

IMPROVEMENT FOR HUMAN SPECIMEN SHIPMENT



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Thesis
entitled
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ABSTRACT

Analysing human specimens is necessary for doctors to diagnose their patients. In Thailand, to analyse the human specimens that are delivered to the Public Health Office requires some expensive medical appliances. Hence, they decided to deliver those human specimens to outer laboratories. The process of delivery sends their transport vehicle to take the human specimens from the Public Health Office to the dispersed outer laboratories. Because there is no standard criterion for the routes, it causes costly expenses and deferring time. In this study, the researcher showed an improved shipment for delivery of some human specimens using the Quick Solution Method, the simple method, and the Mathematical Model. By using the Traveling Salesman Problem to develop delivering system, the results showed both the Quick Solution Method and the Mathematical Model could discover five routes. The Quick Solution Method could reduce 39.09% of expenses and the Mathematical Model shorten the travel time by 39.54%, respectively. From the results, the Mathematical Model is the most suitable method to reduce costly expenses due to its method of ascertaining the best solution and augmenting the frequency of travel by adjusting the traveling time.

KEY WORDS: HUMAN SPECIMEN / MATHEMATICAL MODEL / TRAVELING
SALESMAN PROBLEM

86 pages

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บทคัดย่อ

ในการตรวจวิเคราะห์สิ่งส่งตรวจของหน่วยงานสาธารณสุขในประเทศไทยมีความจำเป็นในการวินิจฉัยโรคให้กับผู้ป่วย ซึ่งต้องใช้เครื่องมือในการตรวจสอบที่มีราคาแพง ดังนั้นเพื่อลดข้อจำกัดในด้านค่าใช้จ่าย จึงได้นำสิ่งส่งตรวจส่งให้กับห้องปฏิบัติการภายนอกเป็นจำนวนมาก จึงต้องมีการบริการของห้องปฏิบัติการ โดยการจัดรถเข้ามารับสิ่งส่งตรวจตามหน่วยงานสาธารณสุข ซึ่งมีหน่วยงานเป็นจำนวนมากและกระจายทั่วไป ซึ่งไม่มีเกณฑ์ในการจัดเส้นทางเข้าไปรับสิ่งส่งตรวจได้อย่างชัดเจนซึ่งก่อให้เกิดค่าใช้จ่ายที่สูง และใช้ระยะเวลาในการเดินทางมากเกินไปจนก่อให้เกิดความล่าช้าในการส่งผลตรวจวิเคราะห์ให้กับหน่วยงาน โดยทางผู้วิจัยได้เสนอแนวทางในการปรับปรุงการจัดรับสิ่งส่งตรวจโดยวิธี quick solution ซึ่งเป็นวิธีอย่างง่าย และตัวแบบทางคณิตศาสตร์ (Mathematical model) โดยเป็นตัวแทนของปัญหาการจัดเส้นทางสำหรับพนักงาน (Traveling Salesman Problem) ใช้ในการปรับปรุงระบบ ซึ่งผลจากการจัดเส้นทางด้วยวิธี quick solution method และตัวแบบทางคณิตศาสตร์สามารถจัดเส้นทางได้ 5 เส้นทาง และสามารถลดค่าใช้จ่ายได้ 39.09% และ 39.54% ตามลำดับ ซึ่งการวิเคราะห์ด้วยวิธีตัวแบบทางคณิตศาสตร์ประหยัดค่าใช้จ่ายได้มากกว่าเนื่องจากสามารถหาคำตอบได้ดีที่สุด โดยสามารถปรับระยะเวลาในการเดินทางเพื่อเพิ่มจำนวนรอบในการเดินทางได้ถูกต้อง

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CHAPTER I

INTRODUCTION

This chapter presents the background and problem statement on the importance of specimen transportation. In addition, the objectives and scope of work will be discussed.

1.1 Background and problem statement

In the current medical diagnosis and treatment, specimen testing has been widely used in discovering abnormality and diseases in humans. Normally, it brings specimens from patients' body and test with high technology equipment. The outcomes would be interpreted by expertise and brought back to the patients. It is found that a number of users has grown through years as shown in the figure 1.1. However, costs for messengers, chemicals, and equipments for the tests are still high; thus, many hospitals and clinics have an alternative process to send the specimen to outside laboratory in order to reduce such expenses.

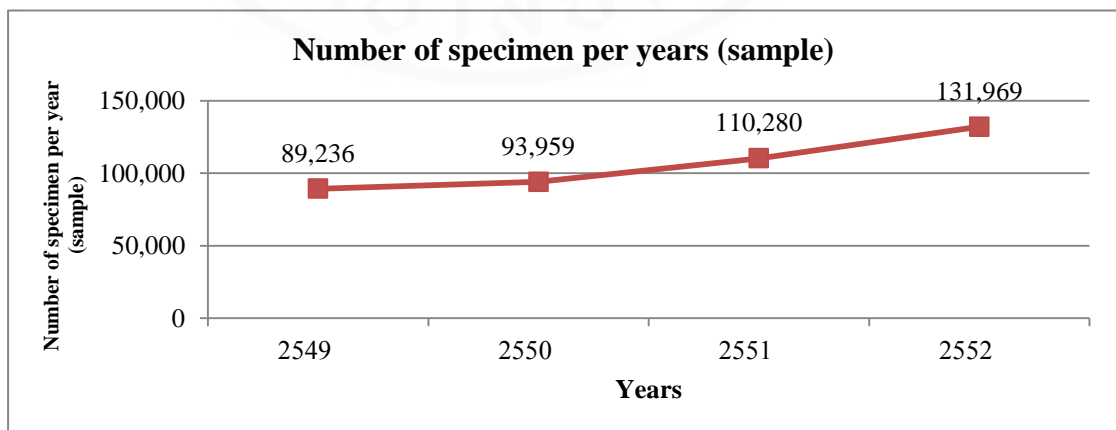


Figure 1.1 Number of specimen per years

Consigning to an external laboratory operating the specimen testing significantly eliminates the limitation of staffs specializing in the diagnosis and medical device investment resulting in not less than 200 hospitals consigning specimen testing to external laboratories. Specimen transportation is escorted by the staffs receiving the specimen from each hospital and prevent specimen. There are about to 20 routes which are available for not less than 10 hospitals on each route and be able to submit the analysis results to those hospitals as shown in Figure 1.2

