Optimization of Vehicle Routing in a Supply Chain

by

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A Project report submitted in partial fulfillment of the requirements for the degree of Master of Science in Engineering in Industrial Engineering & Management.

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Declaration

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------September 2009 Author

ABSTRACT

Supply chain is a sequence of organizations- their facilities, functions and activities- that are involved in producing and delivering a product or service. The sequence begins with basic suppliers of raw materials and extends all the way to the final customers. So product delivery to the final customer is the ultimate physical activity of a supply chain management.

Human civilization has a long outstanding history for the efforts to optimize traveling routes or delivery routes. The first ever systematic initiative, so far known, is The Travelling Salesman Problem. Fixed route transit schedule, Vehicle Routing Problem (VRP), Vehicle Routing Problem with Time Windows (VRPTW), Pickup and Delivery Problem with Time Windows (PDPTW), Single Vehicle Routing Problem with Deliveries and Selective Pickups (SVRPDSP), etc are the initiative for optimizing vehicle routing. The aims are to design a vehicle route of minimum net cost, visiting each customer, performing all deliveries, etc.

Here, A study was accomplished in a systematic manner on the delivery system of a renowned Multinational organization, targeting to optimize their delivery system. They have twenty sales centers around the country. All of their products are sold through these sales centres. From these sales centres, they sold the goods to their dealers and some special customers. They provide transport for the delivery of goods. One of their sales centre was studied which involved one pickup for their delivery purpose to serve about forty eight regular customers.

When we studied their order pattern, we found that the vehicle is sometimes overloaded and some other times under loaded. We further drilled down the issue and found that they have no specific schedule for their deliveries. Our intention was to develop a model for optimizing such delivery schedule.

First of all, we examined the order quantity and order interval of each delivered customer as the model must be capable to handle the demands of the sales centre and individual customer also.

Then we identify feasible routes based on geographical location. Then we try to attach customers with the route. Route wise demand forecasting was done to

rationalize the model. Cumulative order frequency of each route was identified.
The organization, we studied, was intended to maintain high standard of safety of the driver and the vehicle. They are also keen to maintain all the rules and regulations of the government. So, they have their own embargo on the daily duty hours of the drivers, their speed limit, rest period, rated vehicle capacity, etc.

Considering all the factors, for generic approach, let there are m numbers of routes and n numbers of time periods (days). A single vehicle was considered to perform the whole distribution system ensuring all the embargo of safety and demand. An integer transportation model was considered to solve the problem. Time periods were plotted in the rows and Routes were plotted across the columns of the model.

Two objective functions were formulated to solve the problem. First one was considering to minimize numbers of total trip of a time period. The constraint equations were formulated to represent total driving time of a day, total demand constraints, disbursement of trips in the whole time period, limitation of parallel routes, etc. In the second objective function, the idle time of a day was introduced and minimized to ensure optimal utilization of the vehicle in a day.

We used Lindo 6.0 software for optimizing the models. After optimization, it was found that the first model yields an optimized solution satisfying all the constraints. But the second model yields better result compared to the first one in respect of vehicle utilization ensuring all the required constraints of the system.

Finally, some recommendations were proposed for further development of these models.

Contents

List of Tables

List of Figures

Nomenclature

DOA	Delegation of Authority
ID	Identification
KPI	Key Performance Indicator
PC	Personal Computer
VAT	Value Added Tax
TSP	Travelling Salesman Problem

CHAPTER 1

INTRODUCTION

1.1 General

Supply chain is a sequence of organizations- their facilities, functions and activities- that are involved in producing and delivering a product or service. The sequence begins with basic suppliers of raw materials and extends all the way to the final customers. [1] So, product delivery to the final customer is the ultimate physical activity of a supply chain management.

On the other hand, Sales and marketing is one of the most, if not the most important focus area of a modern profitable organization. All the business decisions are governed by the requirements of their customers. Customers "need and wants" are identified and anticipated. Business decisions are usually made to cope up with those "needs and wants". Due to globalization, modern business is a very competitive arena. In such competitive environment, the success of a business organization depends on how efficiently, effectively and economically it can translate the needs and wants of their customer in their business goal.

Delivery of goods to the customer place is one of such "customer's need". specially for the manufacturing and business sectors where product's value is less compared to their weight or volume, for example, cement, welding electrodes, sand, bricks, steel and iron products, furniture, etc. To get a competitive advantage, some of such manufacturer and distributors arrange delivery of their goods to the customers through their own transport. This practice usually brings a competitive edge to the company compared to their competitors who don't have delivery facilities and who deliver their goods via public transport or currier. Delivery of the good to the customers are also important for enabling the organization to ensure proper handling of the product, its quality, safety, etc up to the ultimate selling or using point of the products. It in terns gives higher satisfaction of the customer and users of the products which reinforces goodwill of the organization.

Due to proper penetrating to the market, most of the business organizations engage distributors, dealers, resellers for their products in different areas within the geography. The strategy about the dealer, their incentives, dealer administration, their business terms and conditions, payment mode, etc vary from organization to organizations depending on the product strength, business goodwill, branding, etc. The basic format of the supply chain from finished product store to the customer or to the end user is as follows:

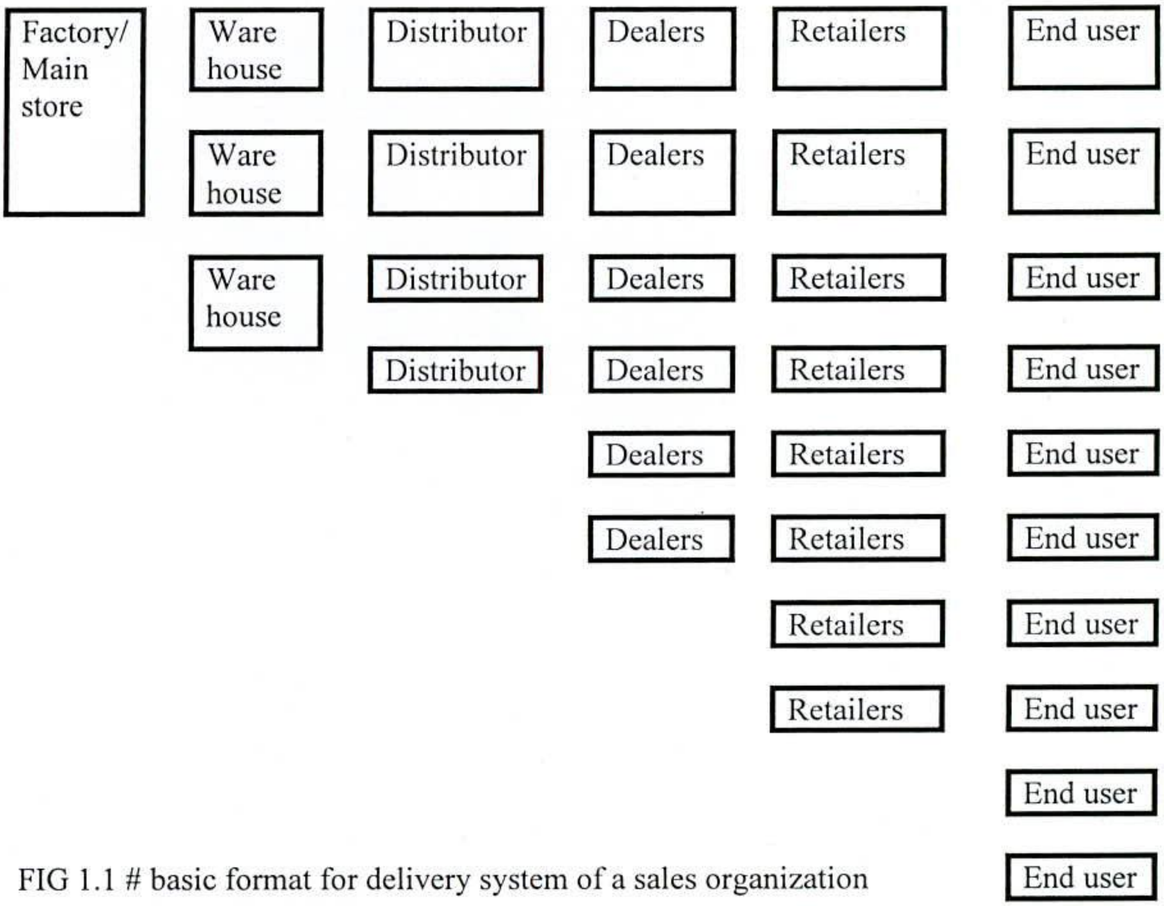


FIG 1.1 # basic format for delivery system of a sales organization

Sales and marketing personnel of the organization usually govern the system and collect information about the market. The organization decides about how far they will provide transportation depending on the competitor's activities, costing of the product, customer's expectations, their market penetrating policy, etc. Usually, they provide transportation up to distributor or dealer end. In such cases, they may use their own fleet or may use rented or contracted vehicles to serve the purpose.

On the other hand, modern organizations consider various factors to reinforce their goodwill, to secure their business and to reduce risk factors. Safety and environment consciousness are such issues. Reliable delivery may ensure customer satisfaction and also can reduce the market risk involved in ensuring uninterrupted supply. Many organizations failed to ensure proper safety in their delivery system which results accident, incident, product damage, loss in goodwill, incur additional insurance premium, etc. when the product itself is hazardous, failing to ensure proper safety in transportation and in use may cause unwanted damage including fatality. Environmentally red or orange products may cause additional cost to the company and also to the society if they fail to ensure proper safety for their products in both the transportation and use.

