AN APPLICATION OF SAVINGS METHOD FOR VEHICLE ROUTING PROBLEM

By

CHATSUREE KAMTHORNSAWAT

Submitted in Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE IN SUPPLY CHAIN MANAGEMENT

Martin de Tours School of Management

Assumption University

Bangkok, Thailand

July, 2017

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1. Dr. Piyawan Puttibarncharoensri (Chair) .....
2. Dr. Srobol Smutkupt (Member) .....
3. Dr. Athisarn Wayuparb (Advisor) .....

Approved for Graduation on: July 27, 2017

Martin de Tours School of Management
Assumption University
Bangkok Thailand

July, 2017

Assumption University
Martin de Tours School of Management and Economics
Master of Science Program in Supply Chain Management

Declaration of Authorship Form

I, Chatsuree Kamthornsawat, declare that this project and the work presented in it are my own and have been generated by me as the result of my own original research.

AN APPLICATION OF SAVINGS METHOD FOR VEHICLE ROUTING PROBLEM

I confirm that:

1. This work was done wholly or mainly while in candidature for the M.Sc. degree at this University;
2. Where any part of this project has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
3. Where I have consulted the published work of others, this is always clearly attributed;
4. Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this project is entirely my own work;
5. I have acknowledged all main sources of help;
6. Where the project is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;
7. None of this work has been published before submission.

Signed Chatsuree K.

Date 27/09/2017

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Assumption University
Martin de Tours School of Management and Economics
Master of Science Program in Supply Chain Management

Student Name: **Chatsuree Kamthornsawat**
ID: 5319580

ADVISOR'S STATEMENT

I confirm that this project has been carried out under my supervision and it represents the original work of the candidate.

Signed _____

(Dr. Athisarn Wayuparb)

Date _____

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Chatsuree Kamthornsawat

Assumption University

July 2017

ABSTRACT

This paper presents the researcher's study on the vehicle routing practices of a company which provides the delivery of Printed Circuit Board Assemble (PCBA) and electronics component to customers in Bangkok Metropolitan Region and neighboring provinces in Central and East regions in Thailand. Currently, the traditional truck management is being practiced which lacks systematic approach and personal experience.

Inefficient truck management problem in this case study was identified as Capacitated Vehicle Routing Problem (CVRP). Therefore, the savings method by Clarke and Wright (1964) was applied to solve the CVRP in Excel worksheets. It consists of four procedures. Firstly, identify the distance matrix from depot to all customers. Secondly, identify the saving matrix. Thirdly, assign customers to the vehicles or routes, which the highest value is the criteria for selection. Lastly, sequence customers within routes.

The results show that the Savings method decreases the total number of vehicles usage and total distribution distances by 16.46% and 15.70% respectively, and increase truck utilization of truck capacity by 19.70%. It leads to create cost saving for the company significantly.

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CHAPTER I

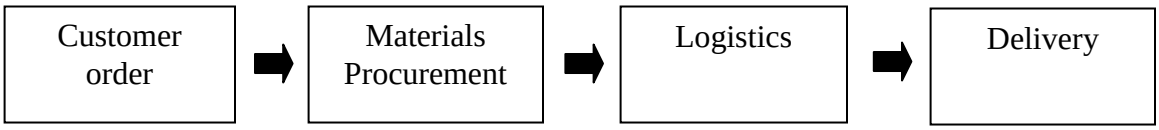
GENERALITIES OF THE STUDY

1.1 Background of the Research

At present, communication technologies are diversified and have grown rapidly, which lead to increasing business opportunities affecting transportation network expansion and complexity of vehicle routing. The competition becomes more intense, including transportation costs which also have increased accordingly, thus become an unavoidable cost for the company. However, if the company has a systematic plan on vehicle routing, it is able to decrease the distance of transportation. A number of vehicles used and appropriate truck utilization by using full-load capabilities of vehicles in each delivery, will show a competitive cost of transportation and higher completion capabilities. Therefore, the problem on the distribution is another criterion which is very important today.

ABC Company is a global business creating added value by fully utilizing its experience over 50 years to systematically link the business requirements of various firms. The main function is a trading and logistics center which provides Printed Circuit Board Assembly (PCBA) and other electronic components. The main activities of this company are purchasing and importing electronic components, entering into intercompany for the assembly of finished goods (FG). After receiving the finished goods (FG), ABC manages and delivers for shipment to the customers. Currently, the company supplies around 39 customers approximately in 20 areas located in Bangkok Metropolitan Region and neighboring provinces in Central and East regions in Thailand. The flow chart is shown in Figure 1.1.

Figure 1.1: Trading Business Model



Source: Author

The products are distributed directly to the customers by four-wheel truck or pickup. The transport department has seven pickups. The maximum load of each truck is not over 4.45 cubic meters. Since FG are electronic components that are small, light weight, high value and sensitive to static electricity, they are packed into conductive boxes to prevent static electrification. As mentioned above, the truck capacity is calculated in terms of dimension (cubic meter – m^3) not in terms of weight (kilogram – kg). The workflow of Transport department is shown in Figure 1.2.

Figure 1.2: Transport Department Workflow

Source: Author

Figure 1.2 shows that the transport department receives the finished goods from the factory and manages the delivery planning by an experienced employee to be

delivered to the customer. It is a daily operation, so the details of the truck management in one day is shown in Table 1.1.

Table 1.1: Truck Management on April 1, 2016

Truck number	Customer code	Node ID	m^3	Total cubic meters per truck (m^3)	Total Distancce per truck (km)
1	MT	11	1.840	1.840	293
2	US	11	2.072	2.072	257
3	TA	18	1.677	1.937	169
	NI	9	0.260	-	-
4	SH	15	0.684	1.433	206
	TC	19	0.749	-	-
5	TY	20	3.977	3.977	327
6	FT	8	2.494	2.494	353
7	NK	14	2.747	2.747	531
Total				**16.500**	**2,136**

Source: Company's Data

Table 1.1 shows that seven trucks are assigned for delivery to customers. Some trucks are used for delivery to more than one customer.

Table 1.2: Loss of Vehicle Routing Management

Truck number	Routing by ID location	Maximum capacity (CBM)	Volume (m^3)	Distance (km)
1	0=>11=>0	4.450	1.840	293
2	0=>11=>0	4.450	2.072	257
3	0=>18=>9=>0	4.450	1.937	169
4	0=>15=>19=>0	4.450	1.433	206
5	0=>20=>0	4.450	3.977	327
6	0=>8=>0	4.450	2.494	353
7	0=>14=>0	4.450	2.747	531
Total		**31.150**	**16.500**	**2,136**

Source: Company's Data

* Each truck leaves from the company and returns back once products have been handed to the customers.

Table 1.2 shows the traditional truck management experienced by employees who are familiar with the old working style, which no pick-up trucks are loaded to full capacity. There is another 15 m^3 which can be loaded but ineffective and inefficient in terms of maximizing the utilization of the truck's capability and transportation cost. This suggests that the traditional truck management, without systematic planning and theory will lead to risk and incur unnecessary costs.

1.2 Statement of the Problems

In the preliminary study, the researcher found that the process of the current routing planning is traditional shipment distribution pattern which lacks systematic approach. The transport department is assigned to distribute the shipments to customers. The employees allocate the delivery area and the pickup trucks by using personal experience, expertise gained from working for a long time, knowledge of the location of customers, and considering the location of each customer located neighboring in the same transport routes without setting a standard routing.

The current routing planning is not effective. If employees who have expertise in the planning leave or resign, the newly-assigned employee (inexperienced staff) spends time on transportation planning, which increases the impact on fleet management. In the future, if the expansion of customers increases, it will reduce the efficiency in routing and not as good as it could be.

As mentioned earlier, the company must improve its delivery efficiency in order to maximize the full capacity of the trucks and minimize the total distances. Therefore, the research question posted in this research was **"How does vehicle routing affect cost reduction?"**

1.3 Research Objectives

This study aimed to improve the distribution to customers, which the main purpose of this study was to improve the daily vehicle routing and utilize the pickup truck capacities. The traditional implementation has not justified the optimization and efficiency of the current transportation routing. To apply the Savings method for improving vehicle routes and other benefits, the research objectives were as follows:

1.3.1 To apply the saving method for designing a vehicle routing with the minimum transportation cost;

1.3.2 To minimize the total number of vehicles usage; and

1.3.3 To improve the total distribution distances and utilize the maximum capacity of the truck.

1.4 Scope of the Research

This study has concentrated on the improvement of the daily vehicle routing to distribute Printed Circuit Board Assembly (PCBA) and other electronic components to 39 customers in 20 areas located in Bangkok and sub-urban areas by using pickup trucks for delivery. The capacity of each truck is calculated in terms of dimension (cubic meter - m^3) which has the capacity to load not over 4.45 m^3. The pickup truck with limited space and capacity, starts from the warehouse to the places of customers assigned in the route.

For electronic components, they are packed in conductive boxes which prevent static electricity and the size of the box depends on each customers. The delivery point starts from the warehouse to the customer's place and return to the warehouse with operational time from 08.00 to 17.00 with unlimited transportation distance per day. The upper bound number of customers visited daily is three customers per pickup truck.

To improve the problem, ABC Company needs to monitor the management of the pickup trucks. Hence, the Savings method was selected for improving the vehicle routes and minimizing the capacity of the pick-up trucks.

The Savings method was applied to simulate and compare between the current (As-is model) and the improved (To-be model) methods of vehicle routing. Thus, Savings method can be applied to other companies in real situation.

1.5 Significance of the Research

This study has focused on the Savings method for improving the daily vehicle routing to 39 customers in 20 areas in order to minimize the total distribution distance, utilize the pickup truck capacity with more efficiency and reduction in the transportation cost.

The Clarke-Wright Savings method is flexible enough to handle a wide range of practical constraints, relatively fast computationally for the problems with a moderate number of stops and capable of generating solutions that are nearly optimum. Comparison with the optimal results for small problems with a limited number of constraints have shown that the "Savings method" gives solutions that are on the average, two percentage over the optimum (Ballou, 2004).

Besides, the method can handle practical constraints, mainly because it is able to form routes and sequence stops on the routes simultaneously.

Moreover, the outcome of this study can be a guideline to other companies or any relevant businesses faced with the same problem, thus realizing the importance of truck management.

1.6 Limitations of the Research

This research has focused on the "Savings method" to enhance vehicle routing by improving the current routing. The expected outcomes were to minimize the distribution distance and reduce the transportation cost. The limitations were as follows:

1. ABC Company is electronic components business; its outcome could be applied to similar business only facing the same problem.
2. The product types were focused only on PCBA and electronic components. The electronic components were packed in the conductive box to prevent from static electricity; hence, the volume of delivery was measured in terms of dimension (cubic meter – m^3) not weight (kilogram - kg).
3. The type of vehicle for transportation was the four-wheel truck or pickup. There were seven pickup vehicles supporting the transportation tasks.
4. This project did not include other costs for production cost, marketing cost, warehouse cost, and others.
5. The problem in this case study was focused on a daily vehicle routing only and did not involve capacity allocation.
6. The period of data reference was focused basically from 1^{st} to 30^{th} April 2016, only the daily data of the distribution of ABC Company.
7. The frequency of delivery was dependent on the customer's order.
8. The distances of any node of roundtrip were presumed as equal.
9. The transportation cost of the company was based on the fuel cost at that period in the market.
10. Regarding simulation only, not applying with the real business.

1.7 Definition of Terms

Conductive box	is an antistatic box used to carry electronic component, normally used in Electronics business. (ESD Journal website, 1998).
Cubic meter (m^3)	is a unit of volume in the International System of Units. CBM calculation formula is Length (meter) x Width (meter) x Height (meter). The symbol for cubic meter is m^3 (Bates College website, 2008).
Pickup truck	is a four-wheel truck (vehicle) having an enclosed driver's compartment (cab) but an open rear with usually low sides and a tailgate. (Author)
Savings algorithm (method)	is a Heuristics algorithm used for the solution of VRP, which minimizes the total distance traveled by all vehicles and to indirectly minimize the number of vehicles needed to serve all and returning to the depot (Clarke & Wright, 1964).

1.8 Chapter Summary

From the above information, the traditional routing planning which lacks systematic approach leads to risk and unnecessary cost. The researcher proposed to apply the Savings algorithm to improve the current process.

CHAPTER II

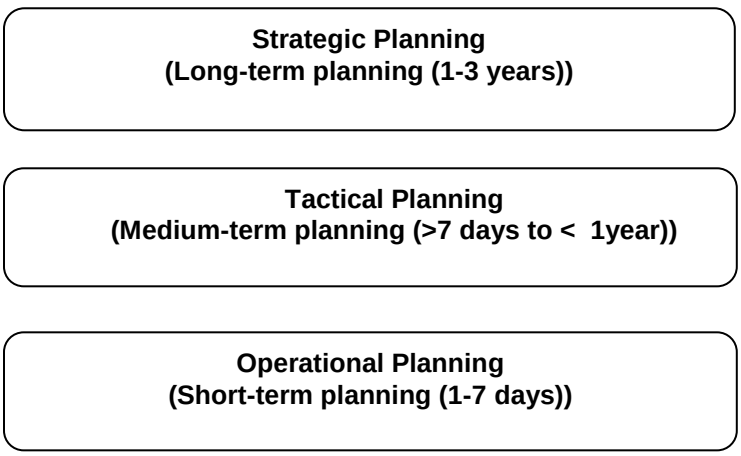
REVIEW OF RELATED LITERATURE

Vehicle Routing Problem (VRP) is an important issue in the distribution network, which involves the transportation of raw materials from the manufacturer to the production factory or the transportation of products from the warehouse to the customers. It is necessary for the company to provide efficient transportation and distribution to reduce the operation cost. As a result, it decreases the number of vehicles usage, maximizes the truck capacity efficiency, minimizes the distance travelled by all vehicles and reduces delay of transportation. The Savings method is applied in this study and the related literatures are discussed in this chapter.

