STUDY ON A MULTI-BRAND AUTO DISTRIBUTION NETWORK SERVING MULTIPLE CITIES TO MINIMIZE THE TOTAL DISTRIBUTION COST

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Abbreviation	Definition
A.P	Assembly Plant
DS	Dealership

ABSTRACT

The current research project consists of minimizing the total cost of an auto dealership supply chain management system that provides two auto brands for five major industrial cities in the Great Lake Area of the United States. The two auto brands are Ford and Chrysler. The five major cities are Chicago, Detroit, Indianapolis, St. Louis, and Cincinnati.

The total cost includes transportation cost from auto assembly plants to individual cities, along with warehouse cost and/or transshipment cost depending on the supply chain management configuration.

Concerning the auto delivery schemes, both centralized and decentralized alternatives are considered. For either the centralized or decentralized alternatives, trucks and/or trains could be adopted. Each brand may utilize an independent delivery scheme.

The objective is to find the best combination of the delivery schemes for both brands that could achieve the minimized total cost while meeting the demand of each city.

The proposed study includes literature review, proposed methodology, and methodology applications using real world data. Finally, the report has a summary and some concluding remarks, as well as future direction of extended research to implement the research products.

CHAPTER 1

INTRODUCTION

1.1. General

The field of logistics was at one time only used in context with the military. It is said the term was first defined as the military's need to supply itself as soldiers and equipment moved from their base to a forward position. Logistics involved the movement of troops, food, equipment, and machinery to and from a battle zone to provide the necessary supplies to compete efficiently in war activities. Logistics played a life-and-death role. Over the years, logistics has become a household word used in nearly every industry and for personal as well as corporate functions. Logistics is the art and science of the integration of information, transportation, inventory, warehousing, material handling, and packaging. In simple terms, it is getting materials to the right places in a timely fashion - getting supply to where there is demand with an optimization of resources at a minimum of cost. Logistics has transformed our culture and placed incredible power with those who do it well and for those who have a vision for continued success.

In the automotive industry these days, many companies are looking at strategic advantages in logistics to reduce costs. For some, it is a near life-or-death proposition for their survival, due to the fact that logistic costs represent the 10% on the total cost. The battle zone for these companies is in reducing inventory and supply chain costs at each transaction and for their customers in the field, on the ground and in the trenches.

Today a broad group of activities are available to automotive manufacturers that represent logistics services such as inbound material flow management, inventory control, kitting, container management, packaging, reverse logistics, cross-docking, just-in-time delivery, warehousing, and transportation. All of these activities can be performed in-house or outsourced to second-party logistics providers or third-party logistics providers (3PLs), which are getting more and more importance. These third-party logistic operators are in charge of the packaging, the warehousing and the transportation and distribution of the goods.

This project is presented as if done by a third-party company, and its objective is to design the optimal distribution network between a group of assembly plants and dealerships. The project scope is reduced to the transportation, distribution and warehousing areas.

1.2. Problem statement

Here in Chicago region there is a business that is in demand for cost reductions. This business is in charge of new vehicle distribution, from assembly plants to dealerships. It is known that a bad logistic and distribution management can affect between 40% and 80% on the final product cost, which explains the importance of finding the optimal delivery network between manufacturers and final costumers.

The objective of this project is to reduce the cost in new vehicles distribution from the assembly plants of two different well-known brands, Ford Motors and Chrysler Group, to five dealerships located in five industrial centers cities.

1.3. Problem definition

There are four Ford Motors assembly plants, their nomenclature in the project and their real names are the next:

- PF1: Chicago Assembly Plant
- PF2: Michigan Assembly Plant

- PF3: Ohio Assembly Plant
- PF4: Kansas City Assembly Plant

The same information for the three Chrysler assembly lants is the next:

- PC1: Belvidere Assembly Plant
- PC2: Jefferson North Assembly Plant
- PC3: Toledo North Assembly Plant

There are five dealerships, their nomenclature and their location is the next:

- O1: Chicago (IL)
- O2: Detroit (MI)
- O3: Indianapolis (IN)
- O4: Saint Louis (MO)
- O5: Cincinnati (OH)

In order to do the supply chain management of the system, it is necessary to know the production in each assembly plant and the demand in each dealership. There are different ways for calculating these parameters. The one used in this project consists in calculating the demand in each dealership by a weighing, which will be explained later, and once all the demands are known, the next step is to calculate the production in assembly plants. This production must satisfy the demand of dealerships and also consider the safety stock, so the production in each assembly plant is the product of the demand in the dealership supplied by that assembly plant (the allocation between assembly plants and dealerships is done by the minimal distance criterion when directly supply from assembly plants to dealerships) and a parameter in charge of considering the safety stock. The value of this parameter depends on the population of the city where the supplied dealership is located.

For Ford assembly plants, when directly supply, the production of PF2, PF3 and PF4 must satisfy the demand of O2, O4 and O5 respectively. The production of PF1 must satisfy the demand of O1 and O3

For Chrysler assembly plants, when directly supply, PC1 must supply O1 and O4, PC2 must supply O2, and PC3 must supply O3 and O5.

For a better understanding see the point *3.2. Methodology Description* where the directly supply system and the allocation between assembly plants and dealerships are explained.

As said before, the demand in each dealership is calculated by a weighing with the population of the city where the dealership is located. The demand of Ford Motors and Chrysler Group cars in the United States, as well as, the population of the country are known, so it is easy to obtain the demand of both brands cars in each dealership. It is assumed that the number of demanded cars in one year is the same number of the annual sales. In 2011 these sales were 667,286 and 319,515 cars, for Ford and Chrysler respectively. The population of the United States is 311,000,000 people. The used demands are per week (it is considered that one year has fifty-two weeks). In *4.2.1. Demand and Production Data* (specifically in *Table 16*) there is all the information that has been necessary for calculating the demands. In the table below there are the number of cars demanded per week in each dealership by brand.

DS name	Location	Weekly Demand of Ford Cars (number of vehicles)	Weekly Demand of Chrysler Cars (number of vehicles)
O1	Chicago (IL)	112	54
O2	Detroit(MI)	30	14
O3	Indianapolis (IN)	35	17
O4	Saint Louis (MO)	14	7
O5	Cincinnati (OH)	13	6

Table 1 Demands in each dealership by brand

As said before, the production of the assembly plants depends on the demand they have to satisfy when directly supply. First of all the allocation between assembly plants and dealerships is done with the criterion of minimal distance between them. After that, the production of each assembly plant is the product of the cars demanded in the allocated dealership (or dealerships) and the parameter that considers the safety stock production. In the point *4.2.1.Demand and Production Data* is shown how the production in each assembly plants is calculated. The values of these productions are in the table below.

Assembly Plant	Location	Production per week (number of cars)
PF1	Chicago (IL)	212
PF2	Wayne (MI)	38
PF3	Avon Lake(OH)	15
PF4	Claycomo (MO)	16
PC1	Belvidere(IL)	89
PC2	Detroit (MI)	18
PC3	Toledo(OH)	28

Table 2 Production in each assembly plant

Notice that the whole geographical coverage is enclosed in the next states: Illinois, Indiana, Michigan, Missouri and Ohio. The next picture shows the whole network between assembly plants and dealerships.

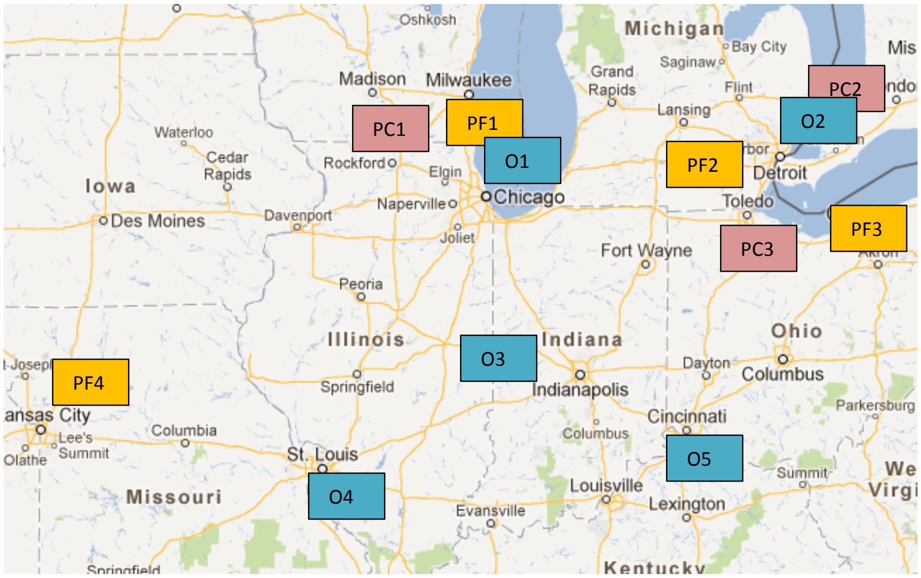

Figure 1 Whole system graph

Considerations and simplifications

- **Assembly Plants**

In all assembly plants are manufactured different models of a specific brand. For example, in Chicago Assembly Plant is assembled the Ford Taurus, the Ford Explorer and the Lincoln MKS (three different models for the same brand) and in the Jefferson North Assembly Plant are assembled the Jeep Grand Cherokee and the Dodge Durango. In this project it is considered all the models of a brand as the same, so there are only two types of cars, Ford cars and Chrysler cars

- **Dealerships**

The dealerships in the current project store and sold both brands, so Ford and Chrysler cars can be delivered to the same dealership.

- **Distances between cities**

It is assumed that the distance between two cities is the same in the two directions. The minimal distances between cities are obtained with *Google Maps*.

1.4. Report Organization

The report is consisted of five chapters. Chapter 1 is the introduction of the problem that pretends to be solved, as well as, the importance of a good logistics management, and the objectives that want to be accomplished. Chapter 2 conducts information search through a literature review. Chapter 3 expands on the proposed methodology for distributing new vehicles, these proposals can tally or not with the ones used in the real world, however, all of them are analyzed. Chapter 4 discusses data collection, processing, and preliminary data analysis. Finally, Chapter 5 presents a summary of the study findings and future research directions.

CHAPTER 2

LITERATURE REVIEW

This point contains theoretical explanations about transportation problems, logistic costs, networks and distribution strategies.

First of all there are some explanations about the most general problems when talking about freight distribution and transportation. After this explanation there is an analysis of the different transportation modes and finally, another analysis of different types of distribution networks. After that, there are four examples of real applications.

2.1. Transportation Logistics Problems

2.1.1. The Shortest Path Problem

It must find the minimum path between two different points. There are many versions on this problem such as: single-source shortest path problem, single-destination shortest path problem and all-pairs shortest path problem. The distances used in this project are taken from Google Maps, and they are supposed to be the minimal ones, so this problem does not need to be studied.

2.1.2. The Transportation Problem

It deals with sources where a supply of some commodity is available, and destinations where the commodity is demanded. The objective is to find the optimal distribution planning that says which sources must supply each destination.

- Objective:

To determine the transport policy that minimizes the global transportation cost.

- Data:

- m factories of the same product. The factory i has a production capacity of a_i

- n costumers of the product. The costumer j has a demand of b_j
- c_{ij} : transportation cost of one unit of product, from factory i to costumer j

- Variables:

X_{ij} : it is the amount of product transported from the factory i to the costumer j

- Mathematic Formulation:

Transportation problem can be modeled with Linear Programming as:

$$[MIN]Z = \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij} \cdot x_{ij} \quad (1)$$

Subject to:

$$\sum_{j=1}^{n} x_{ij} \le a_i \; ; \; \forall \; i = 1, \dots, m \quad (2)$$

$$\sum_{i=1}^{m} x_{ij} \ge b_j \; ; \; \forall \; j = 1, \dots, n \quad (3)$$

$$x_{ij} \ge 0 \; ; \; \forall j = 1, \dots, n \; ; \; \forall \; i = 1, \dots, m \quad (4)$$

The first constraint indicates that is not possible to exceed the capacity production of each of the sources. The second constraint indicates that the demand of each costumer must be supplied.

A necessary and sufficient condition for solving the problem is the one that says that the total demand and the total production capacity have the same value.

$$\sum_{i=1}^{m} a_i = \sum_{j=1}^{n} b_j \quad (5)$$

If not, fictitious sources or costumers will be necessary in order to solve the problem.

- Scheme:

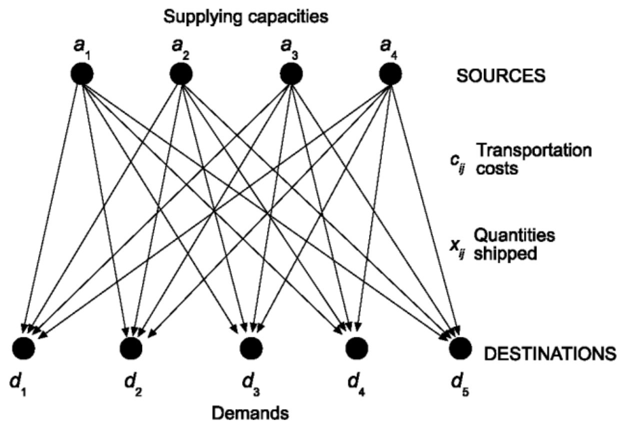

Figure 2 The Transportation Problem Scheme

2.1.3. The Travelling Salesman Problem

Given a list of cities and their pairwise distances, the task is to find the shortest possible route that visits each city exactly once and returns to the origin.

- Objective:

To find a route that goes to all the cities once and only once and has the minimum global distance.

- Data:

- *n* cities
- C_{ij} : cost (or distance) between the city *i* and the city *j*

- Variables:

X_{ij} : it is a binary variable. It means that X_{ij} can only have two values:

$X_{ij} = 0 \rightarrow$ the route between *i* and *j* is not taken

$X_{ij} = 1 \rightarrow$ the route between *i* and *j* is taken

- Mathematic Formulation:

$$[MIN]Z = \sum_{i=1}^{n}\sum_{j=1}^{n} c_{ij} \cdot x_{ij} \quad (6)$$

Subject to:

$$\sum_{j=1, j\neq i}^{n} x_{ij} = 1; \ \forall \ i = 1, \ldots, n \ (7)$$

$$\sum_{i=1, j\neq i}^{n} x_{ij} = 1; \ \forall \ j = 1, \ldots, n \ (8)$$

The first constraint indicates that there is one departure from each city. The second constraint indicates that there is one entry to each city. These two constraints are necessary but not enough because they do not avoid the partial cycle formation. A third constraint is needed in order to avoid that. Having a subset S with a number of |S| cities this constraint avoids that the number of interior arches in the subset has the same value of the number of cities.

$$\sum_{i,j \in S, j\neq i}^{n} x_{ij} \leq |S| - 1 \ (9)$$

The number of constraints increases exponentially with the number of cities, making the problem irresolvable.

- <u>Scheme:</u>

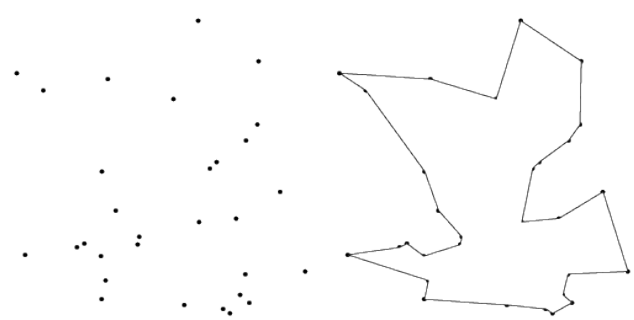

Figure 3 The Travelling Salesman Problem Scheme

2.1.4. The Vehicle Routing Problem

It can be described as the problem of designing optimal delivery or collection routes from one or several depots to a number of geographically scattered costumers, subject to constraints.

- Objective:

To determine the partial cycles (petals) that the distribution vehicles of a fleet must follow to make the global distance of all the petals the minimum one.

- Data:

- n costumers of a product, where the costumer j has a demand of D_j
- Central Warehouse O. Its capacity, Q, is enough to satisfy the demand of all the costumers:

$$\sum_j D_j \leq Q \quad (10)$$

- c_{ij}: distances between Central Warehouse and costumers and also between the different costumers.
- There is a fleet of vehicles with a load capacity of M, which is smaller than the total demand of all the costumers:

$$\sum_j D_j > M \quad (11)$$

Note: if the total demands of all the costumers were M, we would be in front a Traveling Salesman Problem, instead of a Delivery Problem.

- Variables:

- X_{ij} : it is a binary variable.

$X_{ij} = 0 \rightarrow$ the route between i and j is not taken

$X_{ij} = 1 \rightarrow$ the route between *i* and *j* is taken

- q_{ij} : amount of product transported from *i* to *j* .

- Mathematic Formulation:

$$[MIN]Z = \sum_{i=1}^{n}\sum_{j=1}^{n} c_{ij} \cdot x_{ij} \quad (12)$$

Subject to:

$$\sum_{j=0}^{n} x_{ij} = 1; \ \forall \ i = 1, \dots, n \ (13)$$

$$\sum_{i=0}^{n} x_{ij} = 1; \ \forall \ j = 1, \dots, n \ (14)$$

$$q_{ij} \leq M \cdot \ x_{ij}; \ \forall i, j = 0, \dots, n \ (15)$$

$$\sum_{k=0}^{n} q_{ki} = \sum_{j=0}^{n} q_{ij} + D_i \ ; \ \forall \ i = 1, \dots, n \ (16)$$

The first constraint indicates that there must be one, and just one, departure per city. The second one indicates that there must be an entry per city. The third one indicates that for transporting goods from *i* to *j*, the arc from *i* to *j* must have been selected. The last constraint indicates that the amount of goods that arrives to a costumer is the one that it demands and the one that leaves from it.

- <u>Scheme:</u>

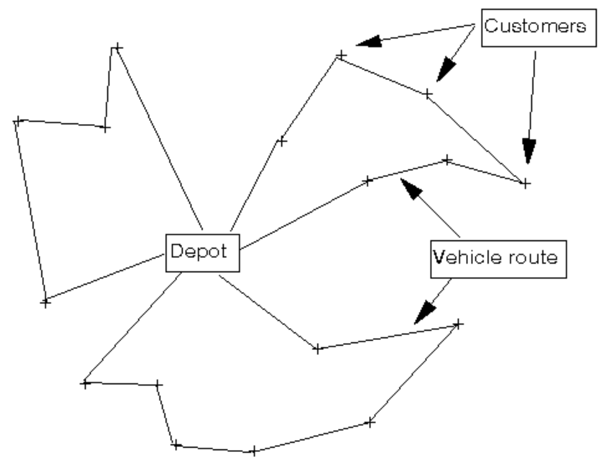

Figure 4 The Vehicle Routing Problem Scheme

The previous problems can be solved with exact and heuristic algorithms. The second ones do not guarantee the optimal solution but they are useful because they give a good solution (diverted only 2 or 3 % from the optimal one) with a very small computational time. They can be solved with exact algorithms because they can me modeled with Linear Programming. These models can be solved with the appropriate algorithm and the most of the times, because of the size of the problem appropriate software is needed.

2.2. Transportation Modes

Once the most general problems have been described, the next topic to talk about is the transportation modes. As known, these modes are: terrestrial, maritime, air and others like pipelines. The one used in this project is the terrestrial, because of the freight, and because of the geographical coverage. Within the terrestrial mode there are two different methods: road (truck or less than truck) and railroad (train). The most important characteristics for these modes are the next:

Highway

- All type of goods
- Flexible
- Geographical coverage can be intensive (manufacturer looks for that sell points of the same sector of the product that is going to be sold) and extensive (the manufacturer looks for that sells point of the same sector of the products and point of other sectors)
- Fast
- Door to door service
- Frequent departures

Railway

- Mass movement of goods
- Huge capacity
- Wide geographical coverage
- Low unit cost
- Efficient energy consume
- All type of goods

In the table below there is a comparison of the most remarkable criteria, between the two modes. The mode with the mark is the best one at that criterion.

Criteria	Railway	Highway
Low Cost	✓	
Speed		✓
Capacity	✓	
availability		✓
frequency		✓
Reliability		✓
Flexibility		✓

Table 3 Comparison between Road and Railroad

2.3. Alternative Distribution Strategies

The different types of problems and the different modes for transportation have already been explained. It is time to talk about the different types of networks and strategies used in freight distribution.

The optimal distribution network must satisfy a balance in all the logistics costs of the distribution process: transportation, stocktaking, goods manipulation and amortization of the facilities (warehouses, hubs…).

First of all, it is necessary to talk about the different distribution costs, which affect directly in the final price of a good. The different distribution costs are the next:

1. **Distribution Vehicles**

There are two cost included in this point. In one hand there is the mileage cost (the more travelled miles the more expensive is this cost), which included fuel consumption, vehicle maintenance, repairs and others. In the other hand there is a fix cost, which includes salaries, insurances and amortization of the vehicle and others.

