optimal solution more flexible. It consists of 5 warehouses and 21 stores. The location of the centers was decided depending on the internet activity and population density.

5. E-MDVRPTW MODEL

5.1. The Description of the Model

After analyzing the best practices, the authors opt for a mixed model that relies on a network of small / medium warehouses with medium automation level and stores considered suitable for the preparation of customer orders and their distribution. Through this flexible model, the growing and unpredicted demand is covered more efficiently.

As defined above, the model proposed by the authors is a MDVRPTW model which includes new additional restriction per depot: the minimum level of use in each automated warehouse in order to ensure the return on investment, the maximum capacity of the warehouses according to the design of the warehouse and the level of investment and the maximum activity allowed in the stores in order to keep acceptable levels of efficiency.

The shops are introduced in this problem like new depots. These stores must be set up for the picking preparation and distribution to consumers and the assignment of clients to depots is considered a dynamic variable covering the MDVRP in a single phase.

In addition, the new model raises new options and restrictions associated with the problem of logistics in e-grocery, such as the use of specific vehicles with compartments for different temperatures, or even the possibility of distributing orders from stores that have been previously prepared at distribution centers, new in the MDVRP literature.

Information on turn restrictions, prohibited addresses and traffic conditions is also used in this model. Impedance matrices are built with times instead of distances by using Geographic Information System (GIS),queries to Google Maps (http://maps.Google.es/maps/api/directions/xml?origin=c/ direccion1,ciudad1&destination=c/direccion2,ciudad2&sensor=false) and queries to the Traffic Department in Spain (DGT) (http://dgt.es/incidencias.xml)

5.2. Mathematical Model

5.2.1. Indices and Parameters

G=(C, α, τ, A, W)

Where:

G is the graph associated to the model.

τ: set of stores that are considered suitable for the preparation of customer orders and their distribution (1,...,e)

α: set of warehouses (e+1,…,m)

C: set of clients (m+1, ..., n).

A: the arc set. Each arc is represented as (i, j) where i ≠ j. It represents the path between depots and clients and between clients.

W: set of travel times associated to each arc. It is represented as t_{ij}.

t_{ij}=travel time to go from i to j + service time in i.

c_{ij}: set of costs associated to each arc (i, j).

V_α y V_τ fleet of vehicles departing from a warehouse, α, or a store, τ.

q-: negative cold capacity of the compartments of the vehicles

q+: room temperature capacity of the compartments of vehicles.

d_i^-: negative cold demand of the client i.

d_i^++: demand of products at room and refrigerated temperature for the client i.

r_α^{min} lower level of activity for the warehouses to guarantee the ROI.

r_α^{max} maximum level of activity for the warehouses.

All warehouses are assumed homogeneous, as well as the e.fit stores.

p_τ capacity or higher level of activity allowed for the stores.

If the client i is located at a lower distance than D (a predetermined constant) from the warehouse α, then the delivery of his order could be made from this warehouse α and the variable $Y_{i\alpha}^{Dist}$ would take the value

$$Y_{i\alpha}^{Dist} = \begin{cases} 0 & \textit{if customer order i cannot be delivered by warhouse } \alpha \\ 1 & \textit{if customer order i can be delivered by warhouse } \alpha \end{cases}$$

If the client i is located at a lower distance than E (a predetermined constant) from the e-fit store τ, then the delivery of his order could be made from this store and the variable $Y_{i\tau}^{Dist}$ would take the value 1.

$$Y_{i\tau}^{Dist} = \begin{cases} 0 & \text{if customer order i cannot be delivered by store } \tau \\ 1 & \text{if customer order i can be delivered by store } \tau \end{cases}$$

If $Y_{i\tau}^{Dist} = 1$, then there is a possibility that the order is prepared in the store or the warehouse although the final delivery is executed from the store.

$$Y_{i\alpha}^{Prep\ Ped} = \begin{cases} 0 & \text{if customer order i cannot be prepared in warehouse } \alpha \\ 1 & \text{if customer order i can be prepared in warhouse } \alpha \end{cases}$$

$$Y_{i\tau}^{Prep\ Ped} = \begin{cases} 0 & \text{if customer order i cannot be prepared in store } \tau \\ 1 & \text{if the customer order i can be prepared in store } \tau \end{cases}$$

