REPUBLIC OF TURKEY

ADANA ALPARSLAN TÜRKEŞ SCIENCE AND TECHNOLOGY UNIVERSITY

GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

DEPARTMENT OF INDUSTRIAL ENGINEERING

A MATHEMATICAL MODEL FOR INDUSTRIAL ELECTRIC VEHICLES LOCATION ALLOCATION PROBLEM

AYSU BUDAK

MASTER OF SCIENCE

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I hereby declare that all information in this thesis has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all information that is not original to this work.

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AYSU BUDAK

ABSTRACT

A MATHEMATICAL MODEL FOR INDUSTRIAL ELECTRIC VEHICLES LOCATION ALLOCATION PROBLEM

Aysu BUDAK
Department of Industrial Engineering
Supervisor: Asst. Prof. Dr. Nuşin UNCU

September 2019, 54 pages

In today's competitive manufacturing world, reducing material handling cost is one of the most important issues to provide a competitive advantage in respect of customer preference. Industrial electric vehicles are efficient material handling facilities for loading and unloading operations in the context of low energy consumption and utilization. The main disadvantage of these vehicles is usability in a limited time period. Thus, their chargeability and utility must be planned in order to be used more effectively. While planning, the manager should consider the maximum distance they travel without being out of charge.

This study aims to minimize the energy consumption considering the distance traveled by each industrial electric vehicle between material- station-charge station points under optimal routing, allocating and locating decisions. Various theoretical approaches regarding to location-allocation problems are discussed, and a new mathematical model is developed for minimizing the distance in a predetermined timeline while locating the charging stations and assigning tasks of picking and loading materials to machines by electric material handling vehicles. The nonlinear model is solved by IBM ILOG OPL IDE.

Keywords: Electric vehicles, Industrial Electric Vehicles Charging Stations, Location Allocation Models, Material Handling Systems

ÖZET

ENDÜSTRİYEL ELEKTRİKLİ ARAÇLARIN YERLEŞİM TAHSİS PROBLEMİ İÇİN BİR MATEMATİKSEL MODEL

Aysu BUDAK
Endüstri Mühendisliği Anabilim Dalı
Danışman: Yrd. Doç. Dr. Nuşin UNCU

Eylül 2019, 54 sayfa

Günümüzün rekabetçi üretim dünyasında, malzeme taşıma maliyetini azaltmak, müşteri tercihine göre rekabet avantajı sağlamak açısından en önemli konulardan biridir. Endüstriyel elektrikli araçlar etkin olarak malzeme taşıma işleminde kullanılır ve en büyük dezavantajı zaman kısıtı göz önünde bulundurularak kullanılabilmesidir. Endüstriyel elektrikli araçlarla malzeme taşıma işlemi yapılan bir tesiste, belirli bir period içerisinde minimum enerji tüketimi ile şarj durumunu optimize etmek enerji tasarrufu açısından önemlidir. Bu optimizasyon işlemi, yöneticiler tarafından gereken işleri makinelerin mesafesi ve siparişleri de dikkate alınarak planlanmalıdır.

Bu çalışma doğru araca, doğru zamanda, doğru işi atama yoluyla gidilecek mesafelerin azaltılarak ve yapılan işler tamamlandığında da bir şarj istasyonu seçerek, enerji tüketimini optimumda tutmayı hedefler. Bu çalışmada yerleşim tahsis problemi tartışılmış ve önceden belirlenmiş zaman çizelgesinde endüstriyel elektrikli araçlar için mesafeyi minimize edip, uygun şarj istasyonu yeri seçilen yeni bir model geliştirilmiştir. Bu doğrusal olmayan optimizasyon modeli IBM ILOG OPL IDE Programı ile çözülmüştür. Varolan elektrikli araçlar ve önceden yerleri belirlenmiş şarj istasyonları dikkate alınmıştır.

Anahtar Kelimeler: Yerleşim-Tahsis Problemi, Elektrikli Araçlar, Elektrikli Araçların Şarj İstasyon Yerleri, Malzeme Taşıma Sistemleri

My dear family

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The project is accomplished with a help as support, encourage. I am indebted to;

My family and my fiance; for all support and encourage and to guide me to learn what I really want in every step of my life.

My directorate Cenk Koçdor; guidance for finding the answers while asking the right questions and teach the statistics in every step of my life. Feeling very lucky to work with him and understand his perspective of how climbing up the steps to be a successful manager. Appreciate for every priceless advice.

My manager Dr. Mustafa Tacettin; always answers my endless questions in a very big patience. Appreciate for being a role model for me and to teach not only being a successful industrial engineer but also how being a successful manager and leader should be.

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A very big thank you!

AYSU BUDAK

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NOMENCLATURE

HSE : Health and Safety Executive

MSDs : Musculoskeletal Disorders

AGVs : Automatic Guided Vehicles

ASRS : Automatic Storage and Retrieval System

CP : Constraint Programming

LARP : Location Allocation Routing Problems

LAP : Location Allocation Problem

VRP : Vehicle Routing Problem

1. INTRODUCTION

In recent years, globalized competition between companies in the economic world, has been increasing very rapidly. The leadership of competition is driven by customer satisfaction since its main goal focuses on customer preference. On-time delivery and cheap products help to increase customer satisfaction. The relationship between customer preferences and cost is very significant. In this study, we will try to decrease manufacturing and energy costs while locating the minimum number of charging stations necessary, and choosing the best route by assigning tasks, vehicles and trips to each other correctly.

Plants and manufacturing facilities both utilize materials handling system. Material handling systems provide storage, transportation, control and protection. For example, products are put on a pallet to be taken to storage since pallets protect products from dirt, and pallets with or without products are transported onto the next location by trucks. Material handling systems are very useful when used effectively. When making plans for facility locations, production flow by material handling should be taken into consideration because poor facility locations cause unproductivity. Since non-value-added movements result in more expensive products, these operations should not be overlooked for customer satisfaction.

Products, materials and equipment should be carried in a manual, semi-automated or automated way. If the weight to be carried exceeds the ergonomic rules, non-manual operations must be preferred. Non-manual operations naturally increase the cost. The mentioned cost is not only total investment cost (CAPEX), but also operational cost (OPEX). When purchasing a vehicle, the purchaser’s awareness of the requirements is key in order for the vehicle to meet the handling needs of the company. Especially, industrial trucks are mostly prefered in facilities. Some functioning industrial trucks are operated by employees. This operation brings investment cost to purchase, labor cost to operate, supply cost according to type of battery (electricity, fuel etc.) and maintenance cost in case of repair or periodical maintenance.

Reducing operational cost is very important in this competitive environment. Investments, taxes and labor costs are nearly stable, but there is an opportunity to decrease the cost of supply and maintenance. Especially electric vehicles are widely prefered in modern facilities not only for an environmental, but also for economic reasons. Assigning correct tasks to correct vehicles in the facility saves energy and reduces the supply cost. Correct operations eliminate any non-value-added operation and increase lifespan of the semi-automated vehicles reducing maintenance costs.

In this study, the lifecycle of industrial trucks starts with carrying products from semi-item machinery to final machinery and terminates with charging stations. We are aiming for reduced transportation trips in a predetermined timeline, increasing productivity by assigning the correct tasks (loading, unloading items between machinery) to the correct trucks and by decreasing the minimum number of charging stations. Literature has been reviewed and a three-stage non-linear assignment and location allocation model has been developed to achieve the objective of low energy consumption and maximum utilization in operations of loading, unloading and charging operations. Minimizing travelling distance, results in energy optimization and maximum utilization.

1.1 Material Handling Systems

Material Handling is movement of materials and products in a lifecycle. As a term of material handling includes protection, transportation, control, storage, and material or products that have physically been in a warehouse, distribution center, facility etc.

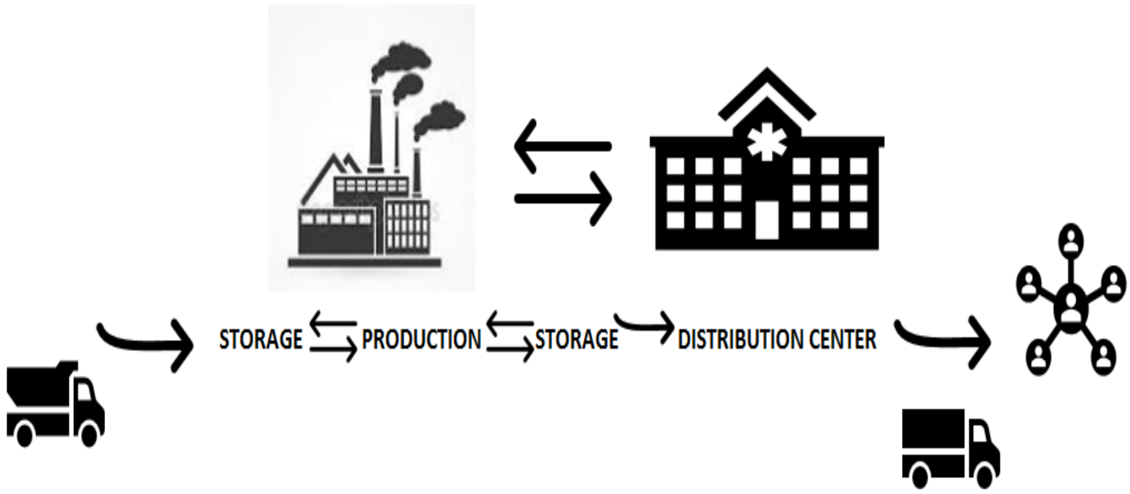

Figure 1.1 Material Flow

Figure 1.1 shows that almost every item that operates as semi-products to processed, final products to warehouse to storage, from warehouse to store of distribution center and from store to customer transports by a conveyor or lift truck, manual or other type of material handling equipment in manufacturing plants, warehouses, or distribution center. There is an important relationship between the layout design of the facility and the design of the material handling system. According to production flow, some material handling equipment can be used in facilities. Material handling systems are inseparable parts of production systems due to the necessity of efficient product flow between the operations or activities of a production system which is heavily dependent on activity layouts. Considering two adjacent operations, the material might be easily handed from one area to the next, according to the material flow direction. Material handling equipment is widely used in various industries to move materials from one area to the next. Better arrangement of material handling; reduces the total fatigue, decreases material damage, ensures product, work and human safety, and decreases cycle time.

1.1.1 Manual Material Handling

Manual material handling refers using operator's hand to move a material for carrying, lifting, loading, unloading. Since, manual handling results with the workers' disorders, there are safety regulations in governments. According to words of Health and Safety Executive (HSE) in United Kingdom related with the risk of carrying in human body. HSE explains that manual handling can be caused workplace injuries. All three workplace injuries because of manual handling. The injuries such as MSDs results with the injury and pain to legs or arms.

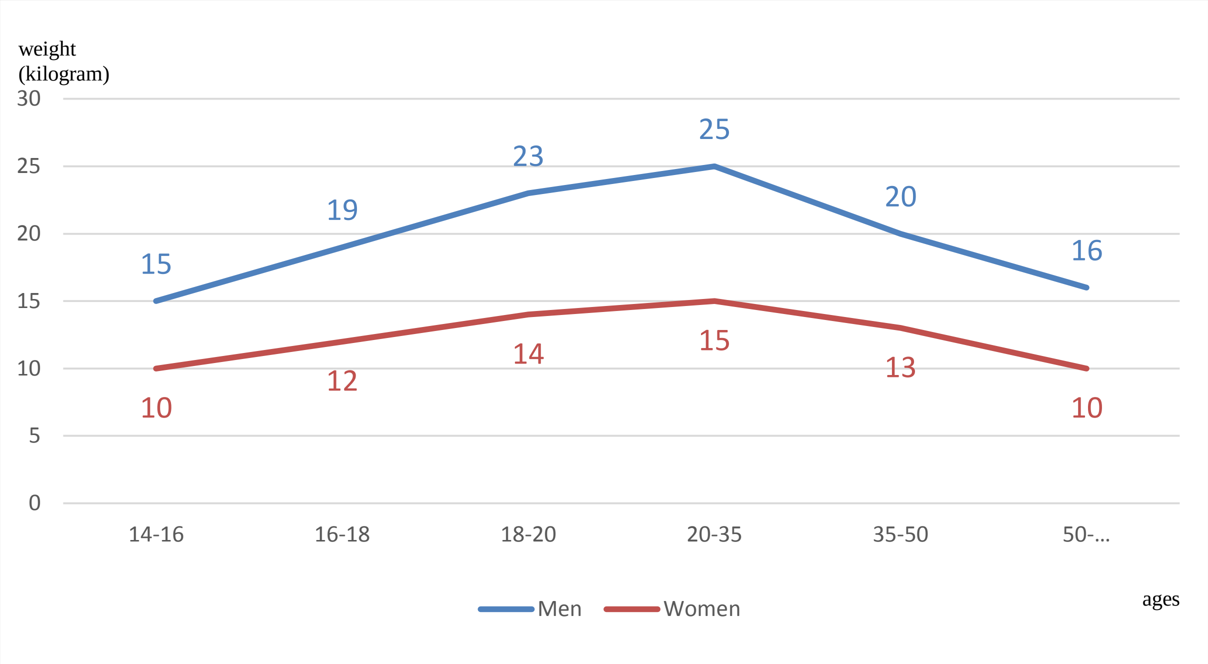

Figure 1.2 Maximal Carrying Loads

One person to lift more than half the weight of its own weight, it may be inconvenient to pulling or pushing operations. In this case, getting help is necessary from any other person or appropriate material handling equipment. Usually this rule is valid for people in the ideal weight. Some rules for maximal weight to carry showed in the figure 1.2 and explained below.