2. Logistics Facilities

This second type of cost includes four different costs: c_t^0 , c_t , c_r, c_r^0 The first is a fix cost of the freight manipulation per unit of time, the second it is a unitary manipulation cost per volume of transported good. The third cost represents the rent of the facility per unit of volume of good [$/(volume·time)]. The fourth cost is a fix cost associated to the rent. There is another cost that could be included in this group. It is the stop cost, c_p.

3. Issues of Goods Depreciation During Delivery

There is a temporal cost associated to the goods, because of their depreciation during the time they spend in warehouses or during transportation. Due to this cost, it is sometimes more important to have a network with high transportation costs, but with a reduced delivery time.

Goods Distribution Strategies

When talking about distribution strategies, there are many organization schemes. The next picture shows some of the most popular ones.

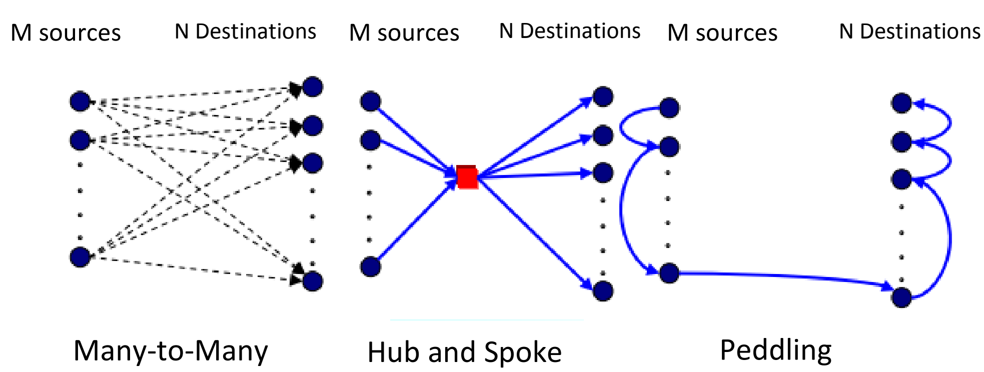

Figure 5 Goods Distribution Strategies

The Many-to-Many Strategy

This strategy is mostly used when long distances have to be traveled and a big number of delivery vehicles are required. Therefore, this alternative is only considered when the fix costs of the distribution vehicles are low, when the demand of the goods can fill the whole capacity of the distribution vehicle and when the temporal constraints are important. These conditions fit to the distribution problem of the current project, so this strategy will be considered when presenting alternatives in the point *3. Proposed Methodology*.

- The transportation cost in this type of delivery is defined with the next formula:

$$z_t = \frac{F}{V} = \frac{\gamma + \sigma + \alpha \cdot D}{V} \quad (17)$$

F: Transportation Cost per shipping

V: Lot size (units/load)

γ: Fix cost for doing a shipping ($/load)

σ: Fix cost for doing a stop ($/stop)

α: Transportation cost per unit length

D: Distance between the origin and the destination

If considering the stocktaking cost (in the origin, in the destination and during the transportation) the total transportation cost (without considering the cost of the goods) is defined as in the next formula:

$$Z = F + P \cdot R \cdot \left(\frac{V^2}{Q} + V \cdot \tau\right) \quad (18)$$

Q= flux (ton/day)

τ=journey time through the arc (days)

R= price of money of the material inventory ($/$·day)

P=value of one unit of good transported ($/tones)

W= vehicle distribution capacity (tones)

The cost that must be minimized in the transportation cost per unit transported, so, the function that must be minimize is:

$$z = \frac{F}{V} + P \cdot R \cdot \left(\frac{V}{Q} + \tau\right) \quad (19)$$

The lot size that minimizes the function above is:

$$V^* = MIN\left\{\sqrt{\frac{F \cdot Q}{P \cdot R}}; W\right\} \quad (20)$$

The Hub and Spoke Strategy

The concentration of the freight in the consolidation centers (hubs) helps to optimize the distribution vehicle capacity when demand is not uniform. This strategy reduces transportation cost and time. Again, this alternative is presented when proposing alternatives for the current problem in the point *3. Proposed Methodology.*

Within this strategy there are two ways to proceed when delivering: centralized and decentralized distribution. The first one consists in going from the hub to the dealerships directly, while the second one visits many hubs or consolidation centers before arriving to the final costumer, the distribution network branches as it progresses. In the table below there is a comparison between both.

	Strenghts	Weaknesses
Centralized distribution	Economies of scale Eliminate redundant costs Consistent data definitions Enterprise view of data Multiple career options	Slow to deploy Higher project costs Less responsive to local needs Costly to customize Project backlogs
Decentralized distribution	Quick to deploy Lower project costs Localized definitions Customized views Greater flexibility	Redundant projects, staff and tools Higher overall costs Conflicting data definitions No enterprise views Uneven capabilities across units

Table 4 Comparison between Centralized and Decentralized Distribution

The Peddling Strategy

The most important benefit of this strategy is the reduction in the number of routes, but in the other hand there are a lot of stops to do by the distribution vehicle. It is useful when the time and the cost of doing a stop is reduced and when the fix costs of the distribution vehicle are high.

2.4. Real World Applications

In this point there are many explanations about how different real distribution networks used in the delivery of different products work:

Automobile Delivery in the USA

Most new automobiles manufactured in the US are transported by rail from assembly plants to special railroad centers called ramps and then by truck to local dealers. This is typically a load-driven system, in this type of distribution networks, vehicles are dispatched only when a specified minimum load is available. Newly assembled automobiles are parked in load lanes at the assembly plant according to their destination ramp. Whenever a sufficient number of vehicles destined for a single ramp accumulate in a load lane, the vehicles are loaded onto a railcar, which is dispatched into the network. Typically, the railcars used to transport automobiles to the ramps are tri-levels capable of carrying 15 sedans, 5 on each deck.

At the final destination ramps, vehicles are off-loaded from the railcars and parked to await delivery to their designated dealerships. When a sufficient number of vehicles destined for dealerships in a given area accumulate, the vehicles are loaded on a rig and delivered. Car hauling rigs typically carry between 8 and 12 sedans.

Note the distinction in the terms “ramps” and “load lanes”. A *ramp* refers to a destination rail facility where vehicles are transferred from rail to car hauling rigs for local delivery. A *load lane* is a designated area at a plant or elsewhere in the distribution network, where we collect vehicles bound for the same ramp.

The *Figure 18* in the *Annex* shows a general scheme about how supply chain management in automotive industry works.

It must be said, that nowadays and in the future the tendency is to subcontract companies that work only in distribution. The company in charge of this project is an example. The advantages and disadvantages of the sub contraction of third companies for doing the distribution are in the next table:

Advantages	Disadvantages
Greater dedication to other areas	Loss of direct control on the costumer
Operating costs are variable and flexible	Feedback and communication problems
Specialized transportation (more efficient)	Risk on reducing the level of service for the costumer
Reduction in the inversion of working capital	Risk on having a lack of information when incidentals
Variables routes and loads can be satisfied	Risk on losing costumers

Table 5 Advantages and disadvantages for sub-contracting a third distribution company

Ford Motor Company's finished vehicle distribution system in final 90's

In late nineties there were many important innovations in new vehicle distribution. Next, there is an explanation about the ones adopted by Ford Motor Company's.

First of all, it is important to introduce the delivery conditions by that time. There were production levels records (around 4millions of vehicles in the USA). The demand shifted from cars to trucks. The rail infrastructure was overburdened what made that the rail service was deteriorating. There were problems of shortage of transport capacity. Initialization in the use of Mixing Centers (a special centers for carry out the cross docking system explained below). The inventory cost was high. The average transit time (time during distribution) of a new vehicle was 15 days, if that time had reduced in one day \$190 million had been reduced in the pipeline inventory and at the same time 1,400 fewer railcars had been needed. Finally, it is important to remark the customer's dissatisfaction. What Ford wanted to do was to reduce the transit time while decreasing the distribution and inventory cost. The solution adopted by Ford was to introduce a load-driven cross-docking system. Cross-docking is an operating strategy that moves items through flow consolidation centers or cross-docks without putting them into storage.

The *Figure 19* in the Annex illustrates a cross-docking system in new vehicle distribution. A cross-docking system has several benefits, one of them are: the service improves in a 23%, the transportation cost is reduced in 17%, the space occupied by warehouses is reduced in 14%, the inventory cost decreases in 9%, the speed in reaching the market increases in 5%, the inventory management improves in 5%.

According to the transportation modes used by Ford in late nineties, the most used practice was the intermodal one. 85% of the vehicles were transported to a hub (mixing centers or distribution centers, its function is similar to an intermediate warehouse) by train, the other 15% were directly transported from the assembly plant to the dealership by truck.

Industrial packages

Although this example has almost nothing to do with new vehicles distribution is pretty useful because it show different types on distribution networks, and it illustrates the most remarkable differences between centralized and decentralized distribution.

The first aspect to be considered in this network is the use of load consolidation centers (or hubs). The goods are transported from the factories where they have been manufactured to these consolidation centers by high capacity distribution vehicles, which have low unitary costs. It is important to notice that there is a hierarchy in the distribution process, so the network is divided in two small networks:

Trunk Network:

- Distribution vehicles with high capacity
- Long distances
- Reduced number of stops

Capillary Network:

- High number of stops
- It only works inside the zone that is associated to a concrete consolidation center.

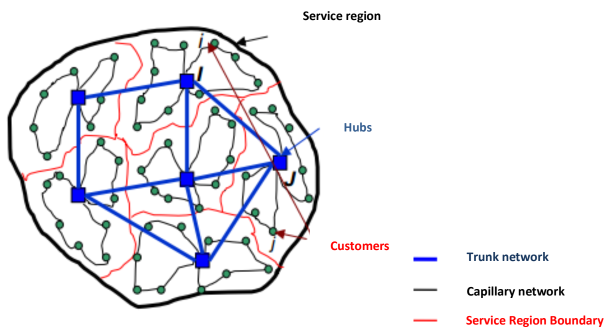

Figure 6 Trunk network

The distribution through the networks below can be done in two different ways: centralized and decentralized distribution. The next picture illustrates both systems.

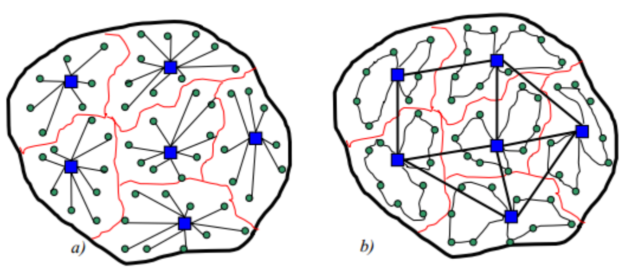

Figure 7 Capillary network. A) Centralized Distribution. B) Decentralized Distribution

Of the Many-to-Many Distribution System in Barcelona

There is a company that works in the distribution sector of many products around the Metropolitan Area of Barcelona. The distribution process consists in recollecting different products from many sources, transporting them to the warehouses or distribution centers, where the final costumer order is prepared, and finally it is sent to the final costumer.

This example is useful because it deals with the possible routes that a distribution vehicle can follow.

The company must determine how many intermediate warehouses (or distribution centers) are necessary, their location and their size.

1. *Number of Distribution Centers*

The most important aspects when making this decision are:

- Freight flow (Kg/day)
- Delivery Area (km^2 or mi^2)
- Warehouses costs
- Ease or complexity when executing the distribution process

The freight flow that has to be moved is 45tones/day. Comparing with the flow moved by other companies this flow is not big (see *Table 31* in the Annex).

The delivery area is 400 km^2 which is quite small. When talking about the delivery area, it is common to divide the whole area into other smaller areas, in order to reduce the initial one. In this case the area is divided into other four smaller areas:

Zone1:60 km^2

Zone2:39 km^2

Zone3:27 km^2

Zone4: 25 km^2

With this division the area that must be covered is 150 km^2, which is much smaller than the 400 km^2. How the territory has been divided is shown in *Figure 20* in the Annex.

As said before, another point to be considered is the warehouse's cost. This cost includes: transportation cost, storage cost, security stock cost and the cost associated to the level of service. The most influential ones are the transportation and storage costs. There is an explanation for all these costs:

- At first, transportation costs decrease when the number of warehouses increases. However, this cost can increase again if the number of warehouses is too big. Transportation costs are represented by hyperbolic functions.
- The storage costs refer to the facility rent or purchase. These cost increase lineally with the number of warehouses.
- Security stock cost and level of service cost have a similar behavior. They both increase with the number of warehouses. The growth of the first one is parabolic and the growth of the second one is hyperbolic.

The last point that must be considered when deciding the number of warehouses is the ease or complexity of the execution of all the distribution process. What this company does, is to prove how the system works with two and with one warehouse.

- **Two warehouses**

First of all, it must be said that the company has two types of costumers: sources or origin (factories or plants) and destination or final costumers. It is important to know, that the most of the times, the sources will have products with the same destination. This fact must be considered when designing the routes of the distribution vehicles.

There are two different ways to proceed if having two warehouses:

a) The freight of a certain number of sources is transported to the *Warehouse 1* and the rest to the *Warehouse 2*.

In the first type of organization the freight distribution from the sources to the distribution centers is easy. The problem appears when the goods have to be transported from the distribution center to the final costumer. What happens now is that there are goods in the *Warehouse 1* and in *Warehouse 2* with the same destination. So, two travels will have to be done to the same destination (one from each warehouse). It multiplies the number of trips and the number of distribution vehicles for two, making the total cost of the process higher. In *Figure 21* in the Annex is represented how this distribution system works.

b) The freight of a certain number of final costumers is transported to *Warehouse 1* and the rest to the *Warehouse 2*.

The freight from different sources will be sent to one of the warehouses depending on which is its destination. As a consequence of that, it may be possible, that the same truck has to go to both warehouses, increasing the travel time and also the unloading time, so the time for preparing the orders in the distribution centers decreases. The disadvantage of this system is not about the cost, but about the risk of not having the order ready on time. In *Figure 22* in the Annex is represented how this distribution system works.

- **One warehouse**

Because of the freight flow and the delivery area are not big and because of the problems that appear when having to warehouses (in both organization) this company choose the option of having just one distribution center. In *Figure 23* in the Annex is represented how this distribution system works.

2. *Distribution Centers Location*

Once decided how many warehouses are necessary, the next decision to be taken is the warehouse's location. The first aspect to be considered is the geographical area where the warehouse has to operate and the communication and transportation infrastructures. The next step is to determine the concrete location. The most important aspects when making this decision are: industrial land availability and its cost and the proximity to roads and highways network.

The studied company only works in the Metropolitan Area of Barcelona, so the warehouse must be located in this area.

There are two types of industrial land: occupied and available. The zone where the company works can be divided in two circles, one is adjacent to the center of the metropolitan area and the other is a bit further from this. The second center has three advantages: it is nearer the roads and highways networks, it has a bigger amount of available industrial land (the first circle is almost saturated with industrial land) and the cost of the land is cheaper. So the warehouse will be located in the second circle.

3. *Distribution Center Size*

Ultimately, the size of the warehouse must be calculated. The most important data in this decision is the freight flux. The bigger is this flow, the bigger has to be the warehouse. This company makes a comparison with other distribution companies. Companies that move 75 or 80tons/day need a warehouse with an area of 4,000m^2, so having a flow of 45tons/day it is enough with an area of 2,000m^2. It must be said that there has to be an additional area designated to loading and unloading dock and for allowing the trucks maneuvers.

CHAPTER 3

PROPOSED METHDOLOGY

3.1. General

Once the most typical theoretical problems when talking about distribution are described and many real world examples are explained, it is time to propose different methodologies that can be used in new vehicle distribution. At first, both brands, Ford and Chrysler, are treated as independent cases, so five huge alternatives are presented for each brand. After that, the objective is to find the best combination for the twenty-five (five alternatives for Ford and five alternatives for Chrysler) possible ones.

The five alternatives presented for each brand are the next:

The five alternatives presented for each brand are the next:

Alternative 1

Directly supply from assembly plants to dealerships by truck. It must be said, that the trucks used in vehicles transportation are road trains.

Alternative 2

There is a hub in Indianapolis. Direct delivery from assembly plants to the hub. Centralized distribution from the hub to dealerships. All the transportation is by truck.

Alternative 3

Direct delivery from assembly plants to the hub. Decentralized distribution from the hub to the dealerships. All the transportation is by truck. Within this alternative, two options are considered: clockwise delivery starting for the nearest city to the hub and clockwise delivery with a division of the studied territory.

Alternative 4

Directly transportation from assembly plants to the hub by train. Centralized distribution from the hub to dealerships by truck.

Alternative 5

Directly transportation from assembly plants to the hub by train. Decentralized distribution from the hub to dealerships by truck.

3.2. Methodology Descriptions

3.2.1. Ford Auto Distribution Alternatives

Alternative 1

Each dealership is supplied by its closest assembly plant. According to the minimal distances between assembly plants and dealership (see *Table 17* in the 4.2.2. Supply Data) the allocation is next: O1 is supplied by PF1, O2 by PF2, O3 by PF1, O4 by PF4 and O5 by PF3.

The trucks used in vehicle transportation are road trains. Their loading capacity is from 8 to 12 cars. Depending on the number of cars to be transported trucks will have a capacity or another one. It has no sense to use a truck with capacity for 12 cars if transporting a number of cars lower than 8 (because there would be a loss of capacity), in that case, a truck with capacity for 8 cars will be used.

For calculating the shipping cost it is necessary to know the number of trucks, the distance they travel and the number of cars loaded in the truck. These parameters can be calculated because the weekly demand in each dealership and the distance between all the points of the graph are known. The next table contains all the required information for this first alternative.

DS	Demand per week	num. trucks	num.trucks 12 cars capacity (num.trucks)X (cars transported)	num.trucks 8 cars capacity (num.trucks)X (cars transported)	closest A.P	distance A.P-DS (mi)
O1	112	9.33	9X12	1X4	PF1	20
O2	30	2.50	2X12	1X6	PF2	27
O3	35	2.92	2X12 1X11	0X0	PF1	170
O4	14	1.17	1X12	1X2	PF4	252
O5	13	1.08	1X12	1X1	PF3	240

Table 6 Summary Table for Ford Alternative 1

It is important to mention that for calculating the cost would not be necessary to make any difference between the types of trucks (depending on their load capacity), because the formula that will be used, (31) and (32), relates cost only with distance and weight in each shipment. However, this difference is done because in the real world, the cost for having and operating a truck fleet depends on the capacity of the trucks.

Summarizing, the fleet is composed by 16 trucks with capacity for 12 cars, and 4 trucks with capacity for 8.

The travelled distances by the trucks with capacity for 8 cars and the ones with capacity for 12 cars are:

$$d_8 = 1 \cdot d_{PF1-O1} + 1 \cdot d_{PF2-O2} + 1 \cdot d_{PF4-O4} + 1 \cdot d_{PF3-O5} = 539mi$$

$$d_{12} = 9 \cdot d_{PF1-O1} + 2 \cdot d_{PF2-O2} + 3 \cdot d_{PF1-O3} + 1 \cdot d_{PF4-O4} + 1 \cdot d_{PF3-O5} = 1{,}236mi$$

If considering the distances for coming back from the dealerships to the assembly plants, the travelled distances by each type of truck are two times the previous one. This distance is not necessary because the formula for calculating the shipping cost does not consider the travelled distance when travelling in the opposite direction of the shipping one.

Next, there is the scheme about how this alternative works. Notice that the numbers above the arrow correspond to the number of trucks that go through that arc per week and the cars they transport. The information in blue is for trucks with capacity for 12 cars, while the one in red is for trucks with capacity for 8.

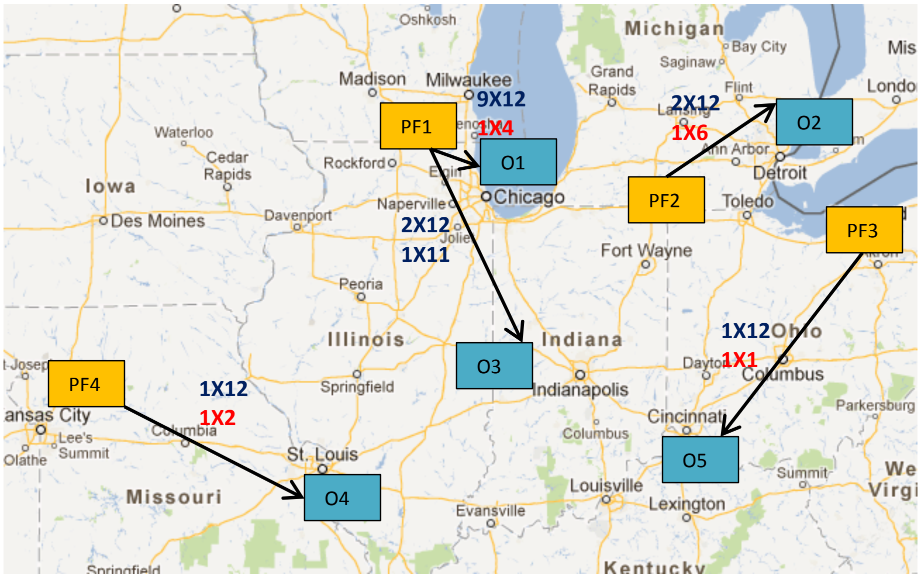

Figure 8 Scheme for Ford Alternative 1

Notice that when returning, the system is exactly the same, but the arrows go in the opposite direction.

