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COST OPTIMIZATION OF MULTIMODAL DISTRIBUTION CHAIN USING ELECTRIC VEHICLES

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Declare that my thesis entitled:

"COST OPTIMIZATION OF MULTIMODAL DISTRIBUTION CHAIN USING ELECTRIC VEHICLES"

Is a complete independent work of mine, completed without using any illegal information, nor the work of others that I recognize as my own work.

All cited and references are listed in the bibliography.

If it turns out that this statement is not true, I am willing to accept the consequences in accordance with the regulations.

Surabaya, 27 July 2016

Sincerely Yours,

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DISCLAIMER

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COST OPTIMIZATION OF MULTIMODAL DISTRIBUTION CHAIN USING ELECTRIC VEHICLES

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ABSTRACT

This study develops a model of cost optimization of multimodal delivery chain using electric vehicle in Rome. Goods are consolidated in a center located outside the urban area, are transported from this on shuttle trains to a distribution center located inside the central area of the city (Multimodal Urban Distribution Center), and are finally transferred from rail to green, by using electric vehicles to reach their final destination. In this process, we have to consider the synchronization of train schedule with the time window of delivery that has been set, number of fleet available and also wagon capacity of the fleet, since the capacity of the wagon is huge, while the capacity of the electric vehicle is significantly different in scale. As the problem of city logistics is recently increasing, the optimal solution for efficient vehicle delivery model is really needed. The research objectives will be accomplished through the building of the model and also by conducting some simulations to show the behavior of the proposed model. The research attempt obtain the optimal configuration of delivery trip that minimize the operation cost of multimodal distribution chain.

Keywords: Electric Vehicle, Last Mile Distribution, Multimodal Delivery Model, Multimodal Urban Distribution Center.

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INTRODUCTION

This chapter will explain about background and research context, research goal and scope, research methodology, steps, and expected result of the research.

1.1 Background and Research Context

The distribution of goods in urban areas, together with private traffic flows, are among the main sources of energy consumption, air pollution and noise. Currently 73% of Europeans already lives in cities, and cities generate 85% of European GDP (Campagna et al., 2017). According to the European Commission, the level of European urbanization is expected to rise up to 82% by 2050. Because of the high population density, lack of infrastructure and pollution problems, urban freight transport faces many difficulties (Faccio & Gamberi, 2015). A large percentage of the oil consumed in regions such as Europe or the USA is used in transport, while road transport accounts for an important percentage of CO_2 emissions of the overall transport activity (Juan et al., 2016). In order to mitigate this situation, one possibility is to incorporate emission costs as an objective to be minimized in routing models, thus trading off environmental and economic goals (Franceschetti et al., 2013). A different approach is the utilization of less polluting means of transport such as plug-in hybrid electric vehicles and electric vehicles (EVs), whose specific characteristics have to be included in adequate routing models (Juan et al., 2016). In effect, as part of the initiative to improve the local air quality, modern cities encourage fleets of vehicles to adopt alternative technologies, such as Electric Vehicles.

The distribution process is usually critical in the last mile of the supply chain, where most of the difficult operational decisions to make are present. Since the necessity of door to door delivery is become the priority for the customers, the companies try to enhance the best way to optimize the used of vehicle for the delivery. Usually small-lot orders are consolidated by the parcel delivery companies. The thick intercity freight transport is deconsolidated at their terminals, and last-mile transport is conducted by small vans or trucks (Visser, Nemoto, & Browne, 2014). In effect, it is in this last mile where more details can affect the quality of the delivery service, where more routes are formed, and where the direct contact with the final customer makes a critical mix between Logistics & Transportations (L&T) and marketing. This situation involves an exhaustive use of L&T resources to achieve the expecting quality of the delivery process. An exhaustive use of resources usually causes more negative externalities (congestion, emissions, and noise, among others). Therefore, the use of EVs in the last-mile activity can help to significantly reduce the level of the aforementioned externalities. In order to solve the problem, this research intend to obtain cost optimization of multimodal distribution chain using electric vehicles by optimizing the model of rail transport from manufacturer to distribution center and also electric vehicle from distribution center to customers. Since optimizing vehicle routing is a key point in logistics distribution optimization system. Reasonably assigning vehicles, further optimizing the distributing routes is very important both to theory and practice in distributing cost cutting down aspect.

1.2 Research Goal and Scope

In this study, we intend to obtain cost optimization of multimodal distribution chain using electric vehicles. Starting from rail transport and road transport until the cost analysis of using small electric vehicles in the last mile distribution or home to home delivery in city logistics.

As the problem of city logistics is recently increasing, the optimal solution for efficient vehicle model is really needed. The research objectives will be accomplished through the building of the model and also by conducting some simulations to show the behavior of the proposed model. The main research question is:

How to design an integration model of rail transport and electric vehicle delivery in last mile distribution?

In order to address the research question, the following works aims to answer the research question as follows:

1. What is the state of art of multimodal distribution model?
2. How is the modelling system of combining the rail and the road transportation in last mile distribution?

Considering the research focus of this work, which is delivery model of multimodal last mile distribution, the research scope would be particularly focus on multimodal integration of the vehicles.

1.3 Research Methodology

In this part, the systematic methodology will be applied to deploy the research framework as shown in the Figure 1. The approach methodology will be applied in this research is a combination of intensive literature review and case study analysis. Related research works have been obtained from various sources for instance research journals, previous dissertation, thesis and other trusted and reliable research works. Based on the findings of literature review, the proposed model of electric vehicle delivery model in multimodal last mile distribution in Rome will be introduced. Further, a case study methodology will be adopted.

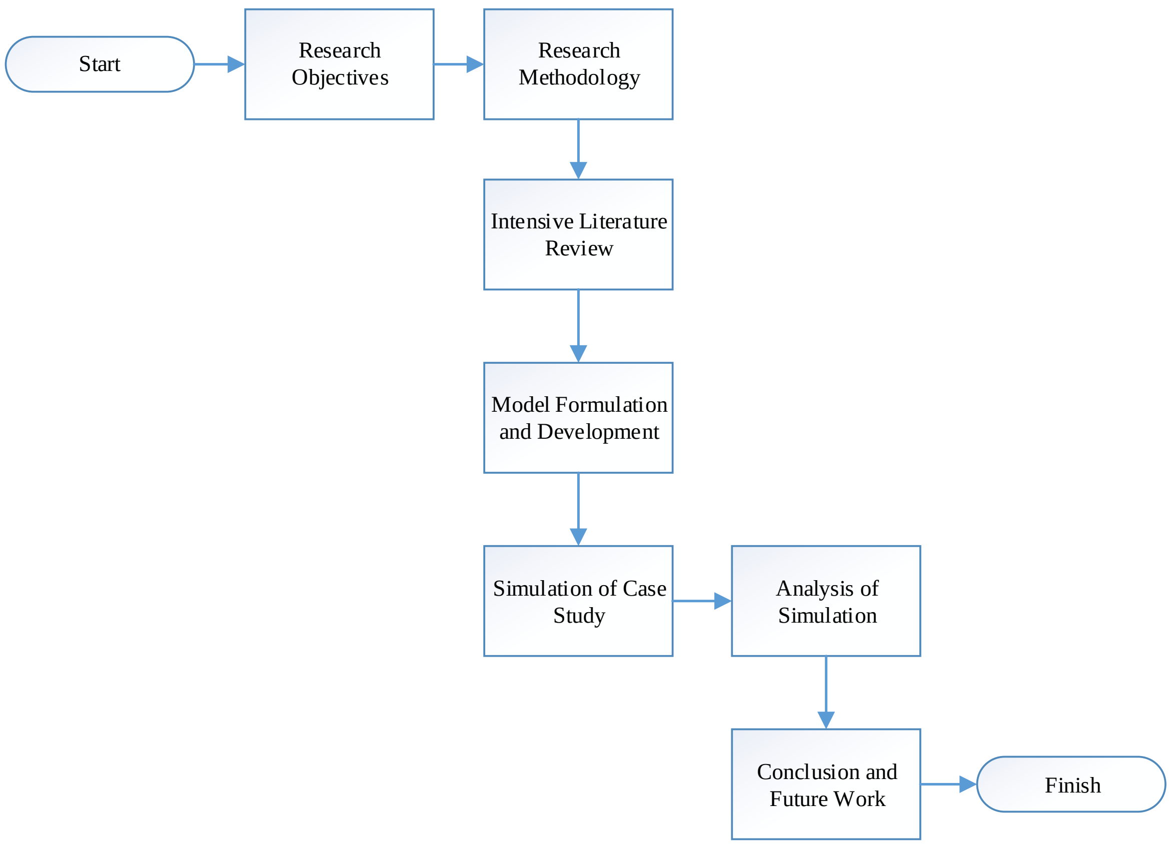

Figure 1 Structure of Research Methodology

At the first stage, research objectives are defined. Based on this information, literature review will be conducted in the area of multimodal distribution model. The result of literature review will lead to some research gaps and findings which will strengthen the completion of this research. After proposing the model of vehicle delivery, the region in Rome will be chosen as a case study. There will be some scenarios related to the type of vehicle, capacity of vehicle and the number of vehicles applied in the simulation. The case study aims to analyze and determine whether the proposed model is fit to the real practice. All the feedbacks from this analysis would be insight to further improvement for the model.

1.4 Steps

In order to achieve the aforementioned objectives, this research will be completed and structured by the following steps:

Chapter 1. Introduction

Explains the research background as well as the research context followed by the research question intended to be answered. The research methodology used to fulfil research conducted is presented as well in this chapter.

Chapter 2. Research Methodology

Present the steps that will be applied to conduct the systematic research.

Chapter 3. Literature Review and Findings

Presents the review of existing studies related to the main research topic. The literature review is started from the general problem of last mile distribution, urban consolidation center, the model of unimodal and multimodal distribution and also the model of electric vehicles in last mile distribution.

Chapter 4. Model Formulation and Development

Present the model formulation for the problem, then develop it based on the result of the simulation.

Chapter 5. Case Study Analysis

In this chapter, it would be explained about the case study analysis in Rome. And there will be some simulations by using some scenarios.

Chapter 6. Conclusion and Future Work

Present the conclusion from the overall research conducted followed by the proposed further steps to accomplish this research topic completely as future work.

1.5 Expected Result

This research expects to have the optimal configuration of delivery trip that minimize the operation cost of multimodal distribution chain.

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LITERATURE REVIEW

This chapter is organized in sections depending on the literature being reviewed. Section 2.1 defines the last mile distribution problem in general. Section 2.2 reviews the application of urban consolidation center in city logistics. Section 2.3 covers previous work of modeling in term of unimodal and multimodal deliveries. And the last, section 4.4 reviews the use of electrical vehicles toward sustainable logistics in green supply chain model.

2.1 Last Mile Distribution

Last mile distribution, also called the home delivery, is growing rapidly. The last mile in a business to customer environment is currently regarded as one of the more expensive, least efficient and most polluting sections in the entire logistics chain (Gevaers et al., 2014). The “Last Mile” in logistics delivery process or the “First Mile” in the case is a common logistics collection/distribution problem under urban condition. The nearer to the aggregated point (delivery destination), the more cost and higher loss in capacity and efficiency. This last process of the supply chain may face serious constraints in fulfillment, higher social, environmental and economic costs and increased complexity in operational arrangement. Last Mile delivery obstacle may be attributed to dynamically interacting but poorly understood reasons (Souza et al., 2014).

Wohlrab et al., (2014) stated that last mile logistics is the last part of a B2C delivery process. It takes place within a predefined delivery area (e.g. urban area); including the upstream logistics to the last transit point until the destination point of the parcel. It involves a series of activities and processes, of critical value to all the involved stakeholders (e.g. Customer, Industry and Institution) within the delivery area. Punakivi et al., (2001) argued that it is a logistics problem which deals with the trade-offs between routing efficiency and customer convenience.

Consumers and companies are getting increasingly aware of environmental issues in the economy and in transportation/logistics. However, in many cases, consumers want companies to be more environmentally friendly, but they do not wish to pay more, or do not accept a longer service time for “green products or services”. Specifically for the last-mile, companies need to make a trade-off between the fast and narrow time windows they offer to the consumers and the level of environmental friendliness they wish to obtain. As already mentioned, the narrower the time windows and the shorter the delivery/lead times, the more polluting the delivery of the parcel becomes. For the future, companies probably will have to keep up several delivery, but they will have to make the consumers aware which environmental implications and also a different price the several delivery options can have. It is a misunderstanding that home deliveries are always more polluting than traditional shopping. The Green Logistics research Initiative has compared the environmental performance of traditional shopping with home deliveries in Edwards et al., (2009). Depending on which assumptions and parameters interfere, in some cases delivery of a parcel was more environmentally friendly than traditional shopping. The results depend in most cases on the aforementioned characteristics like market density, time windows, etc. The factors influencing emissions from home deliveries: drop densities (the number of drops per delivery round); the distance and nature of the delivery round; the type of vehicle used; and the treatment of failed deliveries and returns (Edwards et al., 2009). On average, when a customer buys fewer than 24 items per shopping trip (or fewer than 7 items for bus users) it is likely that the home delivery will emit less CO2 per item purchased. These findings require several qualifications, they assume that: the car-based trip was solely for the purpose of shopping (no other activity was undertaken during the course of the trip); the online purchase was delivered successfully the first time; the shoppers was satisfied with the purchase and did not return the item; home deliveries and shopping trips were made over average distances; no allowance was made for different types of road network or traffic conditions; only the last mile and not the upstream supply chain has been considered in the analysis (although reference was made to previous studies). As an important observation, it can be stated that some of the characteristics discussed earlier do not only have impacts on the efficiency and cost structures, but are also highly correlated with the environmental performance of the last-mile.

Based on (Gevaers et al., 2014), there are five generalized characteristics of last mile problem: consumer service levels, security & type of delivery/reception, geographical area & market penetration, fleet & technology and the environment. In the following paragraphs, these generalized characteristics are described more in detail and hereafter, they will be classified in last mile sub flows.

- *consumer service levels*

  Too narrow time windows can have important effects on the efficiency of the last-mile. These time windows are a sub-characteristic of consumer service levels. Not only are those time windows sub-characteristics. Also the agreed maximum lead times, the frequency of delivery and the possibility of returning goods are sub characteristics of consumer service levels. To stress the importance of these aforementioned sub-characteristics, some figures in the following paragraphs will show the significant impacts on the efficiency and costs of the last-mile.

- *security & type of delivery/reception*

  The security & type of delivery characteristic is important because depending on the level of security needed for the reception. Some deliveries will have to take place by handing the goods over to another natural person, while other deliveries can take place by just leaving these goods in a box at the front door of the consignee/consumer. Also the type of product plays an important role, especially when products need special treatment, for example refrigerating, etc. The sub-characteristics within this generalized characteristics are the types already described above: attended/unattended deliveries, collection points, delivery boxes, etc.

- *geographical area & market penetration*

  It was already stated that the market penetration within specific areas and the related market densities in these regions are of significant importance. The most important sub-characteristics for this generalized characteristic are density of the region/market & average distance between the different points of reception and the percentage of the number of goods that can be pooled/clustered during delivery routes. Just as for traditional retail shops, market density and market penetration are very important market issues for last-mile efficiency and economics. It should be clear that when in a specific area only one parcel has to be delivered, the delivery route for this parcel will be very uneconomic and inefficient due to the high number of kilometers dedicated to that specific parcel.