A woman who is over 50 years old, shouldn't carry more than 10 kilograms, a man who is over 50 years old shouldn't carry more than 16 kilograms. Maximal weight is determined for carrying as 20 kilograms for a 35-50-year-old man, 13 kilograms for a 35-50-year-old woman. A 20-35-year-old male can lift a weight of up to 25 kilograms, a female can lift to 15 kilograms. Maximal weight for a man aged 18-20 years is determined as 23 kilograms, for a woman 14 kilograms. The age between 16-18, carrying limits determined up to 19 kilograms in men, 12 kilograms for women. Between the ages of 14-16 men can lift a weight of up to 15 kilograms, women 10 kilograms.

From this graph, women always can carry less than men because of physically capacity. More than 35 years, both men and women maximal weight carry limit is decreasing.

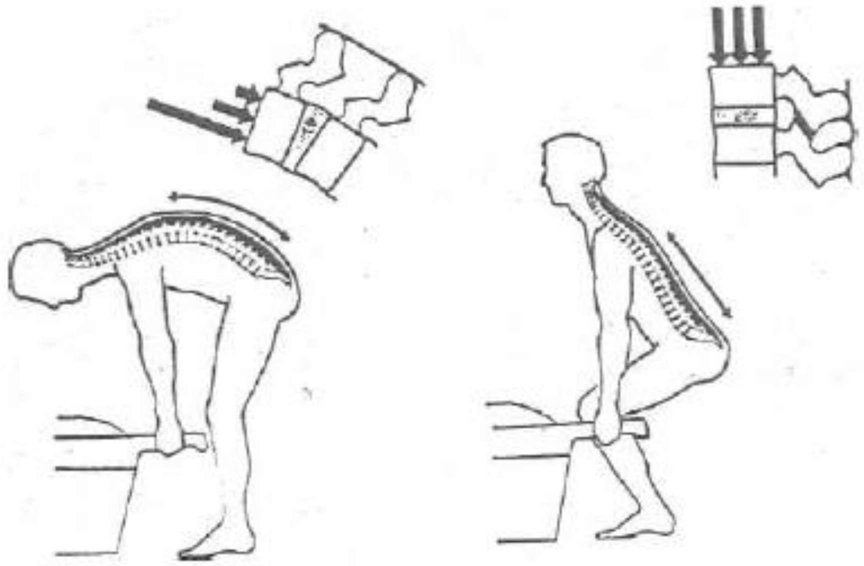

Figure 1.3 Position During Manual Material Handling Operation

Figure 1.3 shows that position in which lifting occurs is very important for the human skeleton because of the distribution of the loads on the vertebra while tilting forward and kneeling. When bent over from the waist, it can be seen that the vertebrae can cause compression by pressing on one side. The necessity to lift a weight above these values can cause problems with the skeletal system. Failure to use proper techniques may also cause problems with the skeletal system at lower weight values. Because of the above limits for carrying weights, some material handling equipment can be useful.

1.1.2 Semi-Automated and Fully Automated Material Handling Systems

As lifts that carry the weights get higher, manufacturing facilities require more and more systems to operate with or without employees. In this case, automation is the key solution. Automation is basically a technology where an operation is performed with less human assistance. Semi-automatic material handling combines both man and machine. The systems require manual functions as well as machine-aided assembly. Fully automatic material

handling doesn’t require any human interaction. Transferring material or product is loaded automatically into the next step. The system decides loading, unloading, testing and storing operations itself.
Some basic types of material handling equipments are: Conveyors, Industrial trucks, Cranes and Hoists, Containers, Pallets and Racks, Elevators and Lifts, Automatic Guided Vehicles (AGVs), Automatic Storage and Retrieval System (ASRS).

Conveyors; There are fully automated material handling systems. Products transfer to the next area onto special rollers. Some special sensors can be installed inside some of these rollers. Some industries such as mining, automotive, agricultural, computer, electronic, food processing, aerospace, pharmaceutical, chemical, bottling and canning, print finishing and packaging use mostly conveyors to transfer products. Conveyors are safer than other procedures, especially in the industries which operate with big loads such as automotive and aerospace.

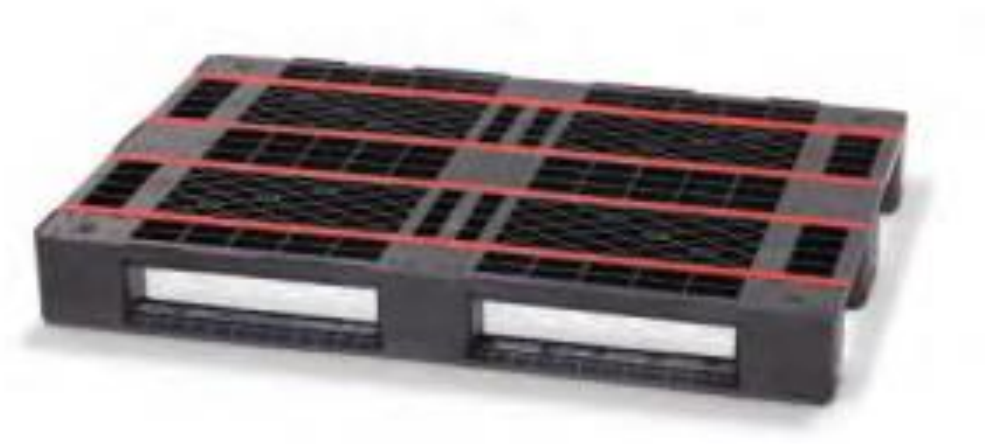

Figure 1.4 European Pallet

Pallets, Racks and Material Handling Carts; Pallets can be either wooden or plastic. Euro Pallets can be preferred in world-wide shipping as can be seen in figure 1.4. Standard measurement is 47.3x31.5x5.7 inches. Forklift's forks handle pallet from its special spaces.

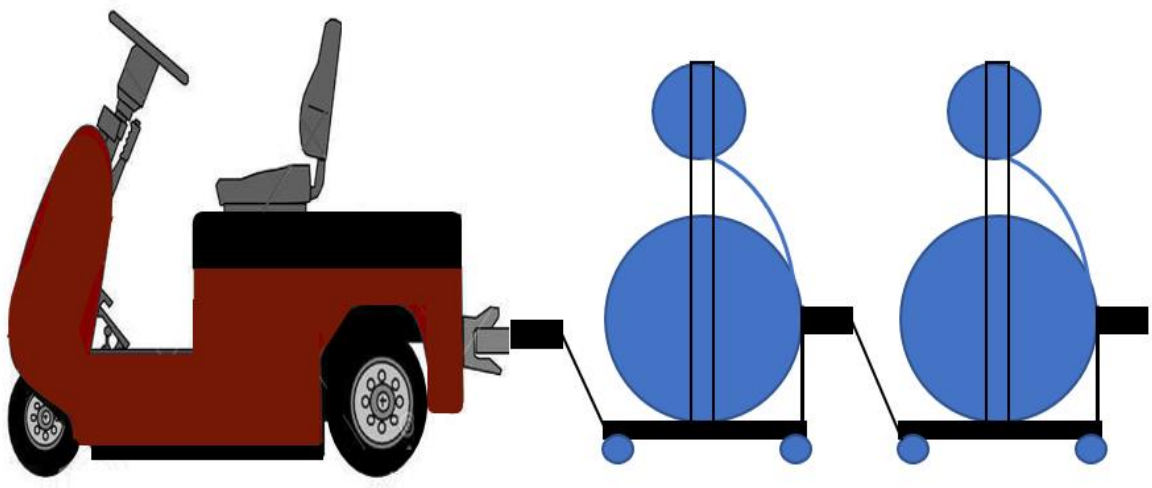

Figure 1.5 Material Handling Cart with Liner

Material handling carts which illustrated in figure 1.5 are special material handling equipments that needs to be handled when it carries continuous products. Generally, there is a liner on a mechanic roll, and the special product is continuously winded. If the cart has a wheel, the tow tractor can carry the product from one place to another. For confidentiality purposes, the visual cannot be shared.

Elevators and Lifts; carry products to up or down floor.

Cranes and Hoists; Cranes are used to transport loads over variable paths within a defined area. Cranes differs according to axis such as vertical, horizontal, up and down.

Automatic Guided Vehicles (AGVs); No man operated. The fully automated vehicles carry a product and follow a marker or laser etc. on the floor.

Automatic Storage and Retrieval System (ASRS or AS/RS). An automated storage and retrieval system include variety of computer-controlled systems for automatically storing and when necessary retrieving loads from defined storage locations.

Industrial trucks are semi-automated material handling equipment widely used in the industry. Trucks need an operator to drive them. Trucks can vary according to requirements such as special rotating attachments, draw bolt, dumper etc. Industrial trucks are very useful, especially in job shop production. According to Wayne's information, vehicles are used for transporting any material or equipment over several paths during which the load is usually not continuous. It is the fact that industrial trucks provide connections and material flow like an automatic bridge between areas or fields. The cost of using industrial trucks is very high not only because of its investment cost, but also because of its operational cost. Hence, facilities search for ways to decrease the cost. If sources not operated effectively, even after lowering investment costs, other expenses such as maintenance, labor etc. would become increase meaningfully. Using materials more economically while reducing transportation trips is very critical as a cost improvement technique these days. Transportation is provided by industrial trucks such as forklifts, tow tractors, transpallets, reach trucks etc.

Industrial trucks have different four categorize as tasks; stacking, storage, transporting and order picking. This is a substantial investment of capital and required good research and fully informed decision-making. Each business has specific needs for material handling, impacted by factors. The factors as according to the fuel, the tasks (attachments, hours of usage), dimensional requirements(maneuverability) and capacities (tonnage, lift height) in material handling operations, forklift, transpallet, reachtruck, tow tractor is used.

1.1.2.1 Forklift

Forklift is a kind of industrial vehicle with a tined device in front for lifting and carrying of heavy loads. Forklift is widely used in many industries. It differs as tonnage capacity.

Forklifts are the material handling vehicles which move finished or semi-finished products between fields or machines. Forklift (forked stacker) is a construction machine in the industry that provides lifting and stacking of heavy loads which people cannot move from one place to another. The main purpose of these machines is to carry a load capacity between 0.5 and 40 tons with the help of two forks. It is possible to reach all kinds of information about the capacity, load center and class of forklifts with the help of the plates within them.

Some classification related to material handling vehicles will be explained detailed in this study.

Figure 1.6 Forklift (Source: Linde Material Handling, 2019)

Especially has lift and two forks as can be seen in figure 1.6, forklift can be turn able or not, there are suitable for pallet transportation and handling operations. Pallet space width and height should be suitable with forks width and thickness.

1.1.2.2 Reachtruck

When forklifts sometimes couldn’t prefer due to some special requirements such as in narrow aisle, reachtruck can be preferred as in this manufacturing facility.

A reach truck is a narrow-aisle, right-angle truck designed for stacking for unit load handling with rack interface. These lift trucks are basically designed to operate in narrow aisles and are best for storing and retrieving pallets in racks. These lift trucks are operating for maximization unit load capacity in narrowing aisles with helps of balance feet.