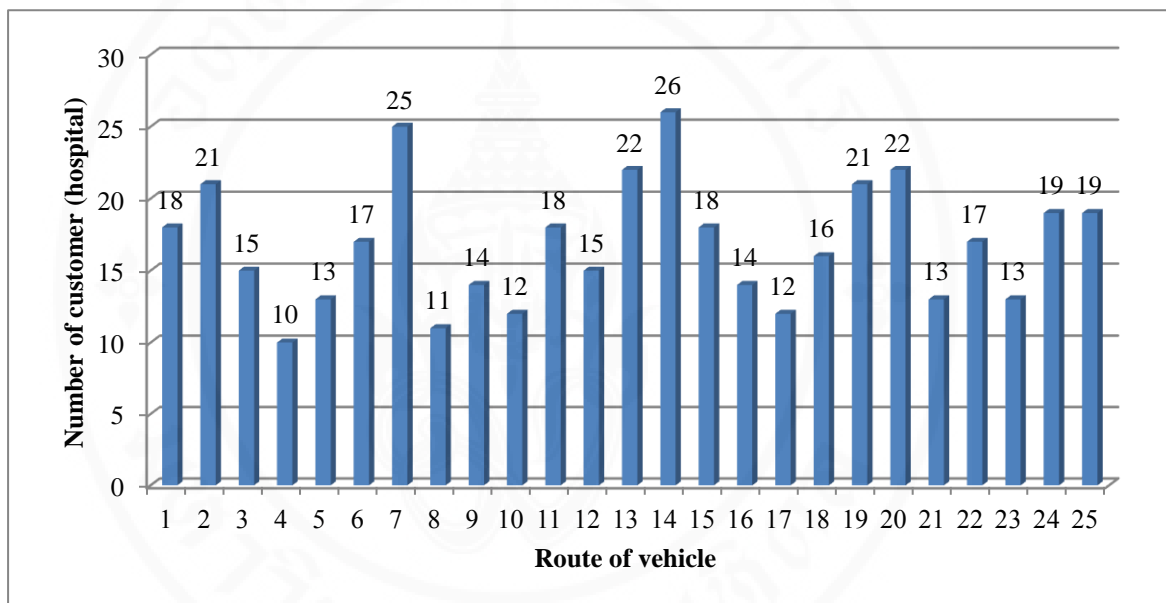


Figure 1.2 A number of customers per each route

The differences between the specimen transportation and general of transport are the periods of time, specimen's shape stability control, specific groups of customer and the transport amounts of specimen. The periods of time which has been taken, submitting the analysis results in well-timed condition, specimen storage controlling proper temperature in packaging supplies require different controls to each other due to the types of specimen. Some specific group of customer (hospitals) are considerably surveyed and reviewed the demands on service before taking any specimen to analyze and submit analysis results. Some hospital has a daily demand on service or even some of them have no specimen for analysis at all. Thus, a certain volume of specimens from any transportation cannot be estimated. More of the time that wasted, more of the delay or even the costs of gas for transportation. Resulting in

significantly increasing in an expense of transportation management comparing with the number of specimens from each available route and eventually end up a loss condition. The efficient management for specimen transportation definitely results in cost saving.

The cost of transportation reduction is planned for increase routing efficiency. The routing problem in transportation is allocated resources, planning the route by considering the needs of the customer and target location. The routing problem has many transits: transportation of food, transportation of goods to customers or distribution center, transportation of personnel. As well as in case studies of this thesis: the transportation of specimens. Each categories of transportation are the purpose of the study and improvement as well as reduced cost of transportation but there are different conditions sometime conditions restricting the travel time, limitation the transportation capacity of the vehicle or limit the resources used in shipping. And find the optimal solution of the routing transportation routes is based on the above criteria.

At present, each company has no tool for planning the service. Therefore, the planner needs to find the optimal route of each vehicle so it is difficult to manage when large problems have found. Some real problems are infeasible that means it is impossible to perform the transportation planning to satisfy all restriction. Thus, finding a solution that does not exist and waste of time. However, the mathematical model formulation can help the company plan the service more easily. The optimal route to provide the service can be found. Moreover, mathematical models can determine whether the service is practical.

Therefore, the research suggests how to efficiently improve a specimen transportation management which are described and studied on route systematization for cost saving of the transportation via mathematic model.

1.2 Objectives

In this thesis have two main objectives is following

1.2.1 Formulate a basic mathematical model to find an optimal solution route that cover all customers' places and minimize the travel distance of central laboratory which consider the vehicle and time limitation.

1.2.2 We compare the total travel distance of the optimal solution obtained by applying model to the real data with the central laboratory plan.

1.3 Scope of work

From the transport processes of specimens, this paper studied specimen transferring procedures from healthcare units to laboratory centers in order to develop the most appropriate routing and minimize transferring costs by mathematic model and heuristic method as shown in Figure 1.3.