Alternative 2

This proposal consist in delivering from a hub or also called consolidation center (in automotive distribution it is called ramp) in Indianapolis, located where the dealership in that city, O3, is. The location of the hub is because Indianapolis is the most centric city in the whole graph. The distribution is done in two phases, the trunk and the capillary one. The first one consists in transporting the cars from assembly plants to the hub. In the second one, the cars in the hub are delivered to the dealerships in a centralized scheme.

As before, the number of trucks, the cars they load and the travelled distance must be known for calculating the shipping cost. The next table contains this information for the distribution from the assembly plants to the hub.

A.P	distance to HUB (mi)	A.P weekly production integer	num.truck A.P-HUB	num.trucks 12 cars capacity (num.trucks)X (cars transported)	num.trucks 8 cars capacity (num.trucks)X (cars transported)
PF1	170	212	17.67	17X12	1X8
PF2	274	38	3.17	3X12	1X2
PF3	309	15	1.25	1X12	1X3
PF4	486	16	1.33	1X12	1X4

Table 7 Summary Table about Ford trunk distribution in Alternative 2

The travelled distances for trucks with capacity for 8 and 12 cars respectively, during the trunk network are:

$$d_{8\_1} = 1 \cdot d_{PF1-O3} + 1 \cdot d_{PF2-O3} + 1 \cdot d_{PF3-O3} + 1 \cdot d_{PF4-O3} = 1{,}239mi$$

$$d_{12\_1} = 17 \cdot d_{PF1-O3} + 3 \cdot d_{PF2-O3} + 1 \cdot d_{PF3-O3} + 1 \cdot d_{PF4-O3} = 4{,}507mi$$

If considering the distances for returning from the hub to assembly plants the previous distance would be two times the ones above.

The numbers of trucks used in the first part are 22 trucks with capacity for 12 cars and 4 trucks with capacity for 8.

The same information, but for the capillary distribution is in the table below:

DS	DS weekly demand integer	distance HUB-DS (mi)	Num.trucks HUB-DS	num.trucks 12 cars capacity (num.trucks)X (cars transported)	num.trucks 8 cars capacity (num.trucks)X (cars transported)
O1	112	183	9.33	9X12	1X4
O2	30	284	2.50	2X12	1X6
O3	35	0	2.92	2X12 1X11	0X0
O4	14	243	1.17	1X12	1X2
O5	13	112	1.08	1X12	1X1

Table 8 Summary Table about Ford capillary distribution in Alternative 2

In the second part of the distribution, the travelled distances for each type of trucks are:

$$d_{8\_2} = 1 \cdot d_{O3-O1} + 1 \cdot d_{O3-O2} + 1 \cdot d_{O3-O4} + 1 \cdot d_{O3-O5} = 822mi$$

$$d_{12\_2} = 9 \cdot d_{O3-O1} + 2 \cdot d_{O3-O2} + 1 \cdot d_{O3-O4} + 1 \cdot d_{O3-O5} = 2{,}570mi$$

If considering the distances for returning from the hub to assembly plants the previous distance would be two times the ones above.

The numbers of trucks used in the second part of the distribution are 16 and 4 for trucks with capacity for 12 and 8 cars respectively. As these two phases are done one after the other, the trucks used in the first part can also be used in the second one, so the fleet is composed by 22 trucks with capacity for 12 cars and 4 trucks with capacity for 8.

The next scheme shows how this alternative works. The black arrows are for the trunk network, while the red ones are for the capillary network. The numbers in blue and red correspond to the number of trucks that go through each arc per week, as well as, the number of cars they transport (in each truck).

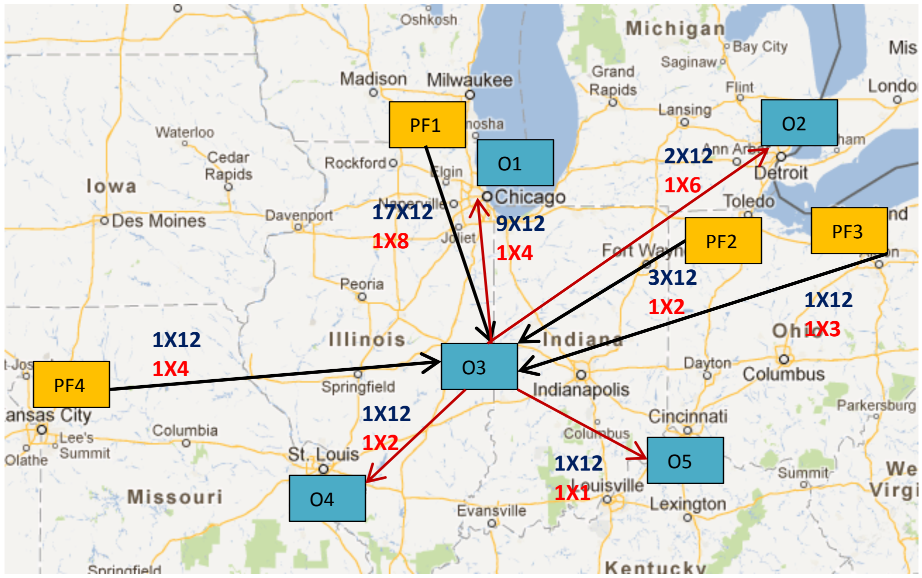

Figure 9 Scheme for Ford Alternative 2

When returning, the system is exactly the same, but the arrows go in the opposite direction.

<u>Alternative 3</u>

This alternative is pretty similar to the previous one, but now, instead of doing a centralized capillary distribution, it is done in a clockwise scheme. Two options are proposed, one consists in a current clockwise delivery, while in the other one, the studied territory is divided in to four subareas, which are studied separately. The first part of the distribution is done as in the previous alternative.

Option 1: clockwise delivery

From the hub, the nearest dealership is O5 (if not considering O3, which is located in the same place). The demand in O5 is 13 cars, so 2 trucks (with capacity for 12 cars each) are sent from the hub to O5. The total capacity of these 2 trucks is 24 cars, so 11 cars (transported in one of the previous trucks) are delivered to the nearest dealership to O5 that has not been supplied, which is O2.

The demand in O2 is 30 cars, but 11 cars are sent from O5, so 19 cars are needed, that means that 2 trucks (with capacity for 12 cars each) are needed from the hub. The capacity of these trucks is 24 cars, so 5 cars go from O2 to the nearest dealership that has not been supplied, which is O1. This operation requires one of the previous trucks.

The demand in O1 is 112, but 5 cars have been already sent from O2, what makes that only 107 cars are needed, so 9 trucks (with capacity for 12 cars each) must go from hub to O1. The total capacity of these 9 trucks is 108 cars, but 107 are necessary in O1, so 1 car transported in one of the previous trucks goes from O1 to O4, following the clockwise delivery.

The demand in O4 is 14 cars, but 1 car has already been sent from O1, so 13 cars are needed, that means that 2 trucks must go from the hub to O4. The capacity if one of the trucks is of 8 cars, instead of 12.

The first part of the distribution is done as it was in *Alternative 2*, so twenty two trucks of 12 cars capacity and 4 truck of 8 cars capacity are necessary. For the second part of the distribution, 14 trucks with capacity for 12 and 1 truck with capacity for 8 cars are necessary. These two phases are done one after the other, so the fleet is composed by 22 trucks with capacity for 12 cars and 4 trucks with capacity for 8 cars.

In the second part of the distribution the travelled distances for each type of trucks are:

$$d_{8\_2} = 1 \cdot d_{O3-O4} = 243mi$$

$$d_{12\_2} = 2 \cdot d_{O3-O5} + 1 \cdot d_{O5-O2} + 2 \cdot d_{O3-O2} + 1 \cdot d_{O2-O1} + 9 \cdot d_{O3-O1} + 1 \cdot d_{O1-O4} + 1 \cdot d_{O3-O4} = 3{,}525mi$$

The next scheme shows the operation of the capillary network. As before, the trunk network is not represented because it works as it does in *Alternative 2*. In the arrows from the hub to the dealerships there are two associated numbers, the one in the left is the number of trucks when going from the hub to the dealerships and the one in the right is the number of trucks in the opposite direction (when returning). The blue numbers are for trucks with capacity for 12 cars, and the red ones are trucks with capacity for 8 cars.

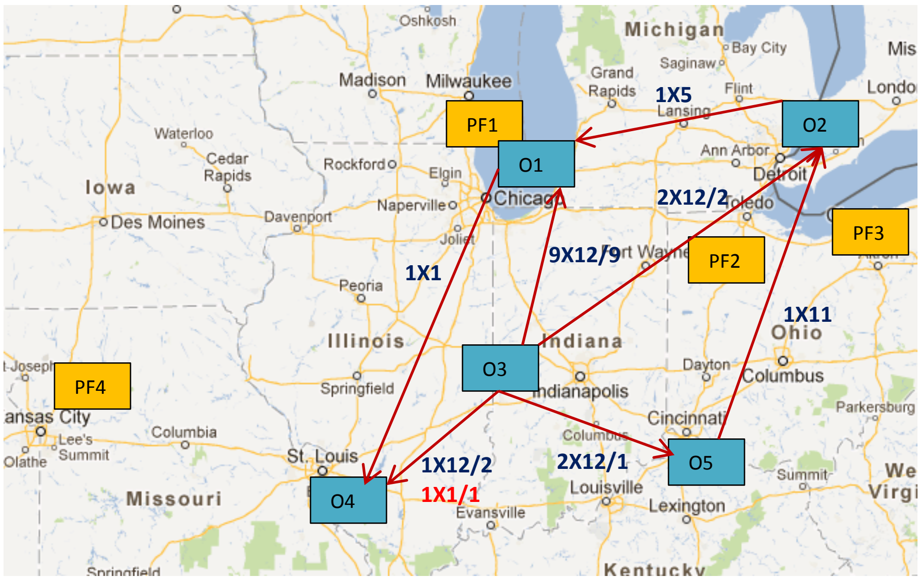

Figure 10 Scheme for Ford capillary distribution in Alternative 3-Option1

Option 2: clockwise delivery dividing the studied territory

When delivering from assembly plants to the hub, there is not any difference with the previous alternative, however, when delivering from the hub to dealerships, instead of study the whole system, this system is divided in three subsystems. The first one includes O1, O2 and O3 (or what is the same, the hub), the second one includes O3 and O5, and the last one includes O3 and O4.

<u>Subsystem 1</u>

From the hub, 10 trucks (with capacity for 12 cars) are sent to O1, where the demand is 112 cars. From O1, 1 truck loading the 8 remaining cars is sent to O2, where the demand is 30 cars (now 22), so 2 trucks (with capacity for 12 cars) are needed from the hub to O2.

Notice that there is not any truck with capacity for 8 cars. The travelled distance for going from the hub to the dealerships is:

$d_{12\_11} = 10 \cdot d_{O3-O1} + 1 \cdot d_{O1-O2} + 2 \cdot d_{O3-O2} = 2{,}681mi$

The numbers of trucks that are required in this subsystem are 12 trucks with capacity for 12 cars.

Subsystem 2

The demand in O5 is 13 cars, so 2 trucks must be sent there from the hub. One truck has a loading capacity for 12 cars (transporting 12 cars) and the other just for 8 (transporting 1 car). So the distance for delivering from the hub to O5 is 224mi. The travelled distance for the trucks with capacity for 8 cars and 12 cars respectively are:

$d_{8\_22} = d_{12\_22} = d_{O3-O5} = 112mi$

Subsystem 3

The demand in O4 is 14 cars. From the hub, 1 truck with capacity for 12 cars (and transporting 12 cars) and 1 truck with capacity for 8 cars (transporting 2 cars) are sent to O4. The distance for going from the hub to O4 is 486mi. So, the travelled distances for both trucks are:

$d_{8\_33} = d_{12\_33} = d_{O3-O4} = 243mi$

Studying the group of the three subsystems the travelled distances in the second part of the distribution for each type of truck are:

$d_{8\_2} = d_{8\_22} + d_{8\_33} = 355mi$

$d_{12\_2} = d_{12\_11} + d_{12\_22} + d_{12_{33}} = 3{,}036mi$

As it happened before the two parts of the distribution are done one after the other, so the trucks in used in one part can be used in the other one. The trucks in the trunk network are the same than in the first part of *Alternative2*, while the trucks used in the capillary network are 14 and 2 with capacities for 12 and 8 cars respectively. So, the fleet is composed, again for 22 trucks with capacity for 12 cars and 4 trucks with capacity for 8 cars.

The next scheme shows the function of the capillary network and also the division of the territory. As before, the trunk network is not represented because works exactly it does is *Alternative 2*. Associated to the arrows from the hub to the dealerships there are two numbers, the one in the left is the number of trucks when going from the hub to the dealerships and the one in the right is the number of trucks in the opposite direction (when returning). The blue numbers are for trucks with capacity for 12 cars capacity trucks, and the red ones are for trucks with capacity for 8 cars.

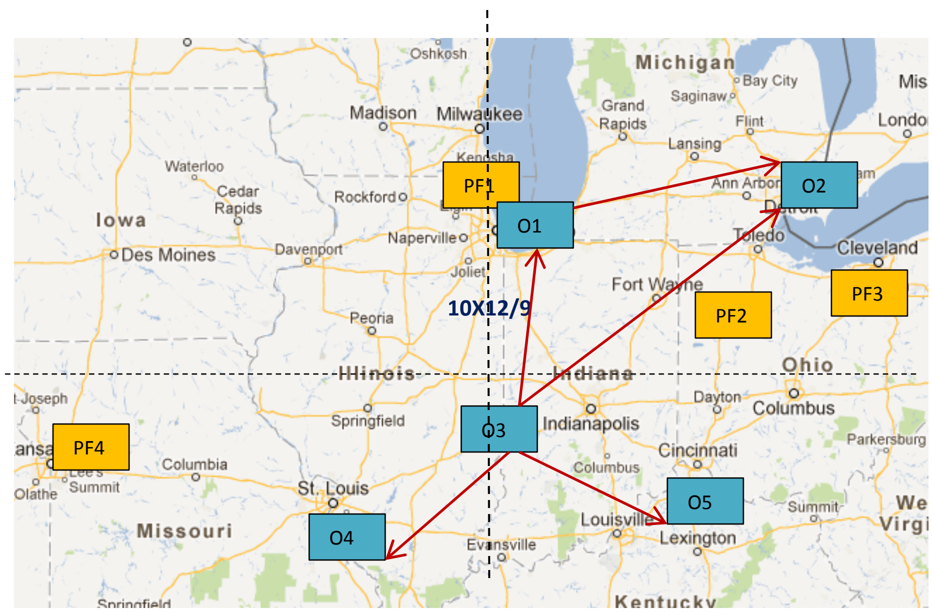

Figure 11 Scheme for Ford capillary distribution in Alternative 3-Option2

Alternative 4

This is an intermodal distribution alternative. The second part of the distribution is done as in *Alternative 2* (centralized distribution). The difference is in the first part of the distribution, where trains are used instead of trucks. This alternative is more similar to the existing new vehicles distribution.

A point to be considered is that the load capacity of trains is higher than the trucks one. A wagon has capacity for 15 cars, and having the option of connecting many of them this capacity can be increased until 215 cars approximately.

First of all, the travelled distances by train, between assembly plants and the hub are necessary. When searching indications for going from a train station to another in Google Maps, it does not give distance, but travelled time, so knowing the average speed of a passengers trains (because Google Maps only works for passenger trains), which is 100 mph, it is possible to know the travelled distance between assembly plants and the hub. All the routes from each assembly plant to the hub stop in Chicago train station, so taking advantage of that two alternatives are proposed.

Option 1: From each assembly plant to the hub

In the first option the cars are sent from each assembly plant to the hub. The travelled distance between the assembly plants and the hub are in the table below. The distance is shown as a sum of the distance for going from the assembly plant to Chicago Union Station and the distance for going from Chicago Union Station to the hub.

	Travelled distance [mi]
PF1	625 (25+600)
PF2	1,150 (550+600)
PF3	1,375(775+600)
PF4	1,400(800+600)

Table 9 Distances by train from Ford assembly plants to the hub

Notice that from Chicago train station the distance to the hub is 600mi for each plant.

Watching at the table and knowing that the whole production of each assembly plant can be loaded in 1 train, the total travelled distance in the first part of the distribution is 4,550mi (the sum of all the distances in the table). The second part of the distribution is done as in *Alternative 2* (Centralized distribution).

The number of trucks that are needed is the same that in the second part of the distribution in *Alternative 2*, that means that the fleet must be composed by 13 trucks with capacity for 12 cars and 4 trucks with capacity for 8 cars.

Next, there is the scheme for the trunk network (the capillary network works exactly as it did in *Alternative 2*, that is why it in not represented). The operation is pretty similar to the previous alternatives, but instead of using trucks, now the used mode is the train. The other important difference is the stop that all the routes have to do in Chicago.

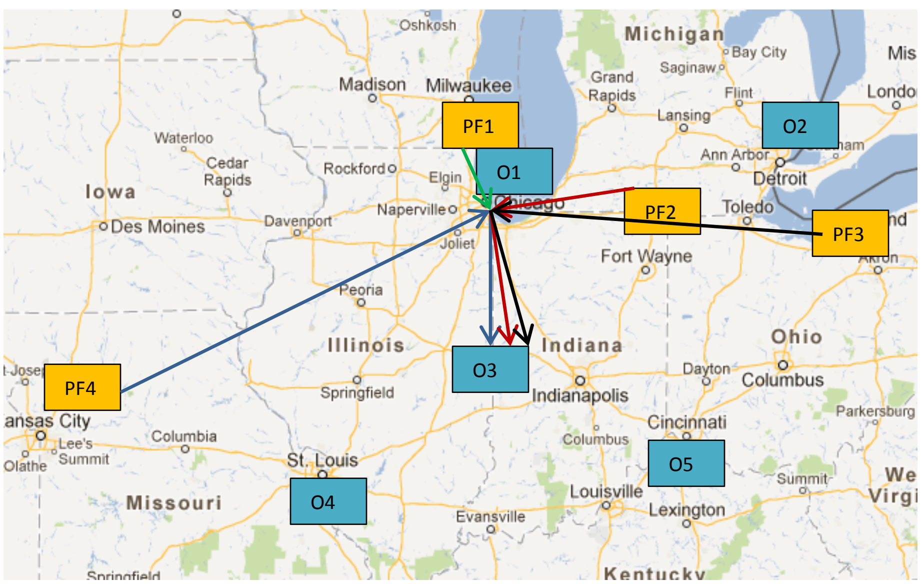

Figure 12 Scheme for Ford trunk distribution in Alternative 4-Option1

Option 2: From Chicago Union Station transporting the total production of cars in two trains. Trunk distribution is completely done by train

Taking advantage of the fact that all the trains must stop in Chicago train station, and that all the trains are transporting below their capacity, it is proposed to distribute all the cars in two trains. This operation is done in Chicago train station, and from there two trains go to the hub.

The total number of cars to be transported is 281. The trains from PF1, PF2, PF3 and PF4 transport 212, 38, 15 and 16 cars respectively, when going from the plant to the Chicago Union Station. As said before, the load capacity of a train can be until 215 (adding more wagons), what means that 2 trains are necessary from Chicago Union Station to the hub, one loads 140 cars and the other the 141 remaining ones.

The fleet of trucks and the distances they travel are the same than in the previous alternative, because the second part of the distribution is done in the same way.

About the scheme, it is almost the same than the one for *Alternative 4-Option1*, but instead of having four arrows from Chicago Union Station to the hub, there are only two.

Option 3: From Chicago Union Station transporting the total production of cars in two trains. Trunk distribution is done by train and truck

This option is pretty similar to the one before, but now, due to the small distance between PF1 and the Chicago Union Station, the cars from PF1 are transported to Chicago Union Station by truck. According to the production in PF1 18 trucks are needed (17 with capacity for 12 cars and 1 for 8cars, using both of them, their whole loading capacity), and the distance between the two points is 20mi, so the travelled distances for the trucks with capacity for 12 cars and the trucks with capacity for 8 cars in the first part of the distribution are:

$d_{8\_1} = 1 \cdot 20 = 20mi$

$d_{12\_1} = 17 \cdot 20 = 340mi$

Once all the trains from PF2, PF3 and PF4 and the trucks from PF1 have arrived, this alternative works as the one before, so two trains go from Chicago Union Station to the hub transporting the whole production of the four plants.