Figure 1.7 Reachtruck (Source: Toyota Forklift, 2019)

Physically, this kind of vehicle has two balance feet to additional two fork as shown in figure 1.7. Due to the balance feet the reach truck does not work for all warehouse operations. This lift truck is not suitable for general dock work such as loading and unloading trailers, case or piece picking and working in very narrow aisles that do not allow right angle stacking. (Raymond Handling, 2014)

In this thesis, it has not worked through on reachtrucks since work hours very low and has not posed of a risk on battery life.

1.1.2.3 Pallet Trucks (Transpallet);

Forklift length 110 centimeter in standard. When longer pallet moves necessities, it is necessary to have longer attachment. When forklifts couldn’t prefered sometimes due to some special requirements such as transportation of longer pallets, pallet trucks can be prefered as in this manufacturing facility.

Figure 1.8 Pallet Trucks (Source: Jungheinreich, 2019)

Pallet trucks lift up to 15 centimeters. Also, either operator-sit, or operator-stand versions in some models as shown in figure 1.8. In this manufacturing facility, in transportation operations, no need to lift more than 15 centimeters. That’s why, pallet trucks prefered in some special operations.

1.1.2.4 Tow Tractors (Tow Trucks)

When the finished or semi-finished materials have additional draw bolt to assemble to a vehicle, tow tractors should be used in order to carry. Since material handling carts with liner pulling one area to another by tow tractors, assembled carriages should have wheels. Capacity differs from 2 tons to 20 tons.

Figure 1.9 Tow Tractor (Source: Still, 2019)

This kind of vehicles are very used to, but some high tonnage versions also used in social life for improperly parked cars, broken cars etc. In this manufacturing facility, tow tractors which capacity has 6 tons used very effectively. A basic tow tractor illustrated in above figure 1.9. Some semi-finished materials have wheels, assembling each other with a help of draw bolts, then assembling these carriages to tow tractors again with a help of draw bolt. A serviceman drives this vehicle, load from the specialized different semi-finished machines, distribute them to the final (customer) machinery.

Plant Industrial Engineers have calculated the maximum carriage amount that a vehicle can carry by considering occupational safety standards. Not only tonnage of one carriage, but also length of one carriage is important. Since there is a limitation of maximum corridor width, tow tractors maneuver capability should be suitable for plant design. There is a factor that is affecting maneuver capability, it is how many carriages it is dragged behind. Engineers decided that maximum six carriage this kind of electrical tow trucks can drag in this facility.

1.1.3 Power of the Vehicles

Battery can be powered by LP gas, CNG (Natural Gas), electricity, gasoline or diesel fuel. In this manufacturing facility it is preferred to be operate with electric vehicles. Because electric vehicles are more trackable, more energy savable and environmental advantages. Electric forklifts are powered by either a battery or fuel cells that provides power to the electric motors. For warehouses and other indoor applications, electric forklifts are prefered since they are not producing carbon monoxide. This is an enormous environmental advantage. Electric vehicles (EVs, also called battery electric vehicles or BEVs) are vehicles whose wheels are turned by electric motors rather than by a gasoline-powered drivetrain. EVs have been long touted as saviors of the environment due to their apparently zero emissions of pollutants but have been also been citicized as limited in range and of less environmental benefit than claimed. (Enclopedia, 2016)

The fact that electric vehicles that can be monitored in the developing technological world, has facilitated efficiency monitoring. In this manufacturing facility, industrial engineers tracking the vehicle working hours, with a help of desktop application. They are connecting directly the database of the vehicle fleet that includes all forklifts, tow tractors, pallet trucks. Management is digitalized, so that engineers and managers can analysis the data of the fleet, attack points easily decided accordingly the analysis. Desk application has log of crashing, speed limitation, working hours, charging situations etc. in a filter of operator and truck based. These informations sometimes very crucial not only operational side but also health and safety regulations. In this manufacturing facility standart speed limit of forklift is 9,6 kilometer per hour. Speed limits are applicable, and they have huge impacts. Usually, manufacturers of forklifts can design governors on velocities that only allow reaching the certain speed.

These machines are heavy machines. The battery type is selected as electricity. The battery consumes some energy in boom movements and transportation movements. A special desktop application has been installed to track these material handling tools at the production facility. A special communication system is required. By placing a communication device in the field charging stations, the vehicle records how long the vehicle has been used when it is fitted to each charge and counts as cyclic. This working hour data used while deciding time-limit as 2 hours.

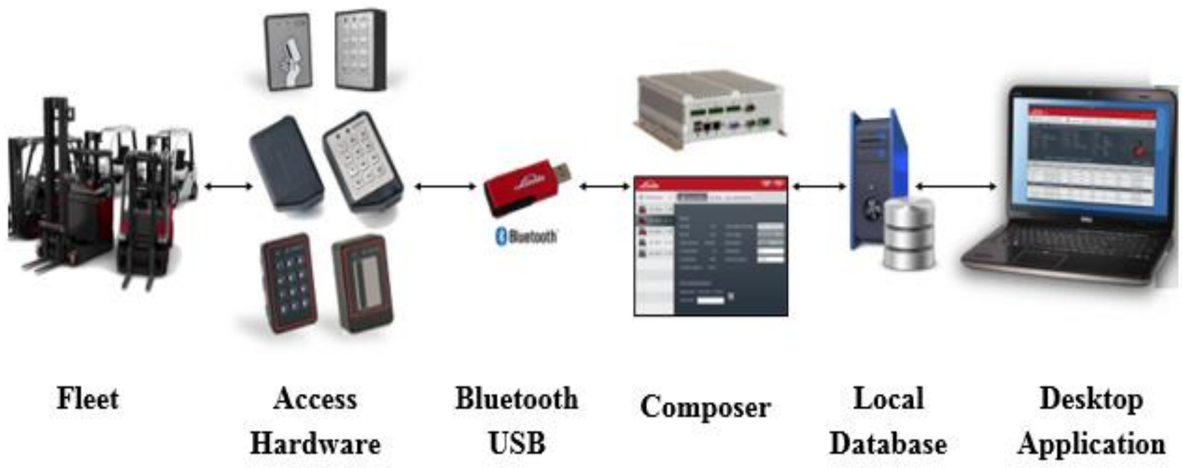

Figure 1.10 Management and Analysis Flow (source: Linde Material Handling, 2019)

How the digitalized system works illustrated in figure 1.10 above and explained below; Vehicle has an access hardware. This hardware has operator authority information. Only authorized operator can use the vehicle. Data started to log while driving. When vehicle goes to charging stations, the information sends to the database. Database which fleet information includes, connected by a thin computer to plant network. Engineers and supervisors can access the data on desktop application by graph.

When purchasing a material handling vehicle, purchaser should know, these heavy machineries includes the big opportunity to manage efficiently and efficiency. According to priorities, some action to take is decided.

In this manufacturing facility, charge station placements are decided according to proximity to offices. Because in every 2 hours operator goes to office to rest or take break and the vehicle should plug in charger. In this case, we calculated the requirement of final machinery in the 2 hours operations in loading, unloading and charging operations. In this manufacturing facility, product flow is just only one direction which is right to left. Right side produces semi-finished products, which means it is necessary to have one or more process before its finalized. That's why left side field its customer.

1.2 Motivation

Forklifts and similar vehicles are very powerful tools used in facilities by well-trained operators. They help to move pallets or other materials such as carts, boxes etc. by eliminating the need to lift and carry loads by hand. Forklifts or material handling vehicles can be classified by methods including power source, operator position and load engagement method. According to Ryan and Ryan in 2006; electric motors run with (powered by) batteries and they're the most common type of power for forklifts in the industry. Vehicles powered by electric motors require only battery. When deciding the type of the vehicles, the purchaser should be aware of the factors such as operational cost besides the purchasing price. The word "electric vehicle" includes other types of industrial trucks such as tow trucks, forklifts etc. used in facilities. Operational costs are the expenses spent in the lifecycle of a vehicle. Minimizing travelling distance, results with energy optimization and maximum utilization.

Producing cheaper and high-quality products, in-time delivery increase customer satisfaction in today's economic world. Engineers can decrease the manufacturing costs while eliminating non-value-added operations. This is where the productivity comes in. More than adequate stock, unnecessary movements should be eliminated, and operations should reach an optimal level. Reaching optimal level in manufacturing steps reveals the main requirement for decreasing the manufacturing costs. In this study, we focused on industrial truck tasks to decrease manufacturing costs by eliminating non-value-added movements and to decrease investment costs by installing required number of charging station.

It is expected that this research makes a significant contribution to the facility location area in terms of cost, time saving, and minimization of travelling distance by assigning correct tasks to correct vehicles.

1.3 Overview

This thesis is organized as follows:

Chapter 2 includes review of literature related with location allocation problems and their various applications.

Chapter 3 explains the problem in detail with proposed mathematical model (location allocation model) for this problem and describes solution method.

Chapter 4 summarizes the results.

Chapter 5 provides concluding remarks for the results obtained in this research.

Chapter 6 provides recommendations for future research.

2. LITERATURE REVIEW

This part is the review of the literature relevant to facility location problems and models. Section 2.1 provides an overview of the facility location problems. Section 2.2 includes discussion of objective functions of mathematical location formulations.

1.1 Facility Location

Modelling location problems can be solved by real-world operations. Understanding the demand and reflecting modeling requirements is the key to solve the problem. Finding optimal location has been a popular issue in urban modelling for years. The research starts from agricultural town in order to reach resources.

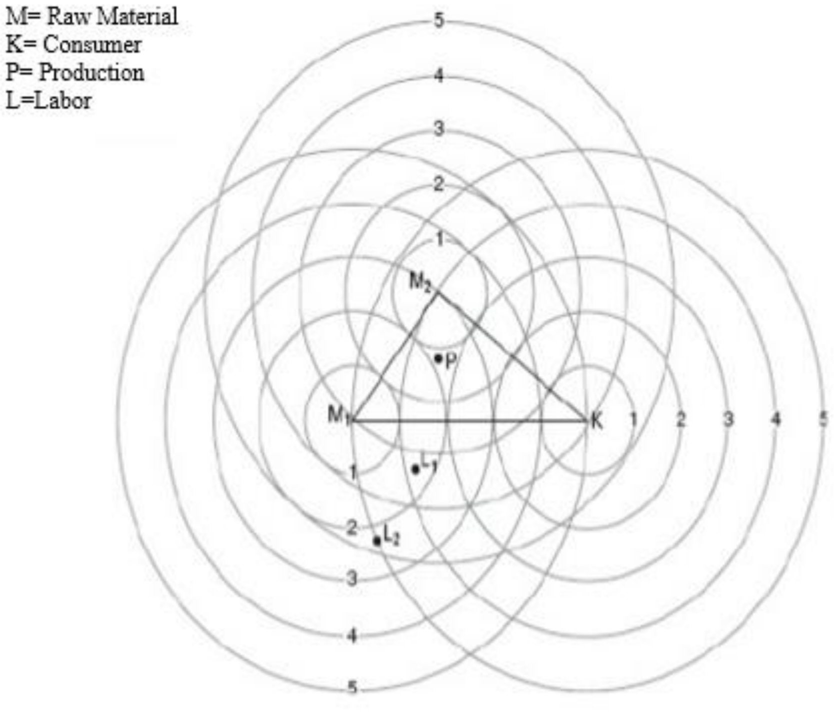

Figure 2.1 Weber’s triangle (1909)

Weber (1909) provided a simple triangle of manufacturer, market location and resources presented as in figure 2.1. The triangle was used to find the optimal location. Triangle tends to use sources such as raw materials (like water) close to market places. Then, Weber developed a model in 1929. Location problems generally include nodes, cells or areas. There is also a network modelling study based on nodes that links one node to another.

The role of locational analysis in planning services for industry and emergency services is very important. One of the tools for such analysis is quantitative location-allocation modeling. It provides a framework for investigating service accessibility problems and involves simultaneously selecting a set of locations for facilities and assigning spatially distributed sets of demands to these facilities to optimize some specific measurable criteria (Rahman and Smith, 2000). The facility location problems are proved by NP-Hard in (Kariv and Hakimi, 1979a, b).

Facility location problems deal with the cost, distance, demand, capacity, requirements and so on. There are many combinations of location problems in wide areas such as: minimization of distance, limitless capacity of demand, minimization number of locations and combinations.