So, modern smart organizations usually put strong control in their transportation system. Regardless, they have their own transport or rented, they put numbers of protections and precautions for their delivery vehicle fleets. Some of them are:

1. Ensuring rated capacity of the vehicle
2. Ensuring speed limit
3. Ensuring Safety belt and other safety equipments.

4. Ensuring protection for the products against damage, fire and water
5. Ensuring proper inspection, maintenance of the vehicles including proper braking capability and testing, tire thread type and depth, etc.
6. Ensuring proper training and motivation of the driver to drive with the principles of "Defensive driving"
7. Ensuring proper planning for reasonable duty hour of the driver. this is very and the most important as driver's fatigue is one the most critical factor for causing an incident or accident.
8. etc.

In Bangladesh, now a days, many organizations including multinational and national, are working on the "Delivery transport system" in a professional manner. Despite all the critical limitations to ensure safety and comfort of the driver, they are trying to optimize their delivery transportation system. Delivery scheduling is such an initiative.

1.2 Motivation Behind The Thesis

Nobody expects loss of business order due to transportation of good to the customer. The means of transport, the number of vehicle involved, their capacities, etc are decided according to the market demand, customer's location, customer's capability to purchase, production capacity of the organization, geographical route conditions, etc. On the other hand smart organizations want to minimize the transportation cost as well as "safety threads" in transportation for their delivery system. So, there is a contradiction and hence should have a "Trade off" between the factors involved. Traditionally, the trade-off between numbers of delivery to the customers which involves customer's cash, drivers safety, and transportation cost has been considered as a dilemma in every delivery system. The fact was that no optimal results regarding all three dimensions could be achieved at a time. The tension between customer's want and transportation cost was seen, in simple terms, as the following: the more numbers of deliveries, the more customer satisfaction will be achieved. However, a conflicting goal is to perform the required deliveries within reasonable transportation cost. The third dimension Drivers safety adds a further tension to this trade-off. ensuring safety of the drivers as well as the deliveries may also put tension on the transportation cost. The interdependence between these three dimensions has become a known dilemma. Now a days, companies sought to achieve the right tradeoff in order to maximize their profits.

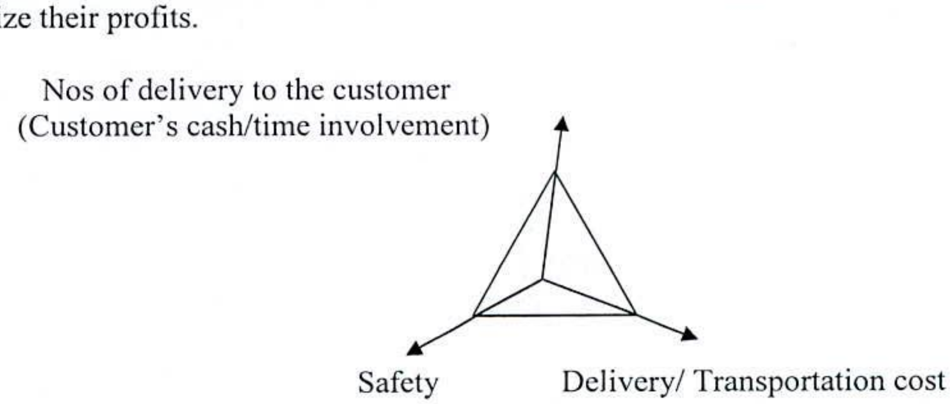


Figure 1.2: Dilemma in delivery scheduling

Frequent and unscheduled delivery may also cause dissatisfaction to the customer. Say, one reseller always gets supply just when he placed the order without any service level agreement. He will definitely be habituated with this "as and when" pattern and his expectation will be like that though it is impractical and non-professional approach. Thus he will not maintain any order frequency and thus no market information about end user will be available at his end. In any case, if the supply takes delay, for any amount of time, the customer will be dissatisfied. There may cause product shortage at the reseller end so ultimately business suffers.

So, there should have a systematic approach for all the delivery process. dealer/ resellers should have a order pattern and delivery schedule should be prepared in advance. Market information is the base for such schedule. If the dealer/reseller finds the schedule in advance, they can tune their stock and reorder level accordingly. When the optimized schedule seems inline with customer's requirements (considering their cash involvement, product storage capacity, receiving process and cost, market demand, etc), it can be terms as an ideal and efficient delivery planning. In such system, the triangle of fig. 1.2 will be of proper unbiased shape. We are in quest of such an optimized delivery system.

The purpose of this study is to develop an effective and optimal delivery routing considering the following aspects:

1. Routes must cover all the potential regular customer points.
2. Road condition must be smooth, safe and free from the risk of unwanted delay or interruptions.
3. Ordering frequency/nature of the customers to be addressed
4. Cumulative ordered quantity for a trip in a route must satisfy the usual carrying load of the vehicle.
5. Time required for a delivery in a route must match to the duty hour of the driver to ensure proper safety.
6. etc

1.3 Objectives of the Research Work:

The followings are the specific objective of the research work:

- Identification of feasible routes for the supply chain.
- Optimization of numbers of trips for each route.
- Assignment of vehicle to each route.

CHAPTER 2

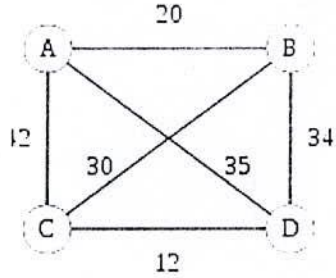
LITERATURE REVIEW

2.1 Related Works

2.1.1 Travelling salesman problem.

Human civilization has a long outstanding history for the efforts to optimize traveling routes or delivery routes. The first ever systematic initiative, so far known, is The Travelling Salesman Problem [*REF# http://en.wikipedia.org/wiki/Travelling_salesman_problem*] It is a problem in combinatorial optimization studied in operations research and theoretical computer science. Given a list of cities and their pair wise distances, the task is to find a shortest possible tour that visits each city exactly once. The problem was first formulated as a mathematical problem in 1930 and is one of the most intensively studied problems in optimization. It is used as a benchmark for many optimization methods. Even though the problem is computationally difficult, a large number of heuristics and exact methods are known, so that some instances with tens of thousands of cities can be solved. The TSP has several applications even in its purest formulation, such as planning, logistics, and the manufacture of microchips. Slightly modified, it appears as a sub-problem in many areas, such as genome sequencing. In these applications, the concept city represents, for example, customers, soldering points, or DNA fragments, and the concept distance represents travelling times or cost, or a similarity measure between DNA fragments. In many applications, additional constraints such as limited resources or time windows make the problem considerably harder. In the theory of computational complexity, the decision version of TSP belongs to the class of NP-complete problems. Thus, it is assumed that there is no efficient algorithm for solving TSP problems. In other words, it is likely that the worst case running time for any algorithm for TSP increases exponentially with the number of cities, so even some instances with only hundreds of cities will take many CPU years to solve exactly.

As a graph problem



Symmetric TSP with four cities

TSP can be modelled as a graph: the graph's vertices correspond to cities and the graph's edges correspond to connections between cities, the length of an edge is the corresponding connection's distance. A TSP tour is now a Hamiltonian cycle in the graph, and an optimal TSP tour is a shortest Hamiltonian cycle. Often, the underlying graph is a complete graph, so that every pair of vertices is connected by an edge. This is a useful simplifying step, because it makes it easy to find a solution, however bad, because the Hamiltonian cycle problem in complete graphs is easy. Instances where not all cities are connected can be transformed into complete graphs by adding very long edges between these cities, edges that will not appear in the optimal tour.

Asymmetric and symmetric

In the symmetric TSP, the distance between two cities is the same in each direction. Thus, the underlying structure is an undirected graph between; especially, each tour has the same length in both directions. This symmetry halves the number of feasible solutions.In the asymmetric TSP, the distance from one city to the other need not equal the distance in the other direction, in general, there may not even be a connection in the other direction. Thus, the underlying structure is a directed graph. For example, the asymmetric case models one-way streets or air-fares that depend on the direction of travel.

With metric distances

In the metric TSP the intercity distances satisfy the triangle inequality. This can be understood as "no shortcuts", in the sense that the direct connection from A to B is never longer than the detour via C.

$$c_{ij} \leq c_{ik} + c_{kj}$$

These edge lengths define a metric on the set of vertices. When the cities are viewed as points in the plane, many natural distance functions are metrics. In the Euclidian TSP the distance between two cities is the Euclidean distance between the corresponding points. In the Rectilinear TSP the distance between two cities is the sum of the differences of their x- and y-coordinates. This metric is often called the Manhattan distance or city-block metric. In the maximum metric, the distance between two points is the maximum of the differences of their x- and y-coordinates. The last two metrics appear for example in routing a machine that drills a given set of holes in a printed circuit. The Manhattan metric corresponds to a machine that adjusts first one co-ordinate, and then the other, so the time to move to a new point is the sum of both movements. The maximum metric corresponds to a machine that adjusts both co-ordinates simultaneously, so the time to move to a new point is the slower of the two movements.

Non-metric distances

Distance measures that do not satisfy the triangle inequality arise in many routing problems. For example, one mode of transportation, such as travel by airplane, may be faster, even though it covers a longer distance. In its definition, the TSP does not allow cities to be visited twice, but many applications do not need this constraint. In such cases, a symmetric, non-metric instance can be reduced to a metric one. This replaces the original graph with a complete graph in which the inter-city distance cij is replaced by the shortest path between i and j in the original graph.

Related problems

An equivalent formulation in terms of graph theory is: Given a complete weighted graph (where the vertices would represent the cities, the edges would represent the roads, and the weights would be the cost or distance of that road), find a Hamiltonian cycle with the least weight. The requirement of returning to the starting city does not change the computational complexity of the problem, see Hamiltonian path problem. Another related problem is the bottleneck travelling salesman problem (bottleneck TSP): Find a Hamiltonian cycle in a weighted graphwith the minimal weight of the weightiest edge. The problem is of considerable practical importance, apart from evident transportation and logistics areas. A classic example is in printed circuit manufacturing: scheduling of a route of the drill machine to drill holes in a PCB. In robotic machining or drilling applications, the "cities" are parts to machine or holes (of different sizes) to drill, and the "cost of travel" includes time for retooling the robot (single machine job sequencing problem). The generalized travelling salesman problem deals with "states" that have (one or more) "cities" and the salesman has to visit exactly one "city" from each "state". Also known as the "travelling politician problem". One application is encountered in ordering a solution to the cutting stock problem in order to minimise knife changes. Another is concerned with drilling in semiconductor manufacturing, see e.g. U.S. Patent 7,054,798. Surprisingly, Behzad and Modarres[6] demonstrated that the generalised travelling salesman problem can be transformed into a standard travelling salesman problem with the same number of cities, but a modified distance matrix.