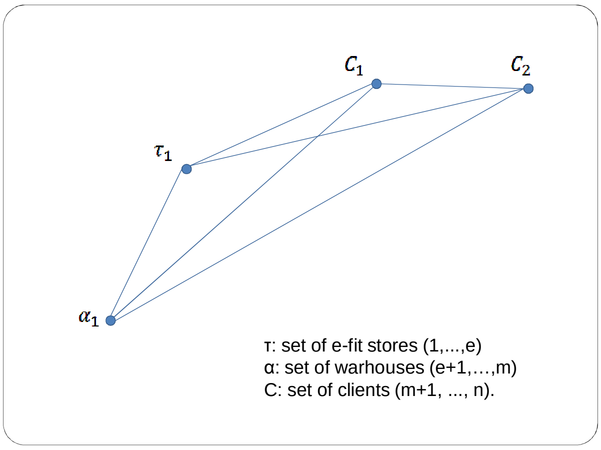


Figura 3.e-MDVRPTW

$[a_i, b_i]$: time window for the client i. The vehicle must arrive to the client i before b_i and it can arrive before a_i but then, it should wait.

$e, m, n, t_{ij}, c_{ij}, v_\alpha, v_\tau, q^+, q^-, d_i^+, d_i^-$ are non negative integers.

The triangle inequality is satisfied for costs c_{ij} and times t_{ij}. For three vertex, i, j y l, $c_{ij} + c_{jl} \geq c_{il}$ and $t_{ij} + t_{jl} \geq t_{il}$.

5.2.2. Variables and Constraints

The model contains three binary variables: x, s and z.

$s_{ik} \in \{0,1\} \forall i \in N, \forall k \in V$

For each arc (i, j), where $i \neq j$, if $i \in (l, \dots, m) \Rightarrow j > m$ and if $j \in (l, \dots, m) \Rightarrow i > m$. That is to say, arcs between depots cannot be considered in this model.

A decision variable is defined for each vehicle k, x_{ijk}, which represents the routing solution when customers i and j are attended by the vehicle k in its route and client i immediately precedes client j:

$$x_{ijk} = \begin{cases} o \text{ if vehicle k doesn't go from i to j} \\ 1 \text{ if vehicle k goes from i to j} \end{cases}$$

$x_{ijk} \in \{0,1\} \forall i, j \in N, \ \forall k \in V$

The decision variable s_{ik} is defined for each node i and each vehicle k. It represents the moment in which the vehicle k begins to serve the client i

$s_{ik} \in \{0,1\} \forall i \in N, \forall k \in V$

In the event the vehicle k does not serve the customer i, the variable has no meaning.

$\forall K, s_{ik} = 0; i \in (l, \dots, m)$.

The decision variables $z_{i\alpha}$ and $z_{i\tau}$ represents the place where the client i is attended from:

$$z_{i\alpha}^{Dist} = \begin{cases} 0 \text{ if client i is not delivered from warehouse } \alpha \\ 1 \text{ if client i is delivered from warehouse } \alpha \end{cases}$$

$$z_{i\tau}^{Dist} = \begin{cases} 0 \text{ if client i is not delivered from store } \tau \\ 1 \text{ if client i is delivered from store } \tau \end{cases}$$

$$z_{i\alpha}^{Prep\ Ped} = \begin{cases} 0 \text{ if client order i is not prepared in warhouse } \alpha \\ 1 \text{ if client order i is prepared in warhouse } \alpha \end{cases}$$

$$z_{i\tau}^{Prep\ Ped} = \begin{cases} 0 \text{ if client order i is not prepared in store } \tau \\ 1 \text{ if client order i is prepared in store } \tau \end{cases}$$

$$z_{i\alpha}^{Dist}, z_{i\tau}^{Dist}, z_{i\alpha}^{Prep\ Ped}, z_{i\tau}^{Prep\ Ped} \in \{0,1\} \forall i, j \in N, \forall \alpha \in (e+1, \dots, m), \forall \tau \in (1, \dots, e)$$

This way, every choice to give service to the clients has been covered:

$$z_{i\tau}^{Dist} \begin{cases} 0 \\ 1 \begin{cases} z_{i\alpha}^{Prep\ Ped} \begin{cases} 0 \\ 1 \text{ if distribution is made from store } \tau \text{ but picking fulfillment from } \alpha \end{cases} \\ z_{i\tau}^{Prep\ Ped} \begin{cases} 0 \\ 1 \text{ if distribution and picking for client order i are fulfilled from store } \tau \end{cases} \end{cases} \end{cases}$$

5.2.1. Objective Function and Constraints

The first part of the objective function represents fixed costs of each vehicle taking into account that there will be the same number of vehicles as routes. The second part, shows variable costs.

Variable costs combine three cost terms: distribution and picking preparation in warehouse, distribution from store and in-warehouse picking preparation and distribution and picking preparation in store.