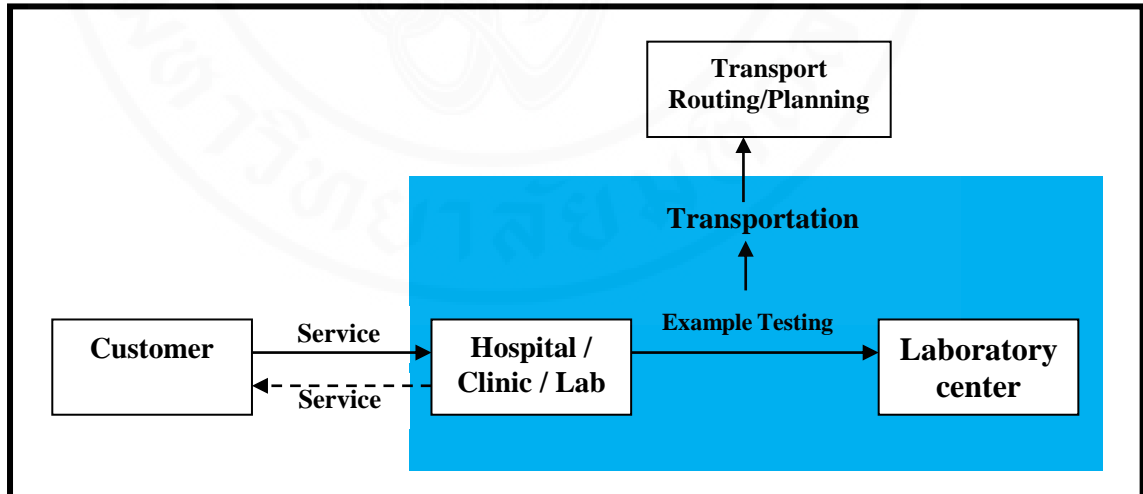


Figure 1.3 Scope of work

CHAPTER II

BACKGROUND THEORY AND LITERATURE REVIEW

In this thesis aim to study an application of Traveling Salesman Problem (TSP) for transportation specimens service, we need to know the theoretical and relation of work about to vehicle routing problem of transportation specimens service. Thus, this chapter will show briefly discussion about background theory and literature review for this research.

2.1 Background theory

This section will discuss on the background theory of this research which contains 3 main subsections as following: process of specimen transportation, mathematical model in Assignment problem Traveling salesman problem and vehicle routing problem (VRP).

2.1.1 Process of specimen transportation

In this section, process of specimen transportation mode will be discussed. Process of specimen transportation has three processes: pickup specimens by vehicles, diagnosis of specimen and informing result. Firstly, pickup specimen by vehicle will be discussed. Then diagnosis of specimen will be discussed. Finally, informing result will be discussed.

2.1.1.1 Pickup specimens by vehicles

Since the company send vehicles to pickup specimens each customer' places for providing service. Every vehicle must start at the company, visit the customer's places and pickup specimens and return to the company after finishing the whole service. For each vehicle, will be assigned to the pickup specimens at customer's places. Each customer's places is in the route specified. The travel time

along the route to get up to 3 hours without taking into account the carrying capacity of vehicle.

2.1.1.2 Analysis of specimens

After for pickup specimens, passenger bring specimens to the company by vehicle, staff will install a barcode registration and screening process checking the customer need analyze specimens by machine or chemical and approve informing result before send back to customer by doctor and scientist. This process is following diagram as shown in figure 2.1

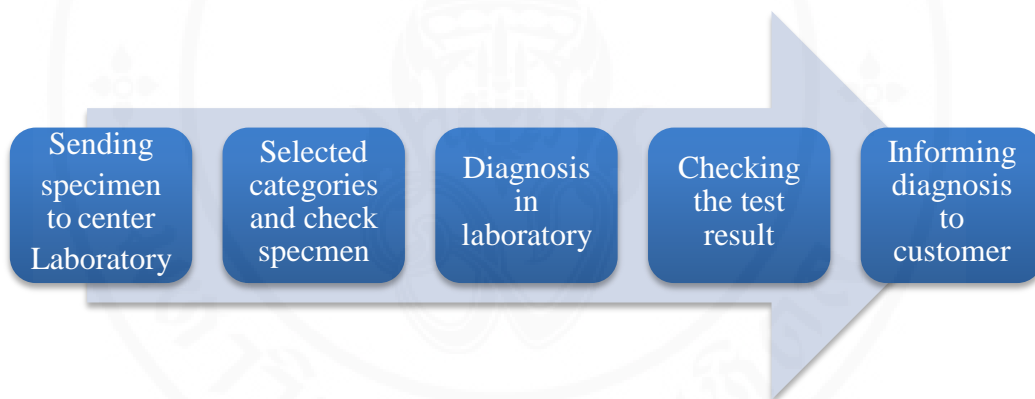


Figure 2.1 Process flow in internal company

Type of diagnosis specimens testing are seven type: Immunology , Chemical , CBC , Culture , Pathology and Toxicology consequently. Firstly, Immunology and chemical testing used serum extracted from blood to analyst by automate machines and take in the examination no more than 3 minutes. Then, complete blood count (CBC) is checking the completeness of the blood. Then, culture and pathology testing cut the tissue from the internal organ of human to the culture. Identify any abnormality of the body. The tissue can be collected and preserved by a solution to the maintenance of the tissue. So, it cans long-term storage of approximately 1 - 2 months. Finally, Toxicology testing is diagnosis of toxins in the human body. Type of diagnosis specimen testing is shown in table 2.1

Table 2.1 Detail of the examination specimen in a different category

| Testing | Process | | | Resource | | | Period | Time of expired |
|------------|---------------------------------|------------------|-----------|----------|------------|--------|--------|----------------------|
| | Registration prepare | Laboratory | Approve | Automate | Analytical | Manual | | |
| Serum | Immunology Chemical Total | 50 min – 1.5 hr. | 2 – 3 min | √ | | | High* | 24 hours |
| | | 30 – 60 min | 2 – 3 min | √ | | | | 24 hours |
| | | 0.5 – 1.5 hr. | 2 – 3 min | | | | | |
| CBC | | 3 min – 1 hr. | 2 – 3 min | √ | | √ | High | 24 hours |
| | | 0.5 – 1 hr. | 2 – 3 min | √ | | √ | | 24 hours |
| | | 0.5 – 1 hr. | 2 – 3 min | | | √ | √ | High |
| Urine | | 2 – 4 days | 2 – 3 min | | | √ | High | 24 hours |
| | | 3 – 4 days | 5 min | | | | √ | Storage to long time |
| Stool | | 2 days – 1 month | 2 – 3 min | | | √ | Low* | Storage to long time |
| | | | | | | | | |
| Culture | | | | | | | | |
| | | | | | | | | |
| Pathology | | | | | | | | |
| | | | | | | | | |
| Toxicology | | | | | | | | |
| | | | | | | | | |

2.1.1.3 Informing result

Results of diagnosis specimens send to customers two type: send result of diagnosis specimen using by vehicles for customer near center laboratory and send by post, e-mail or fax for customer far from center laboratory.