About the number of trucks in the fleet it is the same than in the previous option but adding the number of trucks that do the transportation between PF1 and Chicago train station (17 of 12 cars capacity and 1 of 8 cars capacity). So the fleet is composed by 30 trucks of 12 cars capacity and 5 trucks of 8 cars capacity.

The scheme that represents the operation of this alternative is similar to the one in *Alternative 4-Option1, but* the green arrow, from PF1 to Chicago represents the route followed by the 18 trucks that go from PF1 to Chicago.

Alternative 5

This alternative is a combination between *Alternative 4* and *Alternative 3*. The first phase of the distribution process is done as in *Alternative 4*, so new vehicles are transported from assembly plants to the hub by train. The second part of the distribution works as it did in *Alternative 3*. So from the hub the cars are delivered to the dealerships by truck in a clockwise scheme.

Both, *Alternative 3* and *Alternative* 4 have other subalternatives. For deciding which of these subalternatives is better (the one with minimum cost) to be used it is necessary to calculate their costs. This calculation is done in *4.2.3*, *4.2.4* and *4.2.5*. And in 4.3, the obtained results are analyzed, and that permits to make the decision of which subalternative is used in *Alternative 5*.

In the point *4.3. Data Analysis*, it is proved that within *Alternative 3*, the one with minimal cost is *Option 2*, and within *Alternative 4*, the one with minimal cost is *Option 1*. So, in *Alternative 5*, the first part of the distribution is done by train. There are four trains shipping from each assembly plant to the hub. About, the capillary distribution, it is done in a clockwise scheme and dividing the whole graph in to three subsystems.

3.2.2. Chrysler Auto Distribution Alternatives

Alternative 1

As it happened with Ford, this alternative consists in a directly supply from each assembly plant to its corresponding dealership. The followed criterion for the allocation between assembly plants and dealerships is the one, where the demands of the dealerships are covered by the nearest assembly plants. So, O1, O2, O3, O4 and O5 are supplied by PC1, PC2, PC3, PC1 and PC3 respectively.

From the weekly demand and the distances between assembly plants and dealerships the number of trucks (with capacity for 12 and 8 cars) and the cars they load can be calculated and it is shown in the table below.

DS	Weekly demand	num. truck s	num.trucks 12 cars capacity (num.trucks)X (cars transported)	num.trucks 8 cars capacity (num.trucks)X (cars transported)	closest A.P	Distance A.P-DS
O1	54	4.50	4X12	1X6	PC1	71
O2	14	1.17	1X12	1X2	PC2	5
O3	17	1.42	1X12	1X5	PC3	226
O4	7	0.58	0X0	1X7	PC1	296
O5	6	0,50	0X0	1X6	PC3	204

Table 10 Summary Table for Chrysler Alternative 1

The total travelled distance for the trucks with capacity for 8 cars is:

$$d_8 = 1 \cdot d_{PC1-O1} + 1 \cdot d_{PC2-O2} + 1 \cdot d_{PC3-O3} + 1 \cdot d_{PC1-O4} + 1 \cdot d_{PC3-O5} = 802mi$$

The total travelled distance for the trucks with capacity for 12 cars is:

$$d_{12} = 4 \cdot d_{PC1-O1} + 1 \cdot d_{PC2-O2} + 1 \cdot d_{PC3-O3} + 0 \cdot d_{PC1-O4} + 0 \cdot d_{PC3-O5} = 515mi$$

If considering the process for returning from the dealerships to the plants, these distances would be two times the previous ones, but this information it is not necessary when calculating the costs.

The fleet is composed by 6 trucks with capacity for 12 cars capacity and 5 trucks with capacity for 8 cars.

The next picture, show how this alternative works. The arrows from the hub to the dealerships have two associated numbers, the one in the left is the number of trucks when going from the hub to the dealerships and the one in the right is the number of trucks in the opposite direction (when returning). The blue numbers are for trucks with capacity for 12 cars capacity trucks, and the red ones are for trucks with capacity for 8 cars. When returning from each dealerships to its associated assembly plant, the graph is the same, but the arrows have the opposite direction.

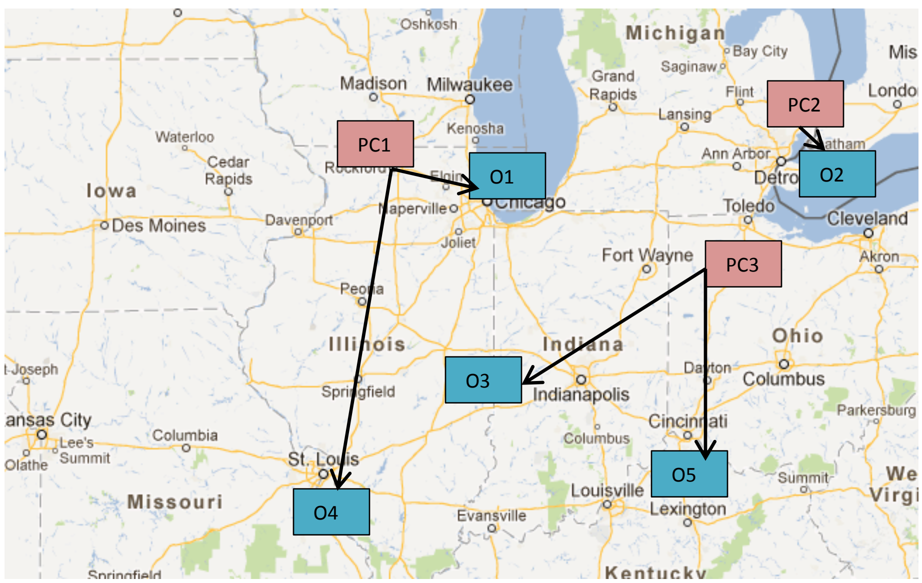

Figure 13 Scheme for Chrysler Alternative 1

<u>Alternative 2</u>

As in Ford *Alternative 2*, now, there is a hub located in Indianapolis; the hub is shared by both brands, Chrysler and Ford. The distribution is divided in two parts: trunk and capillary. The first one consists in delivering from assembly plants to the hub, while the second part is done in a centralized scheme, from the hub to dealerships.

The next table contains the number of trucks with capacity for 12 and 8 cars and the cars they loaded, as well, as the distances between each assembly plant and the hub.

A.P	A.P weekly production	num. trucks	Num.truck 12 cars capacity (num.trucks)X (cars transported)	Num.truck 8 cars capacity (num.trucks)X (cars transported)	distance A.P-HUB (mi)
PC1	89	7.42	7X12	1X5	255
PC2	18	1.50	1X12	1X6	289
PC3	28	2.33	2X12	1X4	226

Table 11 Summary Table about Chrysler trunk distribution in Alternative 2

In the first part of the distribution, the travelled distances by the trucks with capacity for 8 cars and by the ones with capacity for 12 cars are:

$$d_{8\_1} = 1 \cdot d_{PC1-O3} + 1 \cdot d_{PC2-O3} + 1 \cdot d_{PC3-O3} = 770mi$$

$$d_{12\_1} = 7 \cdot d_{PC1-O3} + 1 \cdot d_{PC2-O3} + 2 \cdot d_{PC3-O3} = 2{,}526mi$$

If the distance for returning from the hub to the dealerships were considered, they would be two times the previous ones.

The second part (capillary network) consists in delivering from the hub to the dealerships. Knowing the demand in each dealership the number of trucks of each type and the number of cars they transport is in the next table, as well as the distances from the hub to each dealership.

DS	Weekly demand	num. trucks	Num.truck 12 cars capacity (num.trucks)X (cars transported)	Num.truck 8 cars capacity (num.trucks)X (cars transported)	distance WH-DS (mi)
O1	54	4.50	4X12	1X6	183
O2	14	1.17	1X12	1X2	284
O3	17	1.42	0X0	0X0	0
O4	7	0.58	0X0	1X7	243
O5	6	0.50	0X0	1X6	112

Table 12 Summary Table about Chrysler capillary distribution in Alternative 2

In the second part of the distribution, the travelled distances by trucks with capacity for 8 cars and for the ones with capacity for 12 are:

$$d_{8\_2} = 1 \cdot d_{O3-O1} + 1 \cdot d_{O3-O2} + 1 \cdot d_{O3-O4} + 1 \cdot d_{O3-O5} = 822mi$$

$$d_{12\_2} = 4 \cdot d_{O3-O1} + 1 \cdot d_{O3-O2} = 1{,}016mi$$

As before, if the distance for returning was necessary, it would be two times the previous ones.

In the trunk network 10 trucks with capacity for 12 cars and 3 trucks with capacity for 8 are necessary, while in the capillary network 5 trucks with capacity for 12 cars and 4 trucks with capacity for 8 cars. The two distribution processes are done one after the other, so the trucks used in one part can also be used in the second one, which makes that the number of trucks in the fleet is 10 trucks with capacity for 12 cars and 4 trucks with capacity for 8 cars.

The next picture shows how the trunk (black) and the capillary (red) network work. The arrows from the hub to the dealerships have two associated numbers, the one in the left is the number of trucks when going from the hub to the dealerships, and the one in the right is the number of trucks in the opposite direction (when returning). The blue numbers are for trucks with capacity for 12 cars, and the red ones are for trucks with capacity for 8.

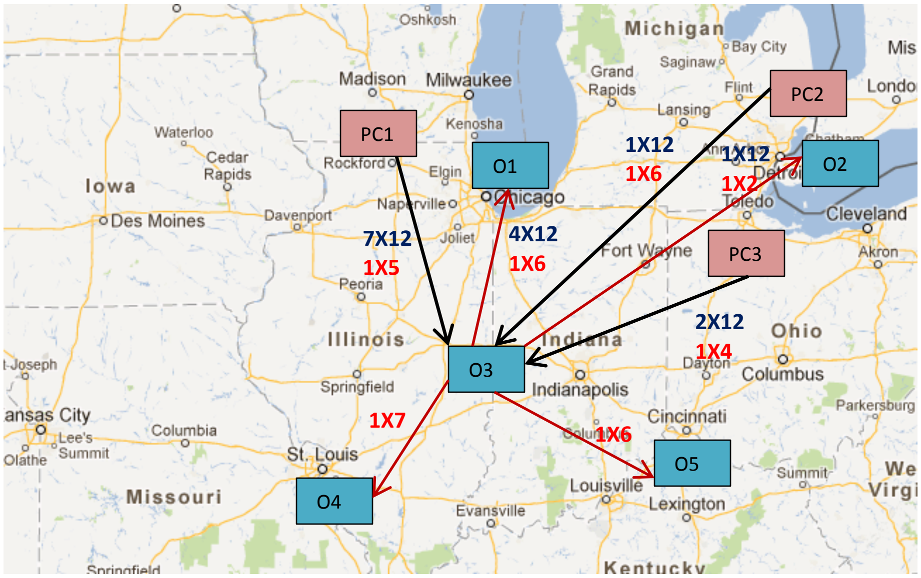

Figure 14 Scheme for Chrysler Alternative 2

Alternative 3

This alternative differs from the one before in the capillary network. Trunk network in *Alternative 3* and *Alternative 2* works in the same way. However, capillary distribution works differently. Now, instead of having a centralized distribution, the capillary distribution is done in a clockwise scheme. As it happened with Ford, there are two options to be considered, the first one corresponds to a current clockwise delivery, while in the second one the studied territory is divided in four areas that are analyzed independently.

Option 1: current clockwise delivery

The first part of the distribution is done as in the first part of *Alternative 2*. So the number of the trucks, the cars they transport and the distances are exactly the same for both alternatives.

The second part of the distribution, as said before, is done in a clockwise scheme. The first dealership to be visited is the nearest to the hub, which is O5. The demand there is 6 cars, that makes that 1 truck must be sent from the hub to O5. The loading capacity of this truck is 12 cars. As the demand in O5 is 6, 6 cars (transported by the same truck) go to the nearest dealership to O5, which is O2.

The demand in O2 is 14 cars, but 6 cars have been already delivered by a truck from O5, so 8 cars are necessary in O2. These cars are sent there by a truck from the hub, the capacity of this truck is 12 cars. As only 8 cars are necessary, the 4 remaining are sent (by the same truck from the hub to O2) to the nearest city to O2, which is O1.

The demand in O1 is 54 cars, but 4 cars have been already delivered by the truck from O2, so 50 cars must be sent from the hub to O1. This operation requires 5 trucks of 12 cars capacity each. The total capacity of these five trucks is 60 cars, but only 50 are necessary, so 10 cars are sent to the only dealership that has not been supplied yet, it is O4.

The demand in O4 is 7 cars, as the truck from O1 transported 10 cars; no truck has to be sent from the hub.

Observing that there are three remaining cars, it is evaluated the option of using 4 trucks with capacity for 12 cars and 1 truck with capacity for 8 cars when going from the hub to O1. If doing this, the total capacity of the five trucks is 56. Only 50 of these 56 cars are needed in O1, so the 6 remaining go to O4. The demand there is 7 cars, so it is no enough with this truck. Another option is to send, from the hub to O1, 5 trucks with capacity for 12 cars, but not using the whole capacity of one of them, so, instead of transporting 12 cars, one of these trucks transports 9 cars. 7 cars are remaining in O1, this are the 7 cars that are sent to O4 by one of the trucks from the hub to O1.

During the capillary distribution, the travelled distance for the trucks with capacity for 12 cars is:

$$d_{12\_2} = 1 \cdot (d_{O3-O5} + d_{O5-O2}) + 1 \cdot (d_{O3-O2} + d_{O2-O1}) + 4 \cdot d_{O3-O1} + 1 \cdot (d_{O3-O1} + d_{O1-O4}) = 2{,}154mi.$$

Notice that in the second part of the distribution no truck with capacity for 8 cars is used. As before, the trucks used in the trunk network can be used in the capillary one. In the trunk network 10 trucks with capacity for 12 cars and 3 trucks with capacity for 8 cars are necessary. In the capillary network 7 trucks with capacity for 12 cars are necessary and no truck with capacity for 8. So, the fleet is composed by 10 trucks with capacity for 12 cars and 3 trucks with capacity for 8 cars.

Next, there is a picture that shows how the capillary network works. The trunk network is not represented because it works as it does in *Alternative 2*. The arrows from the hub to the dealerships have two associated numbers, the one in the left is the number of trucks when going from the hub to the dealerships and the one in the right is the number of trucks in the opposite direction (when returning). The blue numbers are for trucks with capacity for 12 cars and the red ones are for trucks with capacity for 8. The green arrow from O4 to the hub represents the truck that is returning.

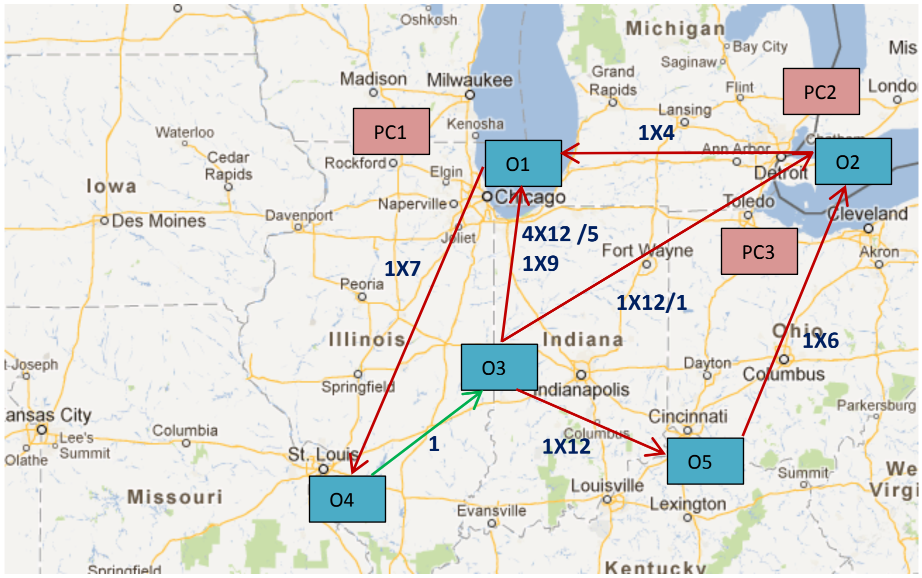

Figure 15 Scheme for Chrysler capillary distribution in Alternative 3-Option1

Option 2: clockwise delivery dividing the studied territory

This alternative is pretty similar to the one before, but now, the studied area is divided in four sub areas, which contain the three subsystems to be studied. Despite of having four zones, the dealerships of the current project are located in three of these zones. The subsystems are the next:

<u>Subsystem 1</u>

It includes the dealerships O1 and O2. The demand in O1 is 54 cars, so 5 trucks are needed from the hub to O1. The total capacity of these 5 trucks is 60 cars, so 6 cars go from O1 to O2 (by one truck of the five ones). The demand in O2 is 14 cars, but 6 cars have already been sent from O1, so 8 cars are needed in O2. That means that 1 truck go from the hub to O2. The capacity of this truck is for 8 cars.

The travelled distances by the trucks of both capacities are in this subsystem are:

$$d_{8\_11} = 1 \cdot d_{O3-O2} = 284mi$$

$$d_{12\_11} = 4 \cdot d_{O3-O1} + 1 \cdot (d_{O3-O1} + d_{O1-O2}) = 1{,}198mi$$

<u>Subsystem 2</u>

This subsystem includes the dealership O4. The demand there is 7 cars, so 1 truck must go from the hub to O4. The capacity of this truck is for 8 cars. The traveled distance for this truck is:

$d_{8\_22} = 1 \cdot d_{O3-O4} = 243mi$

<u>Subsystem 3</u>

This subsystem includes the dealership O5. The demand there is 6 cars, so 1 truck must go from the hub to O5. The capacity of this truck is for 8 cars. The traveled distance for this truck is:

$d_{8\_33} = 1 \cdot d_{O3-O5} = 112mi$

Considering the three subsystems, the travelled distances for each type of trucks in the second part of the distribution are:

$d_{8\_2} = d_{8\_11} + d_{8\_22} + d_{8\_33} = 639mi$

$d_{12\_2} = d_{12\_11} = 1{,}198mi$

The required number of trucks with capacity for 12 and 8 cars in the first part of the distribution was 10 and 3 respectively. In the second part of the distribution these numbers are 5 and 3 for trucks with capacity for 12 cars and for the ones with capacity for 8. So, the fleet is composed by 10 trucks with capacity for 12 cars and 3 trucks with capacity for 8.

The next picture shows how this alternative works. The trunk network is not represented because it works exactly as in *Alternative2* does. As before, the arrows from the hub to the dealerships have two associated numbers, the one in the left is the number of trucks when going from the hub to the dealerships and the one in the right is the number of trucks in the opposite direction (when returning). The blue numbers are for 12 cars capacity trucks, and the red ones are for 8 cars capacity trucks.

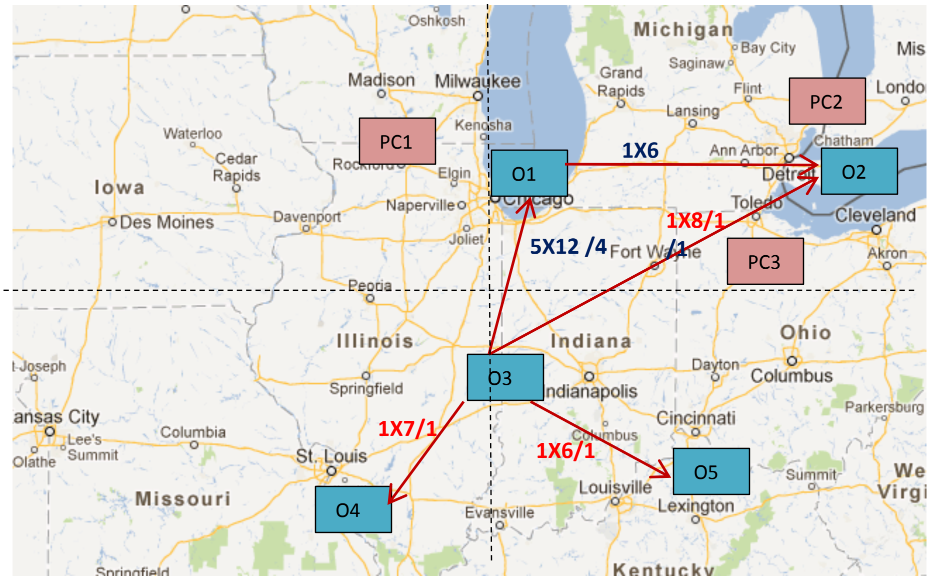

Figure 16 Scheme for Chrysler capillary distribution in Alternative 3-Option2

Alternative 4

The distribution operation is done as in Ford *Alternative 4*. The distribution in the trunk network is done by train while in the capillary network is done by truck.