2.1.2 Fixed route transit scheduling

To optimize this transport system, "Fixed route transit scheduling" [2] can also be considered as a primary reference for a possible alternative. Fixed route transit scheduling is an undervalued and often misunderstood task of public transit agencies. It is a complex process that involves several detailed analytical procedures. Trip building, blocking, run cutting, and rostering are all sub-tasks of the overall task of scheduling. This project examines the basic framework of the scheduling process to provide a general understanding of the subject. The main objective of this project was to examine current scheduling practices at transit systems in Florida and assess each agency's scheduling issues and potential need for technical assistance in schedule development. A scheduling survey was designed and distributed to all Florida fixed route transit systems. The results of this survey are presented and analyzed with a specific emphasis on comparing systems that use automated scheduling software versus those that continue to schedule using manual processes. The use of automated scheduling software at the larger transit systems in Florida has yielded various improvements to their scheduling process. Scheduling software is an iterative tool that provides the scheduler with greater flexibility, functionality, and control over scheduling their services. It also works to reduces mistakes, improve vehicle and operator efficiencies, reduce staff time on tedious activities, and provide better reporting capabilities. As reflected in the fixed route scheduling survey, there is an interest among small to medium sized transit systems in realizing the benefits of automated scheduling software. However, scheduling software costs and computer hardware costs in general were seen as the most prohibitive aspects of attaining scheduling software. Furthermore, the learning curve and extensive set-up time required is a potential obstacle for small to mid-sized systems. Based on the findings of this report, a mechanism could be explored that would enable small to medium sized transit systems in Florida the opportunity to provide more efficient services through automated scheduling.

The Scheduling Process: Scheduling for fixed route transit service is a highly technical activity that requires an extensive knowledge of transit terminology. Throughout this section, TCRP Report 30, "Transit Scheduling: Basic and Advanced Manuals" is referenced heavily for definitions and explanations of various transit scheduling terms. The following diagram (Figure 1) assembles these terms and displays the data flow of the various inputs and outputs of the four sub-tasks (trip building, blocking, runcutting, and rostering) in the fixed route transit scheduling process.

2.1.3 Other related works

Martin Savelsbergh [3] of 'The Logistics Institute" of Georgia Institute of Technology, in his presentation, mentioned about various models to address the route planning. Some of them are a) Traveling Salesman Problem (TSP), b) Vehicle Routing Problem (VRP), Vehicle Routing Problem with Time Windows (VRPTW), Pickup and Delivery Problem with Time Windows (PDPTW), etc. To overcome the difficulties in acquiring experts' know-how as well as to realize more efficient deliveries, a delivery route scheduling method that combines a knowledge base with general algorithms was proposed by Tsuruta [4] at IEEE International Conference at

2000. The Single Vehicle Routing Problem with Pickups and Deliveries (SVRPPD) [5] is defined on a graph in which pickup and delivery demands are associated with the customer vertices. The problem consists of designing a least cost route for a vehicle of capacity Q. Each customer is allowed to be visited once for a combined pickup and delivery, or twice if these two operations are performed separately. This article proposes a mixed integer linear programming model for the SVRPPD. It introduces the concept of general solution which encompasses known solution shapes such as Hamiltonian, double-path and lasso. Our intended problem involve single vehicle but it will serve only delivery of the goods to customer end. Irina Gribkovskaia [6] proposed a mixed integer linear programming formulation for the Single Vehicle Routing Problem with Deliveries and Selective Pickups (SVRPDSP). The difference between this model and the single vehicle routing problem with pickups and deliveries (SVRPPD) lies in the fact that it is no longer necessary to satisfy all pickup demands. In the SVRPDSP a pickup revenue is associated with each vertex, and the pickup demand at that vertex will be collected only if it is profitable to do so. The net cost of a route is equal to the sum of routing costs, minus the total collected revenue. The aim is to design a vehicle route of minimum net cost, visiting each customer, performing all deliveries, and a subset of the pickups.

CHAPTER 3
RESEARCH METHODOLOGY

3.1 General

A study was accomplished in a systematic manner on the delivery system of a renowned Multinational organization that is involved in the business of welding electrodes. They have twenty sales centers around the country. All of their products are sold through these sales centres. From these sales centres, they sell the goods to their dealers and to some special customers. Most of the special customers (Mills and Factories) take their supply from the sales centre and transport the products through their own transport means. But, for the dealer segment, they usually provide transport for the delivery of goods. The total dealer uptake is about 90% of the total uptake of the sales centre. From these dealers, the products actually reach to the retail market and the end user, i.e. welding workshops. So, to ensure product availability and proper penetrating to the end market, they provide dealership to the remote areas of the country through their market study. To deliver goods to these dealers they usually use Pick-ups. For most of the sales location the capacity of these Pick-ups are 1250 Kgs each.

In this study, one of their sales locations with a single pick-up of 1250 Kgs capacity was observed. From their Pick-up's daily log sheets, it was found that the vehicle being idle for a reasonable period of time. On the other hand, overtime were provided to cope up with customer's demand for a reasonable numbers of occasions. When their order pattern was studied, it was found that the vehicle was sometimes overloaded and some other times under loaded. The issue was drilled down further and found that they have no specific schedule for their deliveries. They follow some routes for their delivery but the delivery is not systematic. They arrange delivery in each route when any customer places an order. Sometimes the supply delays as the vehicle is not free or the order quantity of the customer or cumulative orders of other customers of that route is not significant. A scope was found to develop a model for optimizing the delivery schedule.

First of all, daily order quantity and order interval of each delivered customers were found out.

Demand forecasting is a vital part of this assessment, as the dealer uptake and overall sales of the sales center is a vital issue for any model. The model must be capable to handle the future demands of the sales centre and individual customer also.

Then feasible routes were identified based on geographical location, road condition, bridge and ferry convenience, etc. After that, customers were attached with the routes. Route wise demand forecasting was done to rationalize the model.

Cumulative order frequency of each route was identified.

The organization is highly sensitive to ethical practice i.e. the safety of the driver and the vehicle have usually been given most attention. They are also keen to maintain all the rules and regulations of the government. So, they have their own embargo on the daily duty hours of the drivers, their speed limit, rest period, etc. The vehicle rated capacity as per it's registration to the "Road Transport Authority" must be strictly maintained.

With all these data, it was tried to accumulate them in the mathematical process and to find out a model for their optimization.

3.2 Research Methodology

Importance of methodology in conducting any research can hardly be over looked. It needs a very careful and sincere consideration. The methodology, which was used in this study, enables to collect valid and reliable information/data and to analyze those data to arrive at correct decision. Keeping this in mind, utmost care has been taken for using proper methods in all aspect of this study. The detailed steps of the methodology to accomplish the objectives of the study are stated in the followings:

3.2.1 Selection of Sample: A reasonable sample size, which can at least satisfy the objectives set for the study, was taken into account. During the research period, data for about eight months were considered and they have on sequential mode to ensure randomness of the order frequency. All the data were collected from the on-line business software package SAP. This is a vast software and worldwide renowned. As all the data is from automated system. The Data reliability is absolute. The whole sales process of the company is governed by this software. No item can be sold or no payment can be received without this software. So, it was reliable of having actual real life data for the sales centre. Due to this software day-wise customer uptake could easily found. So, exact order frequency for each customer could be identified.

3.2.2 Sampling Technique: Sample selected in such a way that collected data fulfill the objectives of the study. As the total numbers of samples were very large, considering the limitations of time, efforts, purposive sampling technique were used in this study.

3.2.3 Period of Research: Like all other businesses, electrodes business has its ups and downs trend. This is also porn to seasonal effects. Other factors that can affect the demand of the products are as follows:

a. Electricity load shedding period

b. Availability of competitive brands (especially short-term imported electrodes)

c. Price. Sometimes there is price decrease due to decrease in raw materials or business gives special discount on specific volume of the product as promotional activities. These affect the uptake of the customer.

d. Availability of project works.

e. Overhauling Schedule for major Mills and factories of the territory

f. Production planning of specific seasonal industries like rice mills, char coal block (Tush Kath) producing factories, etc.

g. Boat/ Ship maintenance period

h. Law & order situation of the country. If it runs well, people eager to start new building, infrastructures, etc which in terms increase the demand of construction materials.

i. In remote locations, work force and entrepreneurs are engaged in agriculture, fisheries and also in small industries. So when during harvesting seasons these small businesses are hampered and the uptake of electrodes go down.