2.1.2 Mathematical model in transportation planning process

The transportation planning problem is classified by problem description: propose, objective, constraint, and assumption. It is consisted of Assignment problem, Traveling salesman problem (TSP) and Vehicle Routing problem (VRP) as the following.

2.1.2.1 The Assignment problem

The assignment problem is the problem with assigns each agent to the task. The associated cost of assigning agent i to perform task j is c_{ij} . It is required to perform all tasks by assigning exactly one agent to each task in such a way that the total cost of assignment is minimized. The mathematical model of the assignment problem with n agents and n tasks can be written as the following[1]

$$\text{Min.} \quad \sum_{i=1}^n \sum_{j=1}^n c_{ij} w_{ij} \quad (2.1)$$

$$\text{S.T.} \quad \sum_{i=1}^n w_{ij} = 1 \quad \text{for } j = 1, 2, 3, \dots, n \quad (2.2)$$

$$\sum_{j=1}^n w_{ij} = 1 \quad \text{for } i = 1, 2, 3, \dots, n \quad (2.3)$$

$$w_{ij} = \{0, 1\} \quad \text{for } i, j = 1, 2, 3, \dots, n \quad (2.4)$$

$$\text{where} \quad w_{ij} = \begin{cases} 1 & \text{if agent } i \text{ perform task } j \\ 0 & \text{otherwise} \end{cases} \quad \text{for } i, j = 1, 2, 3, \dots, n$$

The objective function (2.1) is total cost of assignment all agents to service all tasks. Constraint (2.2) each task has to performed by exactly one agent. Similarly, the assumption each agent can be perform only one task is written as Constraint (2.3). The decision variable values w_{ij} are possible value by Constraint (2.4).

2.1.2.2 The Traveling Salesman Problem (TSP)

The traveling salesman problem is special case of the assignment problem. Instead of assigning an agent to perform a task, the next city to travel is assigned to the present city. A salesman has to visit a prescribed set of cities and return to original location in such a way that the total traveling distance is minimized and each city is visit exactly once. The sequence of cities traveled by salesman can be named as the route. The traveling salesman problem is also called a combinatorial mathematical programming.

Let a_{ij} be the distance from City i to City j

$$z_{ij} = \begin{cases} 1 & \text{if the traveling route includes the path from City } i \text{ to City } j \\ 0 & \text{orthervise} \end{cases} \quad \text{for } i, j = 1, 2, 3, \dots, n$$

Then the travelling salesman problem can be formulated is following

$$\text{Min} \quad \sum_{i=1}^n \sum_{j=1}^n a_{ij} z_{ij} \quad (2.5)$$

$$\text{S.T.} \quad \sum_{i=1}^n z_{ij} = 1 \quad \text{for } j = 1, 2, 3, \dots, n \quad (2.6)$$

$$\sum_{j=1}^n z_{ij} = 1 \quad \text{for } i = 1, 2, 3, \dots, n \quad (2.7)$$

$$u_i - u_j + n z_{ij} \leq n - 1 \quad \text{for } i, j = 1, 2, 3, \dots, n \quad (2.8)$$

$$z_{ij} = \{0, 1\} \quad \text{for } i, j = 1, 2, 3, \dots, n \quad (2.9)$$

$$u_i \geq 0 \quad \text{for } i, j = 1, 2, 3, \dots, n \quad (2.10)$$

The objective function (2.5) aim to minimize total distance travel of salesman in the route that passes all cities. Constraints (2.6) and (2.7) are similarity, assure that the salesman has visit and leave each city. Without constraint of assignment problem in (2.1.2.1) is Constraint (2.8) is no subtour because only one tour visit all city as desired [2]. Constraint (2.9) and (2.10) are values of the decision variables.

2.1.2.3 The Vehicle Routing Problem (VRP)

The vehicle routing problem (VRP) is the generalized case of the traveling salesman problem and a combinatorial optimization and integer programming problem seeking to service a number of customers with a fleet of vehicles. Proposed by Dantzig and Ramser [3] in 1959, VRP is an important problem in the fields of transportation, distribution and logistics. Often the context is that of delivering goods located at a central depot to customers who have placed orders for such goods. Implicit is the goal of minimizing the cost of distributing the goods. Many methods have been developed for searching for good solutions to the problem, but for all but the smallest problems, finding global minimum for the cost function is computationally complex. The symbol used to the vehicle routing problem can be writing as the following.

Graph $G(V,A)$ is the depot, customers are their corresponding road network.

V is the set of depot and customers.

A is the set of edge (road network) corresponding to V .

Node o is the center or depot.

n is number of customers to visited.

d_{ij} is the demand of Node i .

b_{ij} is the cost associated to arc (i, j) .

C is the capacity of vehicle.

K is the number of tours which is known value.