First of all, the train distances between Chrysler assembly plants and the hub must be known. Google Maps gives the travelled time between cities, by passenger trains, which have an average velocity of 100 mph, knowing that, the distances can be calculated easily. As it happened for Ford, all the routes from assembly plants to the hub stop in Chicago, and this is a point for taking advantage of, so two options are considered.

Option 1

The weekly production in each assembly plant is lower than the trains load capacity, so one train from each assembly plant to the hub is enough. It must be said, that there is no train station in Belvidere (where PC1 is located), so the vehicles assembled there must be transported by truck to Rockford where there is the nearest train station. The next table contains the train travelled distances from each plant to the hub. These distances are the sum for going from the assembly plant to Chicago Union Station (for PC1, this distance is from Rockford Station to Chicago Union Station).

	Travelled distance (mi)
PC1 (Rockford)	820(220+600)
PC2	1,270(670+600)
PC3	1,050(450+600)

Table 13 Distances by train from Chrysler Assembly Plants to the hub

With all this information, the total travelled distance by train in the first part of the distribution is the sum of the distances from each assembly plant to the hub, which is 3,140mi.

About the transportation from PC1 to Rockford Station, 89 cars must be transported (the production in PC1), so 7 trucks with capacity for 12 cars transporting 12 cars each, and 1 truck with capacity for 8 transporting 5 cars are necessary. The distance between PC1 and Rockford is 13 mi. The travelled distances for transporting the cars assembled in PC1 to Rockford, for each type of trucks are:

$$d_{8\_1} = 1 \cdot 13 = 13mi$$

$$d_{12\_1} = 7 \cdot 13 = 91mi$$

As said before, the second part of the distribution is done as in *Alternative 2*, so the travelled distances in the second part of the distribution are calculated in the explanation of this alternative.

In the first part of the distribution 7 trucks with capacity for 12 cars and 1 truck with capacity for 8 cars are necessary, while in the capillary distribution these values are 5 and

4 for trucks with capacities for 12 and 8 cars respectively. As the two phases are done sequentially, the fleet is composed by 7 trucks with capacity for 12 cars and 4 trucks with capacity for 8 cars.

The next scheme shows the operation of the trunk network. The capillary network is not represented because it works as it does in the second part of *Alternative 2* (centralized distribution). Due to the small distance between PC1 and Rockford there is no arrow between them.

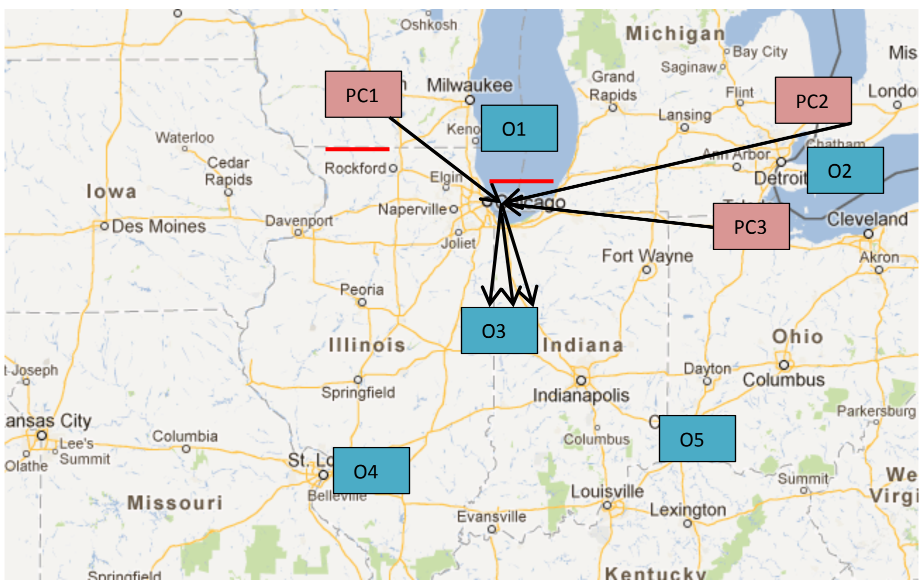

Figure 17 Scheme for Chrysler trunk distribution in Alternative 4-Option1

<u>Option 2</u>

The trains from PC1, PC2 and PC3 are transporting below their capacity. Taking advantage of that, in the stop at Chicago Union Station all the cars transported before for the groups of the three trains can be loaded now, in one of them. So, from Chicago Union Station to the hub, there is only one train transporting the total production of the three assembly plants, which is 135cars.

The scheme is quite similar to the one for the previous alternative (*Figure 17*), but instead of having three arrows from Chicago Union Station to the hub, there is only one.

Alternative 5

This alternative is a combination between *Alternative 4* and *Alternative 3*. So, the first part of the distribution is done by trains, and the second part is done by trucks in a clockwise scheme. Before analyzing this alternative it is necessary to choose the best sub alternatives in *Alternative 4* and in *Alternative 3*.

Analyzing the costs in *4.3. Data Analysis* it is proved that within *Alternative 3,* the option with minimal cost is the one with clockwise delivery dividing the studied territory in to four subareas. In *Alternative 4* the two proposed options have the same costs, but the chosen one is *Option 2*, because there are fewer trains working, which represents lower fixed and indirect costs.

CHAPTER 4

METHODOLOGY APPLICATION

4.1. General

Once all the alternatives for Ford and for Chrysler have been presented is time to decide which combination of them is the best in order to get the minimal distribution and warehousing cost for the whole system. The distribution cost refers to the one of the truck and train shipping.

4.2. Data collection and Processing

4.2.1. Demand and Production Data

As said in *1.1. System Description*, the demand of the dealerships is calculated by a weighing with the population of the city where the dealership is located. That means that the dealerships located in a city with bigger population will demand a bigger number of cars. The demand of Ford and Chrysler cars in the United States, as well as, the population of the country are known, so it is easy to obtain the demand of cars for both brands in each dealership. It is assumed that the number of demanded cars in one year is the same number of the annual sales. In 2011 these sales were 667,286 and 319,515 cars, for Ford and Chrysler respectively. The population of the United States is 311,000,000 people. The used demands are per week (it is considered that one year has fifty-two weeks). With all this information the demand in each dealership, O_i, is calculated as:

$$Annual\ Demand\ (O_i) = \frac{Annual\ Sales\ in\ USA}{Population\ USA} \cdot (population\ city\ O_i)\ (21)$$

For each brand the annual demand in each dealership, O_i is:

Ford:

$$Annual\ Demand\ (O_i) = \frac{667{,}286}{311{,}000{,}000} \cdot (population\ city\ O_i)\ (22)$$

Chrysler:

$$Annual\ Demand\ (O_i) = \frac{319{,}515}{311{,}000{,}000} \cdot (population\ city\ O_i)\ (23)$$

The populations of the different cities, as well as, the demand in each dealership are in the table below.

DS	Location	City Population	Weekly Demand of Ford Cars (number of vehicles)	Weekly Demand of Chrysler Cars(number of vehicles)
O1	Chicago (IL)	2,707,120	112	54
O2	Detroit(MI)	706,585	30	14
O3	Indianapolis (IN)	827,609	35	17
O4	Saint Louis (MO)	318,069	14	7
O5	Cincinnati (OH)	296,223	13	6

Table 14 Dealerships Demand and population of the cities where dealerships are located

It has to be mentioned that the previous data population is for 2011 and it refers just to the cities, not to all the metropolitan areas.

It is assumed that the production does not have to satisfy only the demand but also consider the safety stock. Because of this, for calculating the production of each assembly, the demand that it has to satisfy is multiplied by a parameter that depends on the size of the dealership, or what is the same, the population of the city where it is located. The different values that this parameter takes depending on each dealership are in the next table.

O1	1.5
O2	1.25
O3	1.25
O4	1.1
O5	1.1

Table 15 Safety stock parameter in each dealership

Although, there are different allocations between assembly plants and dealership that have to be supplied by them, the one that is taken when calculating the production is the allocation when directly supply from the plants to dealerships, because this alternative is the more restrictive one. This allocation is shown in the next table.

PF1	O1, O3
PF2	O2
PF3	O5
PF4	O4
PC1	O1,O4
PC2	O2
PC3	O3,O5

Table 16 Allocation between assembly plants and dealerships when directly supply

The production in each assembly plant can already be calculated as next.

Ford:

$$Production_{PF1} = \ Demand\ Ford_{O1} \cdot 1.5 + \ Demand\ Ford_{O3} \cdot 1.25 \ \ (24)$$

$$Production_{PF2} = \ Demand\ Ford_{O2} \cdot 1.25 \ \ (25)$$

$$Production_{PF3} = \ Demand\ Ford_{O5} \cdot 1.1 \ \ (26)$$

$$Production_{PF4} = \ Demand\ Ford_{O4} \cdot 1.1 \ \ (27)$$

Chrysler:

$$Production_{PC1} = \ Demand\ Chrysler_{O1} \cdot 1.5 + \ Demand\ Chrysler_{O4} \cdot 1.1 \ \ (28)$$

$$Production_{PC2} = \ Demand\ Chrysler_{O2} \cdot 1.25 \ \ (29)$$

$$Production_{PC3} = \ Demand\ Chrysler_{O3} \cdot 1.25 + Demand\ Chrysler_{O5} \cdot 1.1 \ \ (30)$$

The results of the productions are in *Table 2*.

4.2.2. Supply Data

The supply is done or by road trains (trucks) or by trains. The distribution network is composed by the highways where the trucks travel through and the railways where the trains do. It is necessary to know the distances between all the cities involved in the problem (distance is required instead of time because the distribution is of freight and not of passengers).

The next table contains all the distances (in miles) by truck, between all the cities in the problem. These distances are taken from Google Maps and it is supposed that they are the minimal ones.

	PF1	PF2	PF3	PF4	PC1	PC2	PC3	O1	O2	O3	O4	O5
PF1	0	252	313	501	90	277	231	20	272	170	294	282
PF2		0	146	737	333	31	55	263	27	274	531	257
PF3			0	804	398	158	100	328	153	309	552	240
PF4				0	473	758	717	500	753	486	252	593
PC1					0	35	316	71	353	255	296	367
PC2						0	66	288	5	289	555	268
PC3							0	247	61	226	469	204
O1								0	283	183	297	296
O2									0	284	551	263
O3										0	243	112
O4											0	349
O5												0

Table 17 Minimal distances between all the cities in the problem

The distances by train are also taken from Google Maps. It has to be mentioned that Google Maps gives distances for passenger’s trains, knowing the average speed for a passenger train, which is 100mph and that the infrastructure is the same for freight and passengers trains the distances can easily be calculated. All routes proposed by Google Maps stop in Chicago Union Station, so the distances are composed by the one from the assembly plant to Chicago Union Station and from there to the hub. These distances are in the table below.

	A.P - Chicago Union Station (mi)	Chicago Union Station- HUB (mi)
PF1	25	600
PF2	550	1,150
PF3	775	1,375
PF4	800	1,400
PC1 (Rockford)	220	820
PC2	670	1,270
PC3	450	1,050

Table 18 Travelled distances by train from the Assembly Plants to the hub

Remember that in PC1 there is no train station, so the cars assembled there are transported to the nearest one, which is Rockford Train Station. The distance in *Table 17* is the one from Rockford Train Station to the hub.

4.2.3. Trucks Costs

Trucks Costs can be calculated in two different ways.

The first methodology considers that the cost of having and operating with a truck (or a fleet of trucks) is divided in to direct and indirect costs. The first ones are also divided in to fixed and variable costs. Fixed costs are again divided in to capital costs (amortization and funding) and operating costs (staff, insurances and taxes). Variable costs include fuel consumption, repairs and maintenance, driver's meals and tolls. Indirect costs include commercial and administration costs, and their value depends on the number of trucks in the fleet. This alternative is the one used in real world.

Despite of this, in order to choose the best distribution network, it is enough with using a formula that relates cost with many variables. In this case, the used formula relates the cost with the travelled distance and the weight per shipment. This formula is:

$C_{TRUCK} = TR \cdot W$ (31)

Where W is the weight per shipment in pounds, and TR is the truck rate, calculates as:

$TR = 0.0001 \cdot [2.88 \cdot D \cdot W^{-0.15} + 10{,}120 \cdot W^{-0.33}]$ (32) in $ per pound.

Where D,is the travelled distance per shipment in miles.

C_{TRUCK} is the cost for 1 truck. If more than one truck follows that route, C_{TRUCK} must be multiplied by the number of trucks that follows that route. In order to obtain the annual cost, the obtained value has to be multiplied by 52, because it is consider that one year has 52 weeks.

Notice, that the formula does not make any difference in the capacity of the trucks. The weight for a Ford car is 2,600lbs and for Chrysler car it is 3,000lbs. The costs are calculated with *Microsoft Excel* and the results, in $ per year, are in the tables below.

	A.1	A.2	A.3.1	A.3.2
Ford	1,078,622.31	2,856,004.49	2,950,848.19	2,896,340.99
Chrysler	581,181.99	1,603,672.97	1,721,191.55	1,641,544.99

Table 19 Annual Trucks Costs. Alternatives 1,2 and 3

	A.4.1	A.4.2	A.4.3
Ford	1,071,650.40	1,071,650.40	2,065,571.49
Chrysler	1,046,811.63	1,046,811.63	*

Table 20 Annual Trucks Costs. Alternatives 4

For a better comprehension about how Trucks Costs have been calculated see *Tables* from *32* to *44* for Ford and *Tables* from *45* to *57* for Chrysler in the *Annex*.

4.2.4. Trains Costs

Trains costs are calculated with the next formula:

$$C_{TRAINS} = RR \cdot W \cdot D \quad (33)$$

Where W, is the weight per shipment in lbs, D is the distance in miles and RR is the Railroad rate, which is $0.057 per ton-mile.

As it happened with trucks, the cost for train distribution is much complex and it is also divided in to direct and indirect costs, and the first ones are also divided in to fixed and variable costs. However, in order to choose the best alternative it is correct to use the formula (33).

Knowing the number of cars loaded in each train and the distances travelled by them, the results are next:

	A.1	A.2	A.3.1	A.3.2	A.4.1	A.4.2	A.4.3
Ford	*	*	*	*	1,097,006,040	1,665,738,360	1,648,591,620
Chrysler	*	*	*	*	1,113,634,080	1,113,634,080	*

Table 21 Annual Trains Costs

For a better comprehension about how Trains Costs have been calculated see *Tables 58, 59, 60* and *61* for Ford and *Tables 62, 63* and *64* for Chrysler in the *Annex*.

4.2.5. Warehousing Costs

The warehousing costs include not just the stocktaking costs, but also the cost of the facilities where the cars are stored. As it happened in trucks and trains costs, the warehousing costs are also divided in to direct and indirect costs, an also in to variable and fixed costs. In the current project only the variable ones are studied, because they already permit to choose the alternative with minimal cost, due to the fact that fixed costs have the same value for all the alternatives. There are four different variable costs, which are studied in the next points.

4.2.5.1. Holding Costs

The holding cost refers to the cost for possessing stock. It refers to the units that are stored in the warehouse while waiting for being distributed, so, actually it does not consider the safety stock. However, in this project it does because the unitary cost for holding the normal stock and the unitary cost for holding the safety stock have the same value. That is why both stocks are studied jointly.

The unitary holding cost depends on the purchase price of the object, in this case, of the purchase price of cars. It is known that when the purchase price is \$1,500 per unit, the unitary holding cost, H, is \$6 per unit and per week. Knowing that the purchase prices for a Ford and a Chrysler car are \$20,000 and \$30,000, the holding cost for the cars of each brand are:

$$H_{FORD} = \frac{6 \cdot 20{,}000}{1{,}500} = \$80\ per\ unit\ and\ per\ week$$

$$H_{CHRYSLER} = \frac{6 \cdot 30{,}000}{1{,}500} = \$120\ per\ unit\ and\ per\ week$$

The number of cars that have to be stored is the total number of cars that are assembled, because before going to the dealerships all these cars rest in the warehousing zone of the assembly plant in *Alternative 1* and in the hub in the other alternatives. Despite storing the cars in different places (assembly plant or the hub), the holding cost has the same value because it only depends on the units stored and not on the place where they are. The holding costs, HC, are calculated as next:

Ford

The production of Ford cars in one week is the sum of the production in each Ford plant.

$P_{FORD} = P_{PF1} + P_{PF2} + P_{PF3} + P_{PF4} = 281\ units\ per\ week$

This is the number of cars that have to be stored, so the holding cost for Ford in one year is:

$$HC_{FORD} = \frac{\$80}{unit \cdot week} \cdot 281 units \cdot \frac{52 weeks}{1 year} = \$1{,}168{,}960$$

Chrysler

The production of Chrysler cars in one week is the sum of the production in each Chrysler assembly plant.

$P_{CHRYSLER} = P_{PC1} + P_{PC2} + P_{PC3} = 135\ units\ per\ week$

This is the number of cars that have to be stored, so the holding cost for Ford in one year is:

$$HC_{CHRYSLER} = \frac{\$120}{unit \cdot week} \cdot 135 units \cdot \frac{52 weeks}{1 year} = \$842{,}400$$

4.2.5.2. In-Transit Inventory Costs

In-Transit Inventory Costs refers to the cost of possessing the stock while it is shipped. This cost is a 25% of the holding cost for the fraction of time used for shipping, as shown in the next formula.

$$IC_{IT} = 0.25 \cdot HC \cdot \frac{hours\ for\ shipping\ per\ week}{total\ hours\ per\ week} \quad (34)$$

There is a big difference between this cost in Alternative 1 and the other alternatives. In Alternative 1 only the demanded cars are delivered, while in the other alternatives the whole production is transported to the hub.

First of all, it is necessary to know the holding cost for the cars that are delivered in *Alternative 1*, so for the cars that are demanded in the dealerships.

Ford

The demand of Ford cars in one week is the sum of the demand in each Ford dealership.

$$D_{FORD} = D_{Ford\_O1} + D_{Ford\_O2} + D_{Ford\_O3} + D_{Ford\_O4} + D_{Ford\_O5}$$

$$= 204\ units\ per\ week$$

The cost for holding these cars Ford in one year is:

$$HC_{FORD} = \frac{\$80}{unit \cdot week} \cdot 204units \cdot \frac{52weeks}{1year} = \$848{,}640$$

Chrysler

The demand of Chrysler cars in one week is the sum of the demand in each Chrysler dealership.

$$D_{CHRYSLER} = D_{Chrysler\_O1} + D_{Chrysler\_O2} + D_{Chrysler\_O3} + D_{Chrysler\_O4} + D_{Chrysler\_O5}$$

$$= 98\ units\ per\ week$$

The cost for holding these Chrysler cars is:

$$HC_{CHRYSLER} = \frac{\$120}{unit \cdot week} \cdot 98units \cdot \frac{52weeks}{1year} = \$611{,}520$$

In all the other alternatives, different from *Alternative 1*, the holding cost that is used for calculating the In-Transit Inventory Cost is the one that has been calculated *4.2.5.1. Holding Costs*.

The next step is to calculate the time used for shipping in one week.

Ford

Alternative 1

All the shipment from each assembly plant to its allocated dealership is done simultaneity, so the time used for shipping is the maximum one, between all the shipments. The time used in one shipment is the number of trucks multiplied for the distance these trucks travel and divided for the average speed of a road train, which is 50mph.

$$t_1 = \frac{(9+1) \cdot d_{PF1-O1}}{50} = 4h$$

$$t_2 = \frac{(2+1) \cdot d_{PF2-O2}}{50} = 1.62h$$

$$t_3 = \frac{(9+1) \cdot d_{PF1-O3}}{50} = 10.2h$$

$$t_4 = \frac{(1+1) \cdot d_{PF4-O4}}{50} = 10.08h$$

$$t_5 = \frac{(1+1) \cdot d_{PF3-O5}}{50} = 9.6h$$

$$t_{ship\_A1} = MAX[t_1, t_2, t_3, t_4, t_5] = 10.2h$$

Alternative 2

The time used per shipping is the sum of the time used in the trunk distribution, t_1 , and the one used in the capillary one, t_2.