- *fleet & technology*

  The type of fleet can play an important role on many different cost influencing parameters/factors, such as: fuel consumption, (optimal) load capacity, methods for loading and unloading procedures, safety, etc. Less obvious, but also of significant importance are the used information & communication technologies used. For optimal routing, it is important that the couriers can be informed that they have to pick up parcels on the route they are driving on that specific moment or that a consumer has changed the delivery address/reception point at a late moment. By using communication technologies, in most cases, a significant amount of time and fuel can be saved. Information technologies, for example RFID and routing systems, also play an important role in the efficiency and cost structure of the last-mile. In former decades, when the level of information technologies was significantly lower, much more paper work had to be done, more manual checks and sub-optimal routes were common events. By using the situation-specific information technologies, in most cases, a significant amount of time, fuel and paperwork can be saved. Another result of increased use of IT is the increased level of reliability of deliveries.

- *the environment*

  Consumers and companies are getting increasingly aware of environmental issues in the economy and in transportation/logistics. However, in many cases, consumers want companies to be more environmentally friendly, but they do not wish to pay more, or do not accept a longer service time for "green products or services". Specifically for the last-mile, companies need to make a trade-off between the fast and narrow time windows they offer to the consumers and the level of environmental friendliness they wish to obtain. As already mentioned, the narrower the time windows and the shorter the delivery/lead times, the more polluting the delivery of the parcel becomes.

The summaries of the five generalized characteristics is shown at Table 2.

Table 1 Efficiency characteristics and sub-characteristics of last mile logistics

LEVEL OF CONSUMER SERVICE	SECURITY & TYPE OF DELIVERY	GEOGRAPHICAL AREA & MARKET DENSITY / PENETRATION	FLEET & TECHNOLOGY	THE ENVIRONMENT
Time windows	Home delivery with signature (attended) vs. non-attended	Density	Type of delivery vehicles	Packaging
Lead time	Collection points	Pooling of goods	ICT	Trade-off between time factors and environmental impact
Frequency				
Returns of goods (reverse logistics)				

In the last mile problem, the logistics cost components involve transportation, inventory, facility and handling, and information (Chopra & Meindl, 2014)

- ***Transportation cost*** consists of the costs incurred during delivery using various transportation modes, including the costs incurred during transfer and waiting at intermediate stops. For example, if a peddle-run delivery rather than a one-to-one direct delivery is used, the stop cost at each additional stop is considered part of the transportation cost.

- ***Inventory cost*** is the holding cost for safety stock and the holding cost during transfer (also known as pipeline inventory cost). Usually it is proportional to the product quantities and the holding time.
- ***Facility and handling cost*** consists of the terminal operating cost and the cargo handling fee during the loading/unloading process. Generally speaking, adding an additional facility in the logistics chain (an intermediate stop during the last-mile) leads to an increase in facility and handling cost. It also plays an important role in shifting the inventory cost, depending on the facility location. For example, if the rent rate at the intermediate facility is much cheaper than at the intermodal terminal/customer end, then the total inventory cost in the last-mile could be reduced.
- ***Information cost*** is the cost paid for the new technology and information system, e.g., energy saving vehicles, GPS tracking system, and label tracking system, etc.

2.2 Urban Consolidation Center

Urban Consolidation Centers (UCCs) have been a popular urban logistics solution, particularly in Western Europe. Motivated by the need to make better use of load capacity of freight vehicles, UCCs can be described as logistics platforms used to consolidate and transfer freight coming from external locations onto smaller, less-disruptive vehicles adapted for dense city zones (Allen et al., 2012). In general, no storage and warehousing operations are performed in these platforms. Multiple examples of UCCs and different implementation formats can be found across Western Europe and Japan. The examples of City Porto in Padua, CEMD in Lucca, the Motomachi UCC in Yokohama, or the DHL-operated UCC in Bristol represent the "traditional" UCC system, in which a consolidation center and the fleet of LFVs are administered through public-private partnerships (PPPs). Other cases include the Eco-logistics project in Parma, where restrictions were enforced to unauthorized vehicles in the city center. Carriers, however, were given the option to eco-certify their own vehicles or use an authorized third party logistics service provider. In the Netherlands, Binnenstadtservice, a privately owned logistics service provider offers storage and eco-friendly distribution, and operates in close collaboration with the retail establishments.

Allen et al., (2012) devised a classification system based on the type of operation and geographical area served for all the UCC cases identified. This comprises three categories of UCC:

1. UCCs serving all or part of an urban area: These UCCs are usually associated with the supply of retail products, but are also used for the supply of office products, and occasionally food supplies for restaurants and cafes. These UCC schemes are often intended to serve a specific district in an urban area and are often used to serve locations with features such as narrow streets and historic layouts and therefore have a concentration of freight transport related issues including:
   - vehicle congestion and delay
   - restricted access times and insufficient parking provision
   - a preference for pedestrians only schemes
   - unacceptable levels of air pollution

   The introduction of this type of UCC is usually initially suggested by the local authority which hopes to benefit from the traffic and environmental improvements that are typically associated with it. Existing examples of such UCCs include Reglog in Regensburg, Cityporto in Padua, La Rochelle UCC, Nijmegen UCC and Bristol UCC.
2. UCCs serving large sites with a single landlord: These UCCs are most commonly associated with the supply of retail products and food supplies for restaurants and cafes. There are also examples of them being used for supplying hospital products. The types of large sites served by these UCCs include airports, shopping center and hospitals. In some instances, these UCCs serve only one large site (for example, London Heathrow airport retail UCC and Meadow hall shopping center UCC in Sheffield), while in other cases, they serve several large sites (such as the Hospital Logistics Centre in London which delivers to several major hospitals). Although these UCCs only serve one or a few large sites, these often contain many different outlets (such as various retailers in a shopping center or airport). The interest in UCCs among developers and owners of airports and shopping centers usually stems from the desire to maximize retail space by minimizing on-site storage and the need for multiple delivery bays. In the case of a hospital, the interest is more commonly in reducing on-site stock levels and storage space. These UCCs differ from those serving all or part of an urban area (i.e. type 1 described above) in the following ways:

- the sites served are built as a single development so the UCC can potentially be designed into the planning of the site,
- the site landlord has the potential to insist that tenants use the UCC,
- the unloading points tend to be located off street in a specially designed delivery area with access via a single route, and
- the UCC operation can potentially be made self-financing through charges built into tenants' rental arrangements.

3. Construction project UCCs: These are UCCs that are used for consolidating construction materials for major building projects including housing, office blocks and hospitals. Examples include UCCs established at London Heathrow airport during major development work and in Hammar by in Stockholm for a major housing project. This type of UCC can serve either a single major building project or several. This type of UCC can either exist only for the lifetime of a building project or can be on-going serving new major building projects as they are established, but experience to date suggests that the former is more common. Either the site developer or the main construction contractor would decide to make use of a UCC, or it could be made mandatory through the planning permission process.

Each of these three types of UCC can offer either relatively basic consolidation and delivery services or a wider range of value-added logistics activities such as stockholding facilities, ticketing and pricing, goods return and waste collection services. Similarly, each of the three types of UCC could also potentially offer community collection and delivery point facilities (for other consumer and business products), and home delivery operations could also be operated from the UCC.

2.3 Delivery Model

In this sub-chapter, we would like to deploy the model of unimodal last mile delivery model and multimodal last mile delivery model, and integrate some models to find the optimal one.

2.3.1 Unimodal Last Mile Delivery Model

In the last mile distribution model, most of the literatures are focus on unimodal transportation as the freight forwarder, instead of multimodal transportation. Work in this area includes Wen et al. (2009), Anghinolfi et al. (2011), and Park et al. (2016).

Some literatures mentioned that the goal of optimization in transportation problem is to minimize transportation cost in delivery of goods from points of origin (supply points) to points of destination (demand points). The flow of goods is one directional, meaning that shipments can only go from a supply point to a demand point. Cost is proportional and assigned per unit shipped. Hence, total cost is the summation of units shipped along a route multiplied by the cost of shipping one unit along that route.

The classical transportation problem is as follows:

$$Minimize\ z = \sum_{i=1}^{m}\sum_{j=1}^{h} c_{ij}x_{ij}$$

Subject to

$$\sum_{j=1}^{h} x_{ij} = a_i \qquad for\ i = 1, \dots., m$$

$$\sum_{i=1}^{m} x_{ij} = b_j \qquad for\ j = 1, \dots, h$$

$$x_{ij} \geq 0 \qquad for\ i = 1, \dots, m, \quad j = 1, \dots, h$$

$$\sum_{i-1}^{m} a_i = \sum_{j=1}^{h} b_j = T \quad a_i \geq 0, b_j \geq 0$$

Where:

i = 1,2,…m starting points (sources)

j = 1,2,…h ending points (destinantions)

x_{ij} = units shipped along route ij

c_{ij} = cost per unit shipped along route ij

a_i = units of demand at destinations i

b_j = units of supply at sources j

T = sum of demand or sum of supply

Wen et al. (2009) have discussed the problem of vehicle routing problem in the cross-docking (VRPCD), where in their research a set of homogeneous vehicles (truck) are used to transport products from the intermodal terminals to the corresponding customers via a cross-dock. Products from the intermodal terminals are picked up by a fleet of homogeneous vehicles, consolidated at the cross-dock, and immediately delivered to customers by the same set of vehicles, without intermediate storage. Therefore, the problem involves not only vehicle route design, but also a consolidation decision at the cross-dock. The objective of the VRPCD is to minimize the total traveled distance while respecting time window constraints at the nodes and a time horizon for the whole transportation operation. A small VRPCD instance of five intermodal terminal-customer pairs (requests) is shown in Figure 2. Figure 3 illustrates the pickup and delivery routes for the three vehicles, all of which start and end their routes at the cross-dock. And Figure 4 shows the details of the consolidation process taking place at the cross-dock.

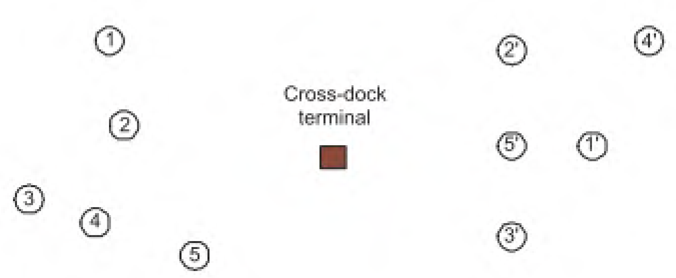


Figure 2 A small instance of the VRPCD (Source: Wen et al., 2009)

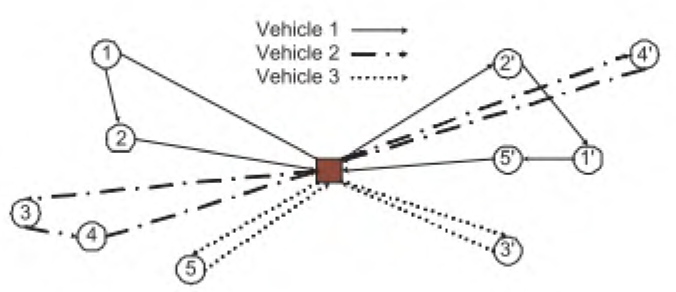


Figure 3 Vehicle routes (Source: Wen et al., 2009)

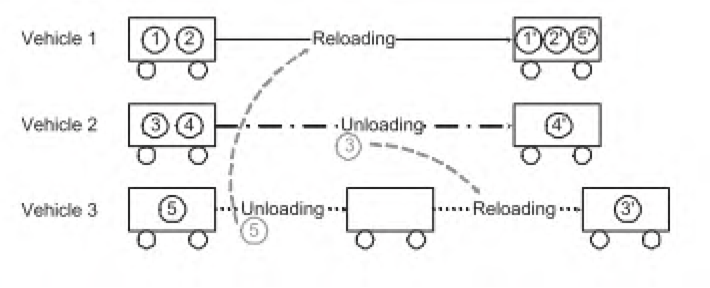


Figure 4 The consolidation process at the cross-dock (Source: Wen et al., 2009)

The authors proposed a mixed integer programming formulation for the VRPCD. The objective is to minimize the total distance traveled. The constraints consist of two parts: vehicle routing and consolidation decisions at the cross-dock. For vehicle routing, the constraints:

- ensure that each node is visited once by one vehicle
- ensure that for each vehicle, the load on the pickup route and on the delivery route does not exceed the vehicle capacity
- state that each vehicle's pickup route must depart from o_1 and delivery route must leave from o_3.
- force each vehicle to return to o_2 on its pickup route and return to o_4 on its delivery route
- compute the traveling time between two nodes if they are visited consecutively by the same vehicle
- ensure that each node is visited within its time window and the whole operation is completed within the time horizon.

For the consolidation decisions at the cross-dock, the constrains:

- if vehicle k picks up i but does not deliver i+n, then it unloads the product at the cross-dock
- if vehicle k does not pick up i but delivers i+n, then it needs to reload the product at the cross-dock
- if the vehicle neither picks up i nor delivers i+n, then it neither unloads nor reloads the product
- force g_k to be 1 if the vehicle needs to unload
- indicate that the unloading duration for a vehicle k consists of a fixed time for the preparation of unloading, and the time for unloading the products, equal to the unit time for unloading a pallet multiplied by the number of pallets to be unloaded from the vehicle

- ensure that a vehicle cannot start reloading until it finishes unloading, and all the products to be reloaded on it are ready.
- The ready time of product i depends on the time at which the pickup vehicle of product i finishes unloading.

A tabu search heuristic is embedded within an adaptive memory procedure to solve the problem. From the experimental conducted, the results shows that this algorithm can produce high quality solutions (less than 5% away from optimal solution values) within very short computational time.

Meanwhile Anghinolfi et al. (2011) have investigated freight transportation in railway networks with automated terminals. The authors tried to make a procedure planning for serving freight transportation requests in a railway network with fast transfer equipment at terminals by mathematical model and MIP heuristic approaches. The planning problem faced in this paper combines two main decisions. The former concerns the routing of boxes in the network and the selection of train changes at terminals; the latter decision deals with the assignment of boxes to wagons of the selected trains. These two decisions have been generally considered separately in the literature. The box routing and train selection are of- ten related to aggregate flows of goods represented as a set of commodities. The goal of the planning procedure is to make the planning of transportation operations for all the orders within a specified time horizon. The problem is to determine for each box of each order: the route that it must follow from its origin to its destination, the sequence of trains that it must use along such route so that the order time constraints are satisfied, and the wagons used to transport it for each train in the sequence.

The authors applied pre-analysis which consist of an algorithm that computes all the sequences of trains available for serving each order, taking into ac- count the network structure, the timetables and the stop sequences of trains, the origin, the destination and the time requirements of the order. This research refer to sequences of trains because each box is generally transported by more than one train from its origin to its destination (the maximum number of trains that a box can change is given by the number of railway links of the route). The pre-analysis algorithm is applied to one order at a time without taking into account capacity constraints but only considering feasibility in terms of time delivery and train connections. More in detail, the algorithm allows to compute all the feasible train sequences (for each order o and for each route p a priori specified) as those available to connect the order origin and destination. The algorithm proceeds backward analyzing the railway links in $l_{o,p}$, starting from the last link of the route, then verifying which trains, among the ones scheduled to cover the links, can be used to serve the order according to their timetable. In particular this is done for the last railway link in $l_{o,p}$ by finding all the trains arriving at the link head not after the deadline t_d^o and leaving from the link tail not before t_s^o. Then, the algorithm proceeds backward along the route, selecting among the trains travelling on the considered link the ones allowing a feasible connection with the feasible trains already determined for the subsequent railway links. For example, in a path including three links which are trains 1, 2 and 3 cover the last link in a feasible way for an order. Proceeding backward, train 1 is also feasible for the second link and it allows a feasible connection with train 2 but not with train 3. Considering the first link, train 1 is still feasible and also train 4 allows a feasible connection with train 1. After the completion of the backward analysis, a forward procedure is applied to determine all the feasible train sequences for an order o on a route p.