Assume that each customer node is visited once and its demand does not exceed the vehicle capacity. Therefore, the mathematical model for vehicle routing problem is formulated as the following [4].

$$\text{Min} \quad \sum_{i \in V} \sum_{j \in V} b_{ij} y_{ij} \quad (2.11)$$

$$\text{S.T.} \quad \sum_{i \in V} y_{ij} = 1 \quad \text{for } j \in V - \{o\} \quad (2.12)$$

$$\sum_{j \in V} y_{ij} = 1 \quad \text{for } i \in V - \{o\} \quad (2.13)$$

$$\sum_{i \in V} y_{io} = K \quad (2.14)$$

$$\sum_{j \in V} y_{oj} = K \quad (2.15)$$

$$u_i - u_j + Cy_{ij} \leq C - d_i \quad \text{for } i, j \in V - \{o\}, i \neq j \quad (2.16)$$

$$d_i \leq u_i \leq C \quad \text{for } i \in V - \{o\} \quad (2.17)$$

$$y_{ij} \in \{0,1\} \quad \text{for } i, j \in V \quad (2.18)$$

Where
$$y_{ij} = \begin{cases} 1 & \text{if Node } j \text{ visited immediately after Node } i \\ 0 & \text{Otherwise for } i, j \in V \end{cases}$$

From above mathematic model, the objective function (2.11) purposes to find the minimize total cost of the transportation. Constraints (2.12) and (2.13) tell that each customer node must be arrived and departed exactly once. Then, the depot has to be arrived and departed K times since there are K tours as in constraint (2.14) and (2.15). Subtour are eliminated by Constraint (2.16) and (2.17). The decision variables are restricted to binary values as in Constraint (2.18). This model is the classical vehicle routing problem with the known as the capacitated vehicle routing problem.

2.1.2.4 Vehicle Routing Problem with Time Windows (VRPTW)

The VRPTW is the same problem that VRP with the additional restriction that in VRPTW a time window is associated with each customer $v \in V$, defining an interval $\{e_v, l_v\}$ wherein the customer has to be supplied. The interval $\{e_o, l_o\}$ at the depot is called the scheduling horizon. Here is a formal description of the problem:

The objective is to minimize the vehicle fleet and the sum of travel time and waiting time needed to supply all customers in their required hours.

The VRPTW is, regarding to VRP, characterized by the following additional restrictions:

A solution becomes infeasible if a customer is supplied after the upper bound of its time window.

A vehicle arriving before the lower limit of the time window causes additional waiting time on the route.

Each route must start and end within the time window associated with the depot.

In the case of soft time windows, a later service does not affect the feasibility of the solution, but is penalized by adding a value to the objective function[5].

2.2 Literature review

This section will discuss on mathematical literature review which corresponding to background theory.

2.2.1 Assignment Problem

The assignment problem is widely used to apply in many problem such as the workforce scheduling [6,7,8,9]. Pastor and Olivella [6] have studied weekly work schedules with working time account. In this problem, they have decided the capacity of employees that meets the level of services and minimized the shortages. In the healthcare service, the nurse scheduling to one of the application of assignment problems which each nurse is assigned to the task specific period [8]. A heuristic approach has been used to improve the nurse training scheduling by Nooriafhar[9]. Applied assignment model to the airport gate by Yan et al. [10]. The university course timetable has been studies by Dimopoulou and Miliotis [11] in order to develop the automate timetable construction system by assigning each course to specific time period.

2.2.2 Traveling Salesman Problem (TSP)

The traveling salesman problem was first formulated 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 heuristic and exact methods are known, so that some instances with tens of thousands of cities can be solved [12].

The traveling salesman problem can be considered as a special case of the vehicle routing problem that uses one vehicle visiting all customers in one tour. Traveling salesman problem is classified as a combinatorial optimization problem because it has a large number feasible solution. Many methods are developed in to find the feasible solutions of traveling salesman problem. Hernandez-Perez [13] have used the branch-and-cut method to solve the traveling salesman problem with pickup and delivery. Cordeau et al. [14] is adding the first-in-first-out policy to solve branch-and-cut method in traveling salesman problem with pickup and delivery.

NP-hard problem is a traveling salesman problem, to find an optimal solution in large problem with is very hard. A heuristic algorithm is popular method used to solve optimization problem so it to find a solution by improving an initial feasible solution. Kahng and Reda [15] have presented heuristic method for construction a tour of traveling salesman problem and Hassin and Keinan [16] have presented greedy heuristic method. And another type heuristic method, genetic algorithm, can use to solve traveling salesman problem[17]. An ant colony optimization, can be use solve the traveling salesman problem. Cheng and Mao [18] have use ant colony optimization and applied to solving the traveling salesman problem with time windows. A special heuristic method called tabu serch has been applied in the problem to find some near-optimal solution by Gendreau et al [19] and neuron network is one a solution method to solve the traveling salesman problem, Jolia and Ghanbari [20] used the Hopfield neuron network technique to solve this problem.

Traveling Salesman problem (TSP) is a problem used for find shortest possible route that visit all customers in one tour. In 2009, Masutti and Castro [21] recommended Real-Valued Antibody Networks designed to solve TSP (RABNET-TSP). The objective of RABNET is to position on network cell on top of each city of the TSP. The paper compared computing time between RABNET and other neural networks and show that computing time of RABNET is the best compared with previous works. In 2012, Roemer, et al. [22] used two-phase method and Liao, et al. [23] used Particle Swarm Optimization (PSO) to solve large TSP problem was used. In real world, these researchers added some constraints or modified to be the problem

suitable for circumstance. Form of Traveling Salesman problem can conclude as following.

First, asymmetric traveling salesman problem (ATSP) is TSP which determines distance from origin to customer and distance from customer to origin did not equal. In 2011, Chen, et al. [24] presented an Improved Extremal Optimization (IEO) for solving the problem. IEO can reduce computation time and their results closed to optimal solutions. In 2012, Nagata and Soler [25] proposed a new competitive genetic algorithm to solve this problem. This algorithm had been verified on a set of 153 examples with known optimal solution and it is the best another heuristic methods. In 2014, LaRusic and Punnen [26] considered the asymmetric bottleneck traveling salesman problem on a complete graph on n node. They can find 270 optimal solutions from 331 problem testes.