There are categorized according to objective functions.
Objective Functions of Mathematical Formulations
• Single-objective
o P-Median
o P-Center
o Covering
o Allocation Model
o Capacitated and Uncapacitated Fixed-Charge Location
o Others
• Multi-objective

Following subsections include the various the facility location problem types review.

2.2 Types of Problems

This subsection reviews the problems and overview of the contribution of literature.

2.2.1 Single and Multiple Objective Problems

Problems can be differed according to objective. Ravi et al in 2004 categorizes the problems in Single and Multiple Product problems. Facility locations are decided according to the supply and demand provided regarding one or multiple types of goods and products.

2.2.2 P-Median Problems

The objective of the P-Median problem is minimizing the total cost, also called as minisum problem or Weber problem. P-Median problem deals with the placement of p locations to minimize the total cost. Cost criteria can be defined as distance, time, currency, number of locations etc. Median problems mainly focus on the worst-case situation. For example, in the case of ambulance location, the problem should be checked by maximum response time to related areas. Therefore, the model minimizes the average response time using a given number of P related vehicles. (Hakimi, 1964-1965) Extended deterministic models were studied by Aly and White (1978) and Weaver and Church (1983b-1984) and Daskin (1982-1983). Simulation models (Swoveland et al.,1973) in case of occupation of the closest vehicles in required timeline in ambulance location problems. Church and Garfinkel (1978) and Minieka (1983) suggested a minisum model that should be considered with regards to population. The main concept was locating p facilities while maximizing population weighted distance and closest sites in disposal waste facilities.

2.2.3 P-Center Problems

The objective of the typical P-Center problem is determining emergency services placement such as fire or ambulance stations. Generally, this deals with the minimization of the maximum distance from an assigned station to a demanded service point. Hakimi, S. (1965) introduces the P-center problems.

2.2.4 Covering Problems

Covering problems focuses on worst-case scenarios. Schilling, Jayaraman, Barkhi (1993) and then Current, Daskin and Schilling (2002) derived covering models for facility location problems. Typical covering models include nodes and links. Set covering problems are the basic type and the objective is finding a minimum facility cost from a finite candidate set of facilities, and every node is covering at least one facility. Set covering models are also studied by Desrochers et al. (1991) in airline crew scheduling. Maximum covering models have the same objective with set covering models but maximize the covered number of the facilities. The model is defined by Church and ReVelle (1974).

2.2.5 Fixed-Charge Location (Capacitated and Uncapacitated) Problems

The concept is keeping the location charge is fixed since the number of facilities to be opened is predetermined according to the objective of cost minimization. The objective of uncapacitated problems is minisum of fixed cost under limitless capacity, depending on the candidate facility placement to be located. The main objective of capacitated problems is minisum cost under limited capacity of demand. Finding electric car charging stations has been studied by Baouche F., Billot R., Trigui R., El Faouzi, N. (2014) using the Fixed Charge Location Model. Most of the healthcare facility location models assumed to be infinite capacity to serve related customer demand. (Schultz, 1970; Mehretu et al., 1983 and Boffey et al., 2003)

2.2.6 Location Allocation Problems

Allocation model deals with the number of facilities to open. Location allocation models are strategically used in some areas. Widely in the health care sector for development, in inventory management, production planning in industry, waste management in governance, and distribution center location in the supply chain. Cooper (1963), explains the objective function which is: minimization of cost, determination of number of facilities, the capacity of each facility, exact locations, and transportation costs. Cho (1998) presents a location-allocation modeling solution approach for the location of medical facilities. The solution approach is called the “equity-efficiency trade-off” model. The model is implemented to determine locations of medical facilities with non-referral pattern in Korea. Location allocation simulation model could be geographical. Harper et al. (2005) developed a stochastic discrete simulation model for location allocation problem of health services. Aboolian et al. (2007) applies location allocation model into Web Service Provider to determine servers, facility and customers. Allocation models, if they’re supposed to show any resemblance with reality, are enormously complicated and require huge amounts of data – which often doesn’t exist. Motoaki Y. (2018) studied the electric vehicle charging stations placement in the city. Alonso (1978) and Adacher (2018) studied the location-allocation problem of electric vehicle charging stations in heuristics.

Our model includes an approach that solves location, allocation. A location allocation routing problem (LARP) point of view generally considers that first, the number of p facilities have been decided, then routing has been done by nodes and links. In our model, first task assignment is done, then the allocation of charging station is made.

2.2.7 Location-Allocation-Routing-Problems

There are less than other facility location literatures available in facility location allocation along with the routing. In recent years, since electric vehicles have recently become popular, the number of studies in literature is gradually increasing. Allocation, as a term in operation research, provides minimization of number of facilities to open. Allocation optimization provides less operational cost. Location routing includes some decisions (questions and answers) that need to be made by the model.

Daskin (2013) explains in his book, “Network and Discrete Algorithms” that these questions are constraints and directly affect the objective functions.
The questions;
**how many facilities should be located
**where should the locations of the facilities be
**which customers can be assigned to which routes
**in what order should customers be served on each trip

LARP is mostly used in healthcare sector and supply chain. Location of warehouses is a very critical level for economic conditions in a company. A warehouse can either be for raw material or for final goods. The final goods will be distributed as requested by customers. Since customers request the products in-time, locations of warehouse can provide faster delivery time of the final product and minimize transportation costs. LARP is mostly used in warehouse locations.

In recent years, since electric vehicles have become very popular, the number of LARP studies in literature is ever increasing. Hakimi (1965) developed a weighted network location-allocation problem, presenting a minimization of the sum of weighted distance between P points.

They considered optimal location of server nodes, optimal allocation of population for each demand node, and allocation of population to routes in a defined travel time for each demand node. Then, Shiripoura, Mahdavi-Amirib, Mahdavia (2014) presented a capacitated-multi-allocation-routing model for a transportation network between nodes and links with travel times. Vankatesh and others (2014) proposed a new model for warehouse allocation in greener perspective for general fuel types of vehicles, not focusing on electric vehicles. Karp (1972) represented that the location-routing decisions are NP-Hard, that's why LARP belongs to NP-Hard problem category. Ebrahimi (2018) proposed a stochastic multi-objective LARP model in greener perspective for tire supply chain.

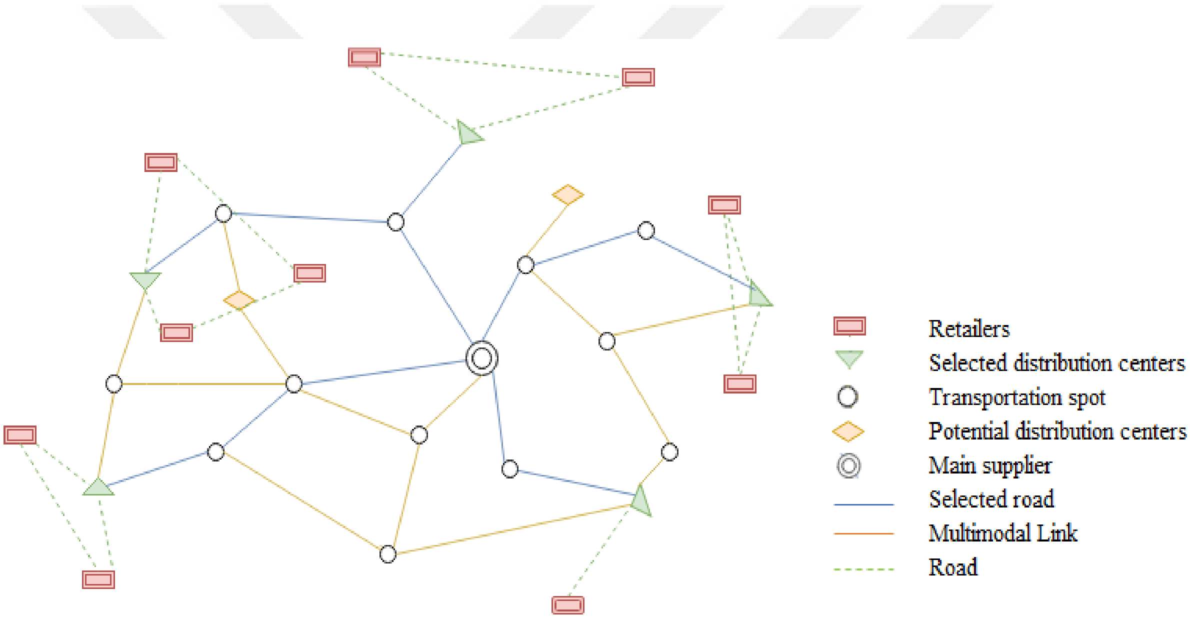

Figure 2.2 LARP Model Nodes

Figure 2.2 shows that nodes of LARP Model between retailers, distribution centers, transportation spot and supplier. Location routing problems include two decisions; first, in a potential depot set with fixed opening costs, assigning customers with known demands. In determining the vehicle routing, the main objective is to minimize the total cost of depots and the total cost related to the routing, published by Naghi and Salhi (2007).

3. MATERIALS AND METHODS

2.1 Facility Layout and Material Handling System

Facility layout refers to the size and shape of a facility as well as related locations of functional areas, equipments, products, workstations, storages, warehouses, aisles etc. in it. All types of facilities have facility layout such as plants, warehouses, stores, hospitals etc. Facility layout is an important factor in deciding about the plants for the overall efficiency and effectiveness of the production or distribution of operations. A poor layout results in inefficient workflow, absenteeism due to unsafe working conditions, and less operation capacity compared to the operational mission.

There is a significant relationship between facility layout design and material handling system design. According to production flow, material handling equipment can be used within the facilities. All items such as machinery, material flow between machinery, material handling systems and operators in facility form the facility layout. Parts, raw materials, work-in-progress materials, final or semi-finished products, and supplies are moved periodically from one location to another. No product or customer should be hampered by the early or late arrival of materials. Materials must always be delivered to the right place at the right time. Materials must be delivered at the correct location without damage and in the required quantity.

This manufacturing facility is a heavy industry facility; very large, requires a lot of space, and is expensive. Cost factors in the heavy industry facilities are construction costs, land costs, raw material, semi-finished and final goods machinery and shipments, proximity to raw materials, huge utilities, dispose of the water, and qualified labor. Due to the huge amount of investment, the location of the facility is very important. Other types of facilities;

- Light-industry facilities;
smaller, cleaner plants and usually less investment.
- Retail and service facilities;
smallest and least costly, small warehouse necessary.

In this manufacturing facility, there is a combination type for the layout including groups of identical machines. From raw material to the warehouse, the layout is constituted of fixed machineries grouped by capability of a special product and fixed direction. That's why material handling direction needs to always be the same. In this manufacturing facility, product flow is in one direction which is right to left. The right side produces semi-finished products, which means it is necessary to have one or more processes before the finalized version. That's why the left side field its dedicated to the customers.

The main goal is lean manufacturing, increasing value-added operations, and eliminating non-value-added operations as much as possible. A task of the material handling vehicle is organizing or stacking a product, picking, and/or transferring to the next station.