The objectives of the research is the minimization of the costs associated with train sequences, train costs, and the penalty for not serving orders. Also with several constraints mentioned below:

- impose that, if served, each box is assigned to one and only one train sequence
- establish that if a box is assigned to a train sequence, then it must be assigned to one wagon of each train belonging to that sequence
- impose for each train that the maximum bearable weight is not exceeded
- impose for each train that the maximum bearable weight is not exceeded
- ensure that boxes assigned to wagons are compatible with the wagon length and weight limitations
- ensure that boxes assigned to wagons are compatible with the wagon length and weight limitations. Constraints (8) impose that the maximum number of handling operations to be performed for each train at a given terminal is not exceeded

The result shows that the planning procedure proposed in this work considers only terminals with fast transfer equipment and the relevant trains. Other trains and terminals of the same net- work can keep being treated with traditional planning methods.

Park et al. (2016) have studied the effects analysis of logistics collaboration in last-mile networks for Courier, Express and Parcel (CEP) delivery services. They formulated CEP delivery behaviors in last-mile networks to estimate the effects of logistics collaboration for apartment complexes by using CDP Vehicle Routing and CDP Horizontal Routing.

The target of logistics collaboration in CEP delivery service is the last-mile network, the service's final step, which is categorized into horizontal and vertical deliveries. As shown in Figure 5, each company (A, B, C, and D) visits each of the buildings (1, 2, 3, and 4) using individual trucks before collaboration. After collaboration, only one company, the cooperative delivery company (CDC), pro- vides an integrated delivery service using an integrated delivery service truck. As shown in Figure 6, before collaboration, each company's serviceperson visits the households individually using the elevators for each line, each group of households serviced by a specific elevator. After collaboration, the CDC's serviceperson provides an integrated delivery service. The objective function to be minimized is the total traveling distance of horizontal and vertical deliveries. And the constraints:

- guarantee that only one vehicle visits each building
- guarantee that K vehicles start at the depot and that all vehicles return to the depot
- indicate whether a vehicle travels directly from building i to building j
- ensure that only one serviceperson visits each household
- enforce the capacity and connectivity of the feasible routes
- indicate whether a serviceperson moves directly from household p to household q.

To solve the problem, the authors proposed algorithm for a CDPHR and a CDPVR. This study formulated a CEP delivery model in last- mile networks to estimate the effects of logistics collaboration for apartment complexes. Reflecting courier delivery behavior, the CEP delivery problem was divided into horizontal and vertical routing problems. Optimization methodologies commonly utilized in the operations research area were employed for the analytical modeling of these two routing behaviors.

2.3.2 Multimodal Last Mile Delivery Model

Some literatures also talking about multimodal transportation delivery model. Work in this area includes Moccia et al. (2008) and Confessore et al. (2013).

Moccia et al. (2008) have discussed about modeling and solving a multimodal routing problem with timetables and time windows by using column generation algorithm. Column generation algorithms are designed to compute lower bounds. These column generation algorithms are also embedded within heuristics aimed at finding feasible integer solutions. Given a set of origin-destination transport requests, one must optimally route these requests in a multimodal network. They assumed that the freight forwarder does not operate a vehicle fleet, but can access a heterogeneous set of transportation services. These services can be classified according to two main characteristics: type of departure time, and cost function. They differentiated between timetabled services and time-flexible services. Usually, rail and short sea shipping modes are operated with fixed departure times while trucks have flexible departures. Some services allow consolidation of shipments between two terminals. A terminal is where a transfer can take place between modes or between different vehicles of the same mode. Consolidation enables fixed costs sharing. This effect is captured by piecewise linear (PL) cost functions that depend upon the total service load. These cost functions are non-convex and, in general, non-concave. Other types of services do not allow consolidation and their cost function is thus that of the single shipment. We therefore distinguish between consolidation and dedicated services. Consolidation services present multiple capacity constraints, e.g. volume, weight, train length, etc. Dedicated services are not viewed as capacitated because they either are feasible or not considered for a given shipment. The pickup and delivery of a transport request is done by selecting between multiple time windows. Similarly there are multiple time windows for the delivery. The chosen route must respect the opening time windows of the terminals. Because of these characteristics, namely multimodal, multiple capacity constraints, and multiple time windows, they denoted the problem as the M++ Routing Problem (M++RP).

Meanwhile Confessore et al. (2013) have studied about production and logistics network model with multimodal and sustainability considerations. They presented a mathematical model describing a network in which nodes represent production plants or distribution centers while arc are multimodal connections. And the model is developed as Mixed Integer Linear Programming (MILP) model, and realistic test instances are exploited for validation purposes of the objective function.

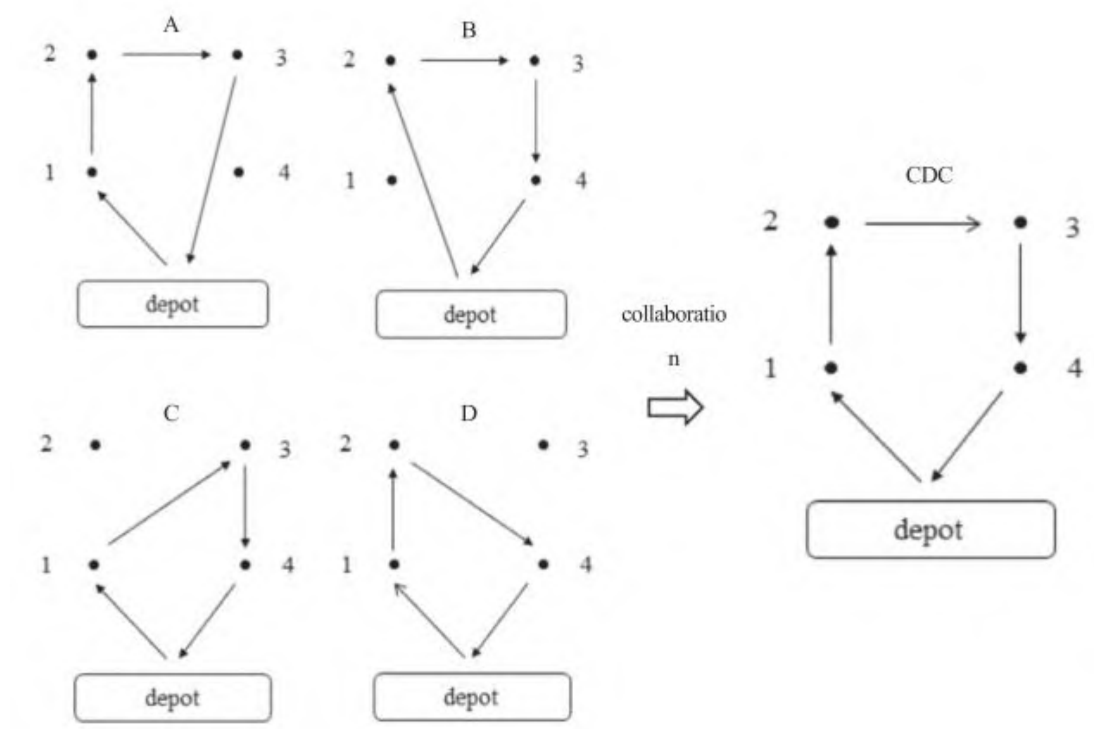


Figure 5 Concept of horizontal delivery with respect to logistics collaboration (Park et al., 2016)

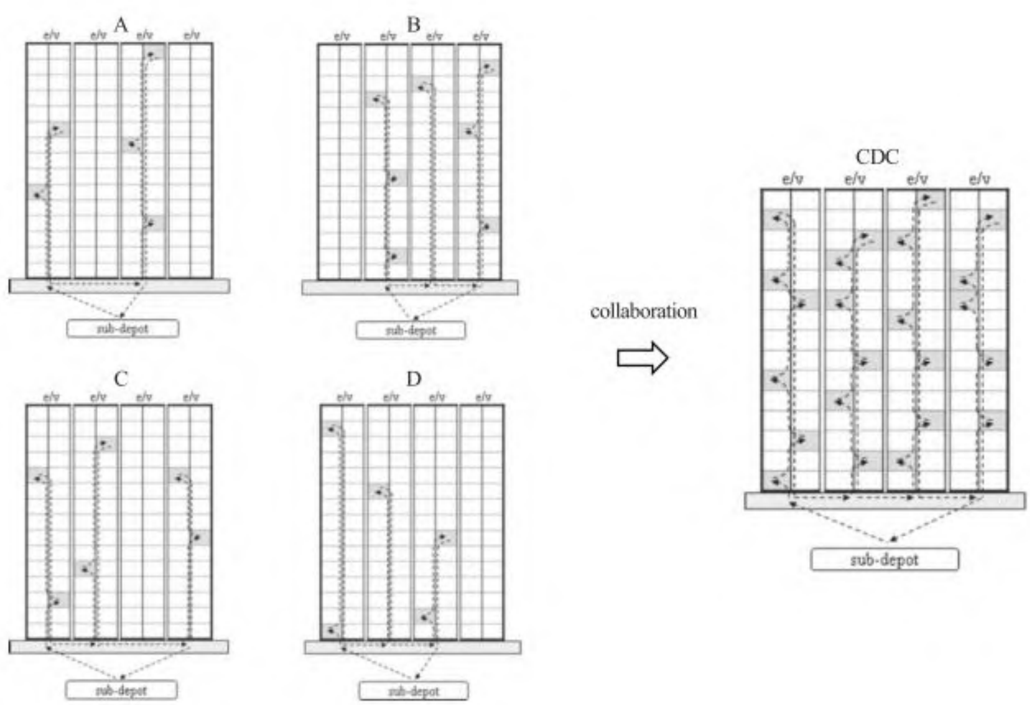


Figure 6 Concept of vertical delivery with respect to logistics collaboration (Park et al., 2016)

The objective of the research is to exploit the transportation point of view of the problem, at operational level. They considered a multimodal distribution network with production plants. The proposed mathematical model presents a network in which nodes represent production plants, distribution centers, or logistics platforms, while arc are multimodal. The model considers costs, sustainability factors and constraints related to distribution, inventory and production. BOM is considered as additional constraint at operation decisional level. Moreover, sustainability factors are considered in the objective function. The problem is to find the optimal routes for serving customers with a given set of vehicles, production plants, logistics platforms, on the given multimodal network. The logistics platforms can be viewed as the network nodes where transportation modes can be changed. When a product is requested by the customer, an origin destination transportation must be fulfilled. BOM considerations imply that additional intermediate travels for required material are needed. This requirements are considered in the model as additional intermediate origin destination transportations requests. The constraint of the model are to:

- characterize the flow to be followed by shipment k without splits in the inner nodes
- guarantee schedule feasibility with respect to time considerations
- guarantee feasibility with respect to capacity considerations.

They outlined a comprehensive logistics scenario in order to encompass all the problem’s characteristics presented in figure 7.

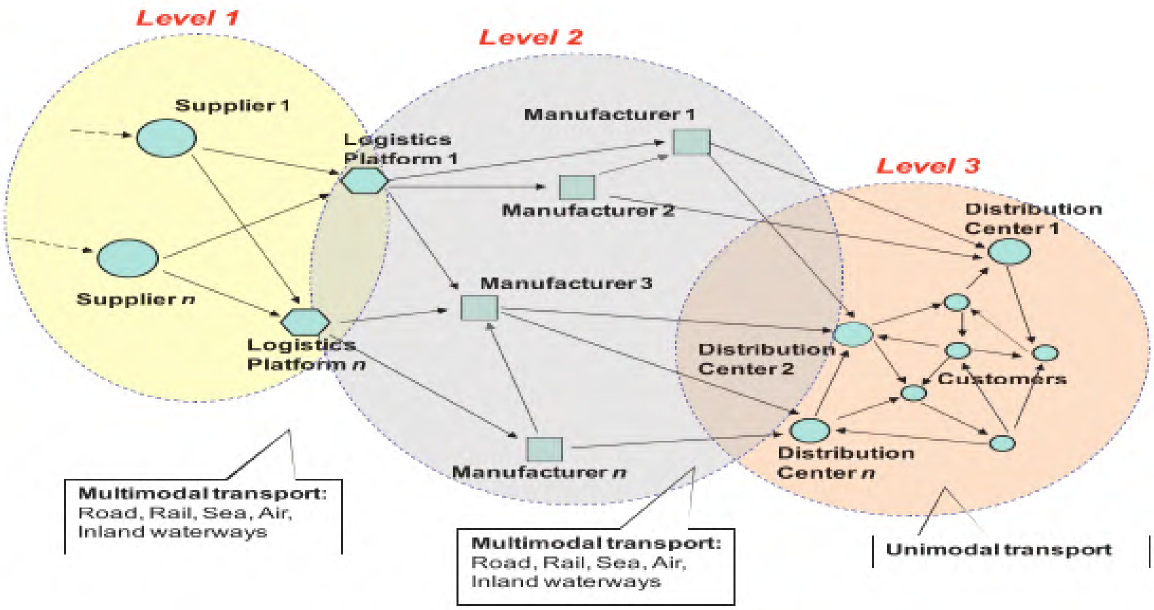


Figure 7 Logistics scenario structure (Confessore et al., 2013)

Thee reference scenario has been fixed on the basis of a logistics network that consists of three levels: (1) supply level, (2) manufacturing level, (3) final distribution level. The last level can be decomposed into a first layer devoted to distribution centers and a second layer dedicated to the final delivery to customers. Intermodal terminals and manufacturers are connected through the logistics platforms while the distribution centers link manufacturing sites and final customers. Multimodal transport is available for the connections among the levels 1 and 2, and the first layer of the level 3. The second layer of level 3 should foresee only unimodal transport. For the purposes of this paper, the optimization model takes into account levels 1, 2 and the first layer of level 3, thus it includes intermodal terminals, logistics platforms, manufacturers, and distribution centers.

Instead of considering the minimum cost, they also considered about the sustainability factors which may occurred during the transportation process. So the objective function is intend to minimize the emissions on environment that are produced by vehicles as well. A sustainability factor can be derived by the CO_2 emissions of each transportation mean.

2.4 Carbon Emission Modeling in Last Mile Distribution

Previous research conducted by Daccarett-garcia (2009) presented an excellent summary of methods to calculate carbon emissions for transport trucks and reports that carbon emission calculations can be based on either the gallons of diesel fuel consumed (which results in 10.1 kilograms of carbon dioxide per gallon of fuel) or the number of miles traveled (which results in an average of 1.01 kilograms of carbon dioxide per kilometer). The following equation is for modeling carbon dioxide emissions (CDE) based upon diesel fuel utilization:

$$CDE = \left(10.1\,\frac{kg}{gal}\right)\left(\sum_{i}\sum_{j}\sum_{k}\left(\frac{X_{ijk}D_j}{E_j}\right)\right)$$

where

i, j, k = defines the truck type, route and day

X_{ijk} = number of trips made by truck type i to route j in day k

D_j, E_j = distance of route j, fuel efficiency of truck type i.

The lead coefficient representing the carbon dioxide emission per gallon of diesel is determined as follows:

CO_2/Gallon = $\left(\frac{carbon\ content}{gallon}\right)(oxidation\ factor)\left(\frac{m.w.\mathrm{CO2}}{m.w.C}\right)$

Entering the following set of parameters to the above equation: oxidation factor for diesel (0.99) and the molecular weights (m.w.) of CO2 and carbon (44 and 12 respectively) yields: CO_2/Gallon = 2,788g/gal*0.99*=10.084g=10.1 kg/kal

and then should be loaded into the electric vehicle by adopting the model of Wen et al. (2009).