All the shipment in the trunk network, and all the shipment in the capillary one, are done simultaneity, so, the time used in each network is the maximum one between all the shipments.

$$t_{PF1-O3} = \frac{(17+1) \cdot d_{PF1-O3}}{50} = 61.2h$$

$$t_{PF2-O3} = \frac{(3+1)\cdot d_{PF2-O3}}{50} = 21.92h$$

$$t_{PF3-O3} = \frac{(1+1)\cdot d_{PF3-O3}}{50} = 12.36h$$

$$t_{PF4-O3} = \frac{(1+1)\cdot d_{PF4-O3}}{50} = 19.44h$$

$$t_1 = MAX\ [t_{PF1-O3}, t_{PF2-O3}, t_{PF3-O3}, t_{PF4-O3}] = 61.2h$$

$$t_{O3-O1} = \frac{(9+1)\cdot d_{O3-O1}}{50} = 36.6h$$

$$t_{O3-O2} = \frac{(2+1)\cdot d_{O3-O2}}{50} = 17.04h$$

$$t_{O3-O4} = \frac{(1+1)\cdot d_{O3-O4}}{50} = 9.72h$$

$$t_{O3-O5} = \frac{(1+1)\cdot d_{O3-O5}}{50} = 4.48h$$

$$t_2 = MAX\ [t_{O3-O1}, t_{O3-O2}, t_{O3-O4}, t_{O3-O5}] = 36.6h$$

$$t_{ship\_A2} = t_1 + t_2 = 97.8h$$

Alternative 3

As before, the time used for shipping is the sum of the time used in the trunk network and the one used in the capillary one. The time used in the first part has the same value than in the first part of *Alternative2*, which is 61.2h.

For the second part of the distribution, two alternatives were proposed. In the first one, the capillary distribution is done in a clockwise scheme, while in the other it is done under the same scheme but dividing the studied are in to four subareas. The two options are studied separately.

- *Alternative 3–Option1*

The time used for going from O3 to O5 and from there to O2 is:

$$\frac{2 \cdot d_{O3-O5} + 1 \cdot d_{O2-O5}}{50} = 9.74h$$

At the same time, 2 trucks are delivering from O3 to O2, the time used in this operation is:

$$\frac{2 \cdot d_{O3-O2}}{50} = 11.36h$$

So, for delivering to O5 and to O2, the used time is the maximum of the previous ones, so 11.36h. From O2, 1 truck goes to O1, which takes:

$$\frac{1 \cdot d_{O2-O1}}{50} = 5.66h$$

Delivering from O3 to O5 and to O3, and from O3 going to O1 takes 17.02h.

While all the previous shipments are being done, 9 trucks are going from O3 to O1, which takes:

$$\frac{9 \cdot d_{O3-O1}}{50} = 32.94h$$

The time for delivering to O5, O2 and O1 is the maximum between 32.94h and 17.02h, so it is 32.94h. To that time it has to be added the time for going from O1 to O4, which is:

$$\frac{1 \cdot d_{O1-O4}}{50} = 5.94h$$

The time used in the capillary distribution in *Alternative 3-Option1* is:

$t_2 = 32.94 + 5.94 = 38.88h$

It has to be said, that the operation for going from O3 to O4 is done while the shipping the 9 trucks from O3 to O1.

The total time (trunk and capillary distribution) in *Alternative 3-Option1* is:

$t_{ship\_A3.1} = t_1 + t_2 = 100.08h$

- *Alternative3-Option2*

The time used in the capillary distribution of this alternative is:

$$t_2 = MAX\big[(1+1) \cdot d_{O3-O5}, (1+1) \cdot d_{O3-O4}, MAX[10 \cdot d_{O3-O1} + 1 \cdot d_{O1-O2}, (1+1) \cdot d_{O3-O2}]\big] = 42.26h$$

$t_{ship\_A3.2} = t_1 + t_2 = 103.46h$

<u>Alternative4</u>

The time is composed by the time in the first part of the distribution, plus the time in the second part. The time in the capillary distribution is the same than in the second part of *Alternative2*. The time in the first part depends on how the first part in done, and there are three different alternatives.

- Alternative4-Option1

There are four trains (one from each assembly plant) shipping at the same time. The time in the trunk distribution is the maximum between the times used by these trains. Remember that all the routes stop in Chicago Union Station for 3h, and that from there to O3 the distance is 600mi. It must be said that, the average speed of a freight train is lower than the average speed of a passenger's train; however, as the second one does a bigger number of stops, it can be considered that the both averages speed have the same value, which is 100mph. So, the time used in the trunk distribution is:

$$t_1 = MAX\left[\frac{25+600}{100}+3;\frac{550+600}{100}+3;\frac{775+600}{100}+3;\frac{800+600}{100}+3\right] = 17h$$

$$t_{ship\_A4.1} = t_1 + t_2 = 53.6h$$

- Alternative4-Option2

When the all the cars transported by the four trains, arrive to Chicago Union Station, they are distributed between two of the four trains, and from Chicago Union Station these two trains go to the hub. So, t_1 is:

$$t_1 = MAX\left[\frac{25}{100},\frac{550}{100},\frac{775}{100},\frac{800}{100}\right] + 3 + \frac{600}{100} = 17h$$

$$t_{ship\_A4.2} = t_1 + t_2 = 53.6h$$

- Alternative4-Option3

The difference between *Option1* and *Option2* is that now, the cars assembled in PF1 are transported by truck to Chicago Union Station, so the time in the first part of the distribution is:

$$t_1 = MAX\left[\frac{(17+1)\cdot d_{PF1-Chi\_Station}}{50}, \quad \frac{550}{100},\frac{775}{100},\frac{800}{100}\right] + 3 + \frac{600}{100} = 18$$

$$t_{ship\_A4.3} = t_1 + t_2 = 54.6h$$

<u>Chrysler</u>

<u>Alternative 1</u>

All the shipment from each assembly plant to its allocated dealership is done simultaneity, so the time used for shipping is the maximum one, between all the shipments. The time used in each shipment is:

$$t_1 = \frac{(4+1)\cdot d_{PC1-O1}}{50} = 7.1h$$

$$t_2 = \frac{(1+1)\cdot d_{PC2-O2}}{50} = 0.2h$$

$$t_3 = \frac{(1+1)\cdot d_{PC3-O3}}{50} = 9.04h$$

$$t_4 = \frac{1\cdot d_{PC1-O4}}{50} = 5.92h$$

$$t_5 = \frac{1\cdot d_{PC3-O5}}{50} = 4.08h$$

$$t_{ship\_A1} = MAX[t_1, t_2, t_3, t_4, t_5] = 9.04$$

<u>Alternative 2</u>

The time used per shipping is the sum of the time used in the trunk distribution, t_1 , and the one used in the capillary one, t_2.

All the shipment in the trunk network, and all the shipment in the capillary one, are done simultaneity, so, the time used in each network is the maximum one between all the shipments.

$$t_{PC1-O3} = \frac{(7+1)\cdot d_{PC1-O3}}{50} = 40.8h$$

$$t_{PC2-O3} = \frac{(6+1)\cdot d_{PC2-O3}}{50} = 40.46h$$

$$t_{PC3-O3} = \frac{(2+1)\cdot d_{PC3-O3}}{50} = 13.56h$$

$$t_1 = MAX\ [t_{PC1-O3}, t_{PC2-O3}, t_{PC3-O3}] = 40.8h$$

$$t_{O3-O1} = \frac{(4+1)\cdot d_{O3-O1}}{50} = 18.3h$$

$$t_{O3-O2} = \frac{(1+1) \cdot d_{O3-O2}}{50} = 11.36h$$

$$t_{O3-O4} = \frac{1 \cdot d_{O3-O4}}{50} = 4.86h$$

$$t_{O3-O5} = \frac{1 \cdot d_{O3-O5}}{50} = 2.24h$$

$$t_2 = MAX\ [t_{O3-O1}, t_{O3-O2}, t_{O3-O4}, t_{O3-O5}] = 18.3h$$

$$t_{ship\_A2} = t_1 + t_2 = 59.1$$

Alternative 3

As before, the time used for shipping is the sum of the time used in the trunk network and the one used in the capillary one. The time used in the first part has the same value than in the first part of *Alternative2*, which is 40.8h.

For the second part of the distribution, two alternatives were proposed. In the first one, the capillary distribution is done in a clockwise scheme, while in the other it is done under the same scheme but dividing the studied are in to four subareas. The two options are studied separately.

- *Alternative 3–Option1*

The time used for going from O3 to O5 and from there to O2 is:

$$\frac{1 \cdot d_{O3-O5} + 1 \cdot d_{O5-O2}}{50} = 7.5h$$

At the same time, 1 truck is delivering from O3 to O2, the time used in this operation is:

$$\frac{1 \cdot d_{O3-O2}}{50} = 5.68h$$

So, for delivering to O5 and to O2, the used time is the maximum of the previous ones, so 7.5h. From O2, 1 truck goes to O1, which takes:

$$\frac{1 \cdot d_{O2-O1}}{50} = 5.66h$$

Delivering from O3 to O5 and to O2, and from O3 going to O1 takes 13.16h.

While all the previous shipments are being done, 5 trucks are going from O3 to O1, which takes:

$$\frac{5 \cdot d_{O3-O1}}{50} = 18.3h$$

The time for delivering to O5, O2 and O1 is the maximum between 13.16h and 18.3h, so it is 18.3h. To that time it has to be added the time for going from O1 to O4, which is:

$$\frac{1 \cdot d_{O1-O4}}{50} = 5.94h$$

The time used in the capillary distribution in *Alternative 3-Option1* is:

$$t_2 = 18.3 + 5.94 = 24.24h$$

The total time (trunk and capillary distribution) in *Alternative 3-Option1* is:

$$t_{ship\_A3.1} = t_1 + t_2 = 65.04h$$

- *Alternative3-Option2*

The time used in the capillary distribution of this alternative is:

$$t_2 = MAX\left[1 \cdot d_{O3-O5} , 1 \cdot d_{O3-O4}, MAX[5 \cdot d_{O3-O1} + 1 \cdot d_{O1-O2}, 1 \cdot d_{O3-O2}]\right] = 23.96h$$

$$t_{ship\_A3.2} = t_1 + t_2 = 64.76h$$

Alternative4

The time is composed by the time in the first part of the distribution, plus the time in the second part. The time in the capillary distribution is the same than in the second part of

Alternative2. The time in the first part depends on how the first part in done, and there are two different options.

- Alternative4-Option1

There are three trains (one from each assembly plant) shipping at the same time. The time in the trunk distribution is the maximum between the times used by these trains. Remember that all the routes stop in Chicago Union Station for 3h, and that from there to O3 the distance is 600mi. Remember, that in PC1 there is no train station and the cars assembled there must be transported to Rockford Train Station by truck (7 trucks with capacity for 12 cars and 1 truck with capacity for 8 were necessary, so the time used in the first part of the distribution is:

$$t_1 = MAX\left[\frac{(7+1)\cdot d_{PC1-Rockford}}{50} + \frac{220}{100} + 3 + \frac{600}{100}; \frac{670+600}{100} + 3; \frac{450+600}{100} + 3\right]$$

$$= 15.7h$$

$$t_{ship\_A4.1} = t_1 + t_2 = 34h$$

- Alternative4-Option2

When the all the cars transported by the three trains, arrive to Chicago Union Station, they are distributed in one of the three trains, and from Chicago Union Station this trains go to the hub. So, t_1 is:

$$t_1 = MAX\left[\frac{(7+1)\cdot d_{PC1-Rockford}}{50} + \frac{220}{100}; \frac{670}{100}; \frac{450}{100}\right] + +3 + \frac{600}{100} = 15.7h$$

$$t_{ship\_A4.2} = t_1 + t_2 = 53.6h$$

Once all the times used for shipping in each alternative are calculated, the In-Transit Inventory Cost can be calculated with the formula (34).

Remember that the holding cost used when calculating the In-Transit Inventory Cost in *Alternative1*, is different from the when calculated in *4.2.5.1 Holding Costs*. So, the In-Transit inventory costs for each brand are:

Ford

Alternative 1

$$IC_{IT} = 0.25 \cdot 848{,}640 \cdot \frac{hours\ for\ shipping\ per\ week}{total\ hours\ per\ week} \quad (35)$$

Alternatives 2, 3 and 4

$$IC_{IT} = 0.25 \cdot 1{,}168{,}960 \cdot \frac{hours\ for\ shipping\ per\ week}{total\ hours\ per\ week} \quad (36)$$

Chrysler

Alternative 1

$$IC_{IT} = 0.25 \cdot 611{,}520 \cdot \frac{hours\ for\ shipping\ per\ week}{total\ hours\ per\ week} \quad (37)$$

Alternatives 2, 3 and 4

$$IC_{IT} = 0.25 \cdot 842{,}400 \cdot \frac{hours\ for\ shipping\ per\ week}{total\ hours\ per\ week} \quad (38)$$

Mention that one week has 168h.

The next table contains the Annual In-Transit Inventory Cost in $ for each alternative and for each brand.

	A.1	A.2	A.3.1	A.3.2	A.4.1	A.4.2	A.4.3
Ford	12,881.14	170,125.43	174,091.54	179,971.13	93,238.48	93,238.48	94,978
Chrysler	8,226.40	74,086.07	81,532.28	81,181.28	42,621.43	42,621.43	*

Table 22 In-Transit Inventory Cost

4.2.5.3. Mean Demand Inventory Costs

The Mean Demand Inventory Cost is calculated defined by:

$$IC_{MD} = H \cdot \frac{Q_0}{2} \quad (39)$$

Where H, is the holding cost and Q_0 is the Economic Order Quantity (EOQ) defined as:

$$Q_0 = \sqrt{\frac{2 \cdot C \cdot R}{H}} \quad (40)$$

Where,

C: Order cost, $50 per order

R: Quantity demanded per week (units/week)

H: Unitary holding cost per week ($/unit·week)

In *Alternative 1*, there are five different Economic Order Quantities (one for each dealership), so there are also five different *R* (the number of cars demanded in each dealership).

For the others alternatives, there are as many Economic Order Quantities as the number of assembly plants, so for Ford, there are four Economic Order Quantities, while for Chrysler there are only 3. In order to calculate these Economic Order Quantities it is necessary to know the demanded cars from each dealership in the hub. This demand is calculated as a weighting with the production of the assembly plant (the higher is the production, the higher is the demand of cars from that plant). The number of cars demanded from each plant is:

<u>Ford</u>

Total demand for Ford = 204 cars per week

Total production for Ford =281 cars per week

$$R_{PF1} = 204 \cdot \frac{212}{281} = 153.91 units/week$$

$$R_{PF2} = 204 \cdot \frac{38}{281} = 27.59 units/week$$

$$R_{PF3} = 204 \cdot \frac{15}{281} = 10.89 units/week$$

$$R_{PF4} = 204 \cdot \frac{16}{281} = 11.62 units/week$$

NOTE: 212, 38, 15 and 16 are the number of cars assembled in PF1, PF2, PF3 and PF4 respectively per week.

Chrysler

Total demand for Chrysler = 98 cars per week

Total production for Chrysler =135 cars per week

$$R_{PC1} = 98 \cdot \frac{89}{135} = 64.61 units/week$$

$$R_{PC2} = 98 \cdot \frac{18}{135} = 13.07 units/week$$

$$R_{PC3} = 98 \cdot \frac{28}{135} = 20.33 units/week$$

NOTE: 89, 18 and 28 are the number of cars assembled in PC1, PC2 and PC3 respectively per week.

Once, the number of cars demanded from each plant is known, the EOQ can be calculated with (40), and once these values are calculated the Annual Mean Demand Inventory Cost can be calculated. Next there are two summary tables with all the parameters calculated.

Ford

	A.1	A.2	A.3.1	A.3.2	A.4.1	A.4.2	A.4.3
Demand 1 (units/week)	112	153.91	153.91	153.91	153.91	153.91	153.91
Demand 2 (units/week)	30	27.59	27.59	27.59	27.59	27.59	27.59
Demand 3 (units/week)	35	10.89	10.89	10.89	10.89	10.89	10.89
Demand 4 (units/week)	14	11.62	11.62	11.62	11.62	11.62	11.62
Demand 5 (units/week)	13						
Q1 (units)	11.83	13.87	13.87	13.87	13.87	13.87	13.87
Q2 (units)	6.12	5.87	5.87	5.87	5.87	5.87	5.87
Q3 (units)	6.61	3.69	3.69	3.69	3.69	3.69	3.69
Q4 (units)	4.18	3.81	3.81	3.81	3.81	3.81	3.81
Q5 (units)	4.03						
Annual Mean Demand Inventory Cost, IC_{MD} ($)	68,192.16	56,666.83	56,666.83	56,666.83	56,666.83	56,666.83	56,666.83

Table 23 Annual Mean Demand Inventory Cost for Ford

Chrysler

	A.1	A.2	A.3.1	A.3.2	A.4.1	A.4.2
Demand 1 (units/week)	54	64.61	64.61	64.61	64.61	64.61
Demand 2 (units/week)	14	13.07	13.07	13.07	13.07	13.07
Demand 3 (units/week)	17	20.33	20.33	20.33	20.33	20.33
Demand 4 (units/week)	7					
Demand 5 (units/week)	6					
Q1 (units)	6.71	7.34	7.34	7.34	7.34	7.34
Q2 (units)	3.41	3.30	3.30	3.30	3.30	3.30
Q3 (units)	3.76	4.12	4.12	4.12	4.12	4.12
Q4 (units)	2.42					
Q5 (units)	2.24					
Annual Mean Demand Inventory Cost, IC_{MD} ($)	57,841.73	46,032.37	46,032.37	46,032.37	46,032.37	46,032.37

Table 24 Annual Mean Demand Inventory Cost for Chrysler

For a better comprehension about how the warehousing costs have been calculated see *Table 65* and *Table 66* in the *Annex*.

4.3. Data Analysis

All the cost for shipping by truck, for shipping by train and for warehousing are already calculated for each alternative. Studying the three costs jointly, the total annual costs for each alternative are:

	A.1	A.2	A.3.1	A.3.2
Ford	2,328,655.61	4,251,756.75	4,350,566.56	4,301,938.95
Chrysler	1,489,650.12	2,566,191.42	2,691,156.21	2,611,158.66

Table 25 Total Annual Cost for shipping and Warehousing. Alternatives 1,2 and 3

	A.4.1	A.4.2	A.4.3
Ford	1,099,396,556	1,668,128,876	1,651,977,796
Chrysler	1,115,611,945	1,115,611,945	*

Table 26 Total Annual Cost for shipping and Warehousing. Alternatives 4

Remember that, a fifth alternative is also proposed in *3.2. Methodology Descriptions*. This alternative is a combination between *Alternative 3* and *Alternative 4*, which have two and three subalternatives. Once the costs for these subalternatives are calculated it is time to decide which subalternative is better, so which subalternative is the one that will be involved in *Alternative 5*. This decision is studied separately for Ford and Chrysler.

Ford

Option 1 and *Option* 2 in *Alternative 3* are done in the same way; the difference is in the second part of the distribution. The option that has a lower total cost is the one that has a minimum cost in the second part of the distribution. This option is the second one, where the capillary distribution is done by zones.

Within the three options in *Alternative 4*, the ones with minimal cost is *Option 1*. As before, for deciding which of these options is the one that has to be used in Alternative 5, the cost that would be necessary to know is the one in the trunk distribution, however in the second part of the distribution the three alternatives work in the same way, so they will have the same costs, and that is why it is correct to decide with the total cost instead of the one in the first part of the distribution.

The costs in *Alternative 5* are explained as next:

The costs in the first and in the second part of the distribution are calculated with *Microsoft Excel*. The first part of the distribution is done by a train from each assembly plant, so the cost is the one obtained for trains costs in Alternative 4-Option1, which is $1,097,006,040 per year.

The cost in the second part of the distribution is the cost in the second part of *Alternative3-Option2*. This cost is calculated with *Microsoft Excel*, and its value is $1,111,986.89 per year.

About the warehousing cost, it has to be calculated the time used per shipping in one week, in order to calculate the In-Transit Inventory Cost. This time is the sum of the time used in the trunk distribution (17h) and the time used in the capillary one (42.26h), so it is 59.26h per week. The time used for shipping is the only parameter that changes between Alternative 2, 3,4 and 5. So having calculated this, the total warehousing cost (Holding, In-Transit Inventory and Mean Demand) is $1,328,711.01per year.

Chrysler

Within the two options in *Alternative 3*, the one with minimal cost is the second one, as the first part of the distribution is done in the same way for both options, which means that the second part of the distribution has a minimal cost in *Option 2*.

The two options in Alternative 4 have the same cost, but the one that is chosen for taking part in Alternative 5 is the second one, because there are fewer trains involved.

The costs in *Alternative 5* are explained as next:

The trunk distribution is done as in *Alternative4-Option2*, so the cost is the trains cost in this alternative ($1,115,611,945 per year) plus the cost of the trucks that go from PC1 to Rockford Train Station ($459,824.14).

The capillary distribution is done as in *Alternative3-Option2*, so the cost is the one in the second part of the distribution. It is calculated with *Microsoft Excel* and its value is $624,859.51

For the warehousing cost, the only parameter that differs from Alternative 2, 3 and 4 is the time used for shipping in one week. This time is the sum of the time used in the trunk network (15.7h) and the time used in the capillary network (23.96h), and it is 39.66h. Both times, the one used in the first part and the one used in the second part are calculated in *4.2.5.2. In-Transit Inventory Cost*.