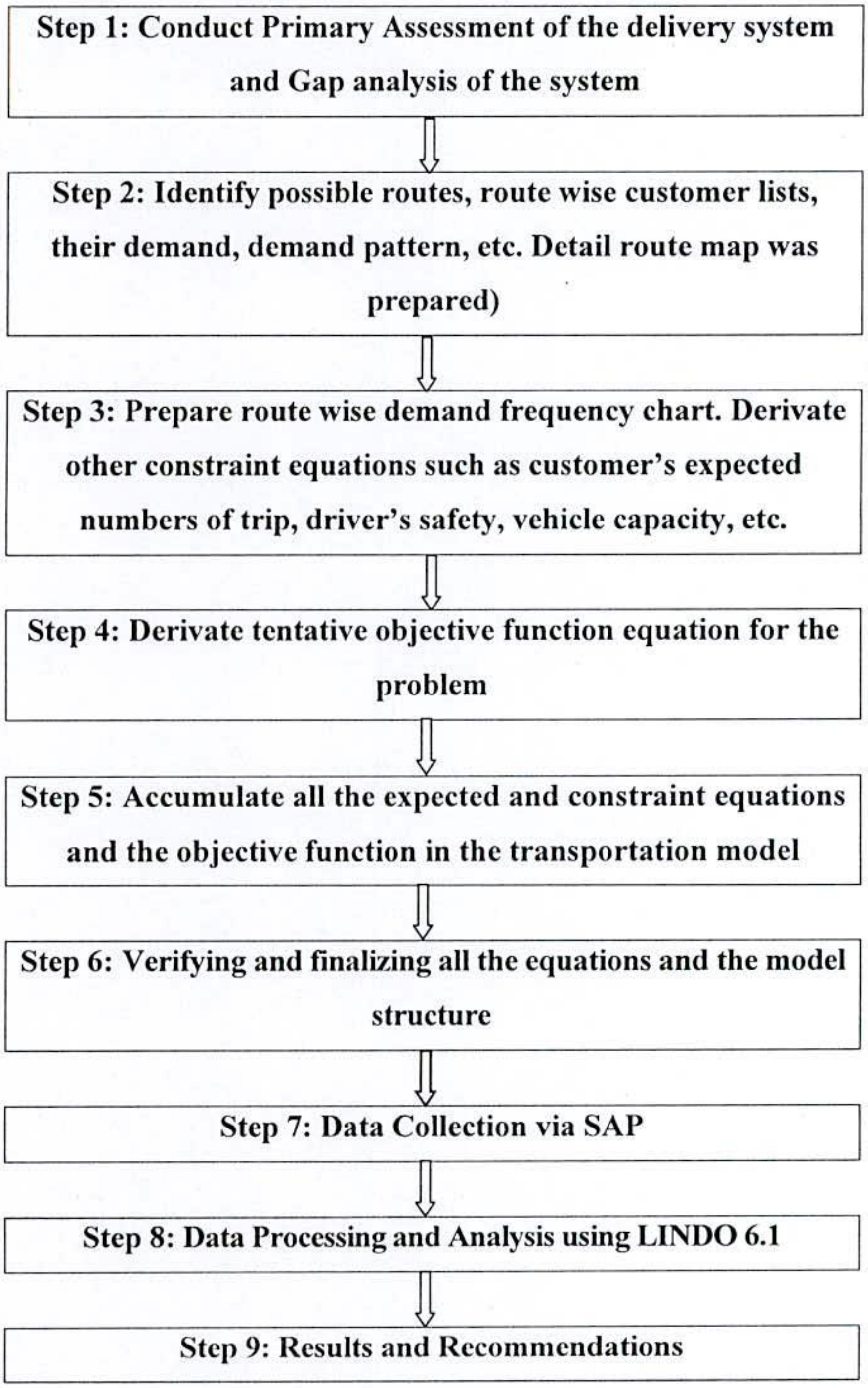
Therefore the research work was conducted with the data of the sales location from September, 2008 to April, 2009 for daily product uptake values. This period covers all the factors that can affect the demand or demand frequency. This time period also includes smooth and interference free demand periods. So the data is unbiased and can be considered as the true replica of the real life situation.

3.2.4 Research Instruments: In order to collect information, SAP software was used. It provided day wise customer uptake. Order frequency and also the order quantity of each customer for the mentioned period of time were available. Further more, it provides, monthly customer's uptake for each customer. These data were actually used for the forecasting of the customer and as well as for the individual route. Further calculations and processing of the data was done by Microsoft Excel. Lindopro software was used for optimization of the order. As the DATA were collected from an automated system, chances of manual errors or data missing were low. All the data information were generated in the automated system (SAP) based on the sales invoice generated for each sales deal. More over, the data were analyzed and processed by the various MS Excel tips like VLOOKUP, SUBTOTALS, AUTOSUM, etc. So, the chances for manual error in the analysis were very low. The data collected for this thesis work from the SAP software were shown in appendix A.

3.2.5 Procedure of Data Collection: Data for this study were collected from the business software SAP which provides vast and huge information about the business. In fact, if anyone gets an user ID with proper authorization, he can deep into the business secrets of the company, even the profitibility, pricing, raw material sources, etc. Similarly in relevance to our study, data regarding customers, their location, demand pattern, vehicle routes, pricing, discount provided to the individual customer, their payment mode, etc are considered as very secret and confidential business information. An organization usually invests a lot of money, time and efforts of their intellectual workforce to gather these information. Then, they compile the data to figure out their business strategy for the market. So, the real information about the customer and their demand pattern, etc are very sensible issue for an organization. We convinced the management of the organization that the data would be used for study purpose only and would not mention any customer's name, location, routes, etc. Only, the data pattern would be used of the real life situation to have a replica of the real life. For further protection against information vulnerability, codes were used against real routes and customers.

3.2.6 Techniques of Data Analysis: Based on the above mentioned principles, data on the variables were considered and the information were summarized, complied to fit those into tables and finally analyzed in accordance with the objectives of the study. In this way overall picture of the study were identified to be considered with the principles of operation research. Transportation model of the Deterministic Decision models was followed.

3.2.7 Interpretation of the Results: On the basis of the results, necessary recommendations were made for the improvement of management control over delivery scheduling, demand forecasting and acting with proactive approach. The whole process of study work can be shortly explained by the following flowchart:



CHAPTER 4

PROCESS ANALYSIS AND DATA COLLECTION

4.1 Functional Diagram of Delivery Process

Similar to other systematic study of delivery systems, the first step of our research is the development of the functional map to identify the process of delivering goods to the customers. To analyze the whole process of delivering the goods, it was also necessary to know about the delivery process of the organization. Though there is not such set system of the deliveries, the delivery system for welding electrodes is governed by the following policy:

a) Dealer contract agreement
b) "Delegation of Authority" of the management of the sales centre
c) Driver's safety & working hours policy

Figure 4.1 shows the process and the functional map of the delivery system.

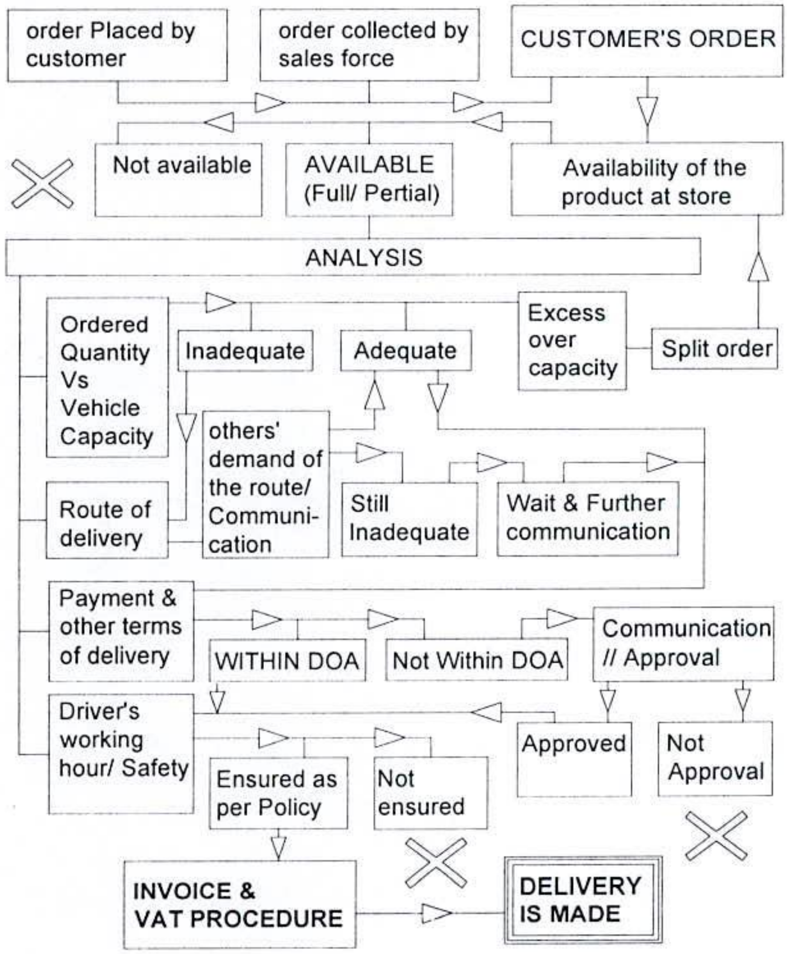


Figure 4.1 # Functional Diagram of Delivery Process

The delivery function actually initialed by the CUSTOMER ORDER. To be a regular delivered customer is governed by another policy of the organization. That issue is not relevant with current study hence is not discussed here. Only for the ease of discussion, A regular customer or dealer of the organization is a resultant of long outstanding business relationship, proven reliability, loyalty and performance of the customer and also, of course, the best judgment of the management of the sales team. After receiving the orders, first step is to check the availability of the products. Usually, there is not any product shortage of the organization. One of the most important **KPI** of the production planning team is to ensure that no stock out situation of any product happens in any sales location. They ensure the production of the products and also ensure delivery of those products to the sales locations. However, the sales management of the location cross-check the product availability of the products at their location. If by any chance, they ordered product is not found in their sales locations, they can check other sales locations from their own PC with the help of sales software SAP. And the delivery is deferred until the products are available at their own hand.

Next step is to analyze the ordered quantity with respect to the vehicle capacity. If the order quantity is adequate compare to the capacity of the vehicle, the next step is processed. About seventy percent to Hundred percent of the full load capacity of the vehicle is considered as "adequate" as per standard practice. Some times, especially for "special discount periods" it was found that the order quantity of a customer or a group of customer of the same route becomes higher than the vehicles rated capacity. Then the order or those groups of orders are split and delivered accordingly. Extensive Communications with the customers are usually required in these cases. Some times, the orders are not adequate for planning a delivery trip to the route. In such cases, again, Extensive communication is made to other customers of the same route for possible orders. In such initiatives, the order quantity is usually become adequate for a trip. Some times, usually in dull seasons, after extensive communication and interpersonal relationship, the sum of collected orders do not become adequate for making a trip. However, in such cases, considering the organizations commitment to the customers about product availability and also ensuring proper customer support, delivery is made with inadequate order. The delivery cost in such cases definitely becomes higher than usual.