2.1 Vehicle Routing Problem (VRP)

Generally, Vehicle Routing and Schedule Planning can be classified into three levels: Strategic Planning, Tactical Planning and Operational Planning (Peter, Roddy, & David, 1994) as shown in Figure 2.1.

Figure 2.1: Vehicle Routing and Schedule Planning



Source: Peter et al. (1994)

Strategic Planning is a long-term period of planning related to the policy, management and operation of the company. For example, planning number, size and, location of distribution depots or planning size and composition of vehicle fleet, etc.

Tactical Planning is short range planning emphasizing on the current operations of the various parts of the organization. For example, provision of basis for decision on whether to use own vehicles or contract distribution or planning of distribution sectors and customer group, etc.

Operational Planning is the process of linking strategic goals and objectives with the tactical goals and objectives. It describes the milestones, conditions for success, and explains how or what portion of a strategic plan will be put into operation during a given operational period.

From the above three planning levels, the VRP is set as a part of the operational planning, that means the company needs to manage the transportation, distribution, and vehicle routing with minimum transportation cost.

2.1.1 Characteristics of Vehicle Routing Problem

The VRP is a classical Combinatorial Optimization problem that was proposed in 1950s. Bodin, Assad and Ball (1981) classified the VRP characteristics to a more detailed list. They focused on Node Routing Problem. Some of these characteristics are described in the network specification as shown in Table 2.1.

Table 2.1: Characteristics of Vehicle Routing Problem

Characteristics	Description
Size of vehicle fleet available	one vehicle more than one vehicle
Type of vehicle fleet available	Homogeneous (all vehicles the same) Heterogeneous (not all vehicles the same)
Depot / Warehouse	Single Multiple
Nature of demands	Deterministic (known demand) Stochastic (unknow demand) Partial
Location of demands	At nodes (point) On arcs (route) Mixed
Underlying network	Undirected Directed Mixed
Vehicle capacity constraints	Uncapacitated Capacitated (same for all vehicles) Capacitated (different)
Maximum vehicle route times	No Single Time Windows Multiple Time Windows Tight Time Windows (scheduling)
Cost	Variable or routine costs Fixed operation or vehicle acquisition costs (Capital costs)
Operations	Delivery / Split Deliveries Pick-up / Split Pick-up Both
Objective	Minimize routing costs incurred Minimize sum of fixed variable costs Minimize number of vehicles required

Source: Bodin et al. (1981)

Comparing the characteristics of VRP studied by Bodin et al. (1981) with this research, the characteristics of VRP are shown in Table 2.2.

Table 2.2: Characteristics of Vehicle Routing Problem

Characteristics	Description
Size of vehicle fleet available	More than one vehicle
Type of vehicle fleet available	Homogeneous (all vehicles the same)
Depot / Warehouse	Single
Nature of demands	Deterministic (known demand)
Location of demands	At nodes (point)
Underlying network	Directed
Vehicle capacity constraints	Capacitated (same for all vehicles)
Maximum vehicle route times	No or Single Time Windows
Cost	Variable or routine costs
Operations	Delivery
Objective	Minimize number of vehicles required Minimize routing costs incurred

Source: Author

In this research, ABC Company has one depot to deliver the goods to the customers with known demand and uses the same type of vehicles and capacity with the main objective to minimize the number of vehicles required and routing costs incurred.

2.1.2 Variants of Vehicle Routing Problem (VRP)

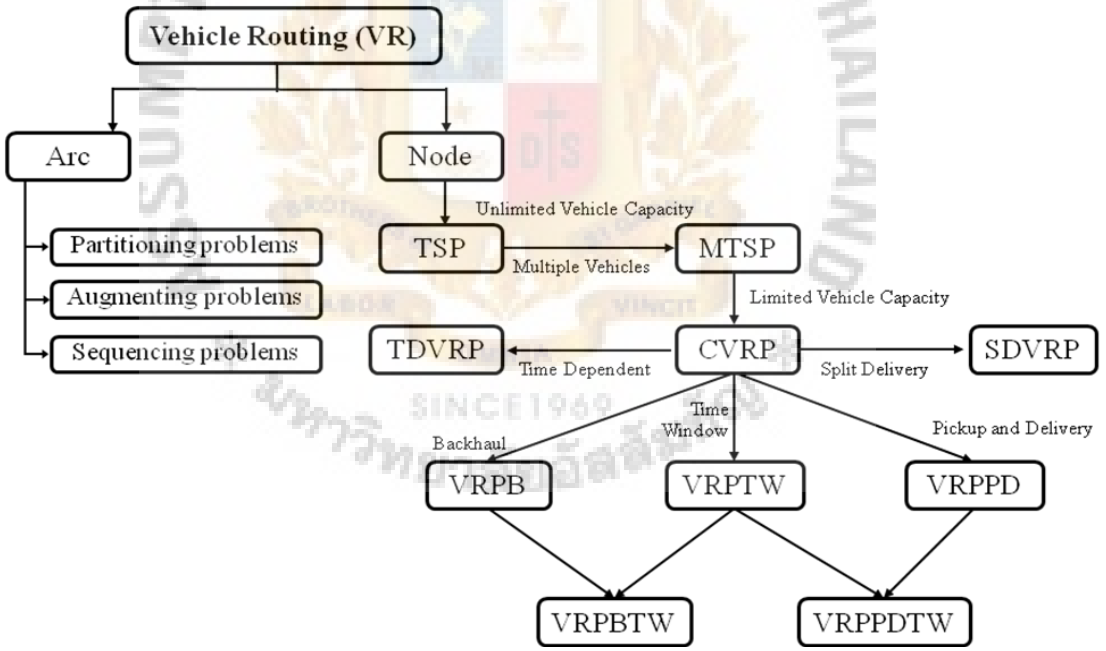
The Vehicle Routing Problem (VRP) was first introduced by Dantzig and Ramser (1959). VRP can be described as the problem of routing a vehicle through a distribution network to find the optimal routes of delivery or pick-up from one or several depots to a number of customers with some satisfying constraints. It starts from a base to serve every assigned node or arc of a distribution network and return to the same base with minimal cost (that can be shown by distances, a number of vehicles used, or some customized ones). The base points can be represented as an arc or as a node of a distribution network, VRP can be classified as follows:

Arc covering problem is divided into three parts: arc partitioning problems, arc augmenting problems, and arc sequencing problems. The objective of Arc covering

problem is to travel through all the assigned arcs in a distribution network and to meet the stated goal of optimization. In addition, it can be solved by considering more than one part of a problem at a time, nevertheless the difficulty and complexity of the problem solving will be increased as more parts of a problem are added (Su & Chang, 1993).

The objective of Node covering problem is to serve all the assigned nodes of a distribution network and to meet the stated goal of optimization. It can be classified into many types of VRP, depending on the variants of VRP along with the various constraints as shown in Figure 2.2.

Figure 2.2: Variants of Vehicle Routing Problem (VRP)



Source: Sandhya (2013)

- Travelling Salesman Problem (TSP)
- Multi Travelling Salesman Problem (MTSP)
- Capacitated Vehicle Routing Problem (CVRP)
- Time Dependent Vehicle Routing Problem (TDVRP)
- Split Delivery Vehicle Routing Problem (SDVRP)

- Vehicle Routing Problem Backhaul (VRPB)
- Vehicle Routing Problem Time Window (VRPTW)
- Vehicle Routing Problem Pickup and Delivery (VRPPD)
- Vehicle Routing Problem Backhaul with Time Window (VRPBTW)
- Vehicle Routing Problem Pickup and Delivery with Time Window (VRPPDTW)

MTSP extends the TSP by using multiple vehicles for delivery. CVRP is related to the capacity problem of the vehicle. In the CVRP, there is one depot/warehouse to deliver goods to a set of customers with known demands on minimum-cost vehicle routes originating from and terminating at a depot. The vehicles are assumed to be homogeneous and having certain capacity. TDVRP extends the CVRP with time dependence. Time window associated with customers is called VRPTW. Time window defines an interval during which the customer must be visited. SDVRP extends the CVRP by allowing each customer to be visited more than once. VRPB and VRPPD are another generalization of CVRP. VRPB includes the backhaul while VRPPD focuses on both pick-up and delivery. VRPBTW and VRPPDTW are transformed into VRPB and VRPPD by associating them with time windows.

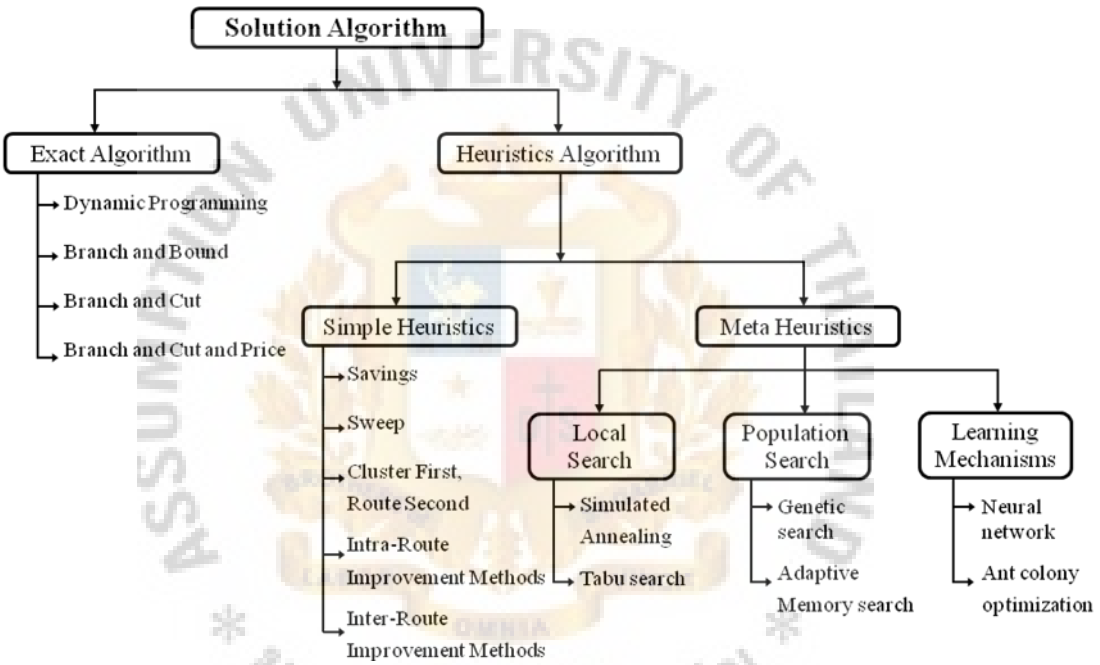
Among the characteristics of VRP, this research has concentrated on Capacitated Vehicles Routing Problem (CVRP) and its solution methods, subject to the following conditions and constraints:

- The demands of all customers must be met.
- Each customer is served by only one vehicle.
- The capacity of the vehicles must not exceed the total demand for each route.

2.1.3 Solution Algorithms for VRP and Its Variant

The Solution algorithms for VRP can be classified into two categories: Exact Algorithm and Heuristics Algorithm. Generally, both algorithms are used to solve VRP under different constraints as shown in Figure 2.3.

Figure 2.3: Solution Algorithm for VRP and Its Variant



Source: Sandhya (2013)

2.1.3.1 Exact Algorithm

It is the symmetric cost structure based on mathematical programming techniques (Integer linear programming (ILP), Dynamic programming, and Branch-and-bound). It can only solve instances of up to 100 customers approximately and with a variable success rate, but its performance is not consistent even for small size problems.

2.1.3.2 Heuristics Algorithm

It is divided into two parts: Simple and Meta Heuristics. The first part contains well-known schemes, such as Savings method, Sweep algorithm, Cluster First, Route Second, and Improvement method. The second part contains three methods: Local search, Population search, and Learning Mechanisms.

In fact, Heuristics algorithm tends to be considerably more flexible, easy to implement with no complex fine tuning requirement as compared to the Exact algorithm and can be more readily adapted with diversity of variants arising in practice. This research has concentrated on Heuristics algorithm, the Savings method.

2.2 Principle of Savings Method

In 1964, Clarke and Wright proposed the Savings method, a well-known Heuristics algorithm to solve VRP in four steps:

- Step 1: Identify the distance matrix from depot to all customers
- Step 2: Identify the saving matrix
- Step 3: Assign customers to the vehicles or routes
- Step 4: Sequence customers within routes

The vehicles or routes can be combined into a feasible route; however, the total deliveries must not exceed the vehicle's capacity. The advantage of this method is to improve vehicle utilization.

2.3 Review of Related Literature

In order to solve VRP in practice more effectively, many algorithms, particularly Heuristics was designed and implemented to deal with this type of problem. Recently the well-known Savings approach of Clarke and Wright was re-considered and some enhanced versions were proposed aiming to achieve improved solutions of VRP.