Once the costs in Alternative 5 are calculated it is time to decide one of the five alternatives is the one with minimal cost for each brand. At first, the comparison is done by the three blocks in the total cost: Trucks, Trains and Warehousing. The next tables show the results that have been obtained.

Annual Trucks Costs

	A.1	A.2	A.3.1	A.3.2
Ford	1,078,622.31	2,856,004.49	2,950,848.19	2,896,340.99
Chrysler	581,181.99	1,603,672.97	1,721,191.55	1,641,544.99

Table 27 Annual Trucks Costs. Alternatives 1,2 and 3

	A.4.1	A.4.2	A.4.3	A.5
Ford	1,071,650.40	1,071,650.40	2,065,571.49	1,111,986.89
Chrysler	1,046,811.63	1,046,811.63	*	1,084,683.56

Table 28 Annual Trucks Costs. Alternatives 4 and 5

For Ford, the alternatives with minimal cost are *Alternative4-Option1* and *Alternative4-Option2*. This result was expected because in Alternative 4, the trunk distribution is done strictly by train, which means that no truck is shipping in that part. About the capillary distribution it is observed, that the one done in a centralized scheme has a lower cost than the one done under clockwise delivery, which explains that the cost in *Alternative 5* is higher than the one in *Alternative4-Option1* and *Alternative4-Option2*.

For Chrysler, the alternative with minimal cost is the first one. In contradiction to what happens for Ford, the alternatives where trains are used in the trunk distribution are not the cheapest ones, but the second cheapest one. As before, the capillary distribution has a lower cost when is done under a clockwise scheme, than when is done under a centralized one.

<u>Annual Trains Costs</u>

	A.1	A.2	A.3.1	A.3.2	A.4.1	A.4.2	A.4.3	A.5
Ford	*	*	*	*	1,097,006,040	1,665,738,360	1,648,591,620	1,097,006,040
Chrysler	*	*	*	*	1,113,634,080	1,113,634,080	*	1,113,634,080

Table 29 Annual Trains Costs for each alternative

For Ford, within the four alternatives that use trains in the trunk distribution, the ones with lowest cost are *Alternative4-Option1* and *Alternative 5*. These results were not expected, because these two options require a higher number trains working. The reason of this happening is explained in the point *4.4. Discussions*.

For Chrysler the three proposals have the same cost, and as before this result was not expected because *Alternative4-Option2* and *Alternative 5* do not need as many trains as *Alternative4-Option1* does.

<u>Annual Warehousing Costs</u>

	A.1	A.2	A.3.1	A.3.2
Ford	1,250,033.30	1,395,752.26	1,399,718.37	1,405,597.96
Chrysler	908,468.13	962,518.45	969,964.66	969,613.66

Table 30 Annual Warehousing Costs. Alternatives 1,2 and 3

	A.4.1	A.4.2	A.4.3	A.5
Ford	1,318,865.31	1,318,865.31	1,320,604.83	1,328,711.01
Chrysler	931,053.80	931,053.80	*	938,149.02

Table 31 Annual Warehousing Costs. Alternatives 4 and 5

The difference between the Warehousing Costs is because of the In-Transit Inventory Cost, it is the only cost that differs in each alternative. The rest of the Warehousing Costs have the same values in each alternative.

It was already expected that the alternative with minimal Warehousing Cost was the first one for both, Ford and Chrysler, because the time used for the shipping in this alternative is much lower than the time used in the others ones, where the distribution is composed by two parts, and the second part cannot start until the first ones finishes. The second cheapest alternatives are for both brands, *Alternative4-Option1* and *Alternative4-Option2*, that is because the time used in shipping by train in lower than the time used by truck. As before, the costs where the capillary distribution is done in a centralized scheme are lower than when it is done in a clockwise delivery scheme.

What is done next is to calculate the percentage of the Trucks Costs, Trains Costs and Warehousing Costs on the total by brand, in order to know which item is the most influent one. These percentages on the total cost are in the next two tables.

Ford

	A.1	A.2	A.3.1	A.3.2	A.4.1	A.4.2	A.4.3	A.5
Tucks Cost	46.32	67.17	67.83	67.33	0.05	0.06	0.13	0.10
Trains Cost	0.00	0.00	0.00	0.00	99.78	99.86	99.79	99.78
Warehousing Cost	53.68	32.83	32.17	32.67	0.12	0.08	0.05	0.12

Table 32 Percentage of each item on the total cost for Ford

Chrysler

	A.1	A.2	A.3.1	A.3.2	A.4.1	A.4.2	A.4.3	A.5
Tucks Cost	39.01	62.49	63.96	62.87	0.09	0.09	*	0.10
Trains Cost	0.00	0.00	0.00	0.00	99.82	99.82	*	99.82
Warehousing Cost	60.98	37.51	36.04	37.13	0.08	0.08	*	0.08

Table 33 Percentage of each item on the total cost for Chrysler

Until now, the costs have studied separately in the three blocks that composed them. It is the moment for studying the three blocks jointly, and deciding which of the proposed alternatives are the ones with minimum cost for both The next table summarizes the total annual cost in $ per year of each alternative. This cost is the sum of trucks costs, trains cost and warehousing cost.

	A.1	A.2	A.3.1	A.3.2
Ford	2,328,655.61	4,251,756.75	4,350,566.56	4,301,938.95
Chrysler	1,489,650.12	2,566,191.42	2,691,156.21	2,611,158.66

Table 34 Total Annual Cost Alternatives 1,2 and 3

	A.4.1	A.4.2	A.4.3	A.5
Ford	1,099,396,556	1,668,128,876	1,651,977,796	1,099,446,738
Chrysler	1,115,611,945	1,115,611,945	*	1,115,656,913

Table 35 Total Annual Cost Alternatives 4 and 5

Observing the table it is possible to see that for Ford the alternative that has a minimum cost is *Alternative 1*, followed by *Alternative 2*.

For Chrysler the option with minimum cost is *Alternative 1*, and again, the second alternative with minimum cost is *Alternative 2*.

4.4. Discussions

The alternatives with minimal cost are already chosen. For the two brands these alternatives are *Alternative 1*, where the distribution is done directly from each assembly plant to its nearest dealership. For both brands, the most influential item on the total cost for *Alternative 1* is the Warehousing Cost. The second alternative with minimal cost is for both brands *Alternative 2,* where the distribution is done in two parts, both done by truck. In that case, the most influential is the cost of the trucks instead of the one for warehousing.

About the alternatives where the first part of the distribution is done by train (*Alternative 4* and *Alternative 5*) it must be said, that these are the ones used in the real world. The explanation about the fact that these alternatives are the most expensive ones is because when calculating the cost, it has been done with a formula that relates cost with weight and travelled distance per shipment. That means that this cost is a variable one. In the real world, fixed costs must also be considered. In that case, the number of trucks in the fleet and the number of trains that take part in the process would affect to the total cost.

Another point to discuss about, are the theoretical Economic Order Quantities, obtained in *4.2.5.3. Mean Demand Inventory Cost*. When transporting the cars from the plants to the hub by train the Economic Order Quantities obtained are much lower than the load capacity of trains. That means that if working in the optimal point, the trains would have to transport under their capacity and do more shipments, instead of shipping with their load capacity completed and doing only one shipment. This contradiction needs a more refined analysis.

CHAPTER 5

SUMMARY AND CONCLUSIONS

This study has conducted an analysis of different possible methods for distributing new vehicles, from assembly plants of two well-known brands to five dealerships located in five major cities in Great Lake Area of the United States, in order to choose the one with minimal distribution and warehousing costs.

After being informed about how different distribution strategies applied nowadays work and where is the tendency pointing to, five alternatives have been presented.

It has been valued the costs for these alternatives, being these costs composed by three items: trucks, trains and warehousing. The costs calculations have been done with different formulas that relate these costs with weight and travelled distance per shipment, so the evaluation has been done only for variable costs.

The results have proved that in contradiction to what actually happens in the real world, the alternative with the minimal warehousing and distribution cost is the one where the new vehicles are directly delivered from the assembly plant to the nearest dealership. In the real world, after leaving the assembly plant the new vehicles go through different consolidation centers, called ramps. The explanation about the difference between what happens in the real world and the results obtained in the project could be find in the fact that the geographical studied area is not as huge as for having different ramps where storing the vehicles in. Another possible explanation is about the way the costs have been calculated. As said in *4.4. Discussions, the costs calculated in this project are* variable costs, and in the real world, fixed costs are also considered. It has been observed that the alternatives with a highest cost are the ones with a fewer number of trucks in the fleet and a fewer number on trains. That means that if not just variables costs, but also the fixed ones had been considered these alternatives could have had a lower global cost (variable and fixed).

About future research directions, they might be focused on the Warehousing Costs, which have not been deeply studied in this project. When calculating them, an unexpected result with the Economic Order Quantities when distributing by train have been obtained. According to the obtained results it has a lower cost to deliver a major number of trains working under their load capacity, than deliver with lowest number of trains working at 100% of their load capacity.

Finally, another point to be mentioned is the possibility of simulating the behavior of the different alternatives with a specific Software. This practice could also be deeply analyzed in future research.

ANNEX

CHAPTER 1

INTRODUCTION

CHAPTER 2

LITERATURE REVIEW

2.1. Transportation Logistics Problems

2.2. Transportation Modes

2.3. Alternative Distribution Strategies

2.4. Real World Applications

Automobile Delivery in the USA

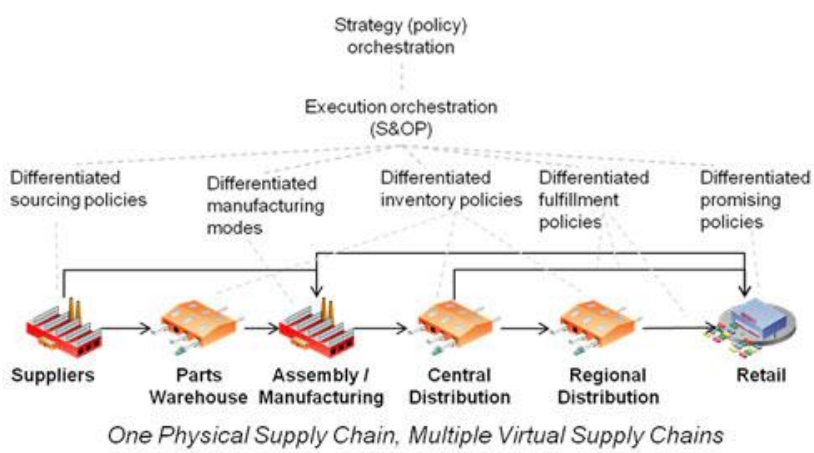

Figure 18 Supply chain scheme in Automotive Industry

Ford Motor Company’s finished vehicle distribution system in final 90’s

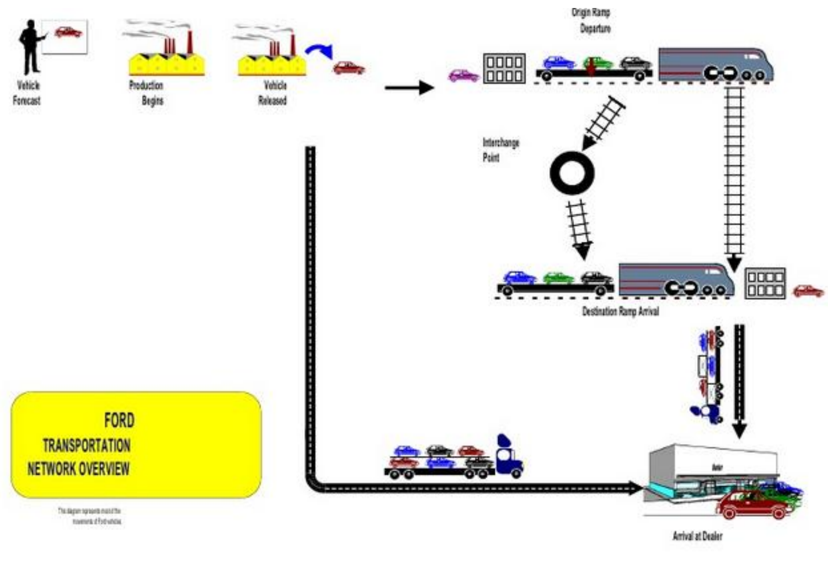

Figure 19 Cross-docking system

Of the Many-to-Many Distribution System in Barcelona

Company Name	Freigh Flow (tones/day)	Number of warehouses	Location
TDN	350	1	CIM Vallés
INTEGRA2	400	1	Pallejà
AZKAR	500	3	CIM Vallés
STD	125	1	Hospitalet

Table 36 Number of warehouses depending on freight flow for real companies in the Metropolitan Area of Barcelona (Spain)

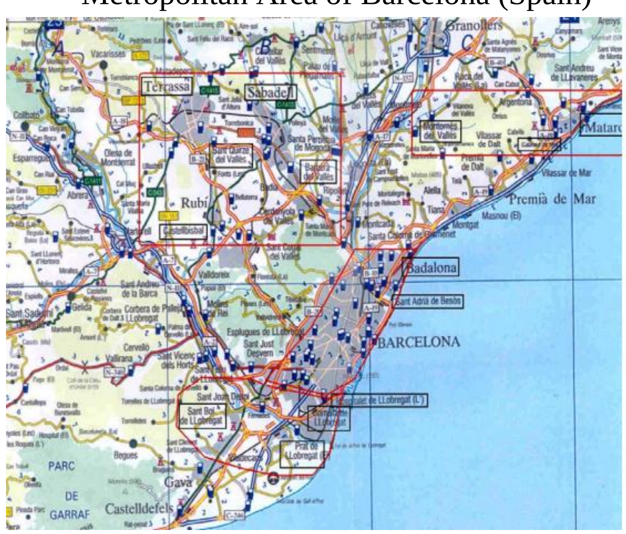

Figure 20 Division of the territory. Four sub zones

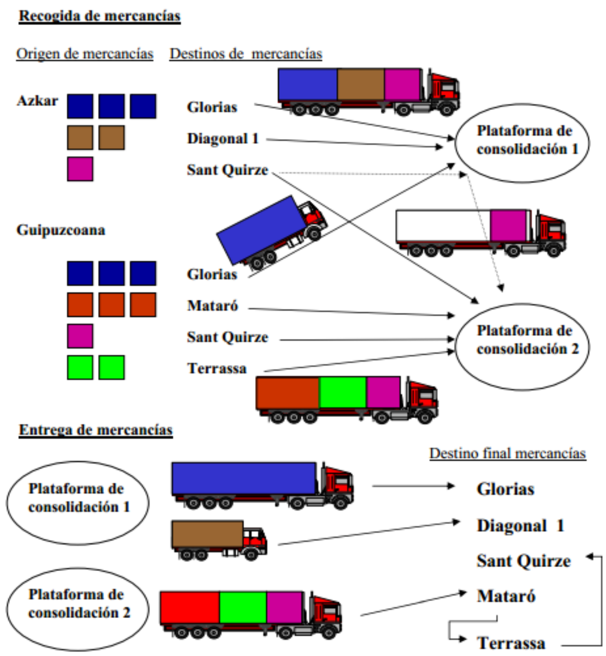

Figure 21 A) Distribution with two warehouses. The freight of a certain number of sources is transported to the Warehouse 1 and the rest to the Warehouse 2.

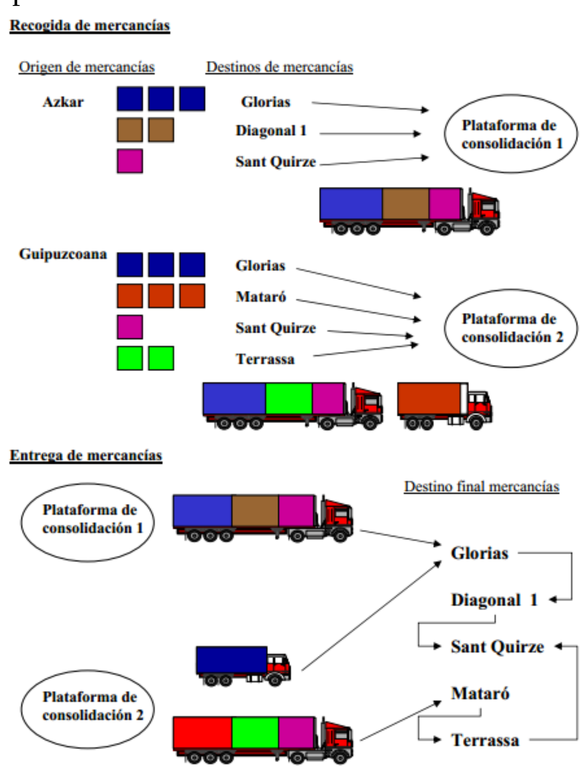

Figure 22 B) Distribution with two Distribution Centers. The freight of a certain number of destinations goes to Warehouse 1 and the rest to Warehouse 2

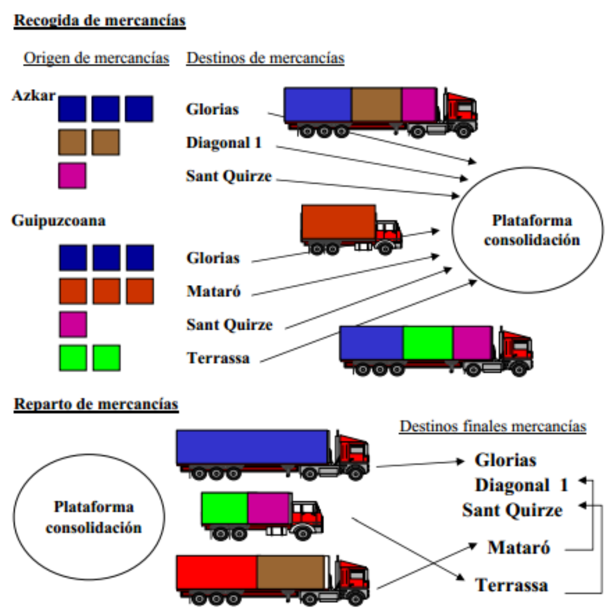

Figure 23 Distribution with one Distribution Center

CHAPTER 3

PROPOSED METHODOLOGY

3.1. General

3.2. Methodology Descriptions

CHAPTER 4

METHODOLOGY APPLICATION

4.1. General

4.2. Data collection and Processing

4.2.1. Demand and Production Data

4.2.2. Supply Data

4.2.3. Trucks Costs

4.2.3.1. Ford Auto Distribution Alternatives

Alternative 1

Number of trucks	1	1	1	1	9
Number of cars loaded	4	6	1	2	12
Travelled distance (mi)	20	27	240	252	20
Shipment cost ($/week)	512.23	680.99	251.68	417.10	9,685.96
Annual shipment cost ($)	26,635.94	35,411.72	13,087.47	21,689.47	503,670.12

Table 37 Ford trucks Costs Alternative 1

Number of trucks	2	1	2	1	1
Number of cars loaded	12	11	12	12	12
Travelled distance (mi)	170	170	27	240	252
Shipment cost ($/week)	2,723.32	1,279.80	2,179.08	1,494.86	1,517.70
Annual shipment cost ($)	141,612.48	66,549.81	113,312.03	77,732.92	78,920.35

Table 38 Ford trucks Costs Alternative 1

TOTAL ANNUAL COST ($)	1,078,622.31

Alternative 2

Trunk Distribution

Number of trucks	17	3	1	1	1	1	1	1
Number of cars loaded	12	12	12	12	8	2	3	4
Travelled distance (mi)	170	274	309	486	170	274	309	486
Shipment cost ($/week)	23,148.19	4,678.69	1,626.17	1,962.99	1,020.38	426.23	591.07	860.77
Annual shipment cost ($)	1,203,706.05	243,291.93	84,560.65	102,075.30	53,059.95	22,164.17	30,735.89	44,760.19
TOTAL ANNUAL COST ($)	1,784,354.09							

Table 39 Ford Trucks Costs Alternative 2-Trunk Distribution

Capillary Distribution

Number of trucks	9	2	1	1	1	1	1	1
Number of cars loaded	12	12	12	12	4	6	2	1
Travelled distance (mi)	183	284	243	112	183	284	243	112
Shipment cost ($/week)	12,477.57	3,157.19	1,500.57	1,251.29	634.15	952.31	413.37	222.21
Annual shipment cost ($)	648,833.60	164,173.70	78,029.78	65,066.99	32,975.54	49,520.35	21,495.28	11,555.20
TOTAL ANNUAL COST ($)	1,071,650.40							

Table 40 Ford Trucks Costs Alternative 2-Capillary Distribution

Alternative 3.1.