Second, traveling salesman problem with time windows (TSPTW) is the problem with additional conditions to determine period of vehicle traveling time. In 2010, Lopez-Ibanez and Blum [27] carried out experiment to study the contribution of each component of Beam-ACO which is a metaheuristic approach to tackle hard combination optimization problem. Beam-ACO is the best another method from literature review in reducing computation time in finding optimal solution. In the same year, Silva and Urrutia [28] presented a General Variable Neighborhood Search (GVNS), which find distant neighborhoods of the current incumbent solution. As a result, this method can reduce significantly the computation time and developing some best known results. In 2012, Mladenovic, et al. [29] proposed new GVNS for solving TSPTW. From the result, their GVNS is faster than previous than GVNS by testing 14 out of 25 best known solutions for large test examples.

Third, one commodity pickup-and-deliver problem find a shortest route to receive and send a product. In 2009, Hernandez-Perez, et al. [30] found a minimum cost Hamiltonian path which is a path in an undirected or directed graph that visits each vertex exactly once, with hybrid algorithm that combined between Greedy Randomized Adaptive Search Procedure (GRASP) and Variable Neighborhood Descent (VND) metaheuristics. Next, Zhao, et al. [31] proposed genetic algorithm for this problem. The algorithm can compute solution with up to 500 nodes. In the same year, Erdogan, et al. [32] compared between a probabilistic tabu search algorithm and

an iterated local search algorithm for solving the problem which is executed in a first-in-first-out fashion. This paper suggested a probabilistic tabu search. In 2010, Cordeau, et al. [33] proposed a branch-and-cut algorithm for a variant of the TSP problem. The algorithm can solve some examples with up to 50 nodes in acceptable computing time. In 2012, researchers [34, 35] recommended a variable neighborhood search approach for solving the TSP problem. The number of customers in [35], which find solution of all benchmark examples, is 100 customers, but Cheang, et al [34] extended the TSP and last-in-first-out loading by adding some conditions which determine many vehicles and limit traveling of vehicle distance. Then, Casazza, et al [36] increased the number of interesting products from a product and recommend Alternating Routing-Loading algorithm to solve the problem. Then, Erdogan, et al. [37] modified the TSP problem with adding handling cost in sub problem. In this paper, they recommend tabu search from comparing between tabu search, iterated tabu search, and iterated local search.

Next, probabilistic traveling salesman problem with deadlines (PTSPD) is an extension of the well-known TSP problem in which, in addition to stochastic presence, customers must also be visited before a known deadline. Campbell and Thomas [38] compared between local-search method and 1-shift neighborhood with PTSPD. Local-search can solve the problem with spending the least computing time compared with another method.

Finally, prize collecting traveling salesman problem means that a salesman collects a prize for each stopped by town and pays penalty for each non-stopped by town. The objective of the problem is to minimize sum of income and expense. Pedro and Saldanba [39] used tabu search approach for solving the Prize Collecting problem. The efficiency of this approach had developed upper bounds of the considered examples. From literature review Traveling Salesman Problem (TSP) are classified objective, methodology, constrain as showed Table 2.2.

Table 2.2 Summary of methods used to solve Traveling Salesman Problem.

| No. | First author | Year | Objective | Problem size | | | Method | Application |
|-----|-----------------------|------|-------------------------------------|--------------|-------|---------|---|----------------------------------|
| | | | | Node | Depot | Vehicle | | |
| 1 | Zhao, et al. | 2009 | Minimize total cost | 500 | 1 | >1 | Genetic algorithm | Pickup and delivery good |
| 2 | Erdogan, et al. | 2009 | Minimize total distance | 101 | 1 | >1 | Probabilistic Tabu search and Iterated Local Search | truckload transportation |
| 3 | Cordeau, et al. | 2010 | Minimize total cost | 50 | 1 | >1 | Branch and Cut | Employee transportation |
| 4 | Lopez-Ibanez and Blum | 2010 | Minimize total distance | 250 | 1 | >1 | Beam-ACO Algorithm and adding time constraint | Food frozen transportation |
| 5 | Silva and Urrutia | 2010 | Minimize total distance | 550 | 1 | >1 | General Variable Neighborhood search and adding time constraint | Fuel transportation |
| 6 | Cheang, et al. | 2012 | Minimize total vehicle and distance | 90 | 1 | >1 | Simulated Annealing and Ejecting Pool Variable Neighborhood Search and Probabilistic Tabu Search | Urban courier service operations |
| 7 | Erdogan, et al. | 2012 | Minimize total distance and cost | 101 | 1 | >1 | Tabu Search, Iterated Local Search, Iterated Tabu Search, and adding pickups, deliveries, and handing costs | Truckload transportation |

2.2.3 Vehicle Routing Problem (VRP)

The vehicle routing problem (VRP) is a combinatorial optimization and integer programming problem seeking to service a number of customers with a fleet of vehicles. Proposed by Dantzig and Ramser in 1960, vehicle routing problem is an important problem in the field transportation, distribution and logistics. Often the context is that of delivering goods located at the central depot to customers who have places for such goods. The goal of vehicle routing problem can be maximizing the profit of the routing plan or minimizing the total cost, the total travel time, the total traveling distance. Most restrictions of the vehicle routing problem are vehicle capacity, customer demand, traveling distance and with time windows. Jozefowicz et al [40] have reviewed research about the vehicle routing problem. They have also compared the problem characteristics, solution method, objective function and restrictions of work in the vehicle routing problem.

The type of vehicle routing problem with time window (VRPTW) will be focus. In general, the depot and the customer are always companies, factory, shop, supermarket or store are certain time to open and close, or working time. As a result, there is available time for visiting these customer's places with the called time windows. Many methods are proposed to solve this kind of problem. Exact methods such as branch-and-bound, branch-and-cut and cutting plane are classical methods for solving an integer programming. Moreover, heuristic methods are widely used to solve the vehicle routing problem with time windows. Hadjar and Soumis [41] have considered the case of multiple depots. In this problem, the vehicles do not depart from the same place because there are many depots. Thus, the vehicles are able to start working at any depots. To solve this problem, they have applied the branch-and-price approach.