Coa (2012) presented an enhanced Clarke and Wright Savings algorithm by introducing enhanced steps in route building, stop assignments, and route balancing to solve CVRP. The algorithm obtains superior results compared to the basic C-W algorithm.

In 2013, Stanojević, Stanojević and Vujošević introduced enhanced savings calculation for CVRP in three various Heuristics algorithms: Extended Saving Algorithm (ESA); Randomized Extended Saving Algorithm (R-ESA); and Set-Covering based Extended Saving Algorithm (SC-ESA). The result showed that these enhanced savings calculation can generate many routes and easily adapted to solve a wide range of VRPs (Stanojević, Stanojević, & Vujošević, 2013).

Additionally, Grasas, Caceres-Cruz, Lourenço, Juan, and Roca (2013) applied Randomized algorithm to find a set of routes to serve all customers' needs and minimize the total distance of all vehicles for a distribution company in the Northeast of Spain. The result showed that it reduced the company distribution costs significantly.

In the same year, Caccetta, Alameen, and Abdul-Niby (2013) proposed the effective hybrid approach that combines domain reduction with the Clarke and Wright's Savings algorithm to solve the CVRP. The results showed that domain reduction can improve the classical Savings algorithm by 18%, while the hybrid approach is better in solving large instances.

Charoenwong and Pathomsiri (2015) examined whether the scientific route planning can improve the company's financial performance significantly by using Web-based routing application (WBRA) based on Clarke and Wright's Savings algorithm. The results implied that the inefficient route planning may be one major cause of the problem.

Wang, Zhao, Hao, and Yan (2016) applied an improved saving algorithm by merging methods based on making use of every large savings, choosing smaller savings, and adding a customer. The result showed that the total distance of routes optimized by improved saving method was shorter than the original saving algorithm.

Berhan (2016) used the Clark and Wright's Savings algorithm to solve VRPPD model in the urban public transport systems called Anbessa City Bus Service Enterprise (ACBSE). The findings of the study showed that the model is feasible and shows improvement on the current routes both on the number of buses used and the total kilometer covered.

Recently, Li, Chang, Zhao, and Lu (2017) have adopted the trip decomposition method to transfer the trip to arc demand so as to propose a vehicle flow formulation for the VRPPD (Container) and used the modified Clarke and Wright's Savings algorithm to solve the problem. The results of small-scale instances and the majority of benchmark instances suggest that the vehicle flow formulation and Heuristics algorithm perform well.

All of the above papers studied the Vehicle Routing Problem with different variants, and each of them applied the classical savings algorithm or the classical savings algorithms with improvement to provide better solution. The researcher applied the Savings algorithm to solve the Capacitated VRP. The solution was being proposed to minimize the total number of vehicles used to service the customers and minimize the distance travelled by all vehicles.

2.4 Chapter Summary

The Clark-Wright Savings method is flexible enough to handle a wide range of constraints, fast computation, and generation solution that are nearly optimum. For small problems with a limited number of constraints, the Savings method gives solution on average over the optimum around two percentage (Ballou, 2004).

The characteristics of Vehicle Routing Problem in this research, which is small size and there are some variants need to be focused on. The Savings method was applied for a proposal for the improvement.

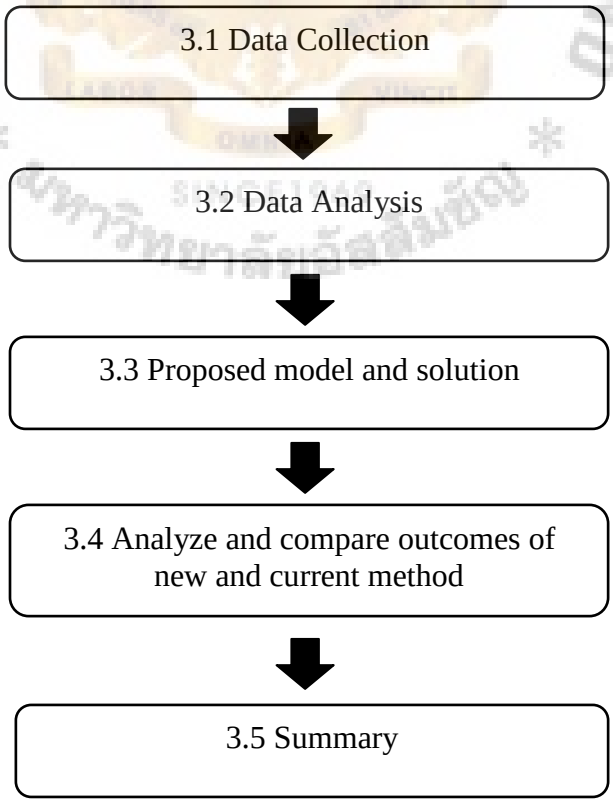
CHAPTER III

RESEARCH METHODLOGY

This chapter explains the details of the case study which consist of the overview of the research methodology and the application of the Savings method in ABC Company. The Savings method was applied to manage the daily vehicle routing to deliver goods to customers by using transport routes in Bangkok Metropolitan Region and neighboring provinces in Central and Eastern regions in Thailand; maximize the truck capacity; and minimize the number of vehicle used and the total distribution distance.

The research methodology is divided into five sections. All data were gathered and analyzed as shown in the research plan in Figure 3.1.

Figure 3.1: Research Plan



Source: Author

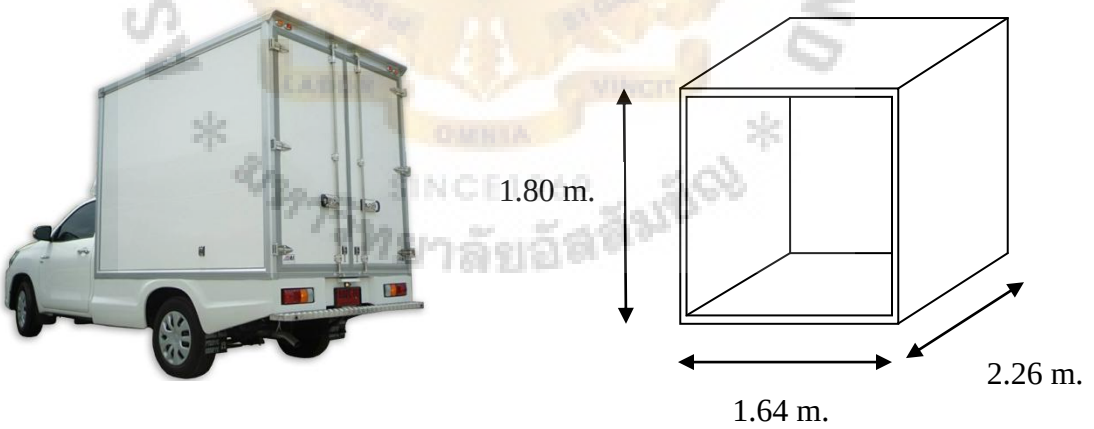
3.1 Data Collection

In order to collect all data for analysis, the data collected consist of vehicle size, packing, traveling time, routing, and transport distance which affect vehicle routing management.

3.1.1 Type of Truck and Capacity of Truck for Delivery

The four-wheel truck (Pickup) is the main vehicle for distributing goods to customers in Bangkok Metropolitan Region and neighboring provinces. The dimension of truck is1.64 meters in width, 2.26 meters in length, 1. 80 meters in height and with a total content 6.67 CBM. Furthermore, in order to have a smooth uploading flow of the products, the pickup must have some space internally and its height should not exceed 1.20 meters. The total capacity load for each pickup is not over 4.45 CBM.

Figure 3.2: Four-Wheel Truck (Pickup) and Its Dimension



Source: Company's Data

3.1.2 Conductive Boxes

ABC Company delivers the electronics components which are sensitive with static electricity. The goods are packed into conductive boxes as shown in Figure 3.3.

Figure 3.3: Sample of Conductive Boxes

Source: Company's Data

3.1.3 Travel Time

The truck leaves from the warehouse at 08.00 am and returns before 5.00 pm. The lunch time of one hour is within the travel time. The maximum delivery time is up to eight hours.

3.1.4 Warehouse location, Customer locations and Distance between each point of delivery

ABC Company uses information to arrange the location of the warehouse, customer locations and the distance in Bangkok and nearby areas. The official distance from the warehouse to the specific destination is referenced from Geographic Information System: GIS, Department of Highways. Each detail is described in Table 3.1 under the condition that the distance between point i (customer) to point j (customer) or point j (customer) to point i (customer) is equal.

Table 3.1: Distance from Warehouse to 39 Customers in 20 Nodes ID and Distance between Customers

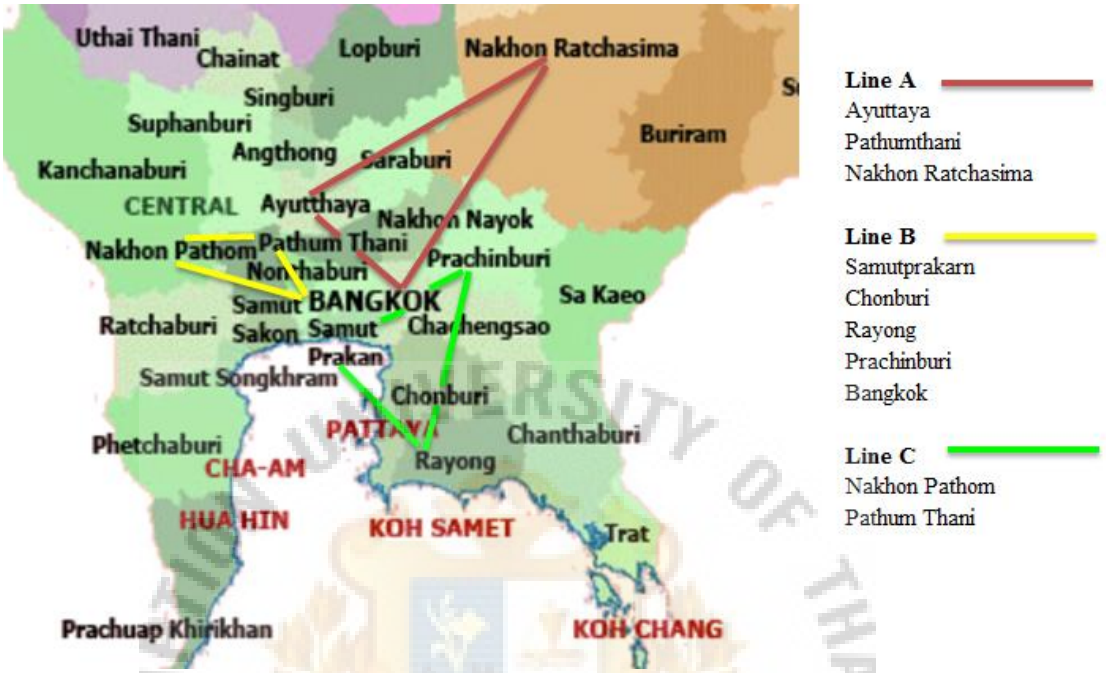
ID	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
0	0	26	56	39	109	98	79	44	179	91	26	143	56	77	250	50	265	270	28	125	167
1		10	68	54	92	102	83	59	163	74	13	126	60	83	254	62	270	275	16	121	158
2			10	60	146	64	45	61	205	128	68	178	33	37	216	58	232	237	77	130	179
3				10	135	116	96	22	205	117	51	169	76	88	267	29	283	288	64	167	192
4					10	161	145	141	74	46	86	45	132	154	299	144	252	288	83	137	140
5						10	27	125	216	128	96	189	53	50	153	123	168	173	103	79	128
6							10	106	207	122	74	181	34	153	174	103	189	194	82	100	149
7								10	210	122	57	174	79	87	267	13	283	288	69	170	197
8									10	100	155	30	189	212	327	214	281	316	153	170	168
9										10	63	74	110	132	264	121	218	253	61	93	105
10											10	121	53	76	244	59	259	264	16	110	152
11												10	162	185	301	177	254	290	116	144	142
12													10	29	201	77	216	221	62	106	154
13														10	194	86	210	215	81	121	169
14															10	259	40	40	240	153	155
15																10	284	288	74	171	198
16																	10	36	254	153	116
17																		10	271	189	152
18																			10	109	142
19																				10	166
20																					10

Source: GIS, Department of Highways

3.1.5 Routing

Currently, the company separates vehicle routing into three routes: Line A, Line B, and Line C as shown in Figure 3.4 by using employee's experience. Each day, the delivery location is assigned by customer order. However, the delivery to all 39 customers in 20 areas may not be possible on the same day.

Figure 3.4: Current Delivery Route



Source: Company's Data

From the above information, Table 3.2 shows truck usage, volume of transportation, and distances. The raw data were collected from the transport department of ABC Company from 1st to 30th April 2016 for analyzing, planning and modeling a daily truck management of vehicle routes from the warehouse to the destination point of customers.