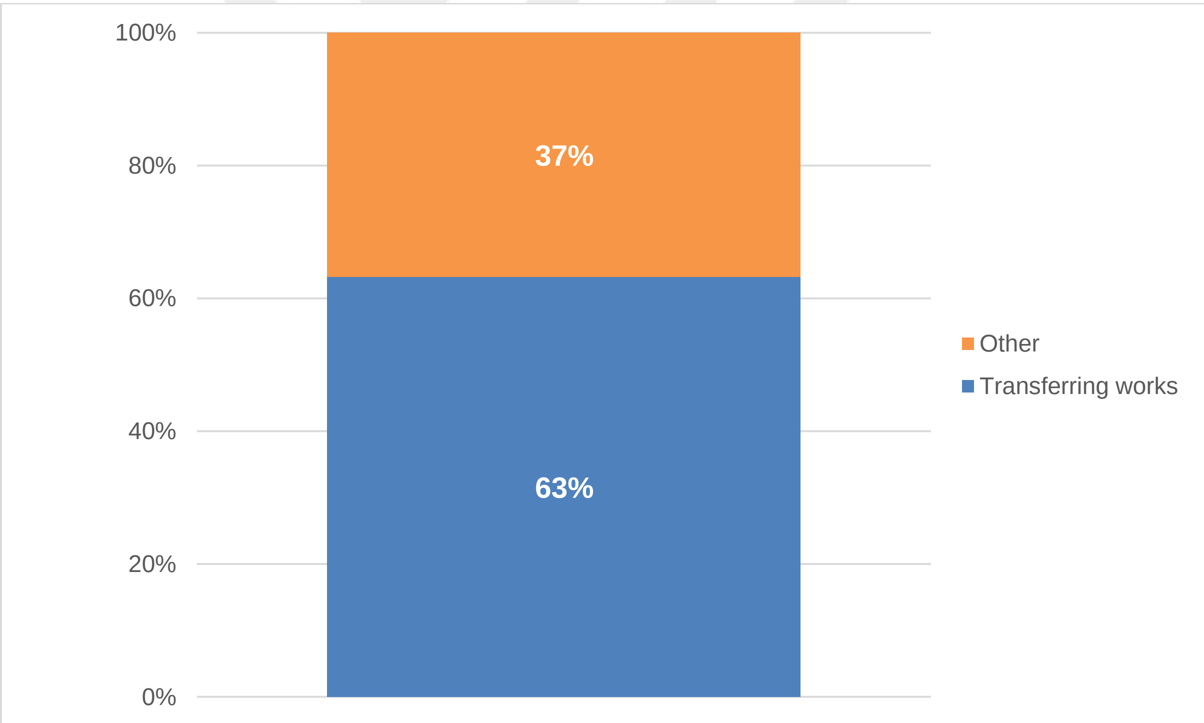

Figure 3.1 Lifecycle of a Towtractor

As seen in the above figure 3.1 transferring is %63 in life cycle of a forklift. That operation can be considered as a non-value-added operation. Industrial engineers should reduce the distance between two stations as much as possible, remaining of course within the facility location scope. Otherwise, the operation time will be longer and that's why forklift will consume more energy for unnecessary movement.

Two material handling items are used in the flow: tow tractor and material handling carts. Material handling carts and tow tractor are connected by a special metal pin. They are designed suitable for pushing and pulling operation by special wheels (see figure 1.5). In this facility, a pushing operation should always be made instead of pulling one, for safety reasons. The main purpose is to avoid carts crashing into humans or places.

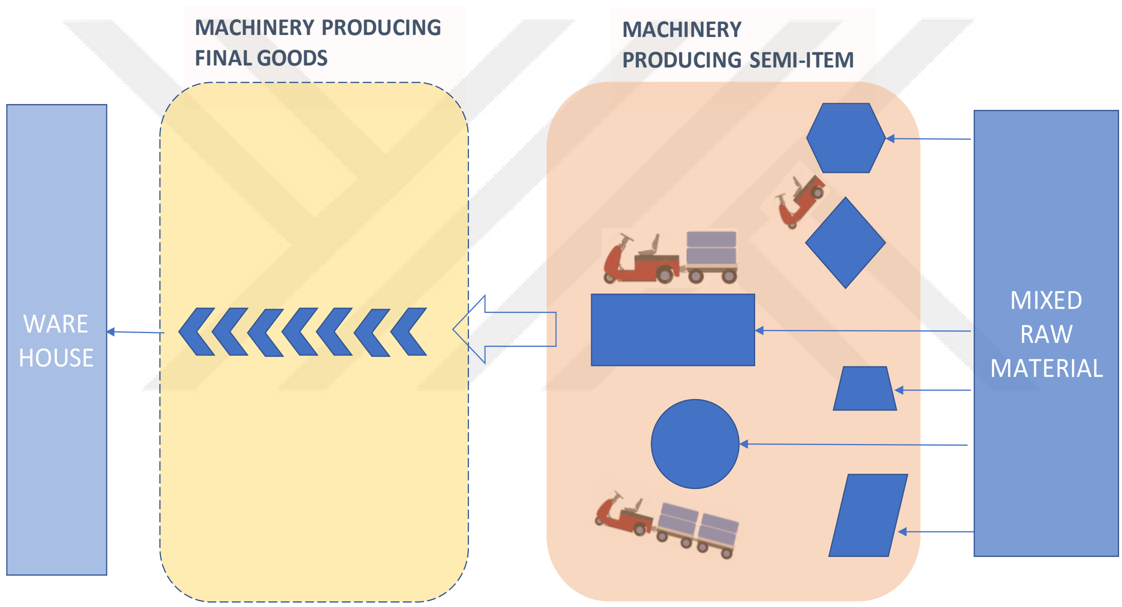

Figure 3.2 Material Flow in the Manufacturing Facility

The above figure 3.2 shows the product flow in the manufacturing facility by using material handling equipment. The symbols in the pink area show the semi-item machinery stock preparation area. The seven identical symbols in yellow area visualize the final machinery placements. Product flow is always from right to left. After mixing raw material with a high temperature, some special semi-items are produced in special machinery, semi-items are stored in the special material handling carts and these items are transported by tow tractors to produce the final goods. Each truck should have semi-items loaded, then should unload them in the next area (final machinery).

When the operator uses the system, which is composed of carts and tow trucks, he should know the standard method. When operators try to separate the system, they can use their foot, push the cart by hand to defined the parking place. After each cart parks in the required machine zone and the tow tractor does not attach to any cart, operators should drive on the same path to take empty carts from defined places into final machinery.

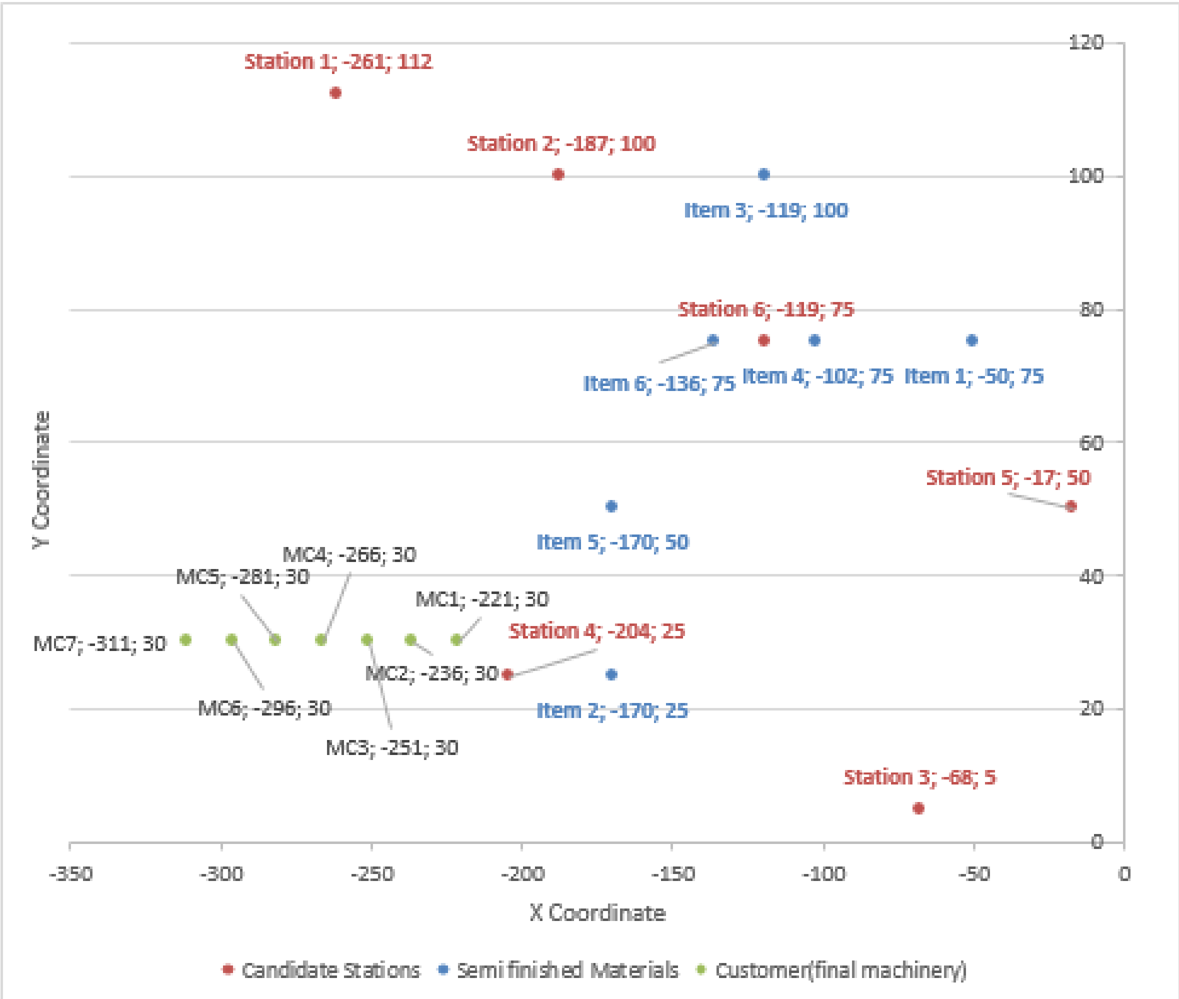

Figure 3.3 Layout of Machinery in the Manufacturing Facility

The following figure 3.3 shows the material flow and the locations of the candidate charging stations. Material Flow is always blue to gray. Blue dots show machine coordinates of semi-finished products and will be used in final machines which are shown by gray dots. Seven final machines are exactly the same as each other. Each item in the list is required in its exact period. The vehicles must be driven to move semi-finished products to final machines. When considering the periods of material flow for each product, the frequencies of flow is converted into integers for 9000 minutes that is the least common multiple.

Table 3.1 Semi-finished Product Requirement

Semi-finished product	Distance traveled (in meters)	Time period for each semi-finished product order release (minutes)	Frequency (number of travels in 9000 minutes)
Type 1 Semi-finished product	170 meters	120 minutes	75
Type 2 Semi-finished product	80 meters	90 minutes	100
Type 3 Semi-finished product	180 meters	72 minutes	125
Type 4 Semi-finished product	160 meters	250 minutes	36
Type 5 Semi-finished product	70 meters	200 minutes	45
Type 6 Semi-finished product	60 meters	250 minutes	36
Type 7 Semi-finished product	180 meters	60 minutes	150

These types of gray products require all semi-finished items in different periods. For example, the machines demanding “Item 3” in once 72 minutes (at least once per hour) explained in table 3.1. In this LAP, loading, unloading operations should be completed at first. Loading operations made by the material handling vehicles should move full products from blue dots to gray dots. Unloading operations made by the same vehicle should move empty carts in these machines back to the final machines. This means that the travel distance is exactly two times the loading operating distance. Orange dots indicate the location of charging stations which can be selected. After the loading and unloading operation, each vehicle should move to the charging station to charge.

Table 3.2 Capacity of Vehicles

Type of Vehicle	Load Capacity	Energy Capacity	Semi-Product
S	6 units per load	8 hours (busy)+4 hours (idle)	Mixed types of semi-product
T	1 unit per load	8 hours (busy)+4 hours (idle)	Unique semi-product

Since these tow trucks has finite capacities, we should consider the model as capacitated in the study. Capacity of industrial electric vehicles used in the facility presented in table 3.2. In this facility two kind of materials should be carried in two different vehicles. S type vehicle presents tow tractor, can carry different types of semi-product, maximum 6 units can carry by this vehicle at a time. T type vehicle carry just unique pallet and presents transpalet. In this study, S type vehicle will be considered.

3.2 Method

Main fiction according to the flow is visualized. Related machine and charging station locations assigned as subnodes, then categorized in node sets. Distance between subnodes is calculated. Capacity of the trucks is considered. The mathematical model has been developed for capacitated trucks. IBM ILOG OPL IDE is preferred for solving the problem. Model is assigned tasks to trucks. When truck needs to get the charge, the truck should go to charging station. Location of the charging station is selecting by model.