The classical vehicle routing problem assumes that the number of vehicles is unlimited. Lau et al. [42] have focused on the vehicle routing problem with time windows and a limited number of vehicles. The extension of this problem to the balanced vehicle load has been studied by Kritikos and Ioannou [43]. They have determined the optimal routes of vehicles that satisfy vehicle capacity, service time and time windows in order to balance the load carried by each vehicle. Sometimes visiting the customers late is able to provide services but it may have extra costs.

Therefore, the time windows can be violated by adding more cost. This situation is known as soft time windows. Calvete et al. have studied the vehicle routing problem with soft time windows by applying a goal programming approach to model and a heuristic method to solve it [44].

Moreover, there are various extensions to the vehicle routing problem. The loading cost which is often considered as a constant in the classical vehicle routing problem is regarded in the work of Tang et al. [45]. Their objective function is a combination of the cost of traveling per unit-distance, the cost of delivering the product per unit-weight and the fixed cost. The scatter search method has been adjusted for solving the benchmark instances. Fallahi et al. [46] have considered the problem that each customer may order several products and the vehicles have several compartments which each of them is used for only one product. One vehicle can deliver the entire demand of one product to every customer. However, the delivery of many products may require several vehicles. Two algorithms, a memetic algorithm which is a hybrid of the genetic algorithm and a tabu search method, are used to solve this problem.

Hoong Chuin Lau et al. [47] introduce a variant of the vehicle routing problem with time windows where a limited number of vehicles is given (m-VRPTW). Under this scenario, a feasible solution is one that may contain either unserved customers and/or relaxed time windows. To solve the problem, they propose a tabu search approach characterized by a holding list and a mechanism to force dense packing within a route. They also allow time windows to be relaxed by introducing the notion of penalty for lateness. In our approach, customer jobs are inserted based on a hierarchical objective function that captures multiple objectives. On m-VRPTW instances, experiments show that our approach produces solutions that are very close to computed upper bounds. Moreover, as the number of vehicles decreases, the routes become more densely packed monotonically. This shows that our approach is good from both the optimality as well as stability point of view.

Kyung Hwan Kang et al [48] studies the vehicle routing problem with due times. The vehicles are supposed to visit customers within the due times, and a penalty cost is imposed in case the vehicle arrives past the due times. The objective is to minimize the weighted sum of the traveling time of vehicles and the tardiness of the

service customers receive. A mixed integer programming formulation and a heuristic based on the tabu search for a practical use are suggested. Performances are compared with other heuristics appeared in the literature using the bench-mark data set modified to be fit to the model. It is shown that the suggested heuristic gives a good solution in a short computation time.

Keivan Ghoseiri et al. [18] presents a new model and solution for multi-objective vehicle routing problem with time windows (VRPTW) using goal programming and genetic algorithm. This paper uses a direct interpretation of the VRPTW as a multi objective problem where both the total required fleet size and total traveling distance are minimized while capacity and time windows constraints are secured. This work aims at using a goal programming approach for the formulation of the problem and an adapted efficient genetic algorithm to solve it. In the genetic algorithm various heuristics incorporate local exploitation in the evolutionary search and the concept of Pareto optimality for the multi-objective optimization. Results show that the suggested approach is quiet effective, as it provides solutions that are competitive with the best known in the literature.

Chi-Bin Cheng et al. [19] present study also adopts the concept of problem decomposition and utilizes the embedded problem structure in the vehicle routing problem with time window (VRPTW) to divide the original problem into a clustering (main) problem and a set of mutually independent traveling salesman sub-problems. In order to assist distribution centers solving their special vehicle dispatching and routing problem, this study first investigates the performance concerns and scheduling restrictions of frozen-food distribution centers. The solution of the original problem is obtained through iterative interactions between the main problem and the set of subproblems. The performance of the proposed approach is compared with the well-known insertion method and a manual scheduling of a distribution center.

Nabila Azi et al. [20] The vehicle routing problem with multiple use of vehicles is a variant of the classical vehicle routing problem. It arises when each vehicle performs several routes during the workday due to strict time limits on route duration. The routes are defined over customers with a revenue, a demand and a time window. In this paper, the first exact branch-and-price algorithm for solving the vehicle routing problem with time windows and multiple use of vehicles was

proposed. Although the algorithm is limited by the problem size and some characteristics of the problem (like the route duration constraint), it can still routinely solve instances with 25 customers and a few instances with up to 50 customers. Clearly, a heuristic approach remains a viable alternative for larger instances and our current research efforts are aimed in that direction.

Xiong Chen et al. [21] present use the vehicle routing problem with time window (VRPTW) of combinational optimization is used to analyze and model the rolling batch planning problem. Genetic algorithm and heuristic are used to solve the problem. Simulation results based on the actual production data show that this model is precise and the genetic algorithm based method are very promising. From literature review vehicle routing problem with time window are classified objective, methodology, constrain as showed Table 2.2.

Table 2.3 Summary of methods vehicle routing problem with time window.

| No. | First author | Year | Method | Remark |
|-----|--------------------|------|---|--|
| 1 | Hoong Chuin Lau | 2003 | A tabu search approach characterized by a holding list | Maximize total number of customers and minimizing the total distance. |
| 2 | Kyung Hwan | 2008 | A mixed integer programming and heuristic base on the tabu search | Minimize the weighted sum of the traveling time of vehicle |
| 3 | Keivan Ghoseiri | 2010 | Gold programming and genetic algorithm | Minimize while capacity and time window constraint |
| 4 | Chi-Bin Cheng | 2009 | Genetic algorithm and sub problem solve by heuristic | Minimize the total cost function |
| 5 | Nabila Azi | 2007 | Element shortage path algorithm | Minimize the total distance travel to serve the customer |