2.5 Critical Review

Last mile delivery, also called the home delivery, is growing rapidly. The last mile in a business to customer environment is currently regarded as one of the more expensive, least efficient and most polluting sections in the entire logistics chain (Gevaers et al., 2014). The “Last Mile” in logistics delivery process or the “First Mile” in the case is a common logistics collection/distribution problem under urban condition. The nearer to the aggregated point (delivery destination), the more cost and higher loss in capacity and efficiency. This last process of the supply chain may face serious constraints in fulfillment, higher social, environmental and economic costs and increased complexity in operational arrangement. Last Mile delivery obstacle may be attributed to dynamically interacting but poorly understood reasons (Souza et al., 2014).

In this work, we are going to analyze the existed model of vehicle delivery including unimodal and multimodal transport. In the unimodal transportation delivery model, we are seeking the possibility to combine the model of rail transportation and road transportation in the last mile distribution. Meanwhile, in the multimodal transportation delivery model, we are keen to find out the possibility to develop it in the case of city logistics.

In the last mile distribution model, most of the literatures are focus on unimodal transportation as the freight forwarder, instead of multimodal transportation. Work in this area includes Wen et al. (2009), Anghinolfi et al. (2011), and Park et al. (2016). Wen et al. (2009) have discussed the problem of vehicle routing problem in the cross-docking (VRPCD), where in their research a set of homogeneous vehicles (truck) are used to transport products from the intermodal terminals to the corresponding customers via a cross-dock. The objective of the VRPCD is to minimize the total traveled distance while respecting time window constraints at the nodes and a time horizon for the whole transportation operation. The authors proposed a mixed integer programming formulation for the VRPCD. Meanwhile Anghinolfi et al. (2011) have investigated freight transportation in railway networks with automated terminals. The authors tried to make a procedure planning for serving freight transportation requests in a railway network with fast transfer equipment at terminals by mathematical model and MIP heuristic approaches. Park et al. (2016) have studied the effects analysis of logistics collaboration in last-mile networks for Courier, Express and Parcel (CEP) delivery services. They formulated CEP delivery behaviors in last-mile networks to estimate the effects of logistics collaboration for apartment complexes by using CDP Vehicle Routing and CDP Horizontal Routing.

Some literatures also talking about multimodal transportation delivery model. Work in this area includes Moccia et al. (2008) and Confessore et al. (2013). Moccia et al. (2008) have discussed about modeling and solving a multimodal routing problem with timetables and time windows by using column generation algorithm. Column generation algorithms are designed to compute lower bounds. These column generation algorithms are also embedded within heuristics aimed at finding feasible integer solutions. Meanwhile Confessore et al. (2013) have studied about production and logistics network model with multimodal and sustainability considerations. They presented a mathematical model describing a network in which nodes represent production plants or distribution centers while arc are multimodal connections. And the model is developed as Mixed Integer Linear Programming (MILP) model, and realistic test instances are exploited for validation purposes of the objective function.

The problem considered in our study is the sustainable vehicle delivery model, which is introduced into more specific mode as electric vehicle delivery model in multimodal last mile distribution. Hence, we have to consider about the integration model between the transportation deliveries from intermodal terminal to urban consolidation center as introduced by using rail transport and also the transportation deliveries from urban consolidation center to the customers using electric vehicle. The problem is similar to that Confessore et al. (2013) where the multimodal vehicle in the logistics delivery process is applied. However, there is still gap need to be fulfilled in term of deepening of the delivery model in the last mile distribution. We also may combine the freight rail distribution introduced by Anghinolfi et al. (2011) and the road transport delivery in the last mile distribution in the apartment complexes by Park et al. (2016). Also we have to consider about the process in the urban consolidation center which the goods should be unloaded from the train and then should be loaded into the electric vehicle by adopting the model of Wen et al. (2009).

MODEL FORMULATION AND DEVELOPMENT

3.1 Model Description

In this research, we propose a delivery model in multimodal last mile distribution. The goods to be satisfied is given by set of orders. Goods are consolidated in a center located outside the urban area, are transported from this on shuttle trains to a distribution center located inside the central area of the city (multi-modal urban distribution centers - MUDC), and are finally transferred from rail to green, by using electric vehicles to reach their final destination. In this process, we have to consider the synchronization of train schedule with the time window of delivery that has been set, number of fleet available and also wagon capacity of the fleet, since the capacity of the wagon is huge. The scheme of MUDC is shown in Figure 2.

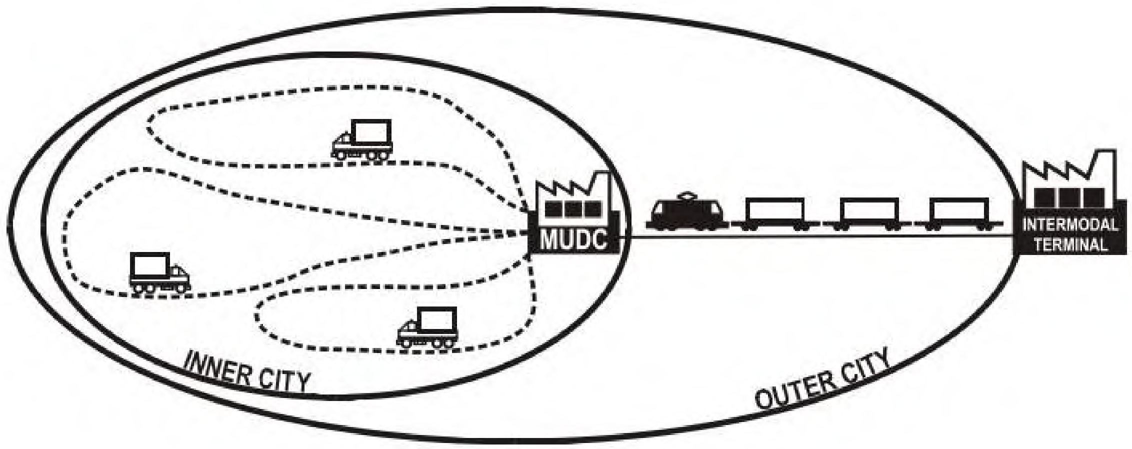


Figure 1 The scheme of MUDC (Source: Centre for Transport and Logistics, university of Rome "La Sapienza")

This research will be focus in three parts. First, in the intermodal terminal, where the consolidation process of the goods from the suppliers is conducted. Second, in the MUDC, where the train will unload the goods and it will be loaded to the small truck to be delivered to the customer. And third is in the last mile distribution where the small trucks have to deliver the good to the customers.

In the intermodal terminal, there will be consolidation process where the supplier brings the goods to the intermodal terminal, then it will be sorted depends on the order status from the customer. After the goods ready, it will be loaded into the train and taken to the MUDC. The goods should be arrived in the intermodal terminal and would be delivered to MUDC in particular time windows, hence, a schedule synchronization of the train is needed.

In the MUDC, the goods that has been delivered by the train would be unloaded and sorted for outgoing shipment in the last mile distribution using small trucks. The train can start unloading immediately after it arrives at the MUDC and the unloading process from the train must be completed before reloading to the truck starts. The duration of the loading-unloading consists of a fixed time for preparation, and the time needed for loading-unloading products, equal to the time for loading-unloading each pallet multiplied by the number of pallets. We also have to consider the activity in the MUDC where the consolidation of the capacity between the transportation modal is significantly different in scale. After the loading process to the small trucks is finish, the goods are ready to be distributed to the customers.

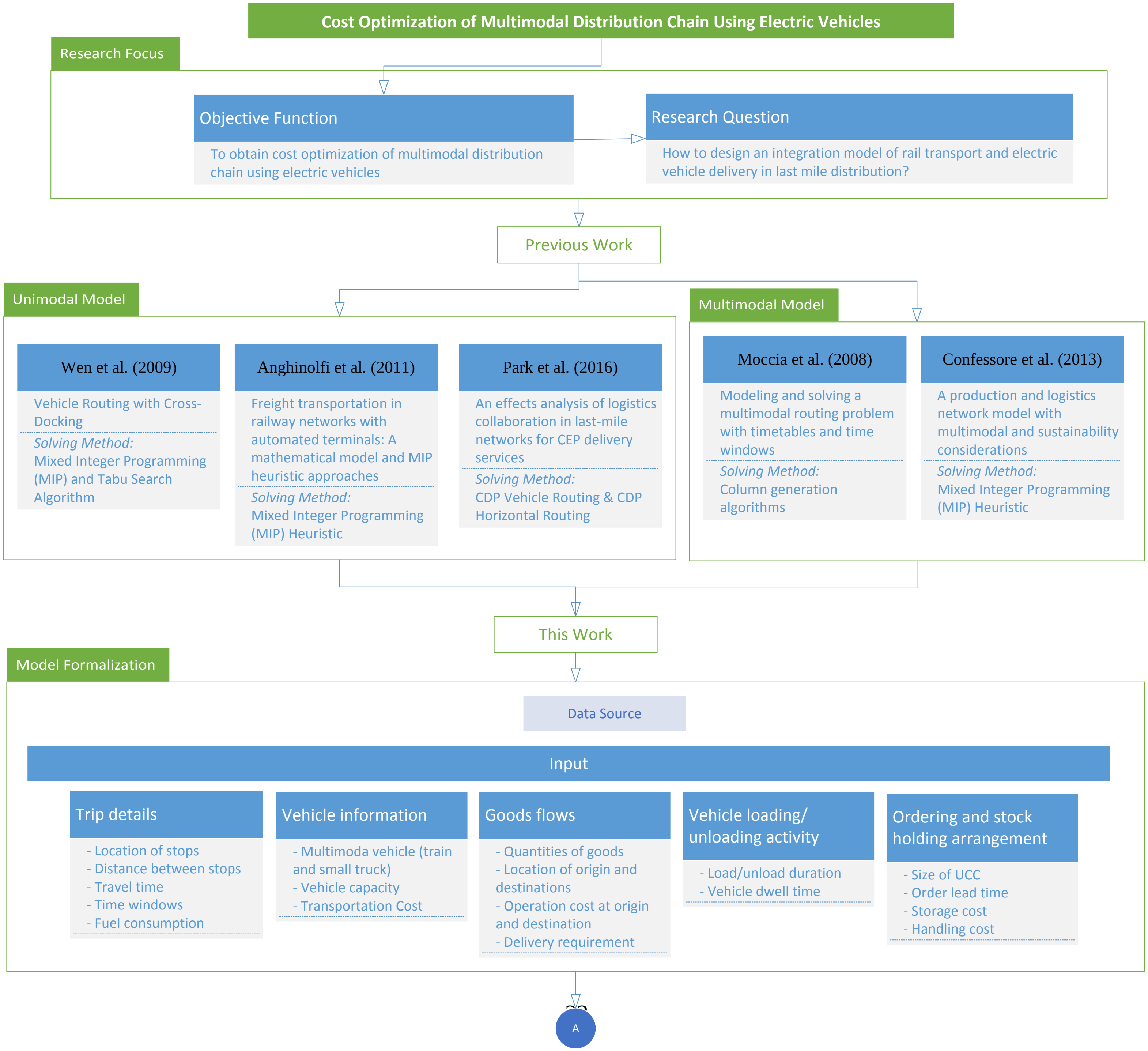
In the last mile distribution, the goods are distributed using small trucks to the customer. The small trucks are intended to increase customer satisfaction towards the shipment process. Since we have to respect the time windows of the delivery, as in the Vehicle Routing Problem with Time Windows (VRPTW), each customer must be served by exactly one vehicle within its time window, the accumulated load of each route must not exceed the vehicle capacity. In this process, we also generate the configuration of delivery trip of the vehicle respect to the time windows.

This research intends to integrate the model of three parts logistics process above. We propose a Mixed Integer Programming (MIP) formulation approach as it had been applied by Confessore et al., (2013) and Anghinolfi et al., (2011). In general terms, this mixed-integer programing model determines the cost-efficient network configuration for last mile delivery by obtaining the number and location of intermediate depots given a set of candidate locations, and the optimal fleet configuration (size and vehicle types) to serve a specific urban area or district. Moreover, using sensitivity analysis and operational scenarios, this model provides insights into the trade-offs between different network configuration alternatives. The concept of multimodal model and also sustainability vehicle by applying electrical vehicle from Confessore et al., (2013) are adopted, however we still need to elaborate more the model in the customer side which is last mile distribution. Hence, we have to consider the model of Anghinolfi et al. (2011) which is talking about freight rail distribution in detail and also integrate with the road transport delivery in the last mile distribution in the apartment complexes by Park et al. (2016). By integrating those model, we expect to get the optimal vehicle delivery model in multimodal last mile distribution, however in this problem we also have to consider the activity in the MUDC where the consolidation of the capacity between the transportation modal is significantly different in scale.

The mathematical optimization model was formulated as a mixed integer linear problem (MIP) (Anghinolfi et al., 2011; Confessore et al., 2013; Wen et al., 2009) with the objective function of cost minimization under several constraints. The proposed optimization model is a cost model that takes into account three other types of parameters, which are the spatial parameters (MUDC capacity and capacity of transport unit), time (duration of delivery and service by MUDC, etc.) and transport mode in multimodal last mile distribution.

Following several constraints which are guarantees feasibility with respect to capacity synchronization between multimodal in the MUDC, and the schedule feasibility with respect to time considerations which involves the decision of shipment size for each customer, delivery frequency, and dispatching time; the routing plan determines the tour pattern and number of stops. Since we also have to consider about the environment sustainability, we will propose the emission estimation model to know the emission reduction rates by having electric vehicles in the last mile distribution. Further, a simulation of case study of last mile distribution in Rome will be introduced.

To conduct the simulation, we need some practical data which are related to the trip details such as the location of stops (location of the customer), the distance between the customer, travel time of the train from supplier terminal to the MUDC, travel time of small truck from the MUDC to the customer (per kilometer distance), specific time windows delivery, and fuel consumption per kilometer which is related to the emission rate. Detail vehicle information is also needed such like the multimodal vehicle used, in this case we will use train and small vehicle with the different capacity in scale, and transportation cost. The information of goods flows is the main point in the order planning such like the quantities of the goods ordered by the customer, detail location of origin goods (supplier), operation cost to carry the goods, and some others delivery requirement. In the MUDC, we have to consider about the vehicle unloading (unloading goods from the train) and loading (loading goods to the small trucks) activity including the duration and the dwelling time as well. And the last data aspect needed is the ordering and stockholding arrangement including the size of MUDC, order lead time, storage cost and handling cost. All the input will be considered in the configuration of delivery trip as the input data. The sequences of model formalization will be represented in the research framework in Figure 3.