Payments and other terms of deliveries are usually governed by the dealer contract with the customer. However, some times, any specific customer requires some special support, such as, special discount for any specific project, credit days, etc. These financial parts are usually governed by the **DOA** (Delegation of Authority) of the central Accounts of the organization. However, to provide customer support, communications are made by the sales offices to the proper authority to get such approvals, if the issue is not covered under their DOA. Till the approval, the delivery can not be made as per policy.

Finally, comes the issue of safety. The organization is very much sensitive to the issues of safety. The delivery process, more specifically, the delivery vehicles are governed by their Safety policy, where the issues are well defined about the day to day operations. Their specific guide lines about the duty hours of the driver are maintained strictly. As per the policy, they allow their driver to ply the vehicle for fourteen hours a day. Within these, twelve hours should be driving time and rest two hours should be rest time. After each three and half hours they must ensure at least fifteen minutes rest. All the information are recorded in their daily duty log book. So, to make a delivery, the sales management must ensure the safety of the driver.

After all, the invoice is made and the **VAT** process is followed accordingly. After that an delivery is made.

4.2 Management Process Identification and Process Breakdown Structure

While studying the delivery process, firstly, the whole delivery process was gone through and the daily vehicle log sheets were checked. Observations about the whole system are as follows:

a) The delivery system is "reactive system", as the order is generated and the whole delivery process is initiated after those orders. Though, it was considered that creating orders or in terms generating sales in the most challenging factor for any business, however, as the organization is delivering goods to their regular patterned customers, they must develop a procedure for the regular deliveries as per their usual demand. Any new or unusual demand may be addressed separately. But the regular routine delivery should be under a systematic approach.

b) **Dealer contract agreement:** The organization is run by strict rules and regulations for their operation. They have specific contracts with their dealers. As per the dealer contract, the company is supposed to deliver the goods at the door step of the dealer. In terms, the dealers have to maintain a certain stock at their end. The stock differs from dealer to dealer as per the market requirements. But a key point was noted that a certain amount of stock for each dealer could be recommended for regularize their delivery system. This will in tern, can be considered as "business commitment" of the respective dealer. In present system, no such commitment is there. This can also be a key point for "the year end dealer appraisal" for their incentives.

c) **"Delegation of Authority" of the management of the sales centre:** According to the accounts procedure of the company, each level of management have a certain authority to provide credit to the dealers. So, the direct management involved in the delivery administration must have a limitation to provide delivery to a dealer. So, the dealer has a credit limit which is also implemented in the SAP invoicing system. So, no one can create invoice in the name of the dealer beyond their credit limit. It is a limitation for the delivery system.

d) **Driver's safety & working hour's policy:** This is strictly maintained in the organization to provide smooth, trouble-free and safe delivery system. They consider an accident cost as something more than the financial losses involved in the accident. They ensure various safety parameters and key issues related to safety. Such as, rated load capacity, defensive driving procedure and training, proper maintenance and checking of the vehicle, tyre & breaking capacity measurement, driver's safety policy, etc. For this discussion, Driver's safety & working hour's policy were considered. Load capacity restriction was directly relevant to this problem. By their rule, the driver cannot work beyond fourteen hours a day. Within which they will drive the vehicle for twelve hours and rest two hours are their rest period. They must ensure rest after each three hours journey. In determining routes length and combination of routes, these limitations to be ensured. For determining any route and delivery pattern, the load bearing limitation of the delivery pick-up was also considered as a deciding factor. Considering all the factors and policy, further initiatives were made to develop the model of the problem. Details of which is in next chapter

CHAPTER 5

DESCRIPTION & FORMULATION

5.1 Description of the Problem

For generic approach, let there are *n* numbers of routes and *m* numbers of time periods (days). A single vehicle was considered to perform the whole distribution system. An integer transportation model was considered to solve the problem. Time periods were plotted in the rows and Routes were plotted across the columns of the model.

5.1.1 Definition of the variable:

- $X_{ij} = \begin{cases} 1, \text{ If a trip is assained in route } j \text{ on day } i \\ 0, \text{ Otherwise} \end{cases}$
- Y_i - Nos of Trip on Time period *i* at the route *j=n+1* (Integer Value)
- T_{ij} - Time required for a trip on Time period *i* at the route *j*
- W_i - Time required for a trip on Time period *i* at the route *j=n+1*
- TS_i - Total run time allotted for a vehicle considering safety in a Time period *i*.
- D_j - Total demand of customers at route *j* in the total Time period.
- TP_{Ej} - Numbers of expected trips of Route *j* in the total Time period.
- TP_{Mj} - Numbers of minimum trips of Route *j* in the total Time period considering demand.
- $TP_{Mj} = D_j \div$ Vehicle capacity

5.1.2 Model:

ROUTES (j = 1,2,....,n, n+1)

Days (i = 1,2,.,m)	$R_{j=1}$	$R_{j=2}$	$R_{j=3}$	......	$R_{j=n}$	$R_{j=n+1}$
$DAY_{i=1}$	X_{ij} [T_{ij}]	X_{ij} [T_{ij}]	X_{ij} [T_{ij}]	......	X_{ij} [T_{ij}]	Y_i [W_i]
$DAY_{i=2}$	X_{ij} [T_{ij}]	X_{ij} [T_{ij}]	X_{ij} [T_{ij}]	......	X_{ij} [T_{ij}]	Y_i [W_i]
$DAY_{i=3}$	X_{ij} [T_{ij}]	X_{ij} [T_{ij}]	X_{ij} [T_{ij}]	......	X_{ij} [T_{ij}]	Y_i [W_i]

....	....	......	......	......	......	......
....	....	......	......	......	......	......

$DAY_{i=m}$	X_{ij} (T_{ij})	X_{ij} (T_{ij})	X_{ij} (T_{ij})	......	X_{ij} (T_{ij})	Y_i (W_i)
demand/ route (Kg)	D_j	D_j	D_j	......	D_j	D_j
Trip/ Period (EXPECTED)	TP_{Ej}	TP_{Ej}	TP_{Ej}	......	TP_{Ej}	TP_{Ej}

Min trip (demand)	TP_{Mj}	TP_{Mj}	TP_{Mj}	......	TP_{Mj}	TP_{Mj}

5.2 Mathematical formulation of the problem:

5.2.1 Formulation 01:

Objective Function:

$$\text{Minimize} \sum_{i=1,j=1}^{i=m,j=n} X_{ij} + \sum_{i=1,j=n+1}^{i=m} Y_i \quad ....[5.2.1]$$

Subject To:

$$\sum_{j=1}^{j=n} X_{ij}T_{ij} + Y_iW_i \leq TS_i \qquad [\text{ i =1,2,3,........,m}] ...[5.2.2]$$

$$\sum_{i=1}^{i=m} X_{ij} \geq TP_{Mj} \qquad [\text{ j =1,2,3,.........,n}] ...[5.2.3]$$

$$\sum_{i=1}^{i=m} Y_i \geq TP_{Mj} \qquad [\text{ j =n+1}] ....[5.2.4]$$

$$\sum_{i=1}^{i=m} X_{ij} \leq TP_{Ej} \qquad [\text{ j =1,2,3,.........,n}] ...[5.2.5]$$

$$\sum_{i=1}^{i=m} Y_i \leq TP_{Ej} \qquad [\text{ j =n+1}] ....[5.2.6]$$

$$\sum_{j=1}^{j=2} X_{ij} \leq 1 \qquad [\text{ where, i =1,2,3,...m}] ...[5.2.7]$$

$$\sum_{j=3}^{j=4} X_{ij} \leq 1 \qquad [\text{ where, i =1,2,3,...,m }] ...[5.2.8]$$

$$\sum_{i=a}^{i=a+2} X_{ij} \leq 1$$ [where, a = 1,2,3,...,m]

[where, i =1,2,3,...,m]
[where, j =1,2,3,...,n] ...[5.2.9]

Descriptions of the above equations are as follows:

a) Equation [5.2.1] is the objective function. It represents the total numbers of trips in the given time limit.
b) Equation [5.2.2] represents the limitation of safe driving time constraints in a day *i*.
c) Equation [5.2.3] and [5.2.4] represent the requirement of minimum trip of a route *j*.
d) Equation [5.2.5] and [5.2.6] represent the expected trips of a route *j*.
e) Equation [5.2.7] and [5.2.8] represent the limitation of parallel routes. As parallel routes were found in this delivery system, it was planned not to make delivery at those routes in the same day. Thus, it was decided not to make trip in the routes 1 and 2 on the same day. Similar is the case for routes 3 & 4.
f) Equation [5.2.9] represents the requirement of disbursement of trips. To disburse the trips of a single route for the whole period of time, it was decided to make trips with a regular interval to create a regular pattern of the trips. Thus considering the minimum trips of a route, some constraints were introduced to drive the trips with an interval for the routes 1,2,3 & 4.
g) As per the demand schedule of the problem, more than one trip is required per day for route 5 to meet the demand of that route in the specific time period. So, general integers were introduced for the trip variables of that route.