Trunk Distribution

Number of trucks	17	3	1	1	1	1	1	1
Number of cars loaded	12	12	12	12	8	2	3	4
Travelled distance (mi)	170	274	309	486	170	274	309	486
Shipment cost ($/week)	23,148.19	4,678.69	1,626.17	1,962.99	1,020.38	426.23	591.07	860.77
Annual shipment cost ($)	1,203,706	243,291.90	84,560.65	102,075.30	53,059.95	22,164.17	30,735.89	44,760.19
TOTAL ANNUAL COST ($)	1,784,354.09							

Table 41 Ford Trucks Costs Alternative 3-Option1-Trunk Distribution

Capillary Distribution

Number of trucks	2	1	2	1	9	1	1	1
Number of cars loaded	12	11	12	5	12	1	12	1
Travelled distance (mi)	112	263	284	283	183	297	243	243
Shipment cost ($/week)	2,502.58	1,444.16	3,157.19	833.34	12,477.57	264.80	1,500.57	252.37
Annual shipment cost ($)	130,133.97	75,096.34	164,173.70	43,333.55	648,833.60	13,769.80	78,029.78	13,123.38
TOTAL ANNUAL COST ($)	1,166,494.09							

Table 42 Ford Trucks Costs Alternative 3-Option1-Capillary Distribution

Alternative 3.2.

Trunk Distribution

Number of trucks	17	3	1	1	1	1	1	1
Number of cars loaded	12	12	12	12	8	2	3	4
Travelled distance (mi)	170	274	309	486	170	274	309	486
Shipment cost ($/week)	23,148.19	4,678.69	1,626.17	1,962.99	1,020.38	426.23	591.07	860.77
Annual shipment cost ($)	1,203,706	243,291.90	84,560.65	102,075.30	53,059.95	22,164.17	30,735.89	44,760.19
TOTAL ANNUAL COST ($)	1,784,354.09							

Table 43 Ford Trucks Costs Alternative 3-Option2-Trunk Distribution

Capillary Distribution

Number of trucks	10	1	1	1	1	1	1
Number of cars loaded	12	8	12	10	12	1	2
Travelled distance (mi)	183	283	284	284	243	112	243
Shipment cost ($/week)	13,863.97	1,172.73	1,578.59	1,381.63	1,500.57	222.22	413.37
Annual shipment cost ($)	720,926.20	60,981.83	82,086.84	71,844.77	78,029.78	11,555.20	21,495.28
TOTAL ANNUAL COST ($)	1,111,986.89						

Table 44 Ford Trucks Costs Alternative 3-Option2-Capillary Distribution

Alternative 4.1

Capillary Distribution

Number of trucks	9	2	1	1	1	1	1	1
Number of cars loaded	12	12	12	12	4	6	2	1
Travelled distance (mi)	183	284	243	112	183	284	243	112
Shipment cost ($/week)	12,477.57	3,157.19	1,500.57	1,251.29	634.15	952.31	413.37	222.22
Annual shipment cost ($)	648,833.60	164,173.70	78,029.78	65,066.99	32,975.54	49,520.35	21,495.28	11,555.20
TOTAL ANNUAL COST ($)								1,071,650.40

Table 45 Ford Trucks Costs Alternative 4-Option1-Capillary Distribution

Alternative 4.2

Capillary Distribution

Number of trucks	9	2	1	1	1	1	1	1
Number of cars loaded	12	12	12	12	4	6	2	1
Travelled distance (mi)	183	284	243	112	183	284	243	112
Shipment cost ($/week)	12,477.57	3,157.19	1,500.57	1,251.29	634.15	952.31	413.37	222.22
Annual shipment cost ($)	648,833.60	164,173.70	78,029.78	65,066.99	32,975.54	49,520.35	21,495.28	11,555.20
TOTAL ANNUAL COST ($)	1,071,650.40							

Table 46 Ford Trucks Costs Alternative 4-Option2-Capillary Distribution

Alternative 4.3

Trunk Distribution

Number of trucks	17	1
Number of cars loaded	12	8
Travelled distance (mi)	20	20
Shipment cost ($/week)	18,295.71	818.16
Annual shipment cost ($)	951,376.90	42,544.19
TOTAL ANNUAL COST ($)	993,921.09	

Table 47 Ford Trucks Costs Alternative 4-Option3-Trunk Distribution

Capillary Distribution

Number of trucks	9	2	1	1	1	1	1	1
Number of cars loaded	12	12	12	12	4	6	2	1
Travelled distance (mi)	183	284	243	112	183	284	243	112
Shipment cost ($/week)	12,477.57	3,157.19	1,500.57	1,251.29	634.15	952.31	413.37	222.22
Annual shipment cost ($)	648,833.60	164,173.70	78,029.78	65,066.99	32,975.54	49,520.35	21,495.28	11,555.20
TOTAL ANNUAL COST ($)	1,071,650.40							

Table 48 Ford Trucks Costs Alternative 4-Option3-Capillary Distribution

Alternative 5

Capillary Distribution

Number of trucks	10	1	1	1	1	1	1	1
Number of cars loaded	12	8	12	10	12	12	1	2
Travelled distance (mi)	183	283	284	284	243	112	112	243
Shipment cost ($/week)	13,863.97	1,172.73	1,578.59	1,381.63	1,500.57	1,251.29	222.21	413.37
Annual shipment cost ($)	720,926.20	60,981.83	82,086.84	71,844.77	78,029.78	65,066.99	11,555.20	21,495.28
TOTAL ANNUAL COST ($)	1,111,986.89							

Table 49 Ford Trucks Costs Alternative 5-Capillary Distribution

4.2.3.2. Chrysler Auto Distribution Alternatives

Alternative 1

Number of trucks	4	1	1	1	1	1	1
Number of cars loaded	12	12	12	6	2	5	7
Travelled distance (mi)	71	5	226	71	5	226	296
Shipment cost ($/week)	5,180.83	1,153.37	1,628.31	802.80	346.33	866.34	1,198.60
Annual shipment cost ($)	269,403.10	59,975.18	84,672.24	41,745.48	18,009.16	45,049.52	62,327.31
TOTAL ANNUAL COST ($)							581,181.99

Table 50 Chrysler Trucks Costs Alternative 1

Alternative 2

Trunk Distribution

Number of trucks	7	1	2	1	1	1
Number of cars loaded	12	12	12	5	6	4
Travelled distance (mi)	255	289	226	255	289	226
Shipment cost ($/week)	11,834.45	1,763.70	3,256.62	895.95	1,062.71	738.21
Annual shipment cost ($)	615,391.23	91,712.58	16,9344.48	46,589.35	55,261.03	38,386.80
TOTAL ANNUAL COST ($)						1,016,685.48

Table 51 Chrysler Trucks Costs Alternative 2-Trunk Distribution

Capillary Distribution

Number of trucks	4	1	1	1	1	1
Number of cars loaded	12	12	6	2	7	6
Travelled distance (mi)	183	284	183	284	243	112
Shipment cost ($/week)	6,143.61	1,752.96	936.33	477.08	1,126.56	851.68
Annual shipment cost ($)	319,467.70	91,153.82	48,689.25	24,807.90	58,581.39	44,287.39
TOTAL ANNUAL COST ($)	586,987.49					

Table 52 Chrysler Trucks Costs Alternative 2-Capillary Distribution

Alternative 3.1.

Trunk Distribution

Number of trucks	7	1	2	1	1	1
Number of cars loaded	12	12	12	5	6	4
Travelled distance (mi)	255	289	226	255	289	226
Shipment cost ($/week)	11,834.45	1,763.70	3,256.62	895.95	1,062.71	738.21
Annual shipment cost ($)	615,391.23	91,712.58	16,9344.48	46,589.35	55,261.03	38,386.80
TOTAL ANNUAL COST ($)	1,016,685.48					

Table 53 Chrysler Trucks Costs Alternative3-Option1-Trunk Distribution

Capillary Distribution

Number of trucks	1	1	1	1	4	1	1
Number of cars loaded	12	6	12	4	12	9	7
Travelled distance (mi)	112	263	284	283	183	183	297
Shipment cost ($/week)	1,383.32	1,031.71	1,752.96	786.36	6,143.61	1,250.28	1,199.96
Annual shipment cost ($)	71,932.58	53,649.09	91,153.82	40,890.46	319,467.70	65,014.40	62,397.98
TOTAL ANNUAL COST ($)	704,506.07						

Table 54 Chrysler Trucks Costs Alternative3-Option1-Capillary Distribution

Alternative 3.2.

Trunk Distribution

Number of trucks	7	1	2	1	1	1
Number of cars loaded	12	12	12	5	6	4
Travelled distance (mi)	255	289	226	255	289	226
Shipment cost ($/week)	11,834.45	1,763.70	3,256.62	895.95	1,062.71	738.21
Annual shipment cost ($)	615,391.23	91,712.58	16,9344.48	46,589.35	55,261.03	38,386.80
TOTAL ANNUAL COST ($)	1,016,685.48					

Table 55 Chrysler Trucks Costs Alternative3-Option2-Trunk Distribution

Capillary Distribution

Number of trucks	5	1	1	1	1
Number of cars loaded	12	6	8	6	7
Travelled distance (mi)	183	283	284	112	243
Shipment cost ($/week)	7,679.50	1,055.56	1,303.21	851.68	1,126.57
Annual shipment cost ($)	399,334.70	54,889.05	67,767.02	44,287.39	58,581.39
TOTAL ANNUAL COST ($)	624,859.51				

Table 56 Chrysler Trucks Costs Alternative3-Option2-Capillary Distribution

Alternative 4.1

Trunk Distribution

Number of trucks	7	1
Number of cars loaded	12	5
Travelled distance (mi)	13	13
Shipment cost ($/week)	8,193.93	648.84
Annual shipment cost ($)	426,084.40	33,739.77
TOTAL ANNUAL COST ($)	459,824.14	

Table 57 Chrysler Trucks Costs Alternative4-Option1-Trunk Distribution

Capillary Distribution

Number of trucks	4	1	1	1	1	1
Number of cars loaded	12	12	6	2	7	6
Travelled distance (mi)	183	284	183	284	243	112
Shipment cost ($/week)	6,143.61	1,752.96	936.33	477.08	1,126.57	851.68
Annual shipment cost ($)	319,467.70	91,153.82	48,689.25	24,807.90	58,581.39	44,287.39
TOTAL ANNUAL COST ($)	586,987.49					

Table 58 Chrysler Trucks Costs Alternative4-Option1-Capillary Distribution

Alternative 4.2

Trunk Distribution

Number of trucks	7	1
Number of cars loaded	12	5
Travelled distance (mi)	13	13
Shipment cost ($/week)	8,193.93	648.84
Annual shipment cost ($)	426,084.40	33,739.77
TOTAL ANNUAL COST ($)	459,824.14	

Table 59 Chrysler Trucks Costs Alternative4-Option2-Trunk Distribution

Capillary Distribution

Number of trucks	4	1	1	1	1	1
Number of cars loaded	12	12	6	2	7	6
Travelled distance (mi)	183	284	183	284	243	112
Shipment cost ($/week)	6,143.61	1,752.96	936.33	477.08	1,126.57	851.68
Annual shipment cost ($)	319,467.70	91,153.82	48,689.25	24,807.90	58,581.39	44,287.39
TOTAL ANNUAL COST ($)	586,987.49					

Table 60 Chrysler Trucks Costs Alternative4-Option2-Capillary Distribution

Alternative 5

Trunk Distribution

Number of trucks	7	1
Number of cars loaded	12	5
Travelled distance (mi)	13	13
Shipment cost ($/week)	8,193.93	648.84
Annual shipment cost ($)	426,084.40	33,739.77
TOTAL ANNUAL COST ($)	459,824.14	

Table 61 Chrysler Trucks Costs Alternative5-Trunk Distribution

Capillary Distribution

Number of trucks	5	1	1	1	1
Number of cars loaded	12	6	8	6	7
Travelled distance (mi)	183	283	284	112	243
Shipment cost ($/week)	7,679.50	1,055.56	1,303.21	851.68	1,126.57
Annual shipment cost ($)	399,334.70	54,889.05	67,767.02	44,287.39	58,581.39
TOTAL ANNUAL COST ($)	624,859.51				

Table 62 Chrysler Trucks Costs Alternative5-Capillary Distribution

4.2.4. Trains Costs

4.2.4.1. Ford Auto Distribution Alternatives

Alternative 4.1.

number of cars loaded 1st	89	38	15	16
number of cars loaded 2nd	89	38	15	16
distance 1st (mi/week)	25	550	775	800
distance 2nd (mi/week)	600	600	600	600
shipment cost ($/week)	8,243,625	6,476,340	3,056,625	3,319,680
annual shipment cost ($/week)	428,668,500	336,769,680	158,944,500	172,623,360
TOTAL ANNUAL COST ($)	1,097,006,040			

Table 63 Ford Trains Cost Alternative 4-Option1

Alternative 4.2.

number of cars loaded 1st	89	38	15	16
number of cars loaded 2nd	0	0	140	141
distance 1st (mi/week)	25	550	775	800
distance 2nd (mi/week)	600	600	600	600
shipment cost ($/week)	329,745	3,097,380	14,171,625	14,434,680
annual shipment cost ($/week)	17,146,740	161,063,760	736,924,500	750,603,360
TOTAL ANNUAL COST ($)	1,665,738,360			

Table 64 Ford Trains Cost Alternative 4-Option2

Alternative 4.3.

number of cars loaded 1st	38	15	16
number of cars loaded 2nd	0	140	141
distance 1st (mi/week)	550	775	800
distance 2nd (mi/week)	600	600	600
shipment cost ($/week)	3,097,380	14,171,625	14,434,680
annual shipment cost ($/week)	161,063,760	736,924,500	750,603,360
TOTAL ANNUAL COST ($)	1,648,591,620		

Table 65 Ford Trains Cost Alternative 4-Option3

Alternative 5

number of cars loaded 1st	89	38	15	16
number of cars loaded 2nd	89	38	15	16
distance 1st (mi/week)	25	550	775	800
distance 2nd (mi/week)	600	600	600	600
shipment cost ($/week)	8,243,625	6,476,340	3,056,625	3,319,680
annual shipment cost ($/week)	428,668,500	336,769,680	158,944,500	172,623,360
TOTAL ANNUAL COST ($)	1,097,006,040			

Table 66 Ford Trains Cost Alternative 5

4.2.4.2. Chrysler Auto Distribution Alternatives

Alternative 4.1.

number of cars loaded 1st	89	18	28
number of cars loaded 2nd	89	18	28
distance 1st (mi/week)	220	670	450
distance 2nd (mi/week)	600	600	600
shipment cost ($/week)	12,479,580	3,909,060	5,027,400
annual shipment cost ($/week)	648,938,160	203,271,120	261,424,800
TOTAL ANNUAL COST ($)	1,113,634,080		

Table 67 Chrysler Trains Cost Alternative 4-Option1

Alternative 4.2.

number of cars loaded 1st	89	18	28
number of cars loaded 2nd	0	0	135
distance 1st (mi/week)	220	670	450
distance 2nd (mi/week)	600	600	600
shipment cost ($/week)	3,348,180	2,062,260	16,005,600
annual shipment cost ($/week)	174,105,360	107,237,520	832,291,200
TOTAL ANNUAL COST ($)			1,113,634,080

Table 68 Chrysler Trains Cost Alternative 4-Option2

Alternative 5

number of cars loaded 1st	89	18	28
number of cars loaded 2nd	0	0	135
distance 1st (mi/week)	220	670	450
distance 2nd (mi/week)	600	600	600
shipment cost ($/week)	3,348,180	2,062,260	16,005,600
annual shipment cost ($/week)	174,105,360	107,237,520	832,291,200
TOTAL ANNUAL COST ($)			1,113,634,080

Table 69 Chrysler Trains Cost Alternative 5

4.2.5. Warehousing Costs

4.2.5.1. Ford Auto Distribution Alternatives

	ALT.1	ALT.2	ALT.3.1	ALT.3.2
Hford ($/unit·week)	80	80	80	80
Total Production Ford (unit/week)	281	281	281	281
Holding Cost, HC, ($/year)	1,168,960	1,168,960	1,168,960	1,168,960
Time shipping per week (hours/week)	10.20	97.80	100.08	103.46
In Transit Inventory Cost, ICIT($/year)	12,881.14	170,125.43	174,091.54	179,971.13
Demand 1 (units/week)	112	153.91	153.91	153.91
Demand 2 (units/week)	30	27.59	27.59	27.59
Demand 3 (units/week)	35	10.89	10.89	10.89
Demand 4 (units/week)	14	11.62	11.62	11.62
Demand 5 (units/week)	13			
Q1 (units)	11.83	13.87	13.87	13.87
Q2 (units)	6.12	5.87	5.87	5.87
Q3 (units)	6.61	3.69	3.69	3.69
Q4 (units)	4.18	3.81	3.81	3.81
Q5 (units)	4.03			
Mean Demand Inventory Cost, ICMD ($/year)	68,192.16	56,666.83	56,666.83	56,666.83
Ford Warehousing Cost ($/year)	1,250,033.30	1,395,752.26	1,399,718.37	1,405,597.96

Table 70 Ford Warehousing Costs. Alternatives 1,2 and 3.

	ALT.4.1	ALT.4.2	ALT.4.3	ALT.5
Hford ($/unit·week)	80	80	80	80
Total Production Ford (unit/week)	281	281	281	281
Holding Cost, HC, ($/year)	1,168,960	1,168,960	1,168,960	1,168,960
Time shipping per week (hours/week)	53.60	53.60	54.60	59.26
In Transit Inventory Cost, ICIT($/year)	93,238.48	93,238.48	94,978	103,084.18
Demand 1 (units/week)	153.91	153.91	153.91	153.91
Demand 2 (units/week)	27.59	27.59	27.59	27.59
Demand 3 (units/week)	10.89	10.89	10.89	10.89
Demand 4 (units/week)	11.62	11.62	11.62	11.62
Demand 5 (units/week)				
Q1 (units)	13.87	13.87	13.87	13.87
Q2 (units)	5.87	5.87	5.87	5.87
Q3 (units)	3.69	3.69	3.69	3.69
Q4 (units)	3.81	3.81	3.81	3.81
Q5 (units)				
Mean Demand Inventory Cost, ICMD ($/year)	56,666.83	56,666.83	56,666.83	56,666.83
Ford Warehousing Cost ($/year)	1,318,865.31	1,318,865.31	1,320,604.83	1,328,711.01

Table 71 Ford Warehousing Costs. Alternatives 4 and 5

4.2.5.2. Chrysler Auto Distribution Alternatives

	ALT.1	ALT.2	ALT.3.1	ALT.3.2
Hford ($/unit·week)	120	120	120	120
Total Production Ford (unit/week)	135	135	135	135
Holding Cost, HC, ($/year)	842,400	842,400	842,400	842,400
Time shipping per week (hours/week)	9.04	59.10	65.04	64.76
In Transit Inventory Cost, ICIT($/year)	8,226.40	74,086.07	81,532.29	81,181.29
Demand 1 (units/week)	54	64.61	64.61	64.61
Demand 2 (units/week)	14	13.07	13.07	13.07
Demand 3 (units/week)	17	20.33	20.33	20.33
Demand 4 (units/week)	7			
Demand 5 (units/week)	6			
Q1 (units)	6.71	7.34	7.34	7.34
Q2 (units)	3.42	3.30	3.30	3.30
Q3 (units)	3.76	4.12	4.12	4.12
Q4 (units)	2.42			
Q5 (units)	2.24			
Mean Demand Inventory Cost, ICMD ($/year)	57,841.73	46,032.37	46,032.37	46,032.37
Ford Warehousing Cost ($/year)	908,468.13	962,518.45	969,964.66	969,613.66

Table 72 Chrysler Warehousing Costs. Alternatives 1,2 and 3

	ALT.4.1	ALT.4.2	ALT.5
Hford ($/unit·week)	120	120	120
Total Production Ford (unit/week)	135	135	135
Holding Cost, HC, ($/year)	842,400	842,400	842,400
Time Shipping per week (hours/week)	34.00	34.00	39.66
In Transit Inventory Cost, ICIT($/year)	42,621.43	42,621.43	49,716.64
Demand 1 (units/week)	64.61	64.61	64.61
Demand 2 (units/week)	13.07	13.07	13.07
Demand 3 (units/week)	20.33	20.33	20.33
Demand 4 (units/week)			
Demand 5 (units/week)			
Q1 (units)	7.34	7.34	7.34
Q2 (units)	3.30	3.30	3.30
Q3 (units)	4.12	4.12	4.12
Q4 (units)			
Q5 (units)			
Mean Demand Inventory Cost, ICMD ($/year)	46,032.37	46,032.37	46,032.37
Ford Warehousing Cost ($/year)	931,053.80	931,053.80	938,149.02

Table 73 Chrysler Warehousing Costs. Alternatives 4 and 5

4.3. Data Analysis

4.4. Discussions

CHAPTER 5

SUMMARY AND CONCLUSIONS

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