Thus, the e-MDVRPTW is mathematically formulated as follows:

Objective function: (1)

$$\min\left(\sum_{k}\sum_{j>m}\sum_{i\in(1,\ldots,m)} H_k x_{ijk} + \sum_{\tau}\sum_{\alpha}\sum_{k}\sum_{j}\sum_{i}\left(c_{ij}x_{ijk}z_{i\alpha}^{Dist} + \left(C_{PEN}^{Dist} + c_{ij}\right)x_{ijk}z_{i\tau}^{Dist}z_{i\alpha}^{Prep\ Ped} + \left(C_{PEN}^{Prep\ Ped} + c_{ij}\right)x_{ijk}z_{i\tau}^{Dist}z_{i\tau}^{Prep\ Ped}\right)\right)$$

Where $C_{PEN}^{Prep\ Ped}$ represents cost penalty for picking fulfillment in stores and C_{PEN}^{Dist} is cost penalty for the orders which are distributed from stores while picking has been fulfilled in warehouse.

$$C_{PEN}^{Dist} = c_{\alpha\tau}/\sum_i z_{i\tau}^{Dist}\, z_{i\alpha}^{Prep\ Ped} \quad (2)$$

Restrictions:

$$\sum_k \sum_{j>m} \sum_{i\in(1,\ldots,m)} x_{ijk} = \sum_k \sum_{i>m} \sum_{j\in(1,\ldots,m)} x_{ijk} \quad (3)$$

$$\sum_\tau Z_{i\tau}^{Dist} + \sum_\alpha Z_{i\alpha}^{Dist} = 1\ \forall i \in C \quad (4)$$

$$\sum_\tau Z_{i\tau}^{PrepPed} + \sum_\alpha Z_{i\alpha}^{PrepPed} = 1\ \forall i \in C \quad (5)$$

$$z_{i\tau}^{Dist}\, y_{i\tau}^{Dist} = z_{i\tau}^{Dist} \quad \forall\tau\ y\ \forall i \in \quad (6)$$

$$z_{i\alpha}^{Dist}\, y_{i\alpha}^{Dist} = z_{i\alpha}^{Dist} \quad \forall\alpha\ y\ \forall i \in C \quad (7)$$

$$z_{i\tau}^{PrepPed}\, y_{i\tau}^{PrepPed} = z_{i\tau}^{PrepPed} \quad \forall\tau\ y\ \forall i \in \quad (8)$$

$$z_{i\alpha}^{PrepPed}\, y_{i\alpha}^{PrepPed} = z_{i\alpha}^{PrepPed} \quad \forall\tau\ y\ \forall i \in \quad (9)$$

$$\sum_{k\epsilon V}\sum_{j>m} x_{ijk} = 1 \quad \forall i \in C \quad (10)$$

$$\sum_{k\epsilon V}\sum_{i>m} x_{ijk} = 1 \quad \forall j \in C \quad (11)$$

$$\sum_{i\in N}\sum_{j>m} d_j^+ x_{ijk} \le q_k^+ \quad \forall k \quad (12)$$

$$\sum_{i\in N}\sum_{j>m} d_j^- x_{ijk} \le q_k^- \quad \forall k \quad (13)$$

$$\sum_{i\in C} d_i z_{i\tau}^{Prep\ Ped} \le p_\tau \quad \forall\tau \quad (14)$$

$$r_\alpha^{min} \le \sum_{i\in C} d_i z_{i\tau}^{Prep\ Ped} \le r_\alpha^{max} \quad \forall\alpha \quad (15)$$

$$\sum_{j>m} x_{ijk} = 1\ \forall k \in V\ y\ \forall i \in (1,\ldots,m) \quad (16)$$

$$\sum_{i>m} x_{ihk} - \sum_{j>m} x_{hjk} = 0 \quad \forall h = 1,\ldots,m, \forall k \in V \quad (17)$$

$$\sum_{i>m} x_{ijk} = 1\ \forall k \in V\ y\ \forall j \in (1,\ldots,m) \quad (18)$$

$$\sum_i \sum_j t_{ijk}x_{ijk} \le T_k \quad \forall k \in V \quad (19)$$

$$s_{ik} + t_{ij} - T_k(1 - x_{ijk}) \le s_{jk}\ \forall i = m+1,\ldots,n, \forall j, \forall k \quad (20)$$

$$a_i \le s_{ik} \le b_i \quad \forall i = m+1,\ldots n\ y\ \forall k \in V \quad (21)$$

$$H_k = \delta_k H_K + (1-\delta_k)H/2 \quad (22)$$

Subject to:

H_k represents fixed cost of each outsourced vehicle and it includes the cost of driver.