Cost Optimization of Multimodal Distribution Chain Using Electric Vehicles
Research Focus
Objective Function
To obtain cost optimization of multimodal distribution chain using electric vehicles
Research Question
How to design an integration model of rail transport and electric vehicle delivery in last mile distribution?
Previous Work
Unimodal Model
Wen et al. (2009)
Vehicle Routing with Cross-Docking
Solving Method:
Mixed Integer Programming (MIP) and Tabu Search Algorithm
Anghinolfi et al. (2011)
Freight transportation in railway networks with automated terminals: A mathematical model and MIP heuristic approaches
Solving Method:
Mixed Integer Programming (MIP) Heuristic
Park et al. (2016)
An effects analysis of logistics collaboration in last-mile networks for CEP delivery services
Solving Method:
CDP Vehicle Routing & CDP Horizontal Routing
Multimodal Model
Moccia et al. (2008)
Modeling and solving a multimodal routing problem with timetables and time windows
Solving Method:
Column generation algorithms
Confessore et al. (2013)
A production and logistics network model with multimodal and sustainability considerations
Solving Method:
Mixed Integer Programming (MIP) Heuristic
This Work
Model Formalization
Data Source
Input
Trip details
- Location of stops
- Distance between stops
- Travel time
- Time windows
- Fuel consumption
Vehicle information
- Multimoda vehicle (train and small truck)
- Vehicle capacity
- Transportation Cost
Goods flows
- Quantities of goods
- Location of origin and destinations
- Operation cost at origin and destination
- Delivery requirement
Vehicle loading/ unloading activity
- Load/unload duration
- Vehicle dwell time
Ordering and stock holding arrangement
- Size of UCC
- Order lead time
- Storage cost
- Handling cost
A

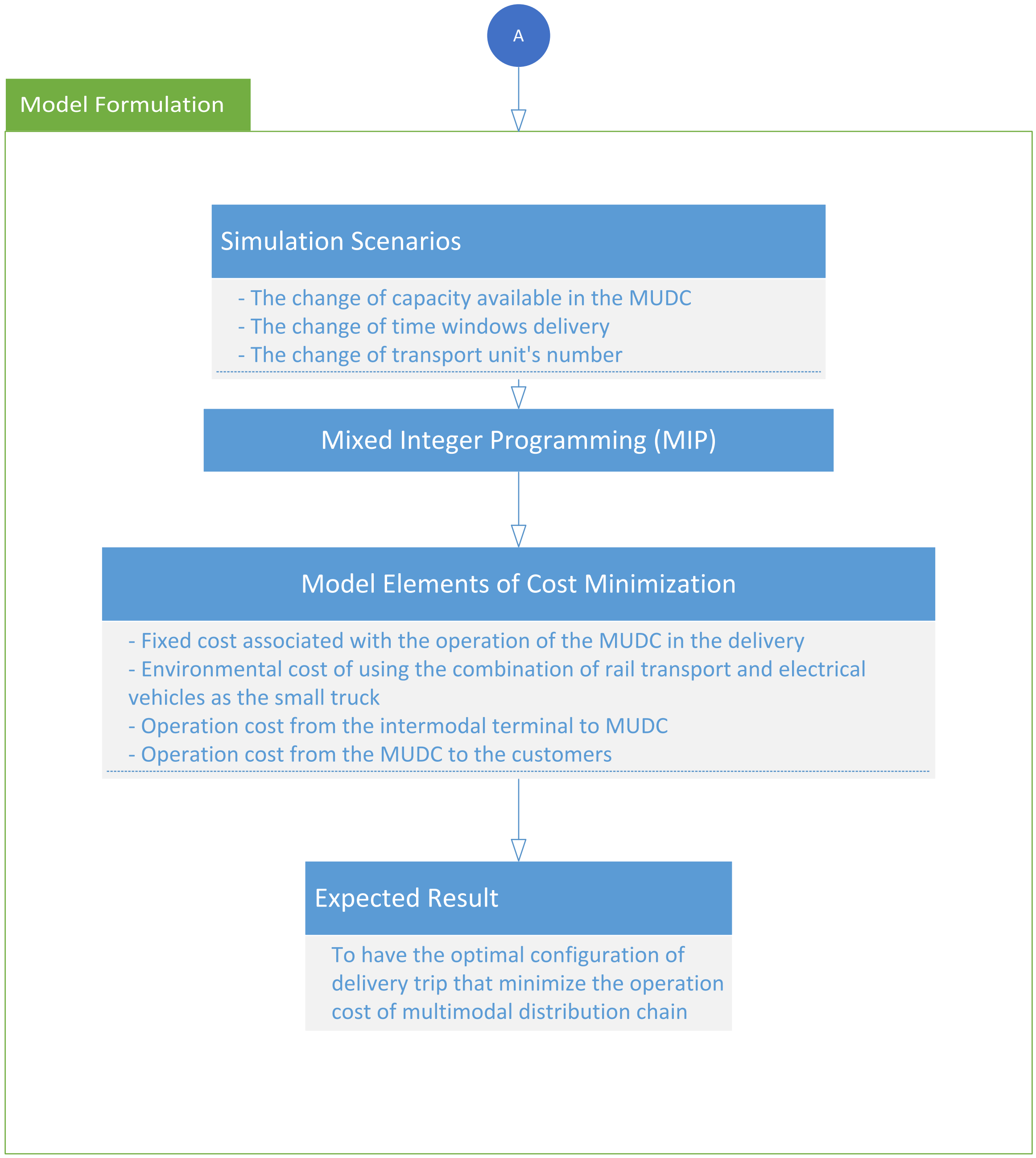


Figure 2 Research Framework

3.2 Model Formulation

The mathematical optimization model was formulated as a mixed integer linear problem (MIP) (Anghinolfi et al., 2011; Confessore et al., 2013; Wen et al., 2009) with the objective function of cost minimization under several constraints. Indices, parameters and decision variables in the model together with their descriptions are provided in Table 2. The proposed optimization model is a cost model that takes into account three other types of parameters, which are the spatial parameters (MUDC capacity and capacity of transport unit), time (duration of delivery and service by MUDC, etc.) and transport mode in multimodal last mile distribution.

Table 1 Summary indices, parameters and decision variables of the mathematical optimization model

Notation	Description
Indices	
i	Intermodal terminal (i=1,...,N)
j	Delivery point/customer (j=1,…,M)
s	Distribution center (s=1,…E)
d	Rail vehicle (d=1,..,L)
h	Electric vehicle (h=1,…,Q)
M	Number of delivery points/customers
N	Number of intermodal terminal
E	Number of distribution center
L	Number of rail vehicle
Q	Number of electric vehicle
Input parameters	
F_s	the fixed cost of distribution center s (s=1..E)
P	the volume occupied
V_s	distribution center s maximum capacity/volume (s=1..E)
W_i	capacity at intermodal terminal i (i=1..N)
R_s	if distribution center s (s=1..E) can deliver the product, then R_s =1, otherwise R_s =0
Tp_s	the time needed for distribution center s (s=1..E) to prepare the shipment
Tc_j	the cut-off time of delivery to the delivery point/customer j (j=1..M)
Z_j	customer demand/order j (j=1..M)
Zt_d	the number of transport units using rail vehicle d (d=1..L)
Zt_h	the number of transport units using electric vehicle h (h=1..Q)
Pt_d	the capacity of transport unit using mode of transport d (d=1..L)
Pt_h	the capacity of transport unit using mode of transport h (h=1..Q)

Notation	Description
$T_{i,s,d}$	the time of delivery from intermodal terminal i to distribution center s using rail vehicle d (i=1..N) (s=1..E) (d=1..L)
$C1_{i,s,d}$	the variable cost of delivery from intermodal terminal i to distribution center s using rail vehicle d (d=1..L) (i=1..N) (s=1..E) (p=1..O)
$R1_{i,s,d}$	if intermodal terminal i can deliver to distribution center s using rail vehicle d then $R1_{i,s,d}$=1, otherwise $R1_{i,s,d}$=0 (d=1..L) (s=1..E) (i=1..N)
$A_{i,s,d}$	the fixed cost of delivery from intermodal terminal i to distribution center s using rail vehicle d (d=1..L) (i=1..N) (s=1..E)
$C_{s,j,d}$	the total cost of delivery from intermodal terminal I to distribution center s using rail vehicle d (d=1..L) (s=1..E) (j=1..M)
$T_{s,j,h}$	the time of delivery from distribution center s to customer j using electric vehicle h (h=1..Q) (s=1..E) (j=1..M)
$C2_{s,j,h}$	the variable cost of delivery of from distribution center s to customer j using electric vehicle h (h=1..Q) (s=1..E) (p=1..O) (j=1..M)
$R2_{s,j,h}$	if distribution center s can deliver to customer j using electric vehicle h, then $R2_{s,j,h}$=1, otherwise $R2_{s,j,h}$=0 (h=1..Q) (s=1..E) (j=1..M)
$G_{s,j,h}$	the fixed cost of delivery from distribution center s to customer j using electric vehicle h (h=1..Q) (j=1..M) (p=1..O)
$C_{s,j,h}$	the total cost of delivery from distribution center s to customer j using electric vehicle h (h=1..Q) (s=1..E) (j=1.M)
Ec_d	the environmental cost of using mode of transport d (d=1..L)
Ec_h	the environmental cost of using mode of transport h (h=1..Q)
Decision Variables	
$X_{i,s,d}$	delivery quantity from intermodal terminal i to distribution center s using rail vehicle d
$Xa_{i,s,d}$	if delivery is from intermodal terminal i to distribution center s using rail vehicle d, then $Xa_{i,s,d}$=1, otherwise $Xa_{i,s,d}$=0
$Xb_{i,s,d}$	the number of trip from intermodal terminal i to distribution center s using rail vehicle d

Notation	Description
$Y_{s,j,d}$	delivery quantity from distribution center s to customer j using mode of transport d
$Ya_{s,j,h}$	if delivery is from distribution center s to customer j using electric vehicle h then $Ya_{s,j,h}=1$, otherwise $Ya_{s,j,h}=0$
$Yb_{s,j,h}$	the number of trip from distribution center s to customer j using electric vehicle h
Tc_s	if distribution center s participates in deliveries, then $Tc_s=1$, otherwise $Tc_s=0$

3.3 Optimization Criteria

The objective function defines the aggregate costs of the entire chain and consists of four elements as shown in equation 1.

$$Min\ z = \sum_{s=1}^{E} F_s * Tc_s + \left(\sum_{d=1}^{L} Ec_d * \sum_{i=1}^{N} \sum_{s=1}^{E} Xb_{i,s,d} + \sum_{d=1}^{L} Ec_h * \sum_{s=1}^{E} \sum_{j=1}^{M} Yb_{j,s,h} \right) + \sum_{i=1}^{N} \sum_{s=1}^{E} \sum_{d=1}^{L} C_{i,s,d} + \sum_{s=1}^{E} \sum_{s=1}^{M} \sum_{h=1}^{Q} C_{s,j,h}$$

…………………….……………………………………………………………………………… (1)

The first element sets out the fixed costs associated with the operation of the distribution center involved in the delivery. The second element is the environmental cost of using the combination of rail transport and electrical vehicles as the small truck which may depend on the use of fossil fuels and carbon-dioxide emissions. The third element determines the cost of delivery from the distribution center to multimodal urban distribution center. The last element is responsible for the cost of delivery from the multimodal urban distribution center to the customer.

3.4 Constraints

The model was developed subject to several constraints as follows:

$$\sum_{s=1}^{E} \sum_{d=1}^{L} (X_{i,s,d}) \le W_i$$

$for\ i = 1, \dots, N$

………………………………………………………………………………………………… (2)

Constraint (2) specifies that all deliveries of product p produced by the intermodal terminal i and delivered to all distribution centers' using mode of transport d do not exceed the intermodal terminal's capacity.

$$\sum_{s=1}^{E}\sum_{h=1}^{Q}\left(Y_{s,j,h} * R_s\right) \geq Z_j$$

$for\ j = 1, \dots, M$

………………………………………………………………………………………………… (3)

Constraint (3) covers all customer j demands (Z_j) through the implementation of supply by distribution center s (the values of decision variables $Y_{i,s,h}$). The constraint was designed to take into account the specificities of the distribution center s resulting from environmental or technological constraints (i.e., whether the distributor s can deliver the product or not).

$$\sum_{i=1}^{N}\sum_{d=1}^{L} X_{i,s,d} = \sum_{j=1}^{M}\sum_{h=1}^{Q} Y_{s,j,h}$$

$for\ s = 1, \dots, E$

………………………………………………………………………………………………… (4)

Constraint (4) shows the balance of each distribution center s.

$$\sum\left(P * \sum_{i=1}^{N}\sum_{d=1}^{L} X_{i,s,d}\right) \leq Tc_s * V_s$$

$for\ s = 1, \dots, E$

………………………………………………………………………………………………… (5)

Constraint (5) defines the delivery dependent on technical capabilities which is represented by distribution center's volume/capacity.

$$Xa_{i,s,d} * T_{i,s,a} + Xa_{i,s,d} * Tp_s + Ya_{s,j,h} * T_j \leq Tc_j$$

$for\ i = 1, \ldots, N, s = 1, \ldots, E, j = 1, \ldots, M,\ \ d = 1, \ldots, L$, h=1,…,Q

…………………………………………………………………………………………………… (6)

Constraint (6) ensures the fulfillment of delivery time.

$$R1_{i,s,d} * Xb_{i,s,d} * Pt_d \geq X_{i,s,d} * P$$

$for\ i = 1, \ldots, N, s = 1, \ldots, E, p, d = 1, \ldots, L$

…………………………………………………………………………………………………… (7)

$$R2_{s,j,h} * Yb_{s,j,h} * Pt_h \geq Y_{s,j,p,h} * P$$

$for\ s = 1, \ldots, E, j = 1, \ldots, M,, h = 1, \ldots, Q$

…………………………………………………………………………………………………… (8)

$$\sum_{i=1}^{N} \sum_{s=1}^{E} Xb_{i,s,d} \leq Zt_d$$

$for\ d = 1, \ldots, L$

…………………………………………………………………………………………………… (9)

$$\sum_{j=1}^{M} \sum_{s=1}^{E} Yb_{j,s,h} \leq Zt_h$$

$for\ d = 1, \ldots, L$

…………………………………………………………………………………………………… (10)

Constraints (7), (8), (9) and (10) guarantee deliveries with available transport taken into account.

$$\sum_{i=1}^{N} \sum_{d=1}^{L} Xb_{i,s,d} \leq CW * Tc_s$$

$for\ s = 1, \ldots, E$

…………………………………………………………………………………………… (11)

$Xb_{i,s,d} \leq CW * Xa_{i,s,d}$

$for\ i = 1, \dots, N, s = 1, \dots, E, d = 1, \dots, L$

…………………………………………………………………………………………… (12)

$Yb_{s,j,h} \leq CW * Ya_{s,j,h}$

$for\ s = 1, \dots, E, j = 1, \dots, M, h = 1, \dots, Q$

…………………………………………………………………………………………… (13)

Constraints (11), (12), (13) set values of decision variables based on binary variables Tc_s, $Xa_{i,s,d}$, $Ya_{s,j,h}$ respectively.

$$C_{i,s,d} = A_{i,s,d} * Xb_{i,s,d} + \sum_{p=1}^{O} C1_{i,s,d} * X_{i,s,d}$$

$for\ i = 1, \dots, N, s = 1, \dots, E, d = 1, \dots, L$

…………………………………………………………………………………………… (14)

$$C_{s,j,h} = G_{s,j,h} * Yb_{j,s,h} + \sum_{p=1}^{O} C2_{s,j,h} * Y_{s,j,h}$$

$for\ s = 1, \dots, E, j = 1, \dots, M, d = 1, \dots, L$

…………………………………………………………………………………………… (15)

Constraints (14) and (15) represent the relationship by which total costs are calculated.