5.2.2 Formulation 02:

The above formulation would give an optimized solution which would spread over all ten days. For further development of the model, details of the problem were again analyzed and some fine tuning of the objective function were done. Within the boundary of the constraints, it was planned to maximize the utilization of the vehicle. A new variable Z was introduced, which will represent the idle time of a vehicle on a day. This idle time is to reduce. The equation of Z is as follows:

$$Z_{ij} = TS_i - \sum_{j=1}^{j=n} X_{ij}T_{ij} - \sum_{j=n+1} Y_iW_i \qquad [\text{ i =1,2,3,........,m}]$$

Z_{ij} variable was introduced into the objective function. New objective function and formulations are as follows:

Objective Function:

$$\text{Minimize} \sum_{i=1, j=1}^{i=m, j=n} X_{ij} + \sum_{i=1, j=n+1}^{i=m} Y_i + \sum_{i=1}^{i=m} Z_{ij} \quad \text{.........[5.2.1.1]}$$

Subject To:

$$\sum_{j=1}^{j=n} X_{ij}T_{ij} + Y_iW_i \le TS_i \qquad [\text{ i =1,2,3,........,m}] \text{...[5.2.2]}$$

$$\sum_{i=1}^{i=m} X_{ij} \ge TP_{Mj} \qquad [\text{ j =1,2,3,.........,n}] \text{ ...[5.2.3]}$$

$$\sum_{i=1}^{i=m} Y_i \ge TP_{Mj} \qquad [\text{ j =n+1}] \text{ ....[5.2.4]}$$

$$\sum_{i=1}^{i=m} X_{ij} \le TP_{Ej} \qquad [\text{ j =1,2,3,.........,n}] \text{ ...[5.2.5]}$$

$$\sum_{i=1}^{i=m} Y_i \le TP_{Ej} \qquad [\text{ j =n+1}] \text{ ....[5.2.6]}$$

$$\sum_{j=1}^{j=2} X_{ij} \le 1 \qquad [\text{ where, i =1,2,3,...m}] \text{ ...[5.2.7]}$$

$$\sum_{j=3}^{j=4} X_{ij} \le 1 \qquad [\text{ where, i =1,2,3,...,m }] \text{ ...[5.2.8]}$$

$$\sum_{i=a}^{i=a+2} X_{ij} \le 1 \qquad [\text{ where, a = 1,2,3,...,m}]$$

[where, i =1,2,3,...,m]
[where, j =1,2,3,...,n]...[5.2.9]

CHAPTER 6

RESULTS & DISCUSSIONS

Formulation 01 and formulation 02 was applied to the following problem.

6.1 Particulars of the problem:

- Nos of the routes are 05 according to route map attached at APPENDIX A
- Route wise cumulative demand of all the customers were determined. APPENDIX B.
- From this cumulative demand, minimum numbers of trips to the respective route were determined.
- Order frequency (order interval) of each customer of each route to address the customers' expected numbers of trips for that particular route.
- The time required for a trip in a specific route is includes the vehicle running time, product unloading time, driver's rest time and payment collection time from the customer.
- Due to the limitation of the capacity of the optimizer software "Lindo 6.0", the study was to be limited into ten days and five numbers of routes.

Finally, the problem was formatted as per the following chart.

ROUTES

	A	B	C	D	E
DAY 1	4.0 X_{1A} 57	5.0 X_{1B} 58	4.5 X_{1C} 63	6.0 X_{1D} 110	4.0 Y_1 38
DAY 2	4.0 X_{2A} 57	5.0 X_{2B} 58	4.5 X_{2C} 63	6.0 X_{2D} 110	4.0 Y_2 38
DAY 3	4.0 X_{3A} 57	5.0 X_{3B} 58	4.5 X_{3C} 63	6.0 X_{3D} 110	4.0 Y_3 38
DAY 4	4.0 X_{4A} 57	5.0 X_{4B} 58	4.5 X_{4C} 63	6.0 X_{4D} 110	4.0 Y_4 38
	4.0	5.0	4.5	6.0	4.0

DAY 5	X_{5A} 57	X_{5B} 58	X_{5C} 63	X_{5D} 110	Y_5 38
DAY 6	4.0 X_{6A} 57	5.0 X_{6B} 58	4.5 X_{6C} 63	6.0 X_{6D} 110	4.0 Y_6 38
DAY 7	4.0 X_{7A} 57	5.0 X_{7B} 58	4.5 X_{7C} 63	6.0 X_{7D} 110	4.0 Y_7 38
DAY 8	4.0 X_{8A} 57	5.0 X_{8B} 58	4.5 X_{8C} 63	6.0 X_{8D} 110	4.0 Y_8 38
DAY 9	4.0 X_{9A} 57	5.0 X_{9B} 58	4.5 X_{9C} 63	6.0 X_{9D} 110	4.0 Y_9 38
DAY 10	4.0 X_{10A} 57	5.0 X_{10B} 58	4.5 X_{10C} 63	6.0 X_{10D} 110	4.0 Y_{10} 38

demand/ route (Kg)	3581	2857	2914	2658	16244
Trip/ Period (EXPECTED)	6	4	3	3	17

Min trip (demand)	3	3	3	3	14

Table 6.1 # Particulars of the delivery problem

6.2 Assumptions of the problem:

- Credit terms and other business terms of the customers must match with the delivery pattern of the customer. Customer regular delivery may hamper due to limitation of the business contract.
- Factors that results sudden thrust of customers' demand like planned price increase, one off large project works, etc was not considered under the regular supply plan.
- Sales growth trend of the territory as well as individual route, individual customer was not considered for the delivery system. So, after certain time the model may require upgrading based on the increased demand of the customers.

- Motivations of the customers are required to match their order pattern with his given slot.
- Adequate order was assumed in hand.
- Sales process involved with delivery system was assumed as smooth. That is, time required for creating sales invoice, loading of the vehicle, etc will not hamper the delivery.
- All the required products to be supplied to the customer are available in sales centre.
- Driver is in good health, vehicle is in good condition. No delay was calculated for these factors. Alternative driver, vehicle is considered to be available if required.

6.3 Solution of the problem according to FORMULATION 01:

Lindo 6.0 software was used for optimizing the problem. Lindo model of the problem was as per APENDIX. C. The solution of the problem was as per follows:

	ROUTES A	B	C	D	E
DAY 1	4.0 1 57	5.0 X_{1B} 58	4.5 1 63	6.0 X_{1D} 110	4.0 Y_1 38
DAY 2	4.0 X_{2A} 57	5.0 X_{2B} 58	4.5 X_{2C} 63	6.0 X_{2D} 110	4.0 3 38
DAY 3	4.0 X_{3A} 57	5.0 1 58	4.5 X_{3C} 63	6.0 X_{3D} 110	4.0 2 38
DAY 4	4.0 1 57	5.0 X_{4B} 58	4.5 X_{4C} 63	6.0 1 110	4.0 1 38
DAY 5	4.0 X_{5A} 57	5.0 X_{5B} 58	4.5 1 63	6.0 X_{5D} 110	4.0 Y_5 38
DAY 6	4.0 X_{6A} 57	5.0 1 58	4.5 X_{6C} 63	6.0 X_{6D} 110	4.0 2 38
DAY 7	4.0 1	5.0 X_{7B}	4.5 X_{7C}	6.0 1	4.0 1

	A	B	C	D	E
	57	58	63	110	38
DAY 8	4.0 / X_{8A} / 57	5.0 / X_{8B} / 58	4.5 / 1 / 63	6.0 / X_{8D} / 110	4.0 / 2 / 38
DAY 9	4.0 / X_{9A} / 57	5.0 / 1 / 58	4.5 / X_{9C} / 63	6.0 / X_{9D} / 110	4.0 / 1 / 38
DAY 10	4.0 / X_{10A} / 57	5.0 / X_{10B} / 58	4.5 / X_{10C} / 63	6.0 / 1 / 110	4.0 / 2 / 38

Table 6.2 # Solution according to Formulation 01

6.4 Solution of the problem according to FORMULATION 02:

To solve the new objective function of Equation [5.2.1.1] of chapter 05 with the set of constraints, LINDO 6.0 was again used. The model becomes as APENDIX D. The solution of the model is as follows:

ROUTES	A	B	C	D	E
DAY 1	4.0 / X_{1A} / 57	5.0 / X_{1B} / 58	4.5 / X_{1C} / 63	6.0 / X_{1D} / 110	4.0 / 2 / 38
DAY 2	4.0 / X_{2A} / 57	5.0 / X_{2B} / 58	4.5 / X_{2C} / 63	6.0 / X_{2D} / 110	4.0 / 2 / 38
DAY 3	4.0 / X_{3A} / 57	5.0 / X_{3B} / 58	4.5 / X_{3C} / 63	6.0 / X_{3D} / 110	4.0 / 3 / 38
DAY 4	4.0 / X_{4A} / 57	5.0 / X_{4B} / 58	4.5 / X_{4C} / 63	6.0 / X_{4D} / 110	4.0 / 1 / 38
DAY 5	4.0 / X_{5A} / 57	5.0 / X_{5B} / 58	4.5 / X_{5C} / 63	6.0 / X_{5D} / 110	4.0 / Y_5 / 38
DAY 6	4.0 / X_{6A} / 57	5.0 / X_{6B} / 58	4.5 / X_{6C} / 63	6.0 / X_{6D} / 110	4.0 / Y_6 / 38
DAY 7	4.0 / X_{7A}	5.0 / X_{7B}	4.5 / X_{7C}	6.0 / X_{7D}	4.0 / 1

			57			58			63			110			38
DAY 8	X_{8A}	4.0	57	X_{8B}	5.0	58	X_{8C}	4.5	63	X_{8D}	6.0	110	2	4.0	38
DAY 9	X_{9A}	4.0	57	X_{9B}	5.0	58	X_{9C}	4.5	63	X_{9D}	6.0	110	2	4.0	38
DAY 10	X_{10A}	4.0	57	X_{10B}	5.0	58	X_{10C}	4.5	63	X_{10D}	6.0	110	1	4.0	38

Table 6.3 # Solution according to Formulation 02

NOTE:

After this optimization, **One day (6th day)** can be made **free of delivery** and thus the whole delivery could be performed within 09 day.