Table 3.2 Truck Usage, Volume of Transportation and Distance Data in April 2016

Delivery date	Number of Truck use	Number of customer	Volume (m^3)	Distances (km)
01-Apr-16	7	9	16.500	2,136
02-Apr-16	7	8	23.656	2,241
03-Apr-16	4	4	11.480	2,292
04-Apr-16	7	8	22.825	2,373
05-Apr-16	6	7	17.971	1,756
06-Apr-16	6	7	17.517	1,600
07-Apr-16	6	7	15.577	2,061
08-Apr-16	7	10	20.773	2,409
09-Apr-16	7	9	25.835	2,172
10-Apr-16	7	7	16.791	2,419
11-Apr-16	7	8	21.635	1,806
12-Apr-16	7	7	21.113	1,658
13-Apr-16	2	2	7.175	664
14-Apr-16	1	1	4.387	83
15-Apr-16	-	-	-	-
16-Apr-16	-	-	-	-
17-Apr-16	3	3	8.846	1,016
18-Apr-16	7	9	25.772	1,663
19-Apr-16	7	9	22.582	1,752
20-Apr-16	7	8	21.641	1,827
21-Apr-16	7	8	19.685	1,676
22-Apr-16	7	10	24.287	2,129
23-Apr-16	6	8	21.292	1,877
24-Apr-16	1	1	3.977	344
25-Apr-16	7	7	15.866	1,828
26-Apr-16	7	7	20.657	1,713
27-Apr-16	7	8	19.790	1,988
28-Apr-16	7	8	19.179	1,821
29-Apr-16	7	10	23.301	1,995
30-Apr-16	3	3	5.627	1,035
Total			**495.736**	**48,334**

Source: Transport department, ABC Company

3.2 Data Analysis

For data analysis, the researcher collected the data and reviewed the current vehicle routing management. Table 3.3 shows the example of current vehicle routing management in one day.

Table 3.3: Example of Current Vehicle Routing Management

Truck number	Routing by ID location	Maximum capacity (CBM)	Volume (m^3)	Distance (km)
1	0=>11=>0	4.450	1.840	293
2	0=>11=>0	4.450	2.072	257
3	0=>18=>9=>0	4.450	1.937	169
4	0=>15=>19=>0	4.450	1.433	206
5	0=>20=>0	4.450	3.977	327
6	0=>8=>0	4.450	2.494	353
7	0=>14=>0	4.450	2.747	531
Total		**31.150**	**16.500**	**2,136**

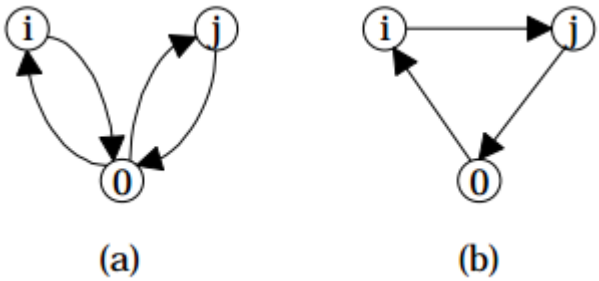
Source: Company's Data

Table 3.3 shows that the delivery planning pattern is unclear, combining delivery and using all trucks without capacity consideration. It may have an impact on higher transportation costs.

3.3 Proposed Model and Solution

Designing the vehicle route to match with the VRP is an important step. This study proposed the Savings method to create a vehicle route based on the customers' locations. The Savings method calculates the cost savings by joining two routes into one route as shown in Figure 3.5, where point 0 represents the warehouse.

Figure 3.5: Principle of the Saving Method



Source: Clarke & Wright (1964)

In Figure 3.5(a), the goods are delivered to customers i and j on separate routes. If two customers are combined on the same route, the route is shown in Figure 3.5(b). The transportation cost in Figure 3.5(a) is $D_a = C_{0i}+C_{i0}+C_{0j}+C_{j0}$ and in Figure 3.5(b), which is a combined route is $D_b = C_{0i}+C_{ij}+C_{j0}$. By combining the two routes, one obtains the savings, S_{ij} is equal to $D_a - D_b = C_{0i}+C_{0j}-C_{ij}$.

Step 1: Compute the savings, the formula is;

$$S_{ij} = C_{i0} + C_{0j} - C_{ji}$$

For i, j = 1,…, n and $i \neq j$

The Savings method calculates all the savings (S_{ij}) between customer i and j. Assuming that C_{i0} is the cost of travelling from warehouse to customer i, and C_{ij} is the cost of travelling from customer i to j, the savings details are shown in Table 3.4.

Table 3.4: Savings Table

Saving Algorithm

ID	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
0	0	26	56	39	109	98	79	44	179	91	26	143	56	77	250	50	265	270	28	125	167
1		10	14	11	43	22	22	11	42	43	39	43	22	20	22	14	21	21	38	30	35
2			10	35	19	90	90	39	30	19	14	21	79	96	90	48	89	89	7	51	44
3				10	13	21	22	61	13	13	14	13	19	28	22	60	21	21	3	3	14
4					10	46	43	12	214	154	49	207	33	32	60	15	122	91	54	97	136
5						10	150	17	61	61	28	52	101	125	195	25	195	195	23	144	137
6							10	17	51	48	31	41	101	3	155	26	155	155	25	104	97
7								10	13	13	13	13	21	34	27	81	26	26	3	1	14
8									10	170	50	292	46	44	102	15	163	133	54	134	178
9										10	54	160	37	36	77	20	138	108	58	123	153
10											10	48	29	27	32	17	32	32	38	41	41
11												10	37	35	92	16	154	123	55	124	168
12													10	104	105	29	105	105	22	75	69
13														10	133	41	132	132	24	81	75
14															10	41	475	480	38	222	262
15																10	31	32	4	4	19
16																	10	499	39	237	316
17																		10	27	206	285
18																			10	44	53
19																				10	126
20																					10

Source: Author

Step 2: Create "Savings list", after calculating the savings, rank the savings list from the largest S_{ij} to smallest S_{ij} as shown in Table 3.5.

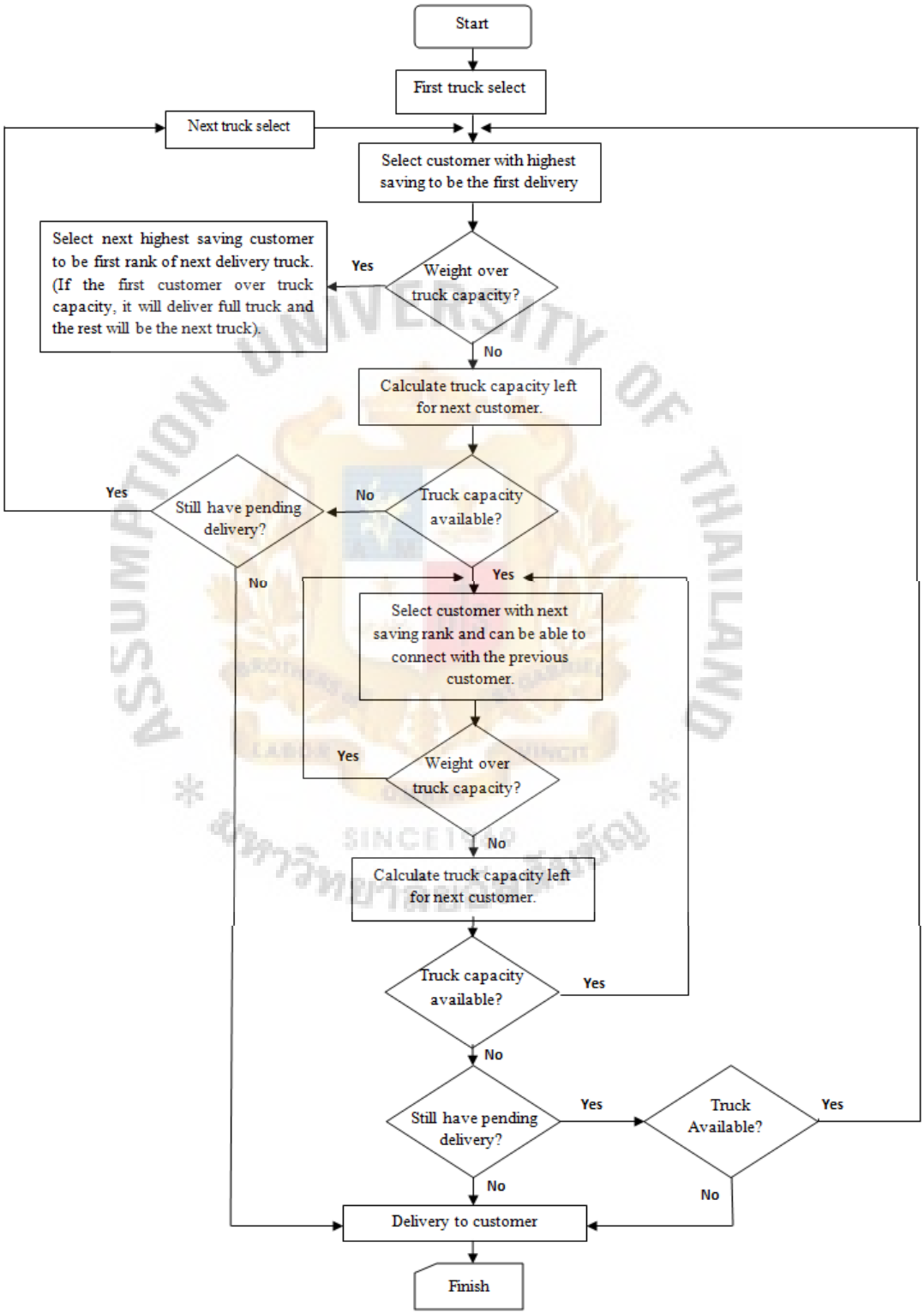
Table 3.5: Savings List

no.	i	j	kms	no.	i	j	kms	no.	i	j	kms	no.	i	j	kms
1	16	17	499	51	6	12	101	101	10	19	41	151	3	16	21
2	14	17	480	52	4	19	97	102	10	20	41	152	3	17	21
3	14	16	475	53	6	20	97	103	1	10	39	153	7	12	21
4	16	20	316	54	2	13	96	104	2	7	39	154	1	13	20
5	8	11	292	55	11	14	92	105	16	18	39	155	9	15	20
6	17	20	285	56	4	17	91	106	1	18	38	156	2	4	19
7	14	20	262	57	2	5	90	107	10	18	38	157	2	9	19
8	16	19	237	58	2	6	90	108	14	18	38	158	3	12	19
9	14	19	222	59	2	14	90	109	9	12	37	159	15	20	19
10	4	8	214	60	2	16	89	110	11	12	37	160	5	7	17
11	4	11	207	61	2	17	89	111	9	13	36	161	6	7	17
12	17	19	206	62	13	19	81	112	1	20	35	162	10	15	17
13	5	14	195	63	7	15	81	113	2	3	35	163	11	15	16
14	5	16	195	64	2	12	79	114	11	13	35	164	4	15	15
15	5	17	195	65	9	14	77	115	7	13	34	165	8	15	15
16	8	20	178	66	12	19	75	116	4	12	33	166	1	2	14
17	8	9	170	67	13	20	75	117	4	13	32	167	1	15	14
18	11	20	168	68	12	20	69	118	10	14	32	168	2	10	14
19	8	16	163	69	3	7	61	119	10	16	32	169	3	10	14
20	9	11	160	70	5	8	61	120	10	17	32	170	3	20	14
21	6	14	155	71	5	9	61	121	15	17	32	171	7	20	14
22	6	16	155	72	3	15	60	122	6	10	31	172	3	4	13
23	6	17	155	73	4	14	60	123	15	16	31	173	3	8	13
24	4	9	154	74	9	18	58	124	1	19	30	174	3	9	13
25	11	16	154	75	11	18	55	125	2	8	30	175	3	11	13
26	9	20	153	76	4	18	54	126	10	12	29	176	7	8	13
27	5	6	150	77	8	18	54	127	12	15	29	177	7	9	13
28	5	19	144	78	9	10	54	128	3	13	28	178	7	10	13
29	9	16	138	79	18	20	53	129	5	10	28	179	7	11	13
30	5	20	137	80	5	11	52	130	7	14	27	180	4	7	12
31	4	20	136	81	2	19	51	131	10	13	27	181	1	3	11
32	8	19	134	82	6	8	51	132	17	18	27	182	1	7	11
33	8	17	133	83	8	10	50	133	6	15	26	183	2	18	7
34	13	14	133	84	4	10	49	134	7	16	26	184	15	18	4
35	13	16	132	85	2	15	48	135	7	17	26	185	15	19	4
36	13	17	132	86	6	9	48	136	5	15	25	186	3	18	3
37	19	20	126	87	10	11	48	137	6	18	25	187	6	13	3
38	5	13	125	88	4	5	46	138	13	18	24	188	7	18	3
39	11	19	124	89	8	12	45	139	5	18	23	189	7	19	-1
40	9	19	123	90	2	20	44	140	1	5	22	190	3	19	-3
41	11	17	123	91	8	13	44	141	1	6	22				
42	4	16	122	92	18	19	44	142	1	13	22				
43	9	17	108	93	4	6	43	143	1	14	22				
44	12	14	105	94	1	4	43	144	3	6	22				
45	12	16	105	95	1	9	43	145	3	14	22				
46	12	17	105	96	1	11	43	146	12	18	22				
47	6	19	104	97	1	8	42	147	1	16	21				
48	12	13	104	98	6	11	41	148	1	17	21				
49	8	14	102	99	13	15	41	149	2	11	21				
50	5	12	101	100	14	15	41	150	3	5	21				

Source: Author

The next step after receiving the savings list is to process the model of the vehicle route by using the Savings method as flow chart shown in Figure 3.6. Then, the result is analyze for the next step.