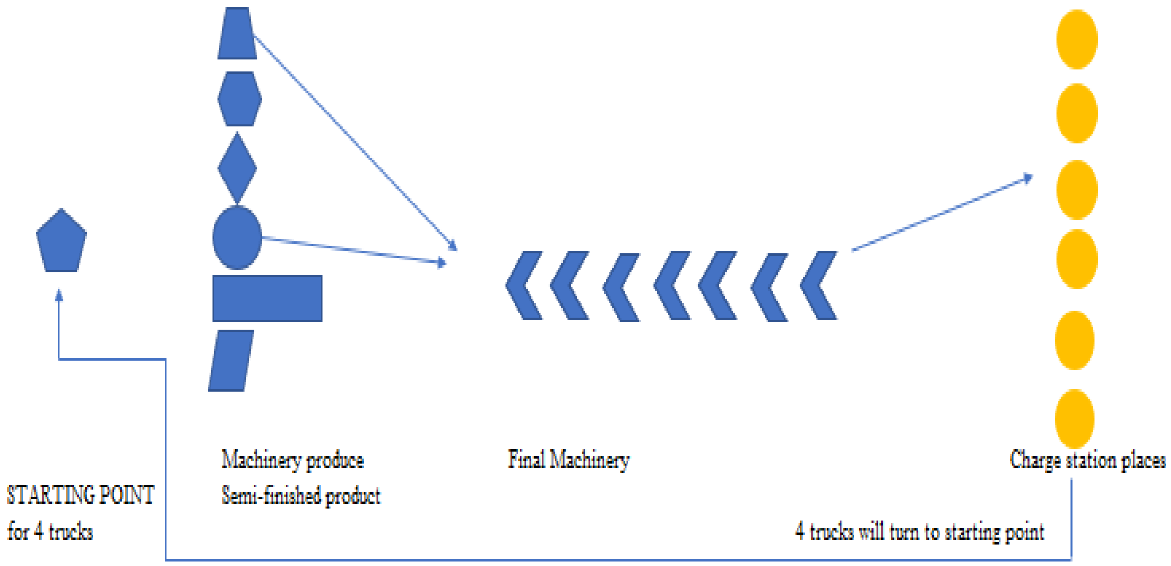

Figure 3.4 Main Flow Sketch Between Areas

As seen in figure 3.4, different semi-finished products might be carried to final machinery to be finished good. After loading and unloading operation has been done, tow tractors should go to the charging stations. In this study, selecting a station according to coordinates and distance from candidate battery charging station.

In mathematical model, we consider machines as subnodes, the model chooses any semi-item from item set to collect and choose any final machinery according to requirement to bring and choose one or more battery charging stations from candidate set to load battery.

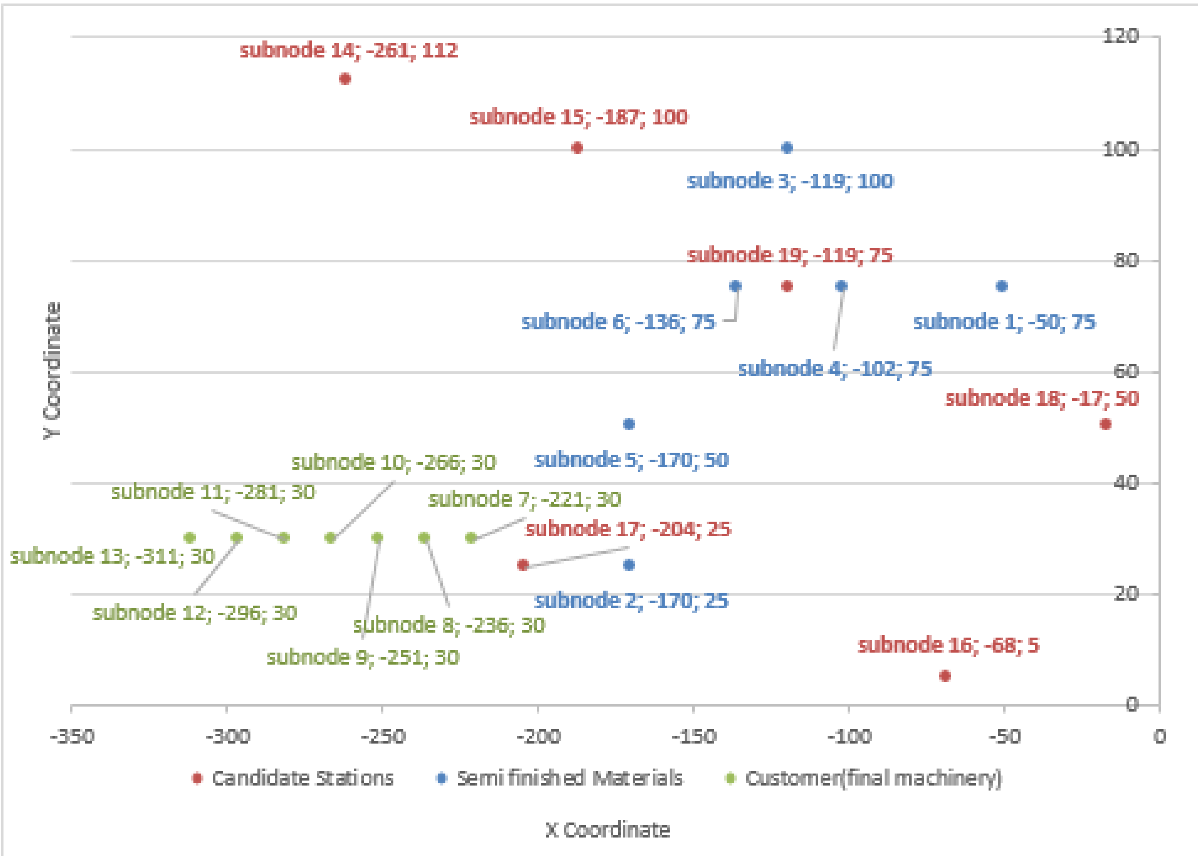

Figure 3.5 Layout of Subnode Sets

Total number of nodes starting from 1 to 19. The node set is dividing 3 subnode sets as subnode 1, subnode 2 and subnode 3 according to arrival and destination locations as showed above figure 3.5.

Table 3.3 "Between Item to Item" Index

	Index Number of Tow Truck	**From Index Number of Semi-Item**	**To Index Number of Semi-Item**	**Index Number of Trip**
X[k,i,j,s]	**k**	**i**	**j**	**s**
Index Number Interval	1 2 3 4	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6 7

Between Item to Item Machinery Index illustrated in table 3.3. Number 1 to 6, elements of subnode 1 set and represents the machinery which is producing different special semi-finished product. Loading operations can be performed while loading semi-items from 1^{st} to 6^{th} machines in the model. In the first stage of model includes a routing between 1^{st} to 6^{th} machines which represents as subnode 1. Collecting semi-items from these machines by tow trucks. Each truck shouldn't come back the previous semi-item machine in each trip. This is one of the critical points which provides the minimization of distance between semi-item machines. Each loading operation includes tow truck number, first semi-item machine number, next semi-item machine number and declares the number of trips. The trucks have six semi-item transportation capacity in each tour. So that, each truck can be loaded up to six carriages from any item. Each truck can be transported same or different semi-items. Totally four tow trucks will be loaded items in seven trips.

Table 3.4 "From Semi-Item Machines to Final Machines" Index

	Index Number of Tow Truck	From Index Number of Semi-Item	To Index Number of Semi-Item	Index Number of Trip
X[k,i,j,s]	**k**	**I**	**j**	**s**
Index Number Interval	1	1	7	1
	2	2	8	2
	3	3	9	3
	4	4	10	4
		5	11	5
		6	12	6
			13	7

From Semi-Item Machines to Final Machines Index illustrated in table 3.4. After loading operation is done, then truck transports to the final machines. Second routing will be done by transporting items to other area named final machinery. That’s why, while second index 1 to 6, third index will be 7 to 13.

Table 3.5 "Between Final Machine to Final Machine" Index

	Index Number of Tow Truck	Index Number of Final Machine	Index Number of Final Machine	Index Number of Trip
X[k,i,j,s]	**k**	**i**	**j**	**s**
Index Number Interval	1	7	7	1
	2	8	8	2
	3	9	9	3
	4	10	10	4
		11	11	5
		12	12	6
		13	13	7

Between final machine to Final Machine Index illustrated in table 3.5. From number 7 to 13, elements of subnode 2 set and represents the machinery which is producing finished product. Loaded items will be unloaded by tow trucks. Unloading operations can be performed only in final machinery area. There is no order of precedence between machines. The truck can be unloaded the required amount of semi-item to each final machine in a same trip. Each truck shouldn’t come back previous final machine in each trip. This is another point that helps the model to minimize the distance. There is another routing that is between final machines.

Table 3.6 "Between Final Machine to Charging Station" Index

	Index Number of Tow Truck	**Index Number of Final Machine**	**Index Number of Charging Station**	**Index Number of Trip**
X[k,i,j,s]	**K**	**i**	**j**	**s**
Index Number Interval	1 2 3 4	7 8 9 10 11 12 13	14 15 16 17 18 19	7

From Final Machine to Charging Station Index illustrated in table 3.6. Number 14 to 19, elements of subnode 3 set and represents the battery charging points. After each truck finish its task at 7th trip, next destination will be charging stations. Since these trucks powered by electricity batteries, vehicles dependent to electricity. In this manufacturing facility it is prefered to use dry type electricity battery. That’s why, vehicles should be charged in two hours. 7 trips allowed in 2 hours in this manufacturing facility.

Totally 4 tow tractors, should be carried of semi-finished items, to final machinery. While collecting semi-finished items, there should be routing, Then, after 2 hours, when lifecycle has been done, these vehicles should go to battery charging points. We define locations as coordinates, calculate the distance between machinery. That's why, this is a three stages assignment includes loading, unloading and charging.

Table 3.7 Selection of Model

	LRP	**LAP**	**Task Assignment**	**LARP**
Number of Facilities Opened	Fixed	Not fixed	Fixed	Not Fixed
Locations	Not fixed	Not fixed	Fixed	Not fixed
Vehicles Routing	Not fixed	Fixed	Fixed	Not Fixed
Tasks Assignment	Fixed	Fixed	Not fixed	Not Fixed
Selection of Model	X	√	X	X

The problem considered as LAP. As showing in Table 3.7 below, charging station placements and numbers and vehicle routing is not defined in the problem. Classical VRP solves routing by nodes; location fixed, allocation fixed, rout not fixed. LRP solves location and routing; allocation fixed. LARP solves location, allocation, routing together. Also, location not fixed, allocation not fixed, and rout not fixed in LARP.

3.2.1 Mathematical Modelling

A nonlinear model is generated based on loading-unloading-charging operations in order to minimize the travelling distance of electric industrial vehicles based on low energy consumption and maximum utilization under capacity and location constraints.

$$\min 2 * \sum_{s}^{S}\sum_{k}^{K}\left(\sum_{j}^{t}\sum_{i=1}^{t} x_{kijs} * d_{ij} + \sum_{i=1}^{t}\sum_{j=t+1}^{f} X_{kijs} * m_{ij} + \sum_{j=t+1}^{f}\sum_{i=t+1}^{f} X_{kijs} * P_{ij}\right) + \sum_{i=t+1}^{f}\sum_{j=f+1}^{j=19} X_{kijs} * h_{ij} \tag{1}$$