6.5 Discussion about the study:

Through the study, the following results were achived:

- Feasible routes for the supply chain were identified.
- Optimized numbers of trips for each route were identified.
- Vehicle was assigned to each route ensuring proper safety of the driver.
- Management involvement in planning individual routes and orders for each time will be reduced.
- Customers will be habituated with a regular cycle of supply thus their business will be smooth. Presently, they ordered on "as and when" basis and sometimes they get supply within day and sometimes within next day or later. There was no firm commitment about delivery timing. After fixing routing, customer will be supposed to be happy as they will also know the routing of the vehicle and can plan for their business. Dealers, as a partner of the business organization will also be able to show their commitment about the whole business growth.
- Due to disciplined systematic approach, optimized involvement of the vehicle can be planned for delivery. Thus, some man-days of the drivers as well as of the vehicle can be spared. This spare capacity of the vehicle can be planned to serve other purposes, even for delivery purposes of other territories.

- The same vehicle may be used for the visit purpose of the marketing people. The visit plan of the marketing people could be more effective if that synchronize with the delivery schedule.

6.6 Financial benefit of these models:

Variable delivery cost, in terms of the vehicle costing, includes the following factors.

1. Vehicle own cost (daily rent/ depreciation)
2. Fuel cost (depending on millage run) & Ferri/ bridge tolls
3. Maintenance cost of the vehicle
4. Driver's overtime
5. Etc.

As the company operated their delivery through rented pick-ups and also for simplification, the daily vehicle rent would only be considered here for costing. This was also the only major cost compared to the other related costs. Currently effective vehicle rent of the company is One Thousand Two Hundred Taka per Day.

From the previous vehicle log sheets, it was observed that the whole delivered quantity, as studied here, was previously delivered in at least fifteen working days.

If formulation 01 is applied, the delivery timing shrinks into ten days. So the net financial benefit, in terms of money, is about Twelve thousand per month. This is about 38% savings from now.

If formulation 02 is applied, another two days can be reduced per month. So, the total savings will be Fourteen Thousand Four Hundred Taka per month. This is about 46% compared to current situation.

Here it should be noted that formulation 02 yields 10% more saving over formulation 01.

CHAPTER 7

CONCLUSIONS & RECOMMENDATIONS

7.1 Conclusions

Delivery system is a vital part of a supply chain management. In every delivery system, it is necessary to use a method to evaluate possible alternatives for the delivery system. In this study, it was tried to develop a systematic approach to address the issues related to delivery system such as, safety issues, the demand pattern, the cost involved with the delivery system, the sales pattern of the customers, etc.

In this study, two integer program formulations were developed. These were applied to practical delivery system. The results obtained seem to be very interesting and effective. Both two models are effective but the second model is more efficient than first model in terms of vehicle utilization in a particular day. Formulation 01 brings 38% financial savings considered to current practice while formulation 02 yields 46%. Formulation 02 also yields 10% more savings considered to formulation 01.

Due to limitation of the software LINDO, the time periods were limited within ten days. If full version of the software can be obtained and if the company uses the software and these formulation for optimizing their delivery system, they can create huge financial benefit ensuring all of the requirements including safety of drivers.

7.2 Recommendations for Further Study

The present study has been devoted to the delivery of goods of a single sales centre through single vehicle. Other than this, there may be many options of delivery systems. It would be an interesting research topic to see the applicability of this model to those other options. Some of the recommendations for further study are as follows:

- This model can be extended for multiple numbers of vehicle of different capacity to fulfill the delivery purpose.

- Due to time and other constraints, cross routes were not considered. Data about cross routes like, distance, demand, road conditions, ferry information, etc were not available right at hand. This model can be used to examine the cross routes and circular routes.
- Merging the sales activities of two or more locations with combined vehicle fleet can be extended.
- Economic order quantity of each individual customer can be integrated with the delivery system.

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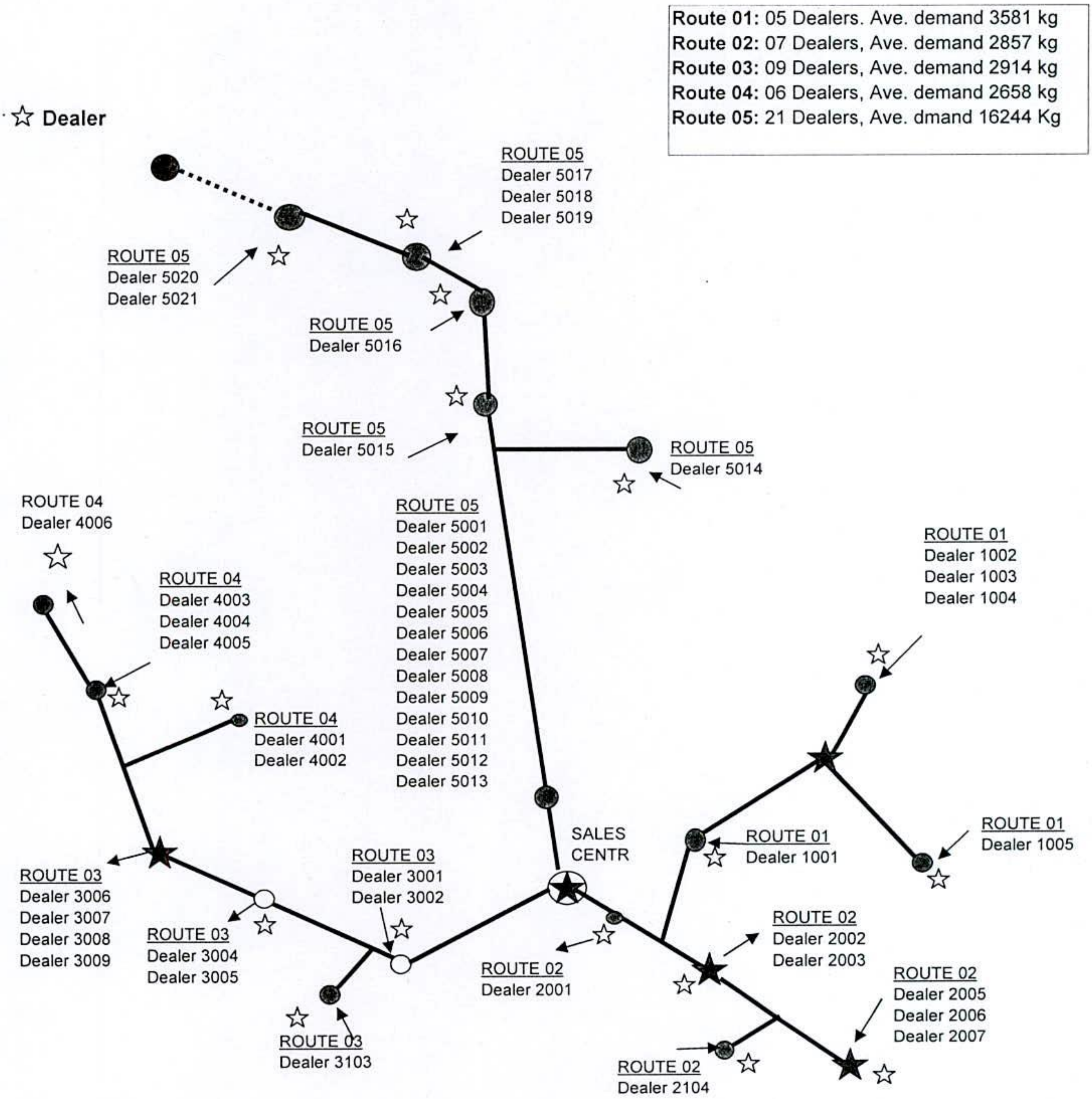

Route Map of the Territory

APPENDIX B

Route wise Dealer chart

Route	Sl No	Dealer	Order freq Min	Order freq Max	Demand (Kg)	Total demand of the route (Kg)	Distance (Km)	Ave. Time reqd. for a trip in the route (Hr)
01	1	Dealer 1001	1	3	250		21	4.0
	2	Dealer 1002	1	3	1000		55	
	3	Dealer 1003	2	6	1431		55	
	4	Dealer 1004	1	2	500		55	
	5	Dealer 1005	1	3	400	3581	57	
02	6	Dealer 2001	1	4	400		10	5.0
	7	Dealer 2002	1	1	250		31	
	8	Dealer 2003	1	1	250		31	
	9	Dealer 2004	1	2	500		58	
	10	Dealer 2005	1	3	800		53	
	11	Dealer 2006	1	4	400		53	
	12	Dealer 2007	1	2	257	2857	53	
03	13	Dealer 3001	1	3	300		32	4.5
	14	Dealer 3002	1	3	150		32	
	15	Dealer 3003	1	1	150		45	
	16	Dealer 3004	1	3	300		50	
	17	Dealer 3005	1	2	300		50	
	18	Dealer 3006	1	3	150		63	
	19	Dealer 3007	1	3	500		63	
	20	Dealer 3008	1	3	800		63	
	21	Dealer 3009	1	2	276	2914	63	
04	22	Dealer 4001	1	2	150		84	6
	23	Dealer 4002	1	3	750		94	
	24	Dealer 4003	1	2	500		95	
	25	Dealer 4004	1	3	300		110	
	26	Dealer 4005	1	2	150		65	
	27	Dealer 4006	2	3	808	2658	72	
05	28	Dealer 5001	1	2	1000		1	4
	29	Dealer 5002	3	6	1200		3	
	30	Dealer 5003	4	7	1500		3	
	31	Dealer 5004	1	6	1000		3	
	32	Dealer 5005	1	2	350		3	
	33	Dealer 5006	1	3	300		4	
	34	Dealer 5007	1	5	500		6	
	35	Dealer 5008	1	7	800		5	
	36	Dealer 5009	1	7	1244		6	
	37	Dealer 5010	1	4	800		6	
	38	Dealer 5011	4	9	2000		5	