δ_k is a binary variable which can take values 0 or 1 depending on the vehicle to perform half or full time.

$$\delta_k = \begin{cases} 1\ si\ \sum_i \sum_j t_{ijk}x_{ijk} \ge \frac{T_k}{2} \\ 0\ otherwise \end{cases} \quad (23)$$

There should be balance between departing vehicles from depots and arriving vehicles to depots (3). Each client can be attended only from one warehouse or store (4)(5). In addition, the variable z has to be linked to y, that is to the association of the customers to default radius of influence for each store or warehouse (6)(7)(8)(9). Each client can be visited once and each client order can be only prepared once (10)(11). Vehicle compartments capacity must not be violated (12)(13). Maximum and minimum levels of activities for warehouses and stores must be respected (14)(15). Each vehicle must departure from one depot (warehouse or store) (16). There should be balance between the number of departing routes and the number or arriving routes for each depot (17). Each vehicle must arrive to the depot to finish the route (18). Each vehicle mustn't work more time than agreed (19). Each vehicle k, must arrive to j after $s_{ik} + t_{ij}$ (20). Client windows must be honored (21)

6. CONCLUSIONS AND FUTURE WORK

This paper tries to define the problem of distribution of goods associated with e-commerce in the grocery industry. It is a complex model because it tries to reflect reality:

- Have been introduced new cost criteria related not only to the transport costs, but also to the order preparation.
- The level of automation of the warehouses was considered.
- The mixed network with heterogeneous deposits (stores and warehouses) and different costs of order preparation was designed.
- There were introduced vehicles with compartments at different temperature.
- The problem solution not only indicates from which deposits and with which vehicle must be made delivery, but also the place where the order should be prepared; which doesn´t have to be the same place from where the capillary distribution starts. This way the stores can function not only like conventional MDVRP

depots, but also like cross docking centers from where the distribution starts to lower transport costs.

From the intersection between the real and the academic worlds emerges the e-MDVRPTW – a highly complex problem. The model works with the peculiarities of the logistics associated with the food sale via Internet, as well as with the studies and software of the traditional transport problem.

Different algorithms were analyzed to solve the MDVRPTW problem and considering the results, there could be formulated different variants of meta-heurestic algorithms and compared solutions and the effects of different variables over problem solution, for example, automation level of warehouses.

A priori, the existence of binary variables in the mathematical formulation inclines future research towards adapting and testing the most important algorithms in solving the MDVRPTW: Ant Colonies, Simulated Annealing, Tabu Search, GRASP, Guided Local Search and Genetic Algorithms.

The authors are in the testing phase of conventional meta-heuristic and design of a new bio-inspired algorithm in order to obtain a good scenario to reduce the overall distribution costs in the sector.

REFERENCES

Auramo, J., Aminoff, A., Punakivi, M. 2002. Research agenda for e-business logistics based on professional opinions. *International Journal of Physical Distribution and Logistics Management*. Vol. 32.

Holmström, J., Tanskanen, K., Kämäräinen, V. 1999. Redesigning the Supply Chain for Internet Shopping - Bringing ECR to the households. *LRN Conference proceedings*. Newcastle.

Kamarainen, V., Punakivi, 2001. M. Development of cost-effetive supply chain in the e-grocery business. *Supply Chain Management and Information Systems in Internet Age Conference Proceedings*. Hong Kong. China.

Kämäräinen, V., Saranen, J., Holmström, J. 2001. The reception box impact on home delivery efficiency in the e-grocery business" *International Journal of Physical Distribution and Logistics Management*, Vol. 31, Number 6.

Lewis , A. 2001. Your Service Future Models of Retail Logistics. *Report to Retail Logistics Task Force of Foresight program*. UK.

Lewis, C., Allen, N. 2000. Eat your own business. *Logistics Europe*.

Prior, M. 2001. On-line grocers still chewing on concept of off- line alliances. *Dsn Retailing Today*.

Punakivi, M. 2003. Comparing alternative home delivery models for e-grocery business. *Forhcoming Doctoral Dissertation*. Helsinki University of Technology.

Rowlands, P. 2001. Consignia's home delivery drive. *E.logistics Magazin* Issue 13.

Rowland, P. 2001. Home delivery – the story so far. *E-logistics magazine,* Iss.14.

Schonjeld, E. 2010. Forrester Forecast: Online Retail Sales Will Grow to $250 billion by 2014. *Forrester.com*

Tanskanen, K. 2000. Logistical strategies for electronic grocery shopping. *Working paper.* Helsinki University of Technology.