$s.t.$

$$\sum_{i=1}^{I\in set1} \sum_{j=1}^{J \in set2} x_{kijs\ q_{kijs}} \leq Q \qquad \forall k, \forall s \tag{2}$$

$$\sum_{s=1}^{S} \sum_{k=1}^{K} x_{kijs\ q_{kijs}} = D_{ij} \qquad I \in set1,\ J \in set2, \forall j, i \tag{3}$$

$$\sum_{i=1}^{i\in set1} \sum_{j=1}^{J\in set1} x_{kijs} \leq 1 \qquad i \neq j, \forall k, s \tag{4}$$

$$\sum_{\mathrm{i}=1}^{j\in set1} X_{kijs} \leq 1 \qquad i \neq j, \forall i \in set1, \forall k, s \tag{5}$$

$$\sum_{\mathrm{i}=7}^{i\in set2} X_{kijs} \leq 1 \qquad i \neq j, \forall j \in set2, \forall k, \forall s \tag{6}$$

$$\sum_{j=7}^{j\in set2} X_{kijs} \leq 1 \qquad i \neq j, \forall i \in set2, \forall k, \forall s \tag{7}$$

$$\sum_{i=7}^{i\in set2} X_{kjis} \leq \sum_{i=7}^{i\in set2} X_{kijs} \qquad i \neq j, \quad \forall j \in set2, \forall k, s \tag{8}$$

$$\sum_{i=1}^{i\in set1} X_{kjis} \leq \sum_{i=1}^{i\in set1} X_{kijs} \qquad i \neq j, \quad \forall j \in set1, \forall k, s \tag{9}$$

$$X_{kiis} = 0 \qquad i \neq j, \forall j \in set1, \forall k, s \tag{10}$$

$$X_{kjjs} = 0 \qquad j \in set2, \forall k, \forall s \tag{11}$$

$$\sum_{i=1}^{I\in set2}\sum_{j=1}^{J\in set3} x_{kijs\ q_{kijs}} \geq 1 \qquad \forall k \tag{12}$$

$$q_{kijs} \geq 0 \qquad I \in set1,\ J \in set2\ , \forall\ k, s \tag{13}$$

$$q_{kijs} \leq 6 \qquad \forall k, \forall s\ , I \in set1,\ J \in set2 \tag{14}$$

$$M\ *\sum_{m=1}^{m\in set1} X_{kims} \geq X_{\ kijs} - \sum_{m=1}^{m\in set2} X_{kjms} \qquad I \in set1,\ J \in set2,\ m \neq j\ , i \neq j, \forall k, s \tag{15}$$

$$X_{kijs} + M * X_{kjis} \geq \sum_{m=1}^{m\in set1} X_{kmis} + \sum_{m=1}^{m\in set2} X_{kmjs} \qquad I \in set1,\ J \in set1, i \neq j, \forall k, s \tag{16}$$

$$X_{kijs} \leq 1 - X_{kjis} \qquad I \in set1,\ J \in set1, \forall\ k, s \tag{17}$$

$$X_{kijs} \leq 1 - X_{kjis} \qquad I \in set2,\ J \in set1, \forall\ k, s \tag{18}$$

$$\sum_{m=1}^{M\in set1} X_{kmjs} \leq 1 - X_{kijs} \qquad I \in set1,\ J \in set1, m \neq i, \forall\ k, s \tag{19}$$

$$\sum_{m=1}^{M\in set2} X_{kmjs} \leq 1 - X_{kijs} \qquad I \in set2,\ J \in set2,\ m \neq j, \forall\ k, s \tag{20}$$

$$X_{kijs} = 0 \qquad \forall j \in set1, \forall i \in set2, \forall k, s \tag{21}$$

Decision Variables;

$$X_{kijs} = \begin{cases} 0, & \textit{if kth tow track do not transport ith item to jth machine in sth trip} \\ 1, & \textit{if kth tow track transport ith item to jth machine in sth trip} \end{cases}$$

$q_i \in \{1..6\}$

Notations;

k : index number of tow track

i, l : index number of semi-items

j : index number of final machines

s : index number of trips (fixed as 7)

n : index number of charging stations

K : total number of tow tracks

I: total number of semi-items (nodes)

J : total number of final machines

s : total number of trips

N: total number of charging stations (fixed as 6)

q_i: quantity of ith type loaded items(semi- products) to tow tracks

D_{ij}: required quantity of ith semi-products for jth final machine.

Q: maximum number of items that a tow tractor can load in one-trip. (fixed as 6)

The objective function which is shown with equation 1 minimizes the total travelled distance between semi-items, final machine and charging stations. The total travelled distance is multiplied by two because the trucks pick up the empty carts following the same path. Equation 2 ensures that the total number of carriages cannot be more than six in each trip in one trip for each truck. The items should be carried to final machinery area according to the demands of the final machinery to semi-item in each trip. Equation 3 ensures the transportation of required quantity of each item by all trucks based on the total demand of each final machinery throughout the trips. Equation 4 is routing constraint between semi-item machines so that each truck shouldn't come back the previous machine that collected in a same trip and equation 5 prevents the loop during routing. Equation 6 and 7 ensure the routing between machines. Equation 8 provides the precedence in items. Equation 9 ensures the precedence in final machines. Equation 10 and 11 prevent the routing between same machines in each trip for each truck. Equation 12 provides that charging station decision is made in last trip. Equation 13 and 14 ensure that quantity in final machinery will be between zero and six. Equation 15 and 16 using big M because of the elimination of returning back while left side of the equation forces bigger than right side. Equation 17 and 18 provide the main direction of material flow will be semi-item to final machinery. They provide that a truck should not go from the same machine to same machine. Equation 19 and 20 together deploy that if a truck shouldn't go to same subnode in the same trip for the same truck. Equation 21 ensures that one truck shouldn't go back from final machine to semi-item machine in the same trip. It eliminates wrong way material flow. Some decision variables should equal to zero in the mathematical model. The reason of assignment zero at the beginning for the necessary combinations provides to increase solver speed. If these constraints were not written in the model, solver would assign zero and try in the objective function, but these decision variables never should be assigned as one.

$$\max z = f(x_1, \ldots, x_n) \tag{22}$$

$$\sum_{j=1}^{n_k} x_j - (n_k - 1) \leq y_k \tag{23}$$

$$\frac{1}{n_k} \sum_{j=1}^{n_k} x_j \geq y_k \tag{24}$$

General optimization problems are to select n decision variables x1, x2, . . . , xn from a given feasible region to optimize in a given objective function. The problem is called a nonlinear programming problem if the objective function is nonlinear and/or the feasible region is determined by nonlinear constraints. Nonlinear modeling is to model complex situations where relationships of different variables are not known. Nonlinear models should be transformed to linear models for facilitating solutions to some problems.

In this study, it is struggled to solve the problem as linearity. Equation 23 and 24 can be used to transform nonlinear model which shown as maximization function in equation 22 to linear model. There are a lot of variables in this electric vehicle location-allocation problem. Using the above inequalities in this model causes complexity onsolution and also increases of variables. Converting the model to the linearmodel makes the solution of the problem harder since the problem is already NP-Hard and contains very variables. As a result, we did not transform this nonlinear model to a linear model since it is not contributing to the result.

4. RESULTS AND DISCUSSIONS

This study includes a combination of real manufacturing material handling and facility location problem. After getting data, mathematical model is improved, solved by OPL. There is a nonlinear programming. Nonlinear programming shows as CP (Constraint Programming) in OPL.

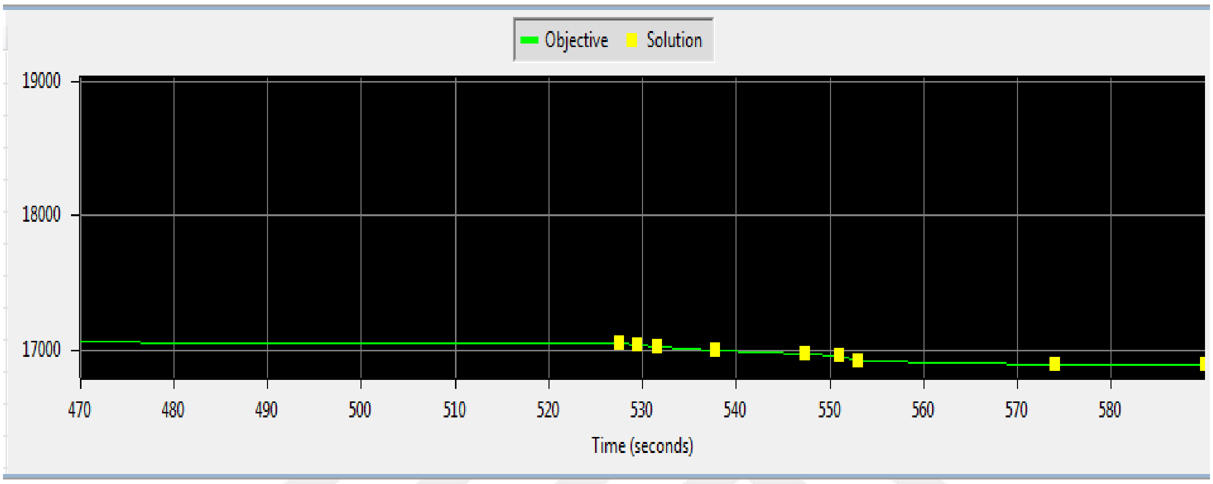

Figure 4.1 OPL Solution Timeline

Figure 4.1 presents as the model result provided the best feasible solution. It was more than 17000 in first 470 minutes, than found the feasible solution.

Statistics	Value
▼ cp	
Memory usage	69003716
Choice points	3568048
Number of solutions	31
Number of branches	4009909
Number of fails	442441
Objective	16,897

Figure 4.2 OPL Solution Output

Solver output shown in figure 4.2. Program executed for 10 minutes; 31 solutions are found in almost 5,7 minutes by OPL using by CP. Total combination number is 8092. Number of total assigned combinations is 2714. Model provides to bring items to final machinery. Each truck will be completed its trip after unloading items to the assigned final machine. After completed loading and unloading operations at the end of six trips, each truck will be charged in the 7th trip. When the trucks finish its unloading operation, the trucks select the nearest charging station.

Table 4.1 Loading-Unloading Operations in Each Trip

[k, i, j, s]	Truck	Semi-item	Final machine	Trip
1281	1	2	8	1
13121	1	3	12	1
2191	2	1	9	1
22101	2	2	10	1
33101	3	3	10	1
42121	4	2	12	1
1582	1	5	8	2
16102	1	6	10	2
16112	1	6	11	2
2182	2	1	8	2
22132	2	2	13	2
3572	3	5	7	2
3582	3	5	8	2
3682	3	6	8	2
41112	4	1	11	2
46132	4	6	13	2
12103	1	2	10	3
13113	1	3	11	3
2293	2	2	9	3
2483	2	4	8	3
3593	3	5	9	3
35113	3	5	11	3
4183	4	1	8	3
44113	4	4	11	3
44133	4	4	13	3

1294	1	2	9	4
13134	1	3	13	4
15104	1	5	10	4
21124	2	1	12	4
2474	2	4	7	4
32134	3	2	13	4
3394	3	3	9	4
42134	4	2	13	4
4374	4	3	7	4
44124	4	4	12	4
4694	4	6	9	4
13115	1	3	11	5
1495	1	4	9	5
14105	1	4	10	5
21105	2	1	10	5
23115	2	3	11	5
3175	3	1	7	5
3395	3	3	9	5
4375	4	3	7	5
12116	1	2	11	6
2276	2	2	7	6
3386	3	3	8	6
4386	4	3	8	6
43126	4	3	12	6
45136	4	5	13	6

In table 4.1, shows only assigned as “1” combinations. The optimal loading and unloading operations are given including the index number of trucks, semi-items, final machines for each trip up to six. the index number combinations of decision variable X are controlled. All the constraints and expected logic of assignments are provided by the model as shown in table. The table shows that semi-item to final machine assignments, final machine to final machine assignments are achieved successfully by the model. Since no more than six semi-item in each trip, each truck obeys the capacity constraint as expected. Each truck selects a charging station only at the correct time (in 7th trip).

Table 4.2 Quantity Assignment of Each Truck at Each Trip

	Truck	From Semi-Item	To Final Machine	Quantity of Item
1st Trip	1	2	8	1
1st Trip	1	3	12	5
1st Trip	2	1	9	4
1st Trip	2	2	10	2
1st Trip	3	3	10	6
1st Trip	4	2	12	6
2nd trip	1	5	8	2
2nd trip	1	6	10	2
2nd trip	1	6	11	2
2nd trip	2	1	8	2
2nd trip	2	2	13	4
2nd trip	3	5	7	3
2nd trip	3	5	8	1
2nd trip	3	6	8	2
2nd trip	4	1	11	4
2nd trip	4	6	13	2
3rd trip	1	2	10	3
3rd trip	1	3	11	3
3rd trip	2	2	9	4
3rd trip	2	4	8	2
3rd trip	3	5	9	3
3rd trip	3	5	11	3
3rd trip	4	1	8	2
3rd trip	4	4	11	2
3rd trip	4	4	13	2
4th trip	1	2	9	2
4th trip	1	3	13	1
4th trip	1	5	10	3
4th trip	2	4	7	2
4th trip	2	1	12	4
4th trip	3	3	9	5
4th trip	3	2	13	1
4th trip	4	3	7	1
4th trip	4	6	9	2

		2	13	1
		4	12	2
5th trip	1	4	9	2
		3	11	2
		4	10	2
	2	1	10	4
		3	11	2
	3	1	7	4
		3	9	2
	4	3	7	6
		5	13	3
6th trip	1	2	11	6
	2	2	7	6
	3	3	8	6
	4	3	8	1
		3	12	2
		5	13	3
7th trip	1	2	10	1
		5	12	3
		6	12	2
	2	3	10	1
		2	8	5
	3	6	7	2
		1	13	4
	4	3	13	6

Table 4.2 shows each trip routing with amount of carried amount of semi-item for four trucks with specific colors. The table is presented the amount of the item that is unloading. According to tow truck number, it should get related semi-item from its semi-item machine, then release it in to the final machine. Some of the trucks get only one item, some of them more than one from related semi-item. The model ensures the optimization of the task assignment. The rule of capacity of a truck is six resulted successfully as table 4.2. It is easily understood that each truck got maximum six item in each trip from this table in "Quantity of Item" column. For example, 1st truck in 1st trip transported totally six items; one cart from item 2, five carts from item 3 and 2nd truck in 1st trip transported totally six items too; four carts from item 1 and two carts from item 2. Model's 1st capacity constraint in is totally

maximum six carriages (material handling carts) can be carried. Result shows that a truck didn't transport less than six items in each trip in order to carry maximum item can be loaded. That's why the model provides energy saving.