Figure 3.6: Process of Modeling the Vehicle Route by Savings Method



Source: Author

3.4 Analyze and Compare Outcomes of New and Current Method

This step compares the outcomes from applying the Savings method with the current method. The objective is to reduce the number of truck usage, total distribution distance, and maximize the truck capacity.

3.5 Summary

From the proposed model, it could be seen that the Savings method applied to the traditional distribution changed the current vehicle routing to minimize the distribution distance and reduce transportation cost with efficiency.

The discussion of results is presented in the next chapter. The outcome of this study is to be suggested to the company to consider for the improvement of the current vehicle routing to minimize the total distribution distance and to gain more profit.

CHAPTER IV

PRESENTATION AND CRITICAL DISCUSSION OF RESULTS

This chapter presents and discusses the results of Savings method which is the main tool applied in this research. The presentation and discussion start with analysis of the current transport routing, proposed method and analysis of the Savings method, respectively. The total number of vehicles usage, the total distribution distances, and the truck utilization of truck capacity are discussed in comparison with the current and new proposed model (Savings method). The last section contains the chapter summary and conclusions.

4.1 Analysis of Current Truck Management

The current truck management was planned by experienced employees dealing in with customers as a daily operation. After analyzing the data for April, 2016 on vehicle usage, the researcher found that there have been 151 trucks (92.07%) with less load and 13 trucks (7.93%) with overload capacity as shown in Table 4.1.

Table 4.1: Summary of the Number of Vehicles Usage of the Current Truck Management

Type of loading	The number of vehicles usage	Percentage
Less than truck loaded (LCL)	151	92.07%
Over truck loaded	13	7.93%
Total	**164**	**100.00%**

Source: Author

For the total distribution distance and truck utilization of the current truck management in April, 2016, 48,334 (67.93%) km have been utilized as shown in

Table 4.2. (The calculation of the truck utilization comes from total capacity usages divide by the number of truck used multiple capacity per truck)

Table 4.2: Total Distribution Distance and Truck Utilization of Truck Capacity of Current Truck Management

	Total distribution distance (km)	The truck utilization
Current truck management	48,334	67.93%

Source: Author

4.2 Proposed Method and Analysis of Savings Method

After analyzing the current process and related data, the new proposed method which is the Savings method has been applied and simulated in the excel worksheets based on the daily operation of the truck management in April, 2016. The results are presented in Table 4.3.

Table 4.3: Summary of the Results of Truck Management by Savings Method

	Saving method
The number of vehicles usage	137
Total distribution distances (km)	40,746
The truck utilization	81.31%

Source: Author

Table 4.3 shows the results from applying the Savings method. The table further shows that the total number of vehicles usage is 137, and the total distribution distance is 40,746 km with the truck utilization of 81.31% . Moreover, there has been no truck assigned with overloading.

4.3 Comparison of Current and Proposed Model

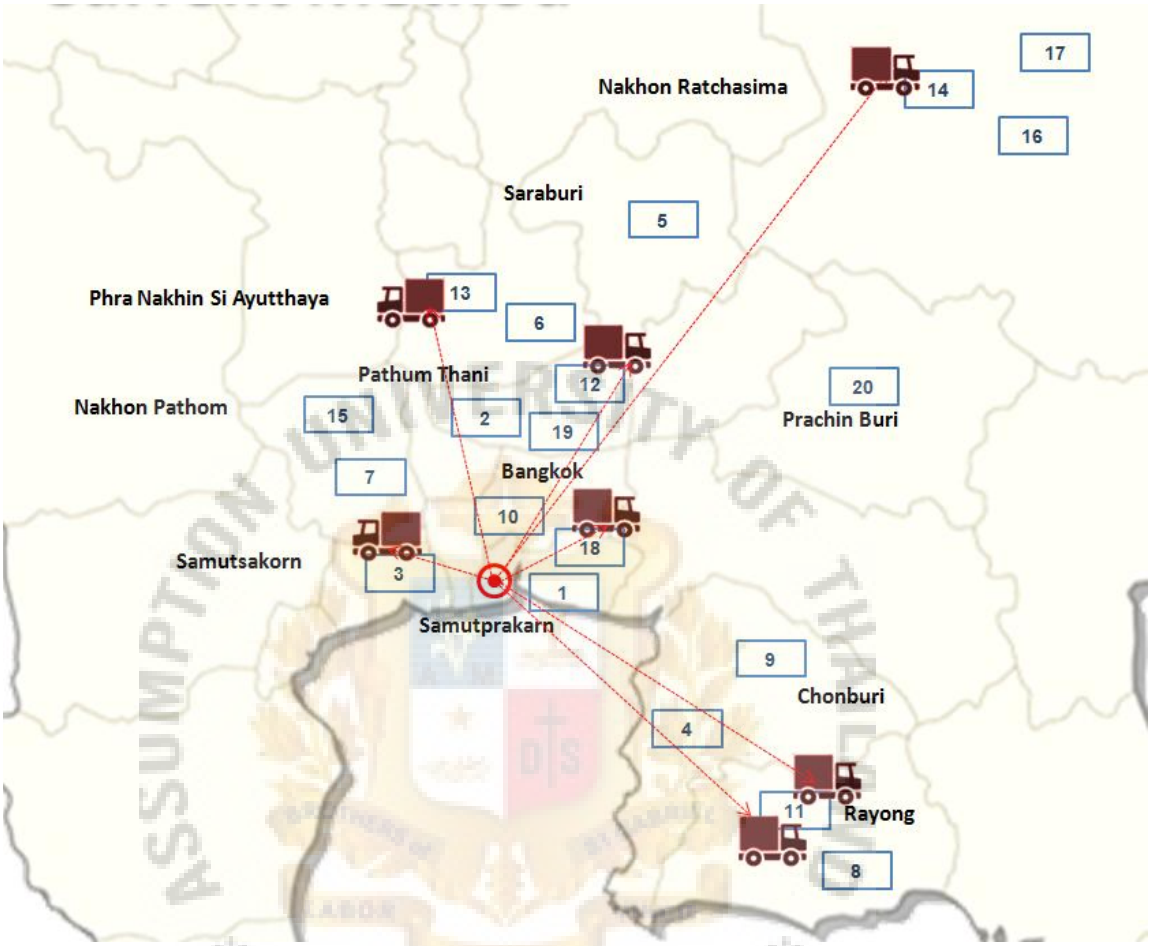
After completing the worksheets, all results are summarized and compared with the current process. The results of the Savings method present that the routing process has been improved. The number of vehicles usage and total distribution distance have been decreased, which improve the percentage of truck utilization of truck capacity accordingly.

Table 4.4: Current Truck Management on April 25, 2016

Date	Truck no.	Location no. 1	Location no. 2	Location no. 3	Total capacity (m3)	Total distance (km)	Truck capacity usage (%)
25/04/2016	1	3			4.264	92	95.82%
25/04/2016	2	11			3.360	313	75.51%
25/04/2016	3	18			1.591	101	35.75%
25/04/2016	4	14			3.075	480	69.10%
25/04/2016	5	12			0.338	216	7.59%
25/04/2016	6	11			2.762	276	62.08%
25/04/2016	7	13			0.476	350	10.70%
Total	**7**				**15.866**	**1,828**	**50.94%**

Source: Company's Data

Figure 4.1: Current Truck Management Routing on April 25, 2016



Source: Company's Data

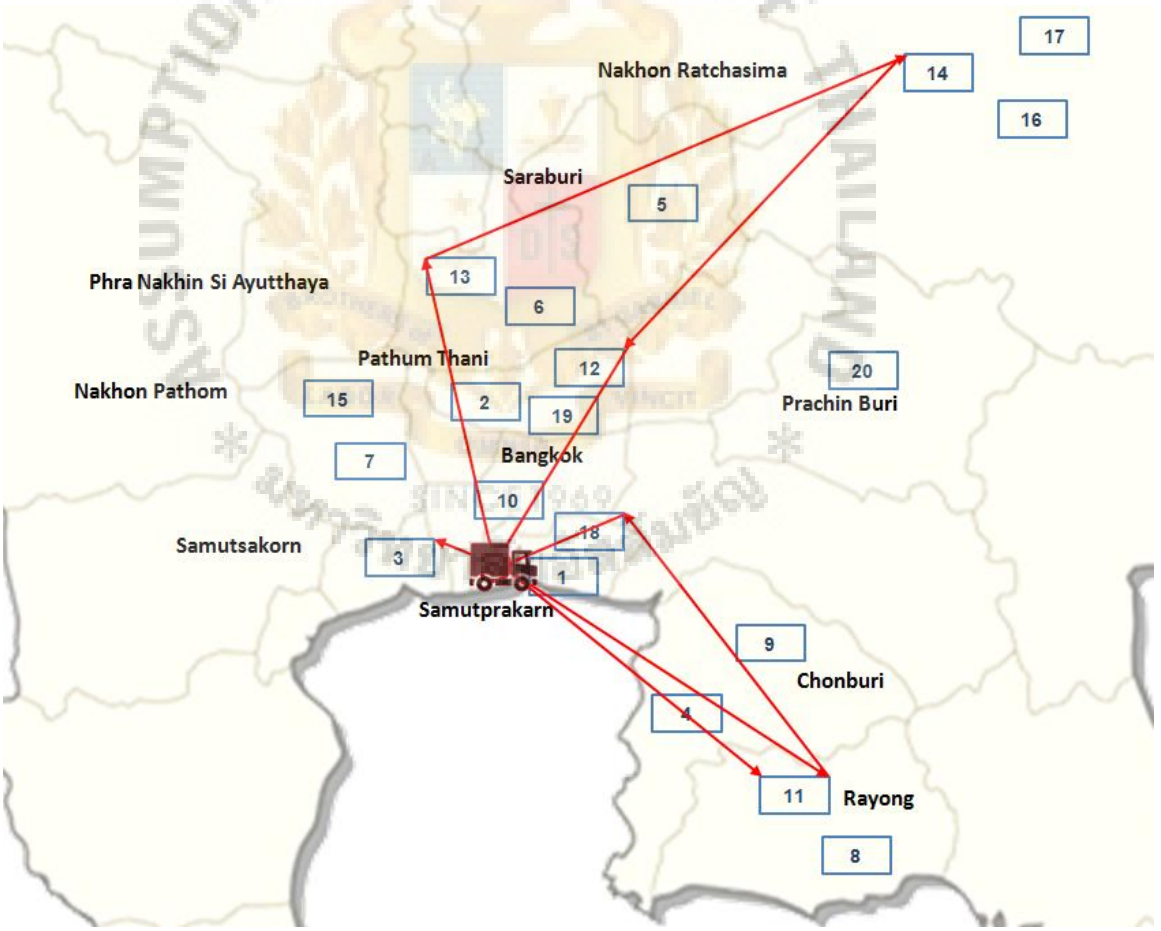
Table 4.4 and Figure 4.1 show the current truck management on April 25, 2016. Seven trucks have been assigned for delivery to each customer with less load capacity. After applying the Savings method, the results are shown in Table 4.5 and Figure 4.2.

Table 4.5: Truck Management by Savings Method on April 25, 2016

Date	Truck no.	Location no. 1	Location no. 2	Location no. 3	Total capacity (m3)	Total distance (km)	Truck capacity usage (%)
25/04/2016	1	13	14	12	3.889	528	87.39%
25/04/2016	2	11	18		4.353	287	97.83%
25/04/2016	3	3			4.264	78	95.82%
25/04/2016	4	11			3.360	286	75.51%
Total	**4**				**15.866**	**1,179**	**89.14%**

Source: Author

Figure 4.2: Truck Management Routing by Saving Method on April 25, 2016



Source: Author

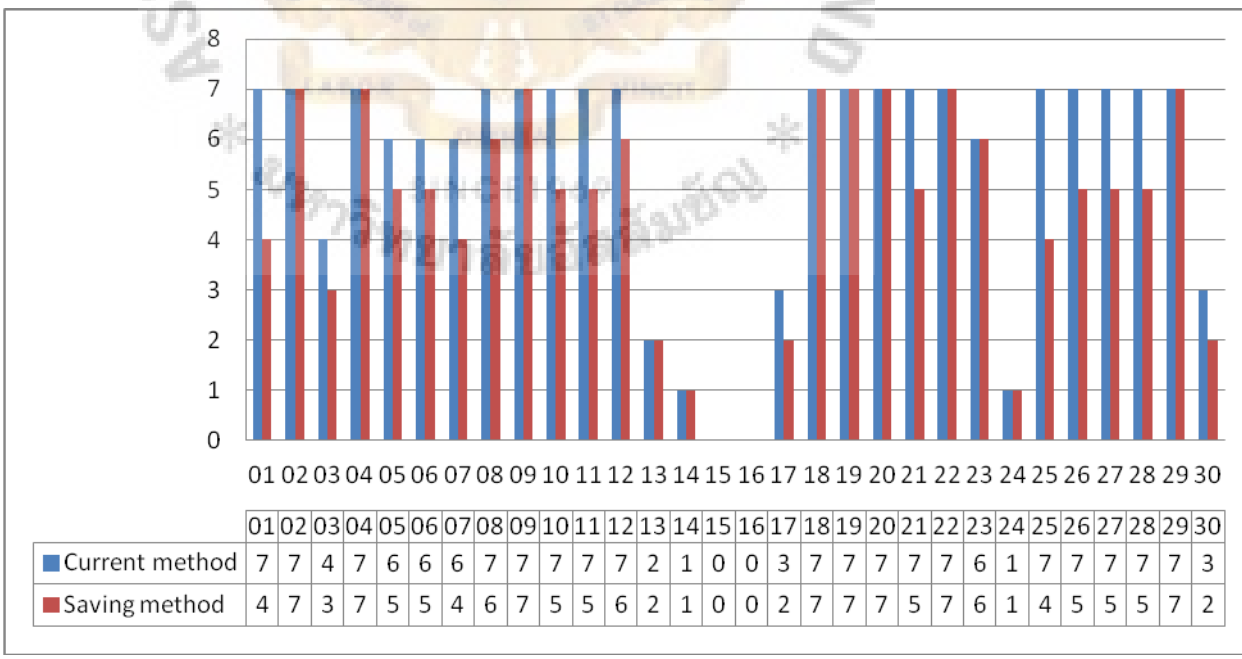
Table 4.5 and Figure 4.2 show the truck management by Savings method on April 25, 2016. The Savings method has helped decrease the total number of vehicles usage from seven to four trucks and the total distribution distance from 1,828 to 1,179 km. Moreover, the truck utilization of truck capacity has been improved from 50.94% to 89.14%.