$X_{i,s,d} \geq 0$

$for\ i = 1, \dots, N, s = 1, \dots, E, d = 1, \dots, L$

…………………………………………………………………………………………… (16)

$Xb_{i,s,d} \geq 0$

$for\ i = 1, \ldots, N, s = 1, \ldots, E,, d = 1, \ldots, L$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(17)}$$

$Yb_{s,j,h} \geq 0$

$for\ \ s = 1, \ldots, E, j = 1, \ldots, M, h = 1, \ldots, Q$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(18)}$$

$X_{i,s,d} \in C$

$for\ i = 1, \ldots, N, s = 1, \ldots, E, d = 1, \ldots, L$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(19)}$$

$Xb_{i,s,d} \in C$

$for\ i = 1, \ldots, N, s = 1, \ldots, E,, d = 1, \ldots, L$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(20)}$$

$Y_{s,j,p,h} \in C$

$for\ \ s = 1, \ldots, E, j = 1, \ldots, M, p = 1, \ldots, O, h = 1, \ldots, Q$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(21)}$$

$Yb_{s,j,h} \in C$

$for\ \ s = 1, \ldots, E, j = 1, \ldots, M, h = 1, \ldots, Q$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(22)}$$

$Xa_{s,j,d} \in \{0,1\}$

$for\ i = 1, \ldots, N, s = 1, \ldots, E,, d = 1, \ldots, L$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(23)}$$

$Ya_{s,j,h} \in \{0,1\}$

$for\ \ s = 1, \ldots, E, j = 1, \ldots, M, h = 1, \ldots, Q$

………………………..…………………………………………………………………………… (24)

$Tc_s \in \{0,1\}$

$for\ \ s = 1, \dots, E$

………………………..…………………………………………………………………………… (24)

For the rest of the constraints arise from the nature of the model.

3.5 Method Developed

The model is implemented in TransCAD. TransCAD is the first and the only Geographic Information System (GIS) based program designed specifically transportation profession which can store, display, manage, and analyze transportation data. TransCAD includes a comprehensive library of logistics procedures that apply to all modes of transportation and can be used to solve a variety of logistics problems that called Vehicle Routing and Logistics. TransCAD offers a vehicle routing program which is able to consider multiple vehicles, mixed pick-up and delivery, multiple time windows at stops and vehicle type constraints at stops. In the case here four time-efficient routes have been generated separately having considered a single vehicle per route. The inputs provided include link travel times, time spent at each stop, quantity delivered at each stop, opening hours at the MUDC and at each stop.

The order from the customers has been set for one month. We simulate the order in TransCAD by applying some constraints in the model to obtain the optimum routing delivery configuration. The routing configuration are both in MUDC-Customers sub process and also DC-MUDC. After that, we synchronize the result of two sub process. Furthermore, the result of the optimum configuration will be the input of cost optimization model.

The capacity constraint of train and electric vehicles is significantly different in scale. Hence we have to consider about the schedule synchronization between the train shipping from intermodal terminal to distribution center, in order the goods that have been delivered do not exit the distribution center capacity. After that, we calculate all the cost related to the fixed cost in the distribution center, environmental cost related to the use of the vehicles, the operation cost from intermodal terminal and the operation cost from distribution center to the customers.

Based on Alessandrini, et al. (2012), fully electric vehicles do still have a problem of range; after 12 hours charging present batteries allow not more than a 40 km range. In the near future, when different batteries will be available, fully electric vehicles can be the best choice for this application.

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SIMULATION AND CASE STUDY ANALYSIS

4.1 Case Study Description

The Fresh Food Centre (FFC) logistics company is located in Pomezia (south of Rome) and operates in the food distribution industry (agro-food, fish, fresh food, frozen food), having the large retailers as main customers (Coop, SMA Auchan, etc.). The company owns a number of refrigerated warehouses (about 80.000 m2 in total) and outsources the last-mile carriage of goods employing trucking companies. The distribution market is Rome.

The current management of the distribution system is manually operated. Customers send the expected arrivals of goods to FFC using their own information system. FFC receives them on a local terminal up to 8 pm on day A. Related goods are then received up to midnight on the same day A. At the same time and up to 8 pm on day A, FFC receives the orders from the PODs (points of delivery). These orders have to be worked during the night (from 0.00 to 4.00 on day B) in order to be delivered to the PODs from 6.00 to 7.30 am on day B.

Every distribution trip is manually elaborated, also taking into account the constraints coming from the requests of the customer. In case of delays or errors, each POD is allowed to complain within 4 hours from the delivery, by sending a fax. Each driver is requested to keep track of the delivery time (arrival, delivery start, closure and departure) and the proof of delivery. These travel sheets are also reporting the quantity delivered at each stop.

The set of order for this case is attached in the Appendix A.

4.2 Simulation Scenarios

In this step, we will conduct the simulation by comparing performance of the model from the given input parameter. The base scenario is performed by having one distribution center, two multi urban distribution centers and 30 point of deliveries. The delivery to the customer is conducted using electric vehicle with the capacity of 5 pallets per vehicle and the time windows delivery from the DC to MUDC is between 00.00 to 04.00 and the goods should be arrived to the customer in between 06.00-07.30. The simulation scenarios are presented in Table 4 below.

Table 2 Simulation Scenarios

No.	Scenarios		Purpose
1	The change of available capacity and location in the Distribution Center		To know the effect of capacity and location changing toward the synchronization schedule of the train and demand from the MUDC
	1.1	1 Distribution Center	
	1.1.1	DC 1 = 250 pallets	
	1.1.2	DC 2 = 250 pallets	
	1.2	2 Distribution Centers	
	1.2.1	DC 1 = 125 pallets	
		DC 2 = 125 pallets	
	1.2.2	DC 1 = 150 pallets	
		DC 2 = 100 pallets	
	1.2.3	DC 1 = 100 pallets	
		DC 2 = 150 pallets	
2	The change of available capacity and location in the Multimodal Urban Distribution Center		To know the effect of capacity changing toward the synchronization schedule of electric vehicle and demand from the customers
	2.1	2 MUDC	
	2.1.1	MUDC 1 = 150 pallets	
	2.1.2	MUDC 2 = 100 pallets	
	2.2	3 MUDC	
	2.2.1	MUDC 1 = 100 pallets	
	2.2.2	MUDC 2 = 100 pallets	
	2.2.3	MUDC 3 = 50 pallets	
3	The configuration of scenario 1 and scenario 2		To know the effect of configuration to obtain the cost optimization
	3.1	DC 1 to MUDC 1 and MUDC 2	
	3.2	DC 1 to MUDC 1, MUDC 2 and MUDC 3	
	3.3	DC 2 to MUDC 1 and MUDC 2	
	3.4	DC 2 to MUDC 1, MUDC 2 and MUDC 3	

No.	Scenarios		Purpose
	3.5	DC 1 and DC 2 to MUDC 1 and MUDC 2	
	3.6	DC 1 and DC 2 to MUDC 1, MUDC 2 and MUDC 3	
4	The change of customer's time windows delivery		To know the effect of time windows delivery changing toward the fleet number needed
	4.1	Time windows delivery between 06.00-07.30 AM	
	4.2	Time windows delivery between 06.00-09.00 AM	
5	The change of fleet capacity		To know the effect of fleet capacity changing toward the vehicle routing delivery distance and time needed
	5.1	Train capacity	
	5.1.1	10 wagons = 220 pallets	
	5.1.2	15 wagons = 330 pallets	
	5.2	Electric vehicle capacity	
	5.2.1	5 pallets	
	5.2.2	10 pallets	

4.3 Parameter of Simulation

The simulation of the model is conducted by using some input parameter as follows:

4.3.1 Assumption of Distribution Center

In this model, we have two sub process of distribution that should be considered. First is distribution process between intermodal terminal and distribution center, and second is distribution process between distribution center and customers.

According to the data of European Pallet Association e.V., the capacity of pallet per wagon are 22 pallets. We assume that each train has 10 wagons. Meaning that total pallet loaded in one trip is 220 pallets. In this case, we assume that the capacity of distribution center is a bit higher which are 250 pallets, to avoid the overloaded pallet in the next day.

4.3.2 Loading Data

Table 3 Loading Data

Loading Data	
Pallet Size	80x120 cm
Item Dimension	40x25x15 cm
Number of item per pallet	10

4.3.3 Travel Data

Table 4 Travel Data

Travel Data	
Average duration of stops	5 minutes
Average urban speed	15 km/h
Average unloading time per item	12 seconds

4.4 Simulation Result and Analysis

In this part, the result of simulation will be performed, further the analysis will be presented as well.

Table 5 Simulation Result

No.		Scenarios	DC to MUDC: Total Distance (km)	DC to MUDC: Number of Route	DC to MUDC: Travel Time (min)	DC to MUDC: Env. Cost (€)	DC to MUDC: Operation Cost (€)	MUDC to Customers: Total Distance (km)	MUDC to Customers: Number of Route	MUDC to Customers: Travel Time (min)	MUDC to Customers: Env. Cost (€)	MUDC to Customers: Operation Cost (€)	Fixed cost in DC	Total Cost
0		Base Scenario	76.7	1	65	0.5	1	356.46	18	1425.6	0.05	1.4	50	€ **627**
1		The change of available capacity and location in the Distribution Center												
	1.1	1 Distribution Center												
	1.1.1	DC 1 = 250 pallets	76.7	1	65	0.5	1	356.46	18	1425.6	0.05	1.4	50	€ **627**
	1.1.2	DC 2 = 250 pallets	35.6	1	45	0.5	1	356.46	18	1425.6	0.05	1.4	50	€ **586**
	1.2	2 Distribution Centers												
	1.2.1	DC 1 = 125 pallets	65.4	1	73	0.5	1	356.46	18	1425.6	0.05	1.4	50	€ **616**
		DC 2 = 125 pallets												
2		The change of available capacity and location in the Multimodal Urban Distribution Center												
	2.1	2 MUDC	76.7	1	65	0.5	1	356.46	18	1425.6	0.05	1.4	50	€ **627**
	2.1.1	MUDC 1 = 150 pallets												
	2.1.2	MUDC 2 = 100 pallets												
	2.2	3 MUDC	47.5	1	135	0.5	1	1248.54	19	312.4	0.05	1.4	50	€ **1,847**
	2.2.1	MUDC 1 = 70 pallets												
	2.2.2	MUDC 2 = 70 pallets												
	2.2.3	MUDC 3 = 70 pallets												
3		The configuration of scenario 1 and scenario 2												
	3.1	DC 1 to MUDC 1 and MUDC 2	76.7	1	65	0.5	1	356.46	18	1425.6	0.05	1.4	50	€ **627**
	3.2	DC 1 to MUDC 1, MUDC 2 and MUDC 3	47.5	1	135	0.5	1	1248.54	19	312.4	0.05	1.4	50	€ **1,847**
	3.3	DC 2 to MUDC 1 and MUDC 2	35.6	1	45	0.5	1	356.46	18	1425.6	0.05	1.4	50	€ **583**
	3.4	DC 2 to MUDC 1, MUDC 2 and MUDC 3	32.7	1	106	0.5	1	1248.54	19	312.4	0.05	1.4	50	€ **1,832**
	3.5	DC 1 and DC 2 to MUDC 1 and MUDC 2	32.7	1	106	0.5	1	356.46	18	1425.6	0.05	1.4	50	€ **583**
	3.6	DC 1 and DC 2 to MUDC 1, MUDC 2 and MUDC 3	65.4	1	73	0.5	1	1248.54	19	312.4	0.05	1.4	50	€ **1,865**
4		The change of customer's time windows delivery												
	4.1	Time windows delivery between 06.00-07.30 AM	76.7	1	65	0.5	1	356.46	18	1425.6	0.05	1.4	50	€ **627**
	4.2	Time windows delivery between 06.00-09.00 AM	76.7	1	65	0.5	1	356.46	18	1425.6	0.05	1.4	50	€ **627**
		The change of fleet capacity												
5	5.1	Train capacity												
	5.1.1	10 wagons = 220 pallets	76.7	1	65	0.5	1	356.46	18	1425.6	0.05	1.4	50	€ **627**
	5.1.2	15 wagons = 330 pallets	76.7	1	65	0.5	1	356.46	18	1425.6	0.05	1.4	50	€ **627**
	5.2	Electric vehicle capacity												
	5.2.1	5 pallets	76.7	1	65	0.5	1	356.46	18	1425.6	0.05	1.4	50	€ **627**
	5.2.2	10 pallets	76.7	1	65	0.5	1	254.77	11	1019	0.05	1.4	50	€ **484**

Table 5 above shows the result of the simulation, where the input of distance and travel time are from the result of TransCAD simulation. We simulated each sub process, then we combined to get the cost optimization. Further analysis for each scenario will be explained below.

4.4.1 Scenario 1

In this scenario, we simulated the effect of changing availability capacity and location of distribution center toward the cost affected. The result of the simulation shows that the single distribution center which is distribution center 2 located in the Scalo San Lorenzo gives the minimum cost in 586 Euro, if we compare by having single distribution center in the distribution center 1 or by combining both distribution center 1 or 2. The comparison among scenarios can be seen in Figure 10.

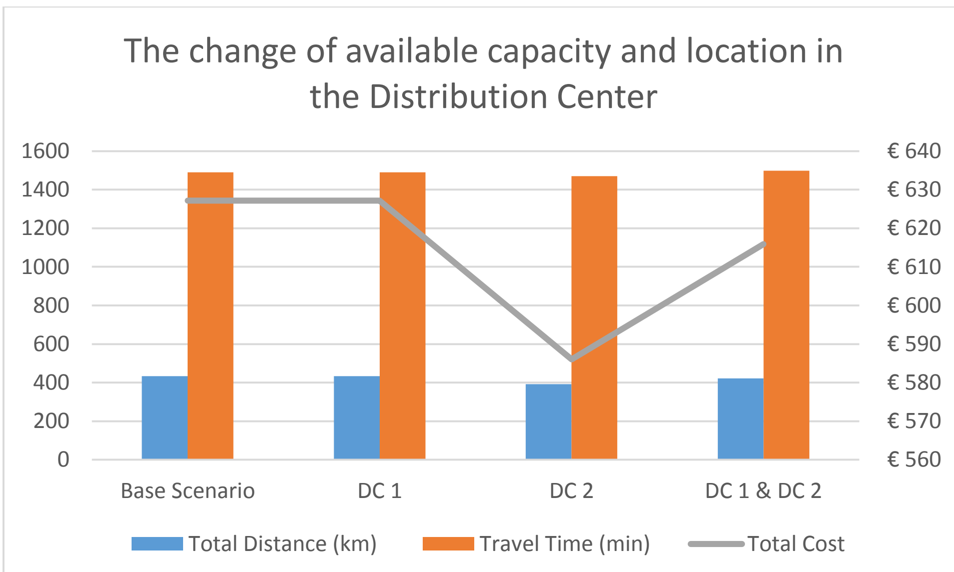


Figure 3 The change of available capacity and location in the Distribution Center

4.4.2 Scenario 2

In this scenario, we simulated the effect of changing availability capacity and location of multimodal urban distribution center toward the cost affected. The result of the simulation shows that the two multimodal urban distribution center which is MUDC 1 located in Via Tiburtina and Via Tuscolana give the minimum cost in 627 Euro, if we compare by having 3 MUDC. The comparison among scenarios can be seen in Figure 11.

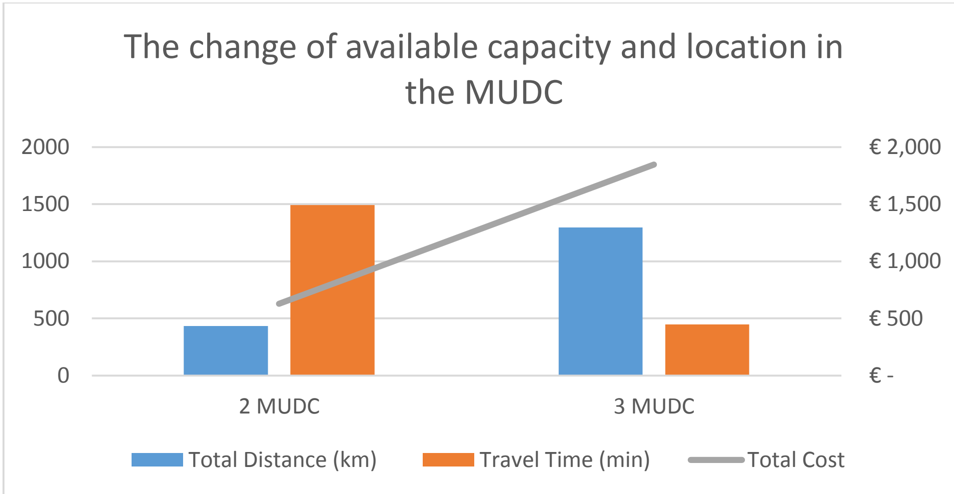


Figure 4 The change of available capacity and location in the MUDC

4.4.3 Scenario 3

In this scenario, we simulated the effect of combining scenario one and scenario two toward the cost affected. The result of the simulation shows that the configuration between single distribution center which is distribution center 2 and two multimodal urban distribution center give the minimum cost in 583 euro. The comparison among scenarios can be seen in Figure 12.