Table 4.3 Demand Quantity Allocation to Final Machines

Semi-Item	Total Transported Quantity of Semi-Item						
	7th final machine	8th final machine	9th final machine	10th final machine	11th final machine	12th final machine	13th final machine
1	4	4	4	4	4	4	4
2	6	6	6	6	6	6	6
3	7	7	7	7	7	7	7
4	2	2	2	2	2	2	2
5	3	3	3	3	3	3	3
6	2	2	2	2	2	2	2
Total	**24**	**24**	**24**	**24**	**24**	**24**	**24**

Model's 2nd constraint ensures that each item can be transported to final machines according to requirement. Requirement of final machines refers demand and showed as "D" in OPL, and data is inputted (for more information please check appendices). Table 4.3 presents the demands reached the final machines. Four carts necessary from Item 1 in each identical final machine. Six carts from item 2, seven carts from item 3, two carts from item 4, three carts from item 5, two carts from item 6 for each final machine. Results show that totally 24 items transported by four trucks to each final machine. This means that the exact number of requirements reached to each final machine.

Table 4.4 Charging Station Assignment

Combination	Assignment	Truck	Item	Final	Trip
18177	1	1	8	17	7
28177	1	2	8	17	7
310177	1	3	10	17	7
47177	1	4	7	17	7

Charging station assignment at the last trip(7^{th}) showed in above table 4.4. Since each truck finished the unloading operations at final machinery and 17^{th} charging station most closed station to final machinery area, assignments for all trucks at last trip is 17. That's why charging station locations should be selected as 17^{th} location. As the location is showed in figure 3.3, coordinates of 17^{th} node is (-170,25).

Results demonstrated that each constraint is contributed the model successfully. The load of trucks didn't over the capacity of truck. All candidate charging stations have enough capacity to utilize four trucks. Since all trucks assigned to one and only charging station which showed as 17^{th} location, only one charging station should be installed in that location. Cost of the installing charging station includes wiring inside facility and purchasing battery charger. Installing charging station requires same amount of cost for each location. All trucks assigned only one location. There is no need to install stations for six different locations. Therefore, there is also cost saving in installing charging station beside energy saving.

5. CONCLUSIONS

This manufacturing facility has different kinds of material handling vehicles. In today's digitalized world, plant industrial engineers take performance data and change the speed limitations to the vehicles through desktop applications. According to the graph that shows working hours, transfer work constitutes of %63 in the lifecycle of a truck in this manufacturing facility. When production amount increases, workload will also increase significantly. Therefore, energy expenditures will be higher in the future. It is possible to decrease energy consumption by reducing traveling distance. Vehicle battery is empowered by electricity where the technology is the dry battery. These dry batteries are designed to be charged once every 2 hours. That means opportunity charge. Opportunity charge will charge much faster than conventional type batteries. Since, two hours is the charging limit, the optimization modelled for 2 hours is required by the final machinery.

Material flow is always left to right. Tow tractors load semi-finished products in 6 different machinery, unload to 7 different and identical final assembling machineries, load empty semi-finished product carriages, bring them back to semi-finished machinery in the same route, then load back. After the same period is completed 7 times, trucks should go to the charging stations at the end of their 7^{th} trip.

After 2 hours of loading-unloading-loading operation loop happening more than once, the vehicle should be charged in the charging stations and trucks should choose a charging station from 6 available charging stations. Since the model for 4 trucks will choose only one charging station amongst 6 available ones, the cost of the battery charging station installation is equal to the cost of only 1 instead of 6 units of charging station.

This study has saved not only 5 units of charging station installation cost, but also energy cost due to the assignment of correct tasks to correct vehicle at the correct time. A nonlinear model solves the problem, determining optimal locations for charging stations for three stage assignment of loading-unloading-charging operations. By this, travelling distance of industrial electric vehicles in minimized in a given period based on low energy consumption and maximum utilization. Optimization model is nonlinear and solved by IBM ILOG OPL IDE.

6. RECOMMENDATIONS

In the future works, different methods can be tried to generate linear modelling and be presented as alternative results. Routing modelling can be used to solve the problem between the same machinery according to production flow instead of different machineries as this model. Scheduling can be applied when facing with the problem which conflicts the situation of trucks as charging only in one charger. Scheduling also provides saving in investment cost while purchasing chargers. Only one charger can be installed to assigned charging station location instead of four chargers and trucks can be charged in sequence.

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APPENDICES

Data Input

```
/*********************************************
 * OPL 6.3 Data
 * Author: ABUDAK
 * Creation Date: 29.Mar.2019 at 19:04:43
 *********************************************/

Q = 6;
NumberofTowTracks =4;
TotalNumberOfSemiItems=6;
TotalNumberofFinalMachines =7;
TotalNumberofTrips =7;

RequiredQuantityofIthTypeLoadedSemiItemsforFinalMachine =24;
dItemItem = [[0,170,94,52,145,86],
[170,0,126,118,25,84],
[94,126,0,42,101,42],
[52,118,42,0,93,34],
[145,25,101,93,0,59],
[86,84,42,34,59,0]
];
dMachineCharge = [[122,104,178,22,244,192],
[107,119,193,37,239,162],
[92,134,208,52,254,177],
[87,149,223,67,269,192],
[102,164,238,82,284,207],
[117,179,253,97,299,222],
[132,194,268,112,314,237]
];
dMachineMachine =
[[0,15,30,45,60,75,90],
[15,0,15,30,45,60,75],
[30,15,0,15,30,45,60],
[45,30,15,0,15,30,45],
[60,45,30,15,0,15,30],
[75,60,45,30,15,0,15],
[90,75,60,45,30,15,0]
];

dItemMachine =[[216,231,246,261,276,291,306],
[51,66,81,96,111,126,141],
[102,117,132,147,162,177,192],
[119,134,149,164,179,194,209],
[51,66,81,96,111,126,141],
[85,100,115,130,145,160,175]
];

D=[[4,4,4,4,4,4,4],
[6,6,6,6,6,6,6],
[7,7,7,7,7,7,7],
[2,2,2,2,2,2,2],
[3,3,3,3,3,3,3],
```

```
[2,2,2,2,2,2,2]
];
```

Mathematical Model Input

```
/**********************************************
* OPL 6.3 Model
* Author: ABUDAK
* Creation Date: 20.Mar.2019 at 23:05:49
*********************************************/
using CP;

range TowTracks = 1..4;
range Trips = 1..7;
range nodes =1..19;
range subnode1 = 1..6;
range subnode2 = 7..13;
range subnode3 =14..19;
int Q = ...;
int NumberofTowTracks =...;
int TotalNumberOfSemiItems=...;
int TotalNumberofFinalMachines =...;
int TotalNumberofTrips =...;
range LastTrips= 7..7;



int RequiredQuantityofIthTypeLoadedSemiItemsforFinalMachine =...;
int MaximumNumberOfItemsThatATowTractorCanLoadOneTrip = 6;
int dItemItem [subnode1,subnode1]=...;
int dMachineCharge [subnode2,subnode3]=...;
int dMachineMachine [subnode2,subnode2]=...;
int dItemMachine [subnode1,subnode2]=...;
int D [subnode1,subnode2]=...;

//DecisionVariables
dvar int q[TowTracks,nodes,nodes,Trips];
dvar boolean X[TowTracks,nodes,nodes,Trips];

minimize
2*sum (k in TowTracks, s in Trips)(sum(i in subnode1, j in
subnode1)X[k,i,j,s]*dItemItem[i,j]+ sum(i in subnode1, j in
subnode2)X[k,i,j,s]*dItemMachine[i,j]+ sum(i in subnode2, j in
subnode2)X[k,i,j,s]*dMachineMachine[i,j])+
sum(k in TowTracks, i in subnode2, j in subnode3) X[k,i,j,7] *
dMachineCharge[i,j];

subject to {
c0:forall (k in TowTracks, s in Trips)
                  sum (i in subnode1, j in subnode2) q[k][i][j][s]*
X[k][i][j][s] <= Q;


c1:forall (i in subnode1, j in subnode2)
      sum (k in TowTracks, s in Trips) X[k,i,j,s] * q[k][i][j][s] ==
D[i,j];

c2:forall (k in TowTracks, s in Trips)
```

```
     sum (i in subnode1, j in subnode1: i!=j) X[k,i,j,s] <=1;


c3: forall (k in TowTracks, s in Trips, i in subnode1)
     sum (j in subnode1: i!=j) X[k,i,j,s] <=1;

c4: forall (k in TowTracks, s in Trips, j in subnode2)
      sum (i in subnode2: i!=j) X[k,i,j,s] <=1;

c5: forall (k in TowTracks, s in Trips, i in subnode2)
      sum (j in subnode2: i!=j) X[k,i,j,s] <=1;

c6: forall (k in TowTracks, s in Trips, j in subnode1)
      sum (i in subnode1: i!=j) X[k,j,i,s] <= sum (i in subnode1: i!=j)
X[k,i,j,s];

c7: forall (k in TowTracks, s in Trips, j in subnode2)
     sum (i in subnode2: i!=j) X[k,j,i,s] <=sum (i in subnode2: i!=j)
X[k,i,j,s];



 c8: forall (k in TowTracks, s in Trips, i in subnode1)
    X[k,i,i,s] ==0;
 c9:   forall (k in TowTracks, s in Trips, j in subnode2)
    X[k,j,j,s] ==0;

 c10: forall (k in TowTracks, s in LastTrips)
 sum ( i in subnode2, j in subnode3)X[k,i,j,s] >=1;

 c11: forall (k in TowTracks, i in subnode1, j in subnode2, s in Trips)
 q[k,i,j,s] >=0;

 c12: forall (k in TowTracks, i in subnode1, j in subnode2, s in Trips)
 q[k,i,j,s] <=6;

c13: forall (k in TowTracks, i in subnode1, j in subnode2: i!=j, s in
Trips)
 (sum ( m in subnode1) X[k,i,m,s]) *100 >= X[k,i,j,s]* (sum (m in
subnode2:m!=j)X[k,j,m,s]);

c14: forall (k in TowTracks, i in subnode2, j in subnode2: i!=j, s in
Trips)
 (X[k,i,j,s]+ X[k,j,i,s])*100 >= (sum ( m in subnode1) X[k,m,i,s]) * (sum
(m in subnode2) X[k,m,j,s]);

 c15: forall (k in TowTracks, i in subnode1, j in subnode1, s in Trips)
 X[k,i,j,s] <= 1 - X[k,j,i,s];

 c16: forall (k in TowTracks, i in subnode2, j in subnode1, s in Trips)
 X[k,i,j,s] <= 1 - X[k,j,i,s];

 c17: forall (k in TowTracks, i in subnode1, j in subnode1, s in Trips)
 sum (m in subnode1: m!=i) X[k,m,j,s] <=1-X[k,i,j,s];

 c18: forall (k in TowTracks, i in subnode2, j in subnode2, s in Trips)
 sum (m in subnode2: m!=i) X[k,m,j,s] <=1-X[k,i,j,s];
```

```
 c19:  forall (k in TowTracks, i in subnode2, j in subnode1, s in Trips)
 X[k,i,j,s] ==0;

}



main {
thisOplModel.generate();
cp.param.TimeLimit = 90;
cp.solve();
for (var k=1;k<=4;k++)
{
for (var i=1;i<=13;i++)
{
for (var j=1;j<=19;j++)
{
for (var s=1;s<=7;s++)
{ writeln(thisOplModel.X[k][i][j][s])};
}
}
}
//{
for (var m=1;m<=4;m++)
{
for (var t=1;t<=6;t++)
{
for (var u=7;u<=13;u++)
{
for (var h=1;h<=7;h++)
{ writeln(thisOplModel.q[m][t][u][h])};
}
}
}
}
```