From above, the significant improvements of this study are focused on the number of vehicles usage, the total distribution distance, and the truck utilization of truck capacity.

4.3.1 The Number of Vehicles Usage

The Savings method is able to reduce the number of vehicles usage compared to the current truck management as shown in Figure 4.3 and Figure 4.4.

Figure 4.3: Comparison of the Number of Vehicles Usage in April, 2016

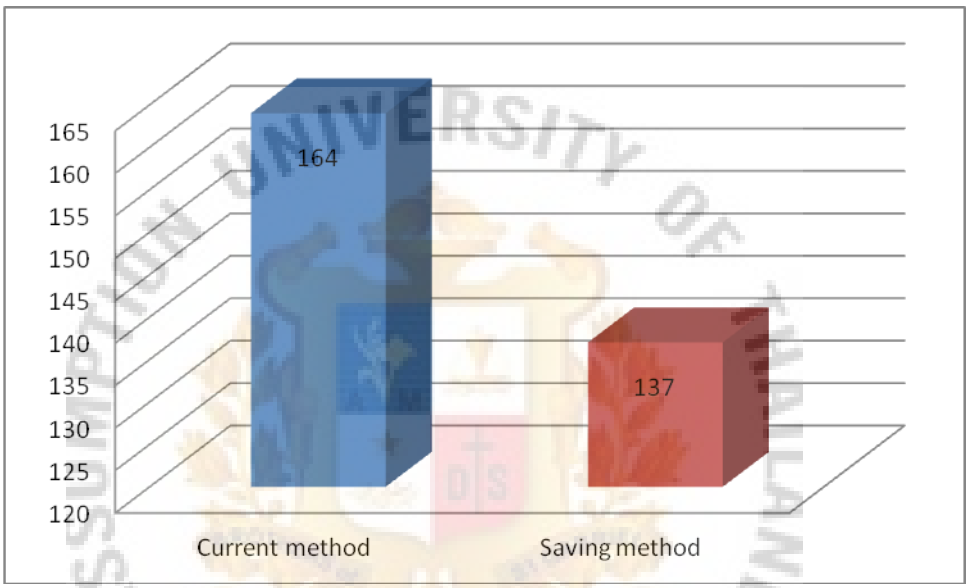


	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Current method	7	7	4	7	6	6	6	7	7	7	7	7	2	1	0	0	3	7	7	7	7	7	6	1	7	7	7	7	7	3
Saving method	4	7	3	7	5	5	4	6	7	5	5	6	2	1	0	0	2	7	7	7	5	7	6	1	4	5	5	5	7	2

Source: Company's Data and Author

Figure 4.3 illustrates that the number of vehicles usage by Savings method is lower than the current method. However, on days when the same number of vehicles are overloaded in the current method, the Savings method cannot provide better solution.

Figure 4.4: Comparison of Summary of the Number of Vehicles Usage in April, 2016



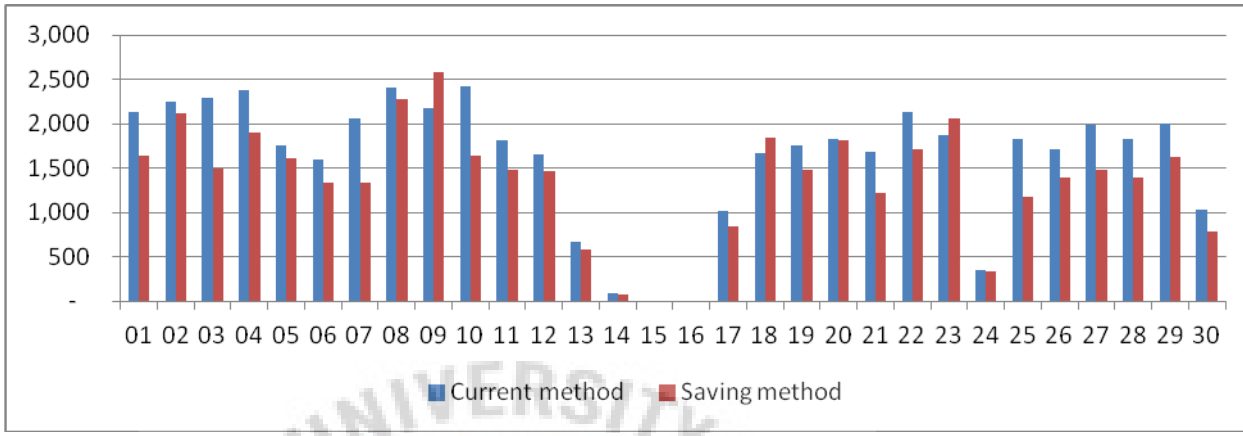
Source: Company's Data and Author

Figure 4.4 shows the comparison between the current method and the Savings method. Savings method reduces the number of vehicles usage by 27 trucks or 16.46% from the current method.

4.3.2 The Distribution Distances

In addition, the Savings method does not only decrease the number of vehicles usage, but also decreases the total distribution distances compared to the current truck management as shown in Figure 4.5 and Figure 4.6.

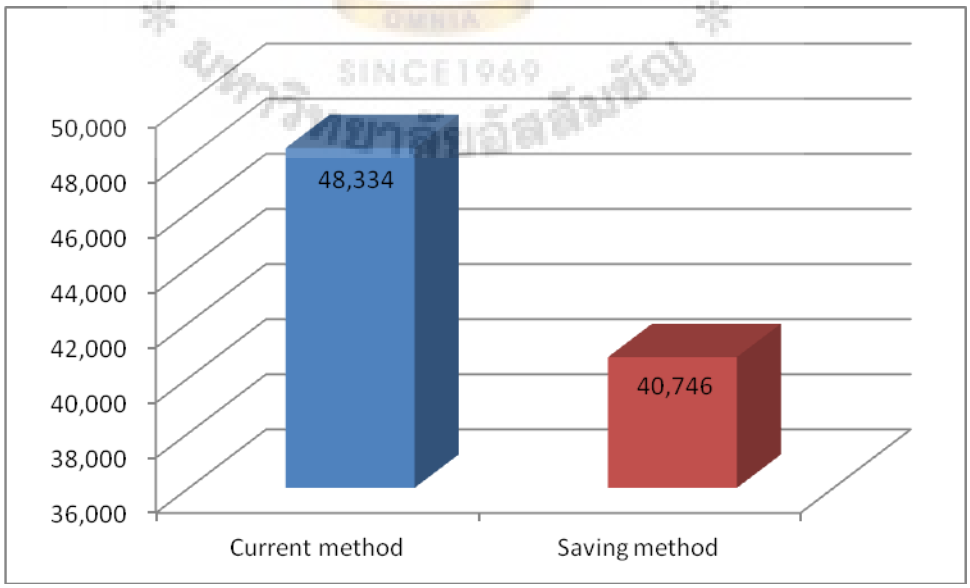
Figure 4.5: Comparison of the Total Distribution Distances in April, 2016



Source: Company's Data and Author

Figure 4.5 shows that the Savings method improves the total distribution distances, except on the 9th, 18th and 23rd of April, 2016 because the assigned trucks have been overloaded in the current method.

Figure 4.6: Comparison of Summary of the Total Distribution Distances in April, 2016



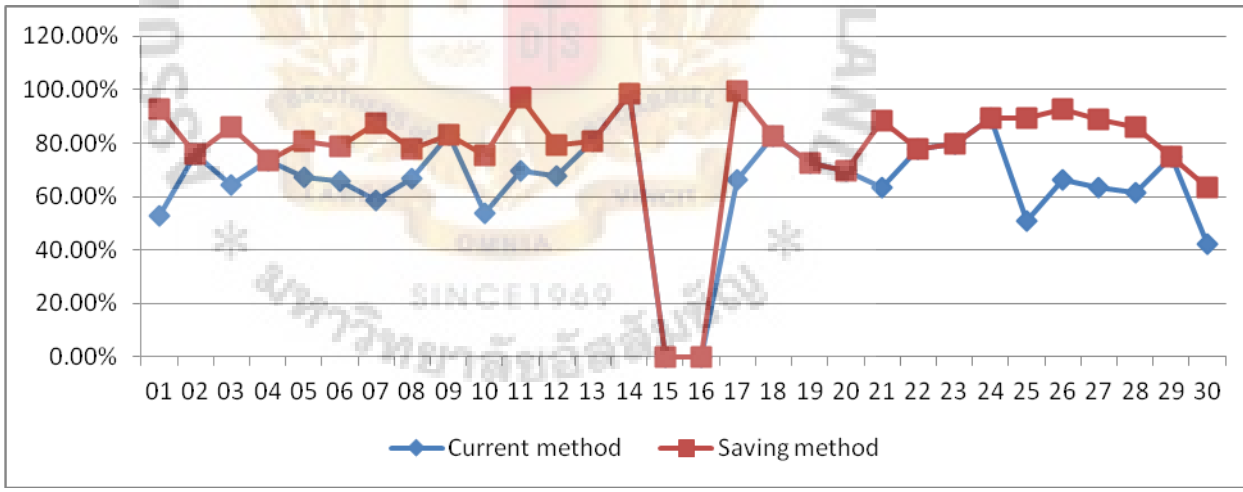
Source: Company's Data and Author

Figure 4.6 shows the comparison between the current method and the Savings method. Savings method reduces the total distribution distances from 48,334 to 40,746 km or 15.70% from the current method. The number of distances saved is 7,588 km. As a result, it has saved a fuel cost of THB 18,203.61 (Calculation is based on diesel price of July 02, 2017 at THB 23.99 per liter).

4.3.3 Truck Utilization of Truck Capacity

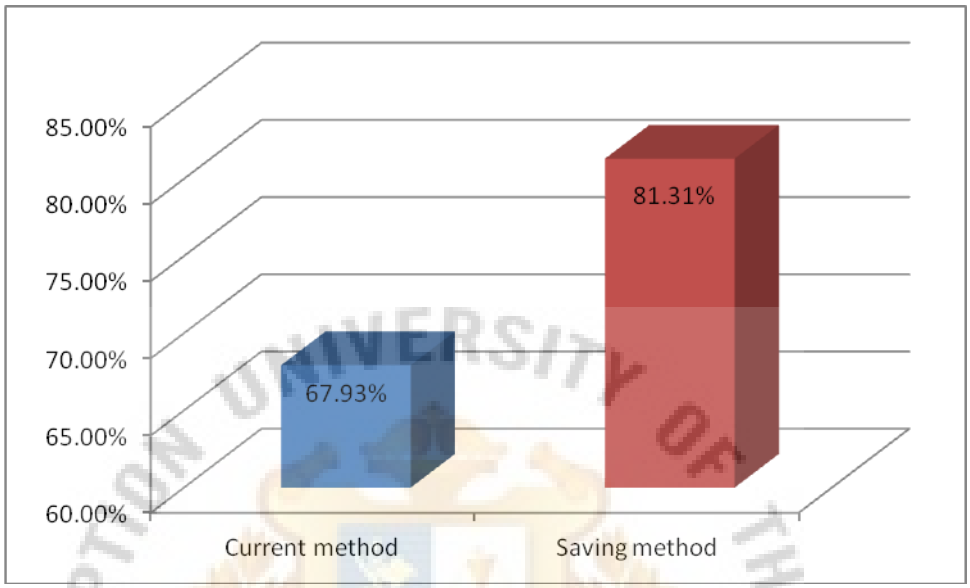
The results of the Savings method show that the total number of vehicles usage and total distribution distances have been improved accordingly. The Savings method has helped improve the truck utilization of truck capacity identically.

Figure 4.7: Comparison of the Truck Utilization of Truck Capacity in April, 2016



Source: Company's Data and Author

Figure 4.8: Comparison of Summary of the Truck Utilization of Truck Capacity in April, 2016



Source: Company's Data and Author

Figure 4.7 shows the graph indicating that the Savings method provides higher truck utilization compared to the current method. The Savings method has helped increase the utilization in April, 2016 from 67.93% to 81.31% or 19.70% improvement as shown in Figure 4.8.