Route	Sl No	Dealer	Min	Max	Demand (Kg)	Total demand of the route (Kg)	Distance (Km)	Ave. Time reqd. for a trip in the route (Hr)
	39	Dealer 5012	1	5	700		6	
	40	Dealer 5013	1	2	700		6	
	41	Dealer 5014	1	5	600		11	
	42	Dealer 5015	2	8	500		12	
	43	Dealer 5016	1	3	800		16	
	44	Dealer 5017	1	3	250			
	45	Dealer 5018	1	5	250		20	
	46	Dealer 5019	1	4	800		28	
	47	Dealer 5020	1	2	250		38	
	48	Dealer 5021	1	5	700	16244	38	

LINDO 6.0 MODEL FOR FORMULATION 01:

MINIMIZE
X1A+X2A+X3A+X4A+X5A+X6A+X7A+X8A+X9A+X10A+X1B+X2B+X3B+X4B+X5B+X6B+X7B+X8B+X9B+X10B+X1C+X2C+X3C+X4C+X5C+X6C+X7C+X8C+X9C+X10C+X1D+X2D+X3D+X4D+X5D+X6D+X7D+X8D+X9D+X10D+X1E+X2E+X3E+X4E+X5E+X6E+X7E+X8E+X9E+X10E

SUBJECT TO

4X1A+5X1B+4.5X1C+6X1D+4X1E<=14
4X2A+5X2B+4.5X2C+6X2D+4X2E<=14
4X3A+5X3B+4.5X3C+6X3D+4X3E<=14
4X4A+5X4B+4.5X4C+6X4D+4X4E<=14
4X5A+5X5B+4.5X5C+6X5D+4X5E<=14
4X6A+5X6B+4.5X6C+6X6D+4X6E<=14
4X7A+5X7B+4.5X7C+6X7D+4X7E<=14
4X8A+5X8B+4.5X8C+6X8D+4X8E<=14
4X9A+5X9B+4.5X9C+6X9D+4X9E<=14
4X10A+5X10B+4.5X10C+6X10D+4X10E<=14

X1A+X2A+X3A+X4A+X5A+X6A+X7A+X8A+X9A+X10A>=3
X1B+X2B+X3B+X4B+X5B+X6B+X7B+X8B+X9B+X10B>=3
X1C+X2C+X3C+X4C+X5C+X6C+X7C+X8C+X9C+X10C>=3
X1D+X2D+X3D+X4D+X5D+X6D+X7D+X8D+X9D+X10D>=3
X1E+X2E+X3E+X4E+X5E+X6E+X7E+X8E+X9E+X10E>=14

X1A+X2A+X3A<=1 X2A+X3A+X4A<=1 X3A+X4A+X5A<=1 X4A+X5A+X6A<=1 X5A+X6A+X7A<=1 X6A+X7A+X8A<=1 X7A+X8A+X9A<=1 X8A+X9A+X10A<=1 X9A+X10A+X1A<=1 X10A+X1A+X2A<=1	X1B+X2B+X3B<=1 X2B+X3B+X4B<=1 X3B+X4B+X5B<=1 X4B+X5B+X6B<=1 X5B+X6B+X7B<=1 X6B+X7B+X8B<=1 X7B+X8B+X9B<=1 X8B+X9B+X10B<=1 X9B+X10B+X1B<=1 X10B+X1B+X2B<=1
X1C+X2C+X3C<=1 X2C+X3C+X4C<=1 X3C+X4C+X5C<=1 X4C+X5C+X6C<=1 X5C+X6C+X7C<=1 X6C+X7C+X8C<=1 X7C+X8C+X9C<=1 X8C+X9C+X10C<=1 X9C+X10C+X1C<=1 X10C+X1C+X2C<=1	X1D+X2D+X3D<=1 X2D+X3D+X4D<=1 X3D+X4D+X5D<=1 X4D+X5D+X6D<=1 X5D+X6D+X7D<=1 X6D+X7D+X8D<=1 X7D+X8D+X9D<=1 X8D+X9D+X10D<=1 X9D+X10D+X1D<=1 X10D+X1D+X2D<=1
X1A+X1B<=1 X2A+X2B<=1 X3A+X3B<=1 X4A+X4B<=1	X1C+X1D<=1 X2C+X2D<=1 X3C+X3D<=1 X4C+X4D<=1

X5A+X5B<=1 X6A+X6B<=1 X7A+X7B<=1 X8A+X8B<=1 X9A+X9B<=1 X10A+X10B<=1	X5C+X5D<=1 X6C+X6D<=1 X7C+X7D<=1 X8C+X8D<=1 X9C+X9D<=1 X10C+X10D<=1 End

int X1A int X2A int X3A int X4A int X5A int X6A int X7A int X8A int X9A int X10A	int X1B int X2B int X3B int X4B int X5B int X6B int X7B int X8B int X9B int X10B	int X1C int X2C int X3C int X4C int X5C int X6C int X7C int X8C int X9C int X10C	int X1D int X2D int X3D int X4D int X5D int X6D int X7D int X8D int X9D int X10D	gin X1E gin X2E gin X3E gin X4E gin X5E gin X6E gin X7E gin X8E gin X9E gin X10E

LINDO 6.0 MODEL FOR FORMULATION 02

Minimize
4X1A+5X1B+4.5X1C+6X1D+4X1E+4X2A+5X2B+4.5X2C+6X2D+4X2E+4X3A+5X3B+4.5X3C+6X3D+4X3E+4X4A+5X4B+4.5X4C+6X4D+4X4E+4X5A+5X5B+4.5X5C+6X5D+4X5E+4X6A+5X6B+4.5X6C+6X6D+4X6E+4X7A+5X7B+4.5X7C+6X7D+4X7E+4X8A+5X8B+4.5X8C+6X8D+4X8E+4X9A+5X9B+4.5X9C+6X9D+4X9E+4X10A+5X10B+4.5X10C+6X10D+4X10E+Z1+Z2+Z3+Z4+Z5+Z6+Z7+Z8+Z9+Z10

SUBJECT TO

Z1+4X1A+5X1B+4.5X1C+6X1D+4X1E=14
Z2+4X2A+5X2B+4.5X2C+6X2D+4X2E=14
Z3+4X3A+5X3B+4.5X3C+6X3D+4X3E=14
Z4+4X4A+5X4B+4.5X4C+6X4D+4X4E=14
Z5+4X5A+5X5B+4.5X5C+6X5D+4X5E=14
Z6+4X6A+5X6B+4.5X6C+6X6D+4X6E=14
Z7+4X7A+5X7B+4.5X7C+6X7D+4X7E=14
Z8+4X8A+5X8B+4.5X8C+6X8D+4X8E=14
Z9+4X9A+5X9B+4.5X9C+6X9D+4X9E=14
Z10+4X10A+5X10B+4.5X10C+6X10D+4X10E=14

X1A+X2A+X3A+X4A+X5A+X6A+X7A+X8A+X9A+X10A>=3
X1B+X2B+X3B+X4B+X5B+X6B+X7B+X8B+X9B+X10B>=3
X1C+X2C+X3C+X4C+X5C+X6C+X7C+X8C+X9C+X10C>=3
X1D+X2D+X3D+X4D+X5D+X6D+X7D+X8D+X9D+X10D>=3
X1E+X2E+X3E+X4E+X5E+X6E+X7E+X8E+X9E+X10E>=14

X1A+X2A+X3A<=1 X2A+X3A+X4A<=1 X3A+X4A+X5A<=1 X4A+X5A+X6A<=1 X5A+X6A+X7A<=1 X6A+X7A+X8A<=1 X7A+X8A+X9A<=1 X8A+X9A+X10A<=1 X9A+X10A+X1A<=1 X10A+X1A+X2A<=1	X1B+X2B+X3B<=1 X2B+X3B+X4B<=1 X3B+X4B+X5B<=1 X4B+X5B+X6B<=1 X5B+X6B+X7B<=1 X6B+X7B+X8B<=1 X7B+X8B+X9B<=1 X8B+X9B+X10B<=1 X9B+X10B+X1B<=1 X10B+X1B+X2B<=1
X1C+X2C+X3C<=1 X2C+X3C+X4C<=1 X3C+X4C+X5C<=1	X1D+X2D+X3D<=1 X2D+X3D+X4D<=1 X3D+X4D+X5D<=1

X4C+X5C+X6C<=1 X5C+X6C+X7C<=1 X6C+X7C+X8C<=1 X7C+X8C+X9C<=1 X8C+X9C+X10C<=1 X9C+X10C+X1C<=1 X10C+X1C+X2C<=1	X4D+X5D+X6D<=1 X5D+X6D+X7D<=1 X6D+X7D+X8D<=1 X7D+X8D+X9D<=1 X8D+X9D+X10D<=1 X9D+X10D+X1D<=1 X10D+X1D+X2D<=1
X1A+X1B<=1 X2A+X2B<=1 X3A+X3B<=1 X4A+X4B<=1 X5A+X5B<=1 X6A+X6B<=1 X7A+X7B<=1 X8A+X8B<=1 X9A+X9B<=1 X10A+X10B<=1	X1C+X1D<=1 X2C+X2D<=1 X3C+X3D<=1 X4C+X4D<=1 X5C+X5D<=1 X6C+X6D<=1 X7C+X7D<=1 X8C+X8D<=1 X9C+X9D<=1 X10C+X10D<=1 end

int X1A int X2A int X3A int X4A int X5A int X6A int X7A int X8A int X9A int X10A	int X1B int X2B int X3B int X4B int X5B int X6B int X7B int X8B int X9B int X10B	int X1C int X2C int X3C int X4C int X5C int X6C int X7C int X8C int X9C int X10C	int X1D int X2D int X3D int X4D int X5D int X6D int X7D int X8D int X9D int X10D	gin X1E gin X2E gin X3E gin X4E gin X5E gin X6E gin X7E gin X8E gin X9E gin X10E