2.2.4 Analysis of literature review

A review of literature on the transportation problem is important problem in Logistic, which transportation problems are divided into two categories: Traveling Salesman Problem (TSP) and Vehicle Routing Problem (VRP). Such problems are characteristic of different performance metrics and data to be analyzed. Traveling Salesman Problem (TSP) is a routing management problem by one vehicle, regardless demand of customer and capacity of the vehicle. Vehicle routing problem (VRP) is the same, but regard demand of customer and restrictions on the capacity of vehicles. This problem research have category of transportation problem same as Traveling Salesman Problem by adding traveling time constraint. In 2010, Lopez-Ibanez and Blum [27] carried out experiment to study the contribution of each component of Beam-ACO and minimize total distance to frozen food transportation which is a metaheuristic approach to tackle hard combination optimization problem. Beam-ACO is the best another method from literature review in reducing computation time in finding optimal solution. The computation times are five hour for finding optimal solution with 250 customers and total traveling time with 3 days. In the same year, Silva and Urrutia [28] presented a General Variable Neighborhood Search (GVNS), which find distant neighborhoods of the current incumbent solution. As a result, this method can reduce significantly the computation time are 4 hours and developing some best known results with 550 customers and total traveling time 5 days by fuel transportation.

The logistic management of human specimen in this research related to Travelling Salesman Problem model by adding travelling time constraint. Even though, the travelling time constraint has also studied by Lopez-Ibanez and Blum [27] and Silva and Urrutia [28] but there are three different perspectives which are included; Research objectives, Duration of travelling time and Nodes. The purpose of this research is to minimize transportation costs whereas the purpose of previous mentioned researches were to minimize total distance. The research has found a time constraint that and average validated period of human specimen is approximately 2-6 hours. Therefore, it allowed spending travelling time to pick up specimen for only 180 minutes per route with 65 customers in Bangkok. Regarding to related research by Lopez-Ibanez and Blum and Silva and Urrutia, there is a different of study dimension since the travelling period was 4-5 days with 400-500 customers nationwide.

CHAPTER III

RESEARCH METHODOLOGY

This chapter will discuss on the research methodology and be separated into two sections. The first section is a step of research methodology. A research time which corresponds to the step of research methodology will be considered in the second section.

3.1 Step of Research Methodology

This section describes the methodology of this thesis. It starts with studying problem and constructing the mathematical formulation. Finally, the conclusions can be drawn from this thesis. Figure 3.1 summarizes all of the processes with the diagram. Each section in this chapter is the step the thesis methodology. The details of these steps are written in the following sections.

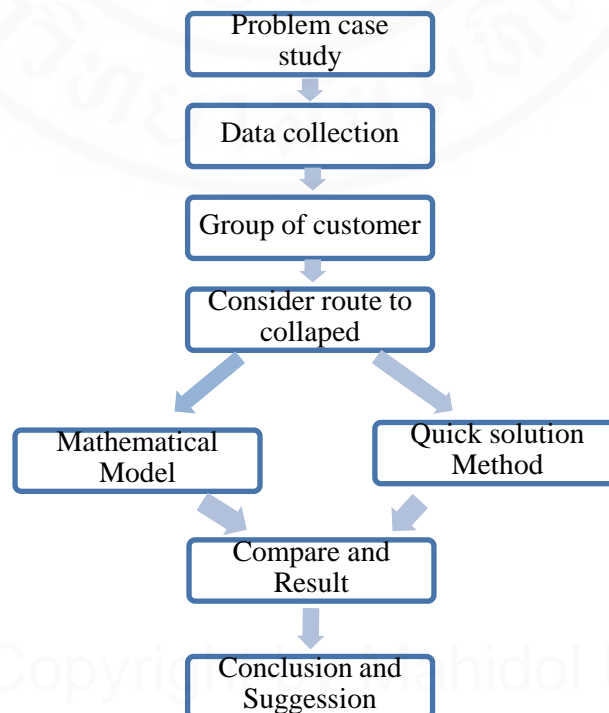


Figure 3.1 Process of research methodology

3.1.1 Problem case study

We first study the transportation of specimen problem by searching the information and interviewed a company about the number vehicles to pickup specimen, route of transport, travel time of specimen transport and customers to service in company. Then we characterize the problem in practice.

In this thesis, we study the vehicle routing problem for specimen transportation. Since the company send vehicles to pickup specimen each customer's place for providing service. Every vehicle must start at the company, visit the customer's place and pickup specimen and return to the company after finishing the whole services.

For each vehicles, will be assigned to the pickup specimen at customer's place. Each customer's place is in the route specified. The traveling time along the route to get up to 180 minutes without taking into account the carrying capacity of the vehicle. The vehicles used to get the specimens with a total of 16 units by 1 unit use only one route. Sometime picking up specimen and returned to the company spent more than 3 hours because the routes have a distance too, so makes cost of transportation. And takes too wait time for pickup the specimens in customer's place, so It's time to analyze the specimens and return the customer delay.

3.1.2 Data collection

We consider data used in the analysis of the problem of routing the specimen transportation and collected by interviewing staff's picking up specimen and information about the transport of customers. The data obtained from this company involves

- Total number of customer's place in each route,
- Total number of route,
- Total number of vehicles to service,
- Total number of customer's place in each zone,
- Time travel matrix from company to each customer's place and customer's place to customer's place,
- Distance matrix from company to each customer's place and customer's place to customer's place,

3.1.3 Group of customer

The marketing department has divided customers into four main types. Customer in Premium (A, B), regular clients (Normal) and customer low level (Fair). Then, the basis criteria for separating the four customer types are following.

- Duration of customer to service (years).
- Revenue from each customer (Bath/month).
- The proportion of payment.

3.1.4 Considering route to collapsed

According problem of case study in section 3.1.1, we use heuristic method to solve specimen transportation problem. Heuristic method is construct self-algorithm to improve transportation system by limit criteria. Step of heuristic method and criteria for improve specimen transportation problem are shown in figure 3.2