4.4 Chapter Summary

The Savings method has been applied and simulated on Excel worksheets and the results have improved significantly. The figures comparing the data between the current method and the Savings method show that the number of vehicles usage has been decreased by 16.49%; the total distribution distance has been decreased by 15.70%; and the truck utilization of truck capacity has been improved by 19.70% respectively.

The Savings method can help the company improve its truck management more systematically and reduce cost of transportation.

CHAPTER V

SUMMARY FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

This chapter presents the results of this case study which can be categorized into five sections: summary of the findings, conclusion, theoretical implications, managerial implications, and limitations and recommendations for future research.

5.1 Summary of the Findings

The Savings method helped improve the truck management of ABC Company, which reduced the number of vehicles usage and total distribution distances. Moreover, the truck utilization of truck capacity was improved significantly. The findings showed that the Savings method developed the truck management more systematically. The results were analyzed by using Excel worksheets. The summary of the key improvements in this research are as follows:

1. The total number of vehicles usage had significantly decreased by 16.46%.
2. The total distribution distances had reduced by 7,588 km or 15.70%. The company saved cost18,203.61 THB in the fuel (Calculation is based on diesel price of July 02, 2017 at THB 23.99 per liter).
3. The truck capacity was arranged with full truck loading. The truck utilization had improved by 19.70%.

5.2 Conclusions

The main objectives of this research are to minimize the total number of vehicles usage, improve the total distribution distances and maximize the truck utilization of truck capacity by applying the Savings method.

Moreover, this research seeks to answer the research question **"How does vehicle routing affect cost reduction?"** According to the results, the Savings method when applied to truck management as the new method, it shows that the total number of vehicles usage has decreased by 16.46%; the total distribution distances has decreased by 15.70%, which gives the company THB 18,203.61 savings; and the truck utilization of truck capacity has improved by 19.70%.

The proposed model (Savings method) confirms that the number of vehicles usage, total distribution distances, and truck utilization have significantly improved.

5.3 Theoretical Implications

In this study, the implementation of the Savings method shows a good result in the improvement of the current truck management, especially in ABC Company. However, it may not apply to other companies in the same business category because each issue has different constraints and limitations.

Generally, the Savings method by Clark and Wright (1964) algorithm presents a good result of solutions for small size instances. In addition, it is easily implemented with no complication and suits for companies with similar situation. However, for large instances, calculating the savings may consider large values which affect the solution**.**

5.4 Managerial Implications

This research is developed for the improvement of the daily operation of truck management of a trading company. This study can be a guideline for the transport department in managing the daily truck operation. The department may need to take about an hour each day to manage the trucks. But, the company can save up to THB 18,000 per month or THB 216,000 per year. It is valuable for a company to apply this method in its transport department.

Actually, there was difficulty in collecting the data because the current data were collected manually and not systematic. In the future, the data could be more accurate and easier to collect; thus, it is recommended that the company provides a better storage system to manage the data.

5.5 Limitations and Recommendations for Future Research

The data collection in this study was done manually. The researcher spent much time in collecting the data; thus, this study cannot show more number of months within the time limitation.

The Savings method helps manage the daily truck operation more systematically. Also, this method is flexible and uncomplicated and may be applied to SMEs to improve the number of vehicles usage, total distribution distances, and truck utilization of truck capacity.

In the future, it is likely that the trading business will continue to grow and supply to more customers. Thus, the company should adapt an appropriate method in its operation to cope with the business expansion. It may apply the application program to serve various customers.

For future research, the Enhanced saving method by considering the constraint of frequency of delivery or high volume concentration, etc., may be applied to be more useful and match with the vehicle routing problem for a trading company or SMEs in the practical situation to manage the operation rather than the Savings method with capacity constraints.

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APPENDICES

APPENDIX A

Group of Customers in Node ID

ID	Customer Code	Province	Amphur
0	LC	Samutprakarn	Phrapradaeng
1	AP	Samutprakarn	Muang
2	AS	Pathum Thani	Ladlumkaew
3	BB	Samutsakorn	Kratumban
3	CC	Samutsakorn	Kratumban
4	CE	Chonburi	Sriracha
5	SH	Saraburi	Nong Khae
6	CI	Phra Nakhon Si Ayutthaya	Wangnoi
6	DW	Phra Nakhon Si Ayutthaya	Wangnoi
6	HI	Phra Nakhon Si Ayutthaya	Wangnoi
6	KT	Phra Nakhon Si Ayutthaya	Wangnoi
6	NT	Phra Nakhon Si Ayutthaya	Wangnoi
7	FO	Nakhon Pathom	Sampran
7	SL	Nakhon Pathom	Sampran
8	FT	Rayong	BanKhai
9	FU	Chonburi	Panthong
9	CK	Chonburi	Panthong
9	NI	Chonburi	Panthong
9	MI	Chonburi	Panthong
10	HE	Bangkok	Bangna
11	MT	Rayong	Puakdaeng
11	US	Rayong	Puakdaeng
12	ME	Pathum Thani	Klongluang
12	RO	Pathum Thani	Klongluang
12	TM	Pathum Thani	Klongluang
12	TS	Pathum Thani	Klongluang
13	NS	Phra Nakhon Si Ayutthaya	Bangpa-In
13	HD	Phra Nakhon Si Ayutthaya	Bangpa-In
13	MN	Phra Nakhon Si Ayutthaya	Bangpa-In
13	WA	Phra Nakhon Si Ayutthaya	Bangpa-In
14	NK	Nakhon Ratchasima	Sung Noen
15	SH	Nakhon Pathom	Nakornchaisri
16	SM	Nakhon Ratchasima	Pakthongchai
17	SI	Nakhon Ratchasima	Muang
18	TA	Samutprakarn	Bangplee
18	MC	Samutprakarn	Bangplee
19	TC	Pathum Thani	Muang
19	TT	Pathum Thani	Muang
20	TY	Prachin Buri	Kabinburi

APPENDIX B

Current Truck Management in April, 2016

Date	Truck no.	Location no. 1	Location no. 2	Location no. 3	Total capacity (m3)	Total distance (km)	Truck capacity usage (%)	Type of loading
01/04/2016	1	11			1.840	293	41.35%	LCL
01/04/2016	2	11			2.072	257	46.56%	LCL
01/04/2016	3	18	9		1.937	169	43.53%	LCL
01/04/2016	4	15	19		1.433	206	32.20%	LCL
01/04/2016	5	20			3.977	327	89.37%	LCL
01/04/2016	6	8			2.494	353	56.04%	LCL
01/04/2016	7	14			2.747	531	61.73%	LCL
02/04/2016	1	3			4.387	101	98.58%	LCL
02/04/2016	2	14			3.403	579	76.47%	LCL
02/04/2016	3	14			2.501	600	56.20%	LCL
02/04/2016	4	18			1.806	99	40.58%	LCL
02/04/2016	5	11	11		6.136	308	137.89%	Overload
02/04/2016	6	8			1.856	334	41.71%	LCL
02/04/2016	7	6			3.567	220	80.16%	LCL
03/04/2016	1	14			3.444	571	77.39%	LCL
03/04/2016	2	14			2.173	592	48.83%	LCL
03/04/2016	3	14			2.091	561	46.99%	LCL
03/04/2016	4	14			3.772	568	84.76%	LCL
04/04/2016	1	2			4.182	163	93.98%	LCL
04/04/2016	2	11			3.000	299	67.42%	LCL
04/04/2016	3	3			3.526	95	79.24%	LCL
04/04/2016	4	6			0.266	236	5.98%	LCL
04/04/2016	5	14			3.239	579	72.79%	LCL
04/04/2016	6	14			3.854	569	86.61%	LCL
04/04/2016	7	8	18		4.758	432	106.92%	Overload
05/04/2016	1	13			0.442	258	9.93%	LCL
05/04/2016	2	2			4.428	156	99.51%	LCL
05/04/2016	3	18	4		4.863	109	109.28%	Overload
05/04/2016	4	8			2.088	357	46.92%	LCL
05/04/2016	5	14			2.624	549	58.97%	LCL
05/04/2016	6	20			3.526	327	79.24%	LCL
06/04/2016	1	11			3.760	290	84.49%	LCL
06/04/2016	2	2			4.264	156	95.82%	LCL
06/04/2016	3	14			2.993	520	67.26%	LCL
06/04/2016	4	18	1		4.059	104	91.21%	LCL
06/04/2016	5	8			2.175	347	48.88%	LCL
06/04/2016	6	12			0.266	183	5.98%	LCL
07/04/2016	1	2			2.993	150	67.26%	LCL
07/04/2016	2	18	1		2.080	108	46.74%	LCL
07/04/2016	3	20			4.387	668	98.58%	LCL
07/04/2016	4	6			0.196	241	4.40%	LCL
07/04/2016	5	14			3.485	554	78.31%	LCL
07/04/2016	6	8			2.436	340	54.74%	LCL
08/04/2016	1	8			2.813	341	63.21%	LCL
08/04/2016	2	15			0.912	145	20.49%	LCL
08/04/2016	3	12			0.820	370	18.43%	LCL
08/04/2016	4	14			1.886	518	42.38%	LCL
08/04/2016	5	18	1		3.410	60	76.63%	LCL
08/04/2016	6	14	17	18	7.832	706	176.00%	Overload
08/04/2016	7	4			3.100	269	69.66%	LCL
09/04/2016	1	3			3.526	92	79.24%	LCL
09/04/2016	2	14	17		4.551	572	102.27%	Overload
09/04/2016	3	8			2.987	329	67.12%	LCL
09/04/2016	4	11	11		6.091	278	136.87%	Overload
09/04/2016	5	14			3.772	577	84.76%	LCL
09/04/2016	6	9			0.480	171	10.79%	LCL
09/04/2016	7	22			4.428	153	99.51%	LCL
10/04/2016	1	5			3.321	405	74.63%	LCL
10/04/2016	2	9			1.480	164	33.26%	LCL
10/04/2016	3	3			4.141	138	93.06%	LCL
10/04/2016	4	14			2.624	477	58.97%	LCL
10/04/2016	5	20			2.952	337	66.34%	LCL
10/04/2016	6	14			2.132	556	47.91%	LCL
10/04/2016	7	12			0.141	342	3.16%	LCL
11/04/2016	1	3			4.387	89	98.58%	LCL
11/04/2016	2	19			4.380	228	98.43%	LCL
11/04/2016	3	18	1		1.776	108	39.91%	LCL
11/04/2016	4	14			3.116	560	70.02%	LCL
11/04/2016	5	20			4.387	326	98.58%	LCL
11/04/2016	6	11			3.320	331	74.61%	LCL
11/04/2016	7	12			0.269	164	6.04%	LCL
12/04/2016	1	3			4.264	88	95.82%	LCL
12/04/2016	2	9			1.500	163	33.71%	LCL
12/04/2016	3	14			3.854	603	86.61%	LCL
12/04/2016	4	15			1.368	116	30.74%	LCL
12/04/2016	5	6			2.665	171	59.89%	LCL
12/04/2016	6	6			3.444	183	77.39%	LCL
12/04/2016	7	20			4.018	334	90.29%	LCL
13/04/2016	1	3			4.182	96	93.98%	LCL
13/04/2016	2	14			2.993	568	67.26%	LCL
14/04/2016	1	3			4.387	83	98.58%	LCL
15/04/2016	-				-	-	0.00%	-
16/04/2016	-				-	-	0.00%	-