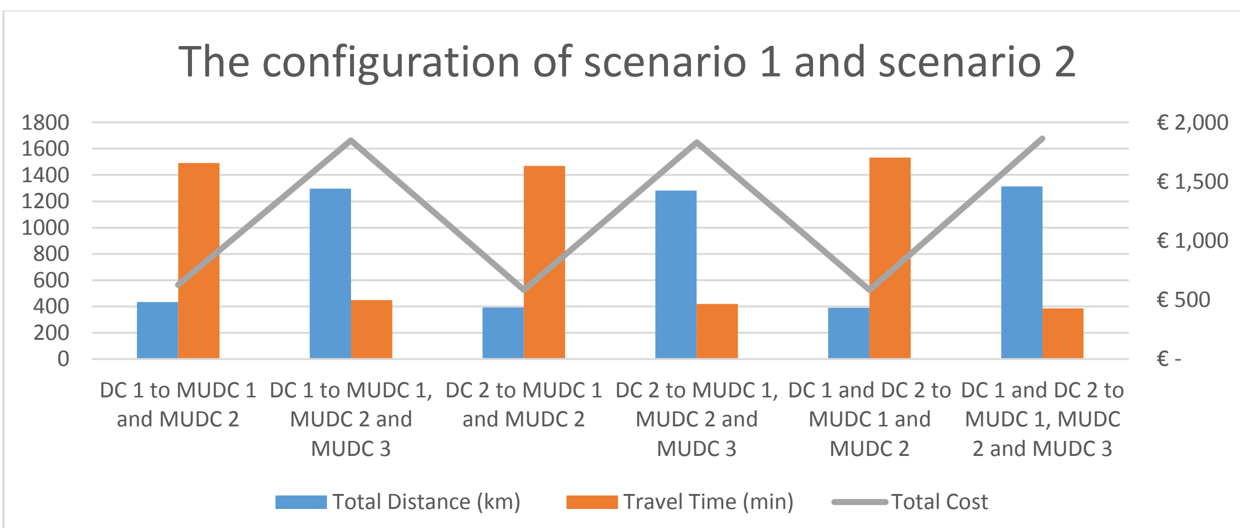


Figure 5 The configuration of scenario 1 and scenario 2

4.4.4 Scenario 4

In this scenario, we simulated the effect of changing customer’s time windows delivery toward the cost affected. The result of the simulation shows that there is no different between the iteration.

Both scenarios give the cost in 627 Euro. The comparison among scenarios can be seen in Figure 13.

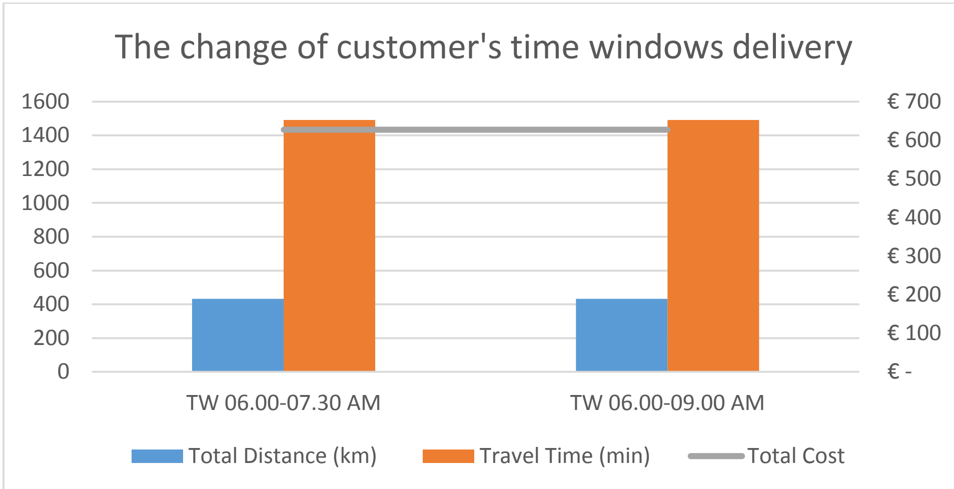


Figure 6 The change of customer's time windows delivery

4.4.5 Scenario 5

In this scenario, we simulated the effect of changing fleet capacity toward the cost affected. The result of the simulation shows the capacity changing of train give no different in term of cost. Meanwhile the capacity changing of electric vehicle from 5 pallets to 10 pallets give minimum cost in 484 Euro, if we compare by having 3 MUDC. The comparison among scenario can be seen in Figure 14.

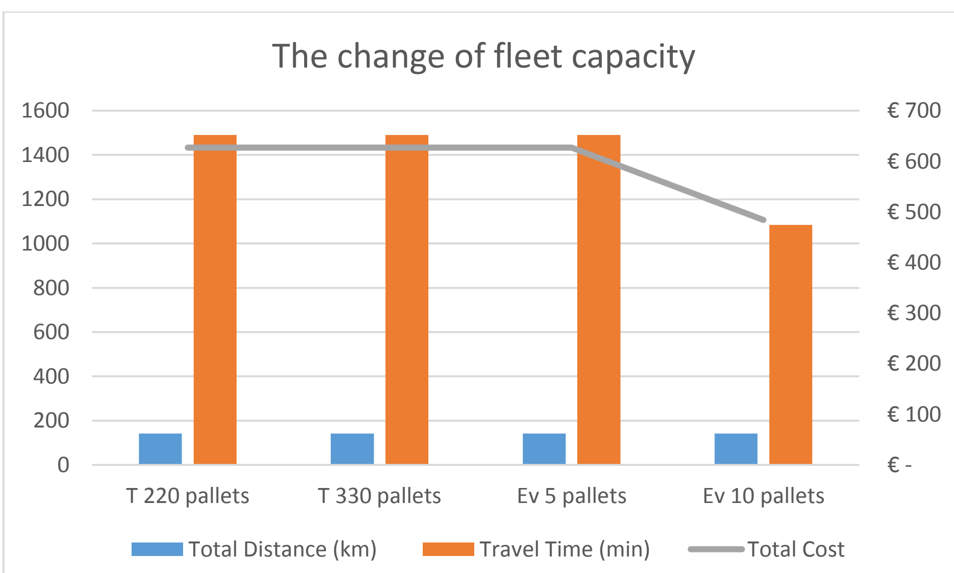
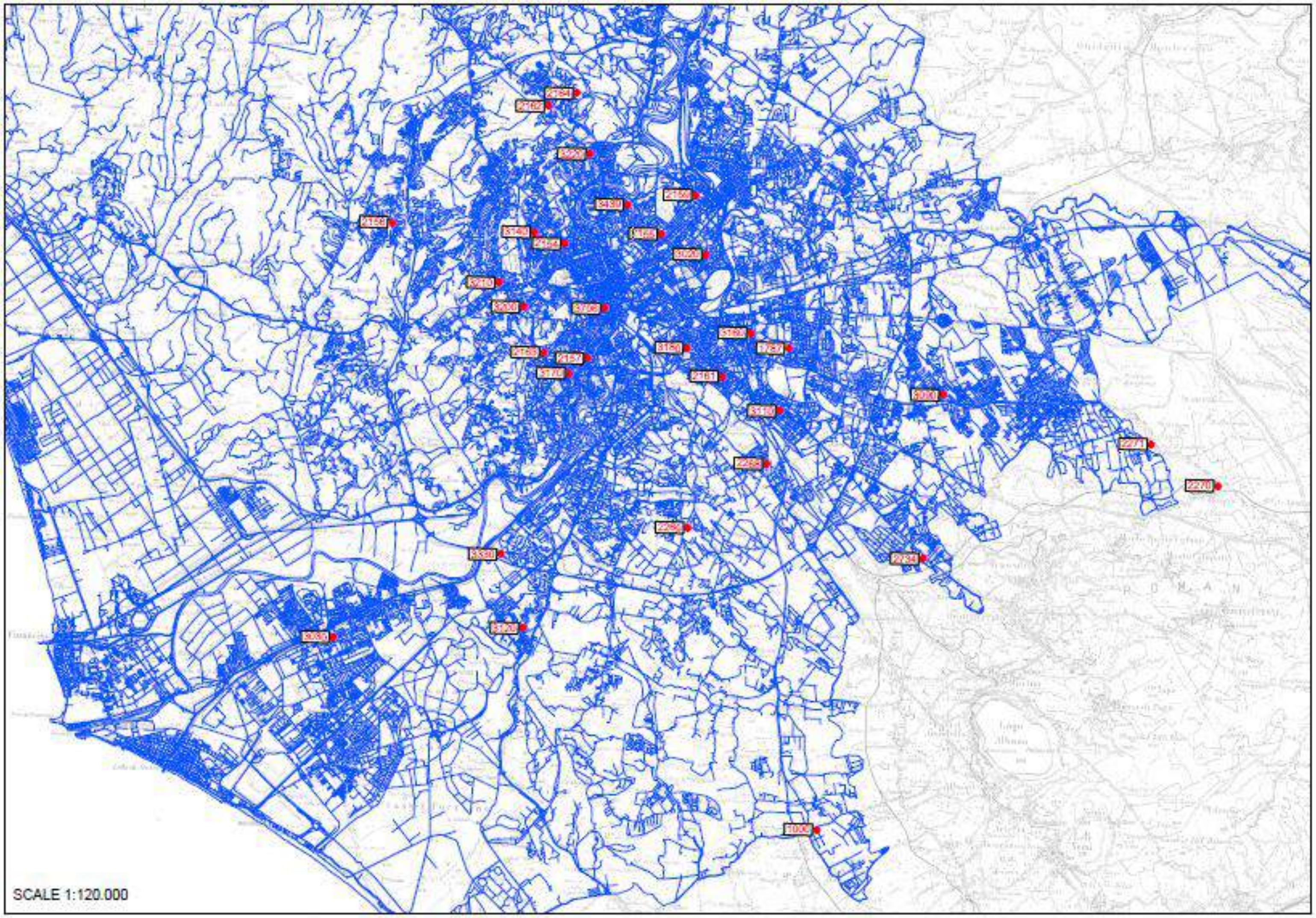


Figure 7 The change of fleet capacity

Among the result of all scenarios, the configuration between single distribution center, two multimodal urban distribution center and increase the capacity of electric vehicle will provide the cost optimization of this model.

APPENDICES

1. Maps of Rome



2. Point of Deliveries

NUM_ID	ADDRESS	DELIVERY START	DELIVERY END	DELIVERY DAYS	CITY
1787	VIA DELLA PRIMAVERA, 194 - 00172 ROMA	06:00	07:30	MON - TUE -WED - THU - FRI -SAT	ROME
2154	VIALE MAZZINI 153 - 00195 ROMA	06:00	07:30	MON - TUE -WED - THU - FRI -SAT	ROME
2155	VIA RUBICONE 39 - 00198-ROMA	06:00	07:30	MON - TUE -WED - THU - FRI -SAT	ROME
2156	VIA BOCCEA, 678	06:00	07:30	MON - TUE -WED - THU - FRI -SAT	ROME
2157	VIA PORTUENSE 97 - 00153 ROMA	06:00	07:30	MON - TUE -WED - THU - FRI -SAT	ROME
2159	VIA PICCININI 19 - 00199 ROMA	06:00	07:30	MON - TUE -WED - THU - FRI -SAT	ROME
2161	VIA DELLE CAVE 99/A	06:00	07:30	MON - TUE -WED - THU - FRI -SAT	ROME
2162	VIA CASSIA 713 - 00189 ROMA	06:00	07:30	MON - TUE -WED - THU - FRI -SAT	ROME
2163	VIA ZAMBARELLI 31 - 00152 ROMA	06:00	07:30	MON - TUE -WED - THU - FRI -SAT	ROME
2164	VIA DUE PONTI 190 - 00191 ROMA	06:00	07:30	MON - TUE -WED - THU - FRI -SAT	ROME
2268	VIA ACERENZA 4/D - 00178 ROMA	06:00	07:30	MON - TUE -WED - THU - FRI -SAT	ROME
2269	VIA MILLEVOI 57 - 00195 ROMA	06:00	07:30	MON - TUE -WED - THU - FRI -SAT	ROME
2270	VIA CASILINA KM 22,800 - 00132 ROMA	06:00	07:30	MON - TUE -WED - THU - FRI -SAT	ROME
2271	VIA CASILINA KM 19,600 - 00132 ROMA	06:00	07:30	MON - TUE -WED - THU - FRI -SAT	ROME
2734	VIA ANAGNINA 471, ROMA	06:00	07:30	MON - TUE -WED - THU - FRI -SAT	ROME
3020	PIAZZA BOLOGNA, ROMA	06:00	07:30	MON - TUE -WED - THU - FRI -SAT	ROME
3030	VIA DI SAPONARA 22O, ROMA	06:00	07:30	MON - TUE -WED - THU - FRI -SAT	ROME
3090	V. A. ASPERTINI ANG. V. PARASACCHI - 00133 RM	06:00	07:30	MON - TUE -WED - THU - FRI -SAT	ROME
3110	V. PONZIO COMINIO 19 - 00175 ROMA	06:00	07:30	MON - TUE -WED - THU - FRI -SAT	ROME
3120	V.LE CADUTI DELLA RESISTENZA 271- 00128 RM	06:00	07:30	MON - TUE -WED - THU - FRI -SAT	ROME
3140	VIA ORLANDO DE TOMMASO 39 -00136 (ROMA)	06:00	07:30	MON - TUE -WED - THU - FRI -SAT	ROME
3160	V. ROBERTO MALATESTA 221/237 - 00176 ROMA	06:00	07:30	MON - TUE -WED - THU - FRI -SAT	ROME
3170	CIRCONVALLAZIONE GIANICOLENSE, 78 ROMA	06:00	07:30	MON - TUE -WED - THU - FRI -SAT	ROME
3180	PIAZZA RE DI ROMA 15/17 ROMA	06:00	07:30	MON - TUE -WED - THU - FRI -SAT	ROME
3200	PIAZZA PIO XI 20, ROMA	06:00	07:30	MON - TUE -WED - THU - FRI -SAT	ROME
3210	PIAZZA GIURECONSULTI 5, ROMA	06:00	07:30	MON - TUE -WED - THU - FRI -SAT	ROME
3220	V.F. DA CAMBIANO 82 - 00191 ROMA	06:00	07:30	MON - TUE -WED - THU - FRI -SAT	ROME
3330	VIA FIUME GIALLO 11 ROMA	06:00	07:30	MON - TUE -WED - THU - FRI -SAT	ROME
3439	VIA S. ELIA, 13 ROMA	06:00	07:30	MON - TUE -WED - THU - FRI -SAT	ROME
3706	VIA MONTI DELLA FARINA S.N.C. ROMA	06:00	07:30	MON - TUE -WED - THU - FRI -SAT	ROME
DEPOT	VIA DEI VERBASCHI 22 - SANTA PALOMBA				ROME