Date	Truck no.	Location no. 1	Location no. 2	Location no. 3	Total capacity (m3)	Total distance (km)	Truck capacity usage (%)	Type of loading
17/04/2016	1	12			0.113	170	2.53%	LCL
17/04/2016	2	20			4.428	327	99.51%	LCL
17/04/2016	3	14			4.305	519	96.74%	LCL
18/04/2016	1	7			3.100	105	69.66%	LCL
18/04/2016	2	11	11		6.211	289	139.57%	Overload
18/04/2016	3	15			1.197	149	26.90%	LCL
18/04/2016	4	19	6		3.456	196	77.66%	LCL
18/04/2016	5	3			4.428	100	99.51%	LCL
18/04/2016	6	20			4.305	327	96.74%	LCL
18/04/2016	7	14			3.075	497	69.10%	LCL
19/04/2016	1	1	15	3	5.755	260	129.33%	Overload
19/04/2016	2	18			2.408	74	54.11%	LCL
19/04/2016	3	20			3.854	335	86.61%	LCL
19/04/2016	4	11			2.560	275	57.53%	LCL
19/04/2016	5	2			4.264	153	95.82%	LCL
19/04/2016	6	14			3.444	484	77.39%	LCL
19/04/2016	7	12			0.297	171	6.67%	LCL
20/04/2016	1	6			2.310	222	51.91%	LCL
20/04/2016	2	3			4.428	92	99.51%	LCL
20/04/2016	3	13			1.891	158	42.49%	LCL
20/04/2016	4	20			3.116	311	70.02%	LCL
20/04/2016	5	14			3.567	516	80.16%	LCL
20/04/2016	6	11			2.440	310	54.83%	LCL
20/04/2016	7	15	19		3.889	218	87.40%	LCL
21/04/2016	1	15	19		3.222	218	72.40%	LCL
21/04/2016	2	2			4.428	158	99.51%	LCL
21/04/2016	3	3			4.346	86	97.66%	LCL
21/04/2016	4	12			0.325	281	7.31%	LCL
21/04/2016	5	11			1.840	349	41.35%	LCL
21/04/2016	6	14			3.116	497	70.02%	LCL
21/04/2016	7	18			2.408	87	54.11%	LCL
22/04/2016	1	3	7		7.487	146	168.25%	Overload
22/04/2016	2	1	11		3.696	302	83.06%	LCL
22/04/2016	3	14			2.747	515	61.73%	LCL
22/04/2016	4	18			1.161	67	26.09%	LCL
22/04/2016	5	15	13		1.183	504	26.58%	LCL
22/04/2016	6	20			4.387	325	98.58%	LCL
22/04/2016	7	11			3.626	270	81.48%	LCL
23/04/2016	1	19			1.835	127	41.23%	LCL
23/04/2016	2	16	5		4.715	569	105.96%	Overload
23/04/2016	3	2			4.428	156	99.51%	LCL
23/04/2016	4	11			2.920	329	65.62%	LCL
23/04/2016	5	14	16		5.330	569	119.78%	Overload
23/04/2016	6	1			2.064	127	46.38%	LCL
24/04/2016	1	20			3.977	344	89.37%	LCL
25/04/2016	1	3			4.264	92	95.82%	LCL
25/04/2016	2	11			3.360	313	75.51%	LCL
25/04/2016	3	18			1.591	101	35.75%	LCL
25/04/2016	4	14			3.075	480	69.10%	LCL
25/04/2016	5	12			0.338	216	7.59%	LCL
25/04/2016	6	11			2.762	276	62.08%	LCL
25/04/2016	7	13			0.476	350	10.70%	LCL
26/04/2016	1	18			1.118	85	25.12%	LCL
26/04/2016	2	15			0.627	200	14.09%	LCL
26/04/2016	3	3			4.428	92	99.51%	LCL
26/04/2016	4	2			4.264	150	95.82%	LCL
26/04/2016	5	11			2.600	313	58.43%	LCL
26/04/2016	6	14			3.444	553	77.39%	LCL
26/04/2016	7	8			4.176	320	93.84%	LCL
27/04/2016	1	15			0.456	150	10.25%	LCL
27/04/2016	2	3			4.346	93	97.66%	LCL
27/04/2016	3	11	11		4.200	305	94.39%	LCL
27/04/2016	4	13			0.374	335	8.40%	LCL
27/04/2016	5	20			4.387	331	98.58%	LCL
27/04/2016	6	14			2.583	545	58.04%	LCL
27/04/2016	7	5			3.444	229	77.39%	LCL
28/04/2016	1	5			2.542	235	57.12%	LCL
28/04/2016	2	11			3.360	290	75.51%	LCL
28/04/2016	3	13			0.306	356	6.88%	LCL
28/04/2016	4	11			1.943	117	43.66%	LCL
28/04/2016	5	18			2.236	86	50.25%	LCL
28/04/2016	6	14			3.526	559	79.24%	LCL
28/04/2016	7	3	9		5.266	178	118.34%	Overload
29/04/2016	1	3			4.346	90	97.66%	LCL
29/04/2016	2	18			1.548	105	34.79%	LCL
29/04/2016	3	13			0.170	360	3.82%	LCL
29/04/2016	4	14			2.624	493	58.97%	LCL
29/04/2016	5	9	11	11	9.654	488	216.95%	Overload
29/04/2016	6	5			3.034	232	68.18%	LCL
29/04/2016	7	12	1		1.925	227	43.27%	LCL
30/04/2016	1	6			0.168	206	3.78%	LCL
30/04/2016	2	14			2.419	494	54.36%	LCL
30/04/2016	3	11			3.040	335	68.31%	LCL
Total	**164**				**495.736**	**48,334**	**67.93%**	

APPENDIX C

Truck Management by Savings Method in April, 2016

Date	Truck no.	Location no. 1	Location no. 2	Location no. 3	Total capacity (m3)	Total distance (km)	Truck capacity usage (%)	Type of loading
01/04/2016	1	8	11		4.334	352	97.39%	LCL
01/04/2016	2	14	19	9	4.440	617	84.40%	LCL
01/04/2016	3	11	18	15	3.749	383	99.62%	LCL
01/04/2016	4	20			3.977	334	89.37%	LCL
02/04/2016	1	8	14		4.357	756	97.91%	LCL
02/04/2016	2	3			4.387	78	98.58%	LCL
02/04/2016	3	6			3.567	158	80.16%	LCL
02/04/2016	4	14			3.403	500	76.47%	LCL
02/04/2016	5	11			3.216	286	72.27%	LCL
02/04/2016	6	11			2.920	286	65.62%	LCL
02/04/2016	7	18			1.806	56	40.58%	LCL
03/04/2016	1	14			3.772	500	84.76%	LCL
03/04/2016	2	14			3.444	500	77.39%	LCL
03/04/2016	3	14	14		4.264	500	95.82%	LCL
04/04/2016	1	6	14		4.120	503	92.58%	LCL
04/04/2016	2	2			4.182	112	93.98%	LCL
04/04/2016	3	3			3.526	78	79.24%	LCL
04/04/2016	4	14			3.239	500	72.79%	LCL
04/04/2016	5	11			3.000	286	67.42%	LCL
04/04/2016	6	8			2.436	358	54.74%	LCL
04/04/2016	7	18			2.322	56	52.18%	LCL
05/04/2016	1	13	14		3.066	587	68.90%	LCL
05/04/2016	2	8	18		3.851	360	86.54%	LCL
05/04/2016	3	2			4.428	112	99.51%	LCL
05/04/2016	4	20			3.526	334	79.24%	LCL
05/04/2016	5	4			3.100	218	69.66%	LCL
06/04/2016	1	12	14		3.259	507	73.24%	LCL
06/04/2016	2	1	8		3.783	368	85.01%	LCL
06/04/2016	3	2			4.264	112	95.82%	LCL
06/04/2016	4	11			3.760	286	84.49%	LCL
06/04/2016	5	18			2.451	56	55.08%	LCL
07/04/2016	1	6	14	18	4.369	521	98.18%	LCL
07/04/2016	2	1	8		3.828	368	86.02%	LCL
07/04/2016	3	20			4.387	334	98.58%	LCL
07/04/2016	4	2			2.993	112	67.26%	LCL
08/04/2016	1	12	14	15	4.110	566	92.36%	LCL
08/04/2016	2	1	18		4.442	70	99.82%	LCL
08/04/2016	3	14	18		3.520	518	79.10%	LCL
08/04/2016	4	4			3.100	218	69.66%	LCL
08/04/2016	5	8			2.813	358	63.21%	LCL
08/04/2016	6	17			2.788	540	62.65%	LCL
09/04/2016	1	8	9		3.467	370	77.91%	LCL
09/04/2016	2	11	14		3.438	694	77.26%	LCL
09/04/2016	3	2			4.428	112	99.51%	LCL
09/04/2016	4	14			3.772	500	84.76%	LCL
09/04/2016	5	11			3.760	286	84.49%	LCL
09/04/2016	6	3			3.526	78	79.24%	LCL
09/04/2016	7	17			3.444	540	77.39%	LCL
10/04/2016	1	9	20		4.432	363	99.60%	LCL
10/04/2016	2	12	14		2.765	507	62.13%	LCL
10/04/2016	3	3			4.141	78	93.06%	LCL
10/04/2016	4	5			3.321	196	74.63%	LCL
10/04/2016	5	14			2.132	500	47.91%	LCL
11/04/2016	1	3			4.387	78	98.58%	LCL
11/04/2016	2	20			4.387	334	98.58%	LCL
11/04/2016	3	19			4.380	250	98.43%	LCL
11/04/2016	4	12	14	18	4.417	525	99.25%	LCL
11/04/2016	5	1	11		4.064	295	91.33%	LCL
12/04/2016	1	3			4.264	78	95.82%	LCL
12/04/2016	2	20			4.018	334	90.29%	LCL
12/04/2016	3	6	9		4.165	292	93.60%	LCL
12/04/2016	4	14			3.854	500	86.61%	LCL
12/04/2016	5	6			3.444	158	77.39%	LCL
12/04/2016	6	15			1.368	100	30.74%	LCL
13/04/2016	1	3			4.182	78	93.98%	LCL
13/04/2016	2	14			2.993	500	67.26%	LCL
14/04/2016	1	3			4.387	78	98.58%	LCL
15/04/2016	-				-	-	0.00%	-
16/04/2016	-				-	-	0.00%	-

Date	Truck no.	Location no. 1	Location no. 2	Location no. 3	Total capacity (m3)	Total distance (km)	Truck capacity usage (%)	Type of loading
17/04/2016	1	12	14		4.418	507	99.27%	LCL
17/04/2016	2	20			4.428	334	99.51%	LCL
18/04/2016	1	3			4.428	78	99.51%	LCL
18/04/2016	2	20			4.305	334	96.74%	LCL
18/04/2016	3	6	14		3.257	503	73.19%	LCL
18/04/2016	4	7	15		4.297	107	96.56%	LCL
18/04/2016	5	11			3.880	286	87.19%	LCL
18/04/2016	6	9			3.274	250	73.57%	LCL
18/04/2016	7	11			2.331	286	52.38%	LCL
19/04/2016	1	2			4.264	112	95.82%	LCL
19/04/2016	2	12	14	15	4.140	566	93.03%	LCL
19/04/2016	3	3			3.100	78	69.66%	LCL
19/04/2016	4	11			2.560	286	57.53%	LCL
19/04/2016	5	18			2.408	56	54.11%	LCL
19/04/2016	6	20			3.854	334	86.61%	LCL
19/04/2016	7	1			2.256	52	50.70%	LCL
20/04/2016	1	3			4.428	78	99.51%	LCL
20/04/2016	2	13	15		2.575	213	57.87%	LCL
20/04/2016	3	14			3.567	500	80.16%	LCL
20/04/2016	4	19			3.205	250	72.03%	LCL
20/04/2016	5	20			3.116	334	70.02%	LCL
20/04/2016	6	11			2.440	286	54.83%	LCL
20/04/2016	7	6			2.310	158	51.91%	LCL
21/04/2016	1	11	19		4.207	412	94.54%	LCL
21/04/2016	2	12	14	15	4.296	566	96.54%	LCL
21/04/2016	3	2			4.428	112	99.51%	LCL
21/04/2016	4	3			4.346	78	97.66%	LCL
21/04/2016	5	18			2.408	56	54.11%	LCL
22/04/2016	1	13	14	15	3.930	580	88.31%	LCL
22/04/2016	2	11	18		2.841	287	63.84%	LCL
22/04/2016	3	3			4.387	78	98.58%	LCL
22/04/2016	4	20			4.387	334	98.58%	LCL
22/04/2016	5	11			3.626	286	81.48%	LCL
22/04/2016	6	7			3.100	88	69.66%	LCL
22/04/2016	7	1			2.016	52	45.30%	LCL
23/04/2016	1	16	19		4.049	543	90.98%	LCL
23/04/2016	2	11	16		4.314	662	96.94%	LCL
23/04/2016	3	2			4.428	112	99.51%	LCL
23/04/2016	4	5			3.321	196	74.63%	LCL
23/04/2016	5	14			3.116	500	70.02%	LCL
23/04/2016	6	1			2.064	52	46.38%	LCL
24/04/2016	1	20			3.977	334	89.37%	LCL
25/04/2016	1	13	14	12	3.889	528	87.39%	LCL
25/04/2016	2	11	18		4.353	287	97.83%	LCL
25/04/2016	3	3			4.264	78	95.82%	LCL
25/04/2016	4	11			3.360	286	75.51%	LCL
26/04/2016	1	3			4.428	78	99.51%	LCL
26/04/2016	2	2			4.264	112	95.82%	LCL
26/04/2016	3	8			4.176	358	93.84%	LCL
26/04/2016	4	11	18		3.718	287	83.55%	LCL
26/04/2016	5	14	15		4.071	559	91.48%	LCL
27/04/2016	1	20			4.387	334	98.58%	LCL
27/04/2016	2	3			4.346	78	97.66%	LCL
27/04/2016	3	13	14	15	3.413	580	76.70%	LCL
27/04/2016	4	5			3.444	196	77.39%	LCL
27/04/2016	5	11	11		4.200	296	94.39%	LCL
28/04/2016	1	9	11		4.280	308	96.18%	LCL
28/04/2016	2	13	14		3.832	521	86.11%	LCL
28/04/2016	3	11	18		4.179	287	93.91%	LCL
28/04/2016	4	5			2.542	196	57.12%	LCL
28/04/2016	5	3			4.346	78	97.66%	LCL
29/04/2016	1	3			4.346	78	97.66%	LCL
29/04/2016	2	13	14	12	2.919	528	65.60%	LCL
29/04/2016	3	1	18		3.348	70	75.24%	LCL
29/04/2016	4	11			3.360	286	75.51%	LCL
29/04/2016	5	11			3.194	286	71.78%	LCL
29/04/2016	6	9			3.100	182	69.66%	LCL
29/04/2016	7	5			3.034	196	68.18%	LCL
30/04/2016	1	6	14		2.587	503	58.13%	LCL
30/04/2016	2	11			3.040	286	68.31%	LCL
Total	**137**				**495.736**	**40,746**	**81.31%**	