3. Simulation Data

ORDERS (SIM.)	1/12	2/12	3/12	5/12	6/12	7/12	8/12	9/12	10/12	12/12	13/12	14/12	15/12
POD	Items	Items	Items	Items	Items	Items	Items	Items	Items	Items	Items	Items	Items
1787	30	30	32	29	31	31	34	33	32	34	28	28	33
2154	27	30	31	32	31	27	33	31	29	30	30	30	31
2155	32	28	28	30	29	29	27	32	29	31	29	31	31
2156	20	22	21	19	19	20	22	19	21	21	20	22	23
2157	23	23	23	26	25	26	26	22	22	26	22	26	24
2159	4	5	5	4	4	5	5	4	5	5	5	5	5
2161	30	31	27	29	27	28	27	26	26	26	30	27	28
2162	9	9	10	8	9	10	9	9	9	10	9	10	10
2163	24	25	24	22	23	23	25	26	24	25	22	22	23
2164	16	16	15	15	15	15	16	14	14	16	16	16	15
2268	35	29	29	29	35	33	34	31	33	33	33	34	35
2269	38	41	35	40	39	41	40	36	40	37	37	41	40
2270	21	21	21	21	19	22	20	20	19	23	22	22	23
2271	24	27	25	26	25	24	23	23	27	24	23	26	27
2734	19	17	19	17	20	20	20	18	20	18	21	18	18
3020	16	14	15	17	17	15	16	17	17	16	15	14	14
3030	42	47	44	48	43	44	40	42	44	45	45	44	48
3090	32	27	28	28	28	30	29	29	28	28	31	28	28
3110	28	30	26	28	25	26	30	25	30	29	26	28	28
3120	30	29	28	27	30	32	31	26	31	30	31	27	31
3140	22	23	26	25	22	26	25	22	24	26	23	22	23
3160	18	21	20	21	20	21	20	18	19	19	20	20	19
3170	25	29	27	25	28	25	29	29	27	27	29	25	24
3180	25	25	21	23	25	22	21	23	23	24	21	24	21
3200	19	21	19	21	22	21	21	21	21	21	18	21	20
3210	20	20	21	23	21	23	20	20	21	24	21	21	22
3220	43	39	37	39	38	41	39	37	42	38	39	38	42
3330	36	39	38	33	39	35	36	34	33	39	34	39	39
3439	33	33	34	34	33	36	38	39	33	34	38	37	38
3706	20	21	18	21	20	19	21	20	19	19	20	20	18
Tot.items	762	773	743	760	760	769	775	747	765	775	757	767	780

ORDERS (SIM.)	16/12	17/12	19/12	20/12	21/12	22/12	23/12	24/12	26/12	27/12	28/12	29/12	30/12	31/12
POD	Items	Items	Items	Items	Items	Items	Items	Items	Items	Items	Items	Items	Items	Items
1787	32	30	28	33	48	44	46	48	45	42	42	43	48	40
2154	28	28	33	29	44	44	43	40	44	46	45	38	39	41
2155	31	31	32	29	39	44	42	40	44	41	39	41	42	42
2156	20	21	23	22	31	31	27	30	30	28	31	29	26	27
2157	26	23	26	27	34	32	38	35	35	32	36	33	37	38
2159	5	4	5	4	7	6	6	6	6	6	7	7	7	7
2161	29	26	27	31	36	39	39	40	43	43	42	43	41	38
2162	9	10	8	10	12	13	12	13	14	13	14	12	13	12
2163	24	26	22	24	31	34	37	34	35	33	32	33	32	31
2164	16	15	16	15	23	23	20	20	22	20	21	20	20	19
2268	31	31	30	29	47	42	44	45	40	44	42	46	43	41
2269	40	38	39	35	50	55	49	55	53	56	56	52	55	51
2270	23	20	22	23	29	5	8	8	3	4	4	7	3	6
2271	22	23	27	23	32	31	32	33	33	37	32	37	36	33
2734	19	21	20	18	24	29	27	24	28	28	29	29	25	26
3020	15	16	17	16	23	23	20	23	24	22	24	23	24	21
3030	47	47	45	41	58	57	58	63	55	59	59	61	62	60
3090	31	29	27	32	43	44	40	42	38	42	38	38	41	38
3110	28	27	27	26	42	41	37	43	40	37	41	42	41	40
3120	30	30	30	27	44	41	38	38	41	40	41	41	39	44
3140	24	26	23	25	34	36	36	35	32	36	37	35	34	32
3160	19	21	17	21	27	29	27	30	29	26	30	28	26	27
3170	29	26	25	25	37	37	37	39	40	39	37	39	40	41
3180	21	23	23	24	35	30	32	30	32	33	32	33	31	30
3200	22	22	18	21	26	30	28	30	27	30	31	27	27	29
3210	21	22	21	21	31	33	28	29	33	30	28	30	30	28
3220	36	41	43	37	59	60	54	53	55	59	52	51	58	51
3330	38	34	38	35	51	49	51	52	49	53	46	49	49	53
3439	35	39	38	38	53	47	47	46	53	47	52	56	48	53
3706	21	20	19	21	29	26	28	28	26	25	27	28	28	27
Tot.items	772	769	770	762	1078	1058	1033	1054	1049	1052	1045	1052	1044	1027

4. Matrix Distance

	Dep	1787	2154	2155	2156	2157	2159	2161	2162	2163	2164	2268	2269
Dep		26,5	40,9	40,8	37,0	27,6	40,4	25,4	46,8	29,3	47,9	20,1	15,0
1787	27,1		15,1	9,6	37,2	11,4	8,1	4,1	15,9	14,7	16,7	7,4	18,5
2154	41,7	14,6		7,3	10,6	8,1	8,3	14,1	7,9	6,3	8,7	17,5	17,5
2155	40,4	10,0	5,8		15,5	9,7	3,9	11,0	9,4	11,0	10,4	14,6	17,8
2156	36,5	37,3	10,9	15,6		11,9	22,1	19,0	12,2	9,1	15,4	33,0	27,5
2157	39,3	12,3	6,8	9,4	12,4		11,3	8,1	15,6	2,9	12,3	11,4	11,5
2159	28,8	4,0	11,9	6,7	18,5	8,4		3,8	29,2	11,6	16,3	9,0	12,3
2161	25,2	7,0	11,4	8,2	18,0	7,9	9,6		43,7	11,1	17,2	5,1	8,9
2162	46,8	16,2	11,0	9,6	13,0	14,1	12,1	18,2		18,6	1,8	37,9	36,4
2163	30,5	16,6	6,4	11,1	9,7	4,2	13,6	12,2	19,0		19,0	15,6	14,0
2164	49,0	16,4	8,3	8,8	15,1	14,4	9,2	18,6	1,8	13,6		22,0	40,9
2268	20,2	8,9	17,0	12,1	32,6	11,9	13,6	5,0	21,3	15,3	21,7		5,9
2269	15,0	18,0	16,7	14,7	28,5	9,9	15,7	8,1	38,3	11,6	39,4	5,4	
2270	37,2	22,3	42,1	36,6	50,5	32,5	24,8	24,6	45,8	42,8	46,9	25,3	27,9
2271	34,2	16,2	36,3	30,9	46,6	28,7	30,4	20,7	40,0	39,0	38,3	21,5	24,6
2734	18,0	22,5	22,5	26,4	37,7	18,8	22,5	10,9	34,1	22,5	35,7	12,5	22,5
3020	38,0	7,3	8,3	4,5	17,1	11,2	3,5	8,3	11,3	14,6	11,2	11,7	14,9
3030	27,6	21,8	21,8	25,2	22,6	15,9	22,4	29,5	31,3	21,8	34,6	24,1	21,8
3090	36,2	5,5	11,1	5,7	18,1	9,3	5,2	5,1	11,5	11,2	10,7	8,6	11,7
3110	23,4	6,3	16,1	11,3	35,8	11,1	12,7	3,1	20,5	14,4	21,3	3,0	13,8
3120	20,8	23,8	25,1	20,8	21,2	11,5	21,4	22,6	31,0	12,9	32,0	17,3	12,4
3140	41,7	17,3	2,7	10,0	10,5	8,6	11,4	16,9	8,1	6,0	8,9	20,2	18,1
3160	28,7	3,6	14,3	7,4	19,3	9,2	8,1	2,9	15,0	11,5	15,8	6,2	12,3
3170	28,2	13,7	7,3	10,3	11,5	1,1	13,9	9,5	13,3	1,9	14,1	12,9	10,6
3180	24,9	6,9	11,3	6,4	16,3	6,2	32,1	2,4	15,6	9,6	16,4	5,8	9,9
3200	38,5	17,6	5,6	11,1	7,9	4,9	13,7	13,2	13,2	2,5	14,0	16,6	15,1
3210	37,3	17,8	6,0	10,2	5,3	6,2	12,8	13,0	9,6	3,7	11,7	17,1	16,5
3220	47,6	13,5	5,3	7,0	16,1	11,4	6,2	15,6	3,1	10,6	3,5	19,0	20,8
3330	23,2	26,9	16,8	19,0	21,2	9,8	21,1	15,8	31,0	11,4	33,1	20,0	15,1
3439	43,3	11,8	6,5	2,4	18,8	11,2	4,6	14,0	5,8	11,8	6,6	17,4	20,5
3706	30,2	13,3	7,0	8,0	12,0	2,8	11,6	8,9	11,0	5,3	11,8	12,3	12,2

	2270	2271	2734	3020	3030	3090	3110	3120	3140	3160	3170	3180	3200	3210	3220	3330	3439	3706
Dep	41,2	33,3	22,6	38,4	29,0	28,4	22,7	20,9	42,5	27,9	29,2	26,1	38,1	37,1	47,5	24,5	44,5	25,9
1787	27,8	17,3	11,8	7,4	32,5	10,5	6,4	24,4	18,7	2,9	14,7	6,1	14,7	16,2	13,3	28,0	12,3	11,0
2154	45,9	35,3	31,8	9,3	26,7	24,2	16,5	24,8	2,8	12,1	7,5	11,8	3,8	5,3	5,5	24,2	4,5	5,9
2155	41,3	30,7	27,4	3,0	25,8	19,8	13,6	20,4	7,9	7,7	12,6	8,8	8,8	10,2	6,8	19,1	2,5	7,5
2156	54,2	46,4	35,6	17,8	21,5	36,9	35,9	19,6	10,7	20,0	10,2	16,8	7,2	5,3	16,5	18,7	14,3	10,7
2157	37,0	26,2	18,3	11,5	16,1	22,8	10,6	10,1	8,8	11,1	1,5	7,8	4,6	6,7	11,3	8,7	9,9	10,8
2159	12,7	12,7	13,4	6,2	22,9	11,5	5,4	16,4	15,3	0,49	11,9	3,3	11,8	13,3	13,3	16,2	8,6	14,0
2161	3,1	1,1	10,9	7,7	22,2	16,7	3,2	22,5	14,8	5,3	11,7	2,0	11,3	12,8	14,8	15,4	13,0	14,1
2162	42,3	39,1	36,2	11,2	31,8	29,0	34,7	29,9	8,7	16,5	12,6	15,7	10,7	16,1	6,4	29,0	9,2	11,9
2163	33,5	30,3	29,7	13,3	18,6	28,6	14,7	13,3	6,5	13,2	0,5	10,1	2,7	4,5	10,5	11,9	9,8	6,2
2164	45,1	40,8	38,4	11,6	35,0	30,5	20,9	32,1	9,0	15,1	14,8	16,2	11,1	12,6	3,6	31,5	6,4	12,1
2268	41,7	22,3	11,7	11,6	25,7	16,3	2,6	16,6	18,8	6,1	15,2	6,1	15,2	16,7	18,7	20,1	17,0	12,9
2269	28,6	25,6	14,3	13,8	21,5	20,0	7,2	12,4	18,1	9,2	11,5	8,0	16,4	15,6	17,6	16,0	16,3	12,2
2270		3,0	23,6	34,3	42,5	12,9	22,1	34,4	48,7	23,7	42,7	26,7	51,6	50,6	43,3	38,0	40,3	42,1
2271	3,2		13,7	28,5	39,7	9,1	18,1	30,6	42,9	15,5	38,9	22,9	47,8	46,7	37,5	34,1	34,5	28,3
2734	12,9	14,0		24,0	29,6	22,5	8,3	21,6	38,4	14,8	22,5	12,9	22,1	37,7	22,5	25,0	22,5	31,9
3020	25,8	22,6	24,5		25,8	17,1	10,8	19,4	10,6	6,8	14,6	6,1	11,5	12,3	8,6	19,1	7,6	9,2
3030	22,0	31,4	26,7	25,0		21,8	26,9	10,7	28,1	22,6	19,7	19,5	3,7	22,7	21,8	8,9	21,8	29,7
3090	20,2	20,2	22,7	3,4	22,4		7,5	16,0	15,9	3,7	11,3	2,7	11,3	12,8	10,5	15,9	9,5	11,0
3110	19,0	22,2	8,2	11,0	28,9	14,1		19,8	17,9	4,5	14,3	5,3	14,4	15,9	17,8	23,3	16,1	12,1
3120	27,0	23,8	19,9	19,4	11,5	24,5	19,9		26,6	16,6	11,3	13,6	22,3	21,2	33,8	8,7	19,8	15,8
3140	34,5	31,0	34,5	12,0	27,8	25,8	19,2	24,8		16,2	8,3	14,8	3,7	5,3	5,7	24,2	7,2	8,4
3160	14,2	11,1	12,4	5,3	34,2	10,0	4,3	25,1	16,1		12,4	3,8	12,5	14,0	13,5	28,6	8,6	10,2
3170	24,0	20,9	27,0	12,9	17,0	25,4	11,8	10,6	8,3	10,7		7,1	4,5	6,3	11,3	9,5	9,0	5,2
3180	15,0	11,8	12,6	5,9	21,5	17,6	4,7	14,2	13,1	4,7	9,5		9,5	11,0	13,0	14,1	11,3	5,8
3200	25,6	22,4	37,7	13,3	24,6	28,3	15,7	14,3	6,6	15,3	3,7	11,1		2,6	10,6	21,1	9,8	6,3
3210	43,5	40,3	36,4	12,5	23,3	27,2	16,0	20,4	5,4	15,8	5,2	11,3	2,0		9,1	19,8	9,0	5,3
3220	38,5	38,3	34,1	8,6	36,0	26,5	17,9	33,0	5,4	12,1	11,8	13,2	8,1	9,1		32,5	3,4	9,1
3330	33,3	36,5	22,6	19,2	13,9	28,4	22,7	6,3	26,6	17,9	11,4	13,4	13,8	21,3	34,2		18,1	14,0
3439	35,4	33,2	30,1	6,9	38,6	22,5	16,3	21,6	8,6	10,4	13,0	11,6	9,3	10,8	3,5	20,5		8,7
3706	29,4	27,2	19,1	10,2	19,7	23,8	11,2	13,3	8,8	11,0	5,2	6,5	5,2	6,7	8,3	12,2	7,0	

CONCLUSION

The research questions to be answered in this research was: *How to design an integration model of rail transport and electric vehicle delivery in last mile distribution?*.

To be able to simulate the problem, a cost optimization model was developed using input from the simulation result of TransCAD by getting the optimal routing configuration to minimize the distance and the travel time of the vehicles.

The changing of capacity and location of distribution center will give the impact toward the distance of the delivery and the travel time as well. The best configuration to obtain the optimum cost is by combining one single distribution center, two multimodal urban distribution center and increase the capacity of electric vehicles. While, the changing of customer's time windows delivery would not give any impact since the capacity of vehicle are still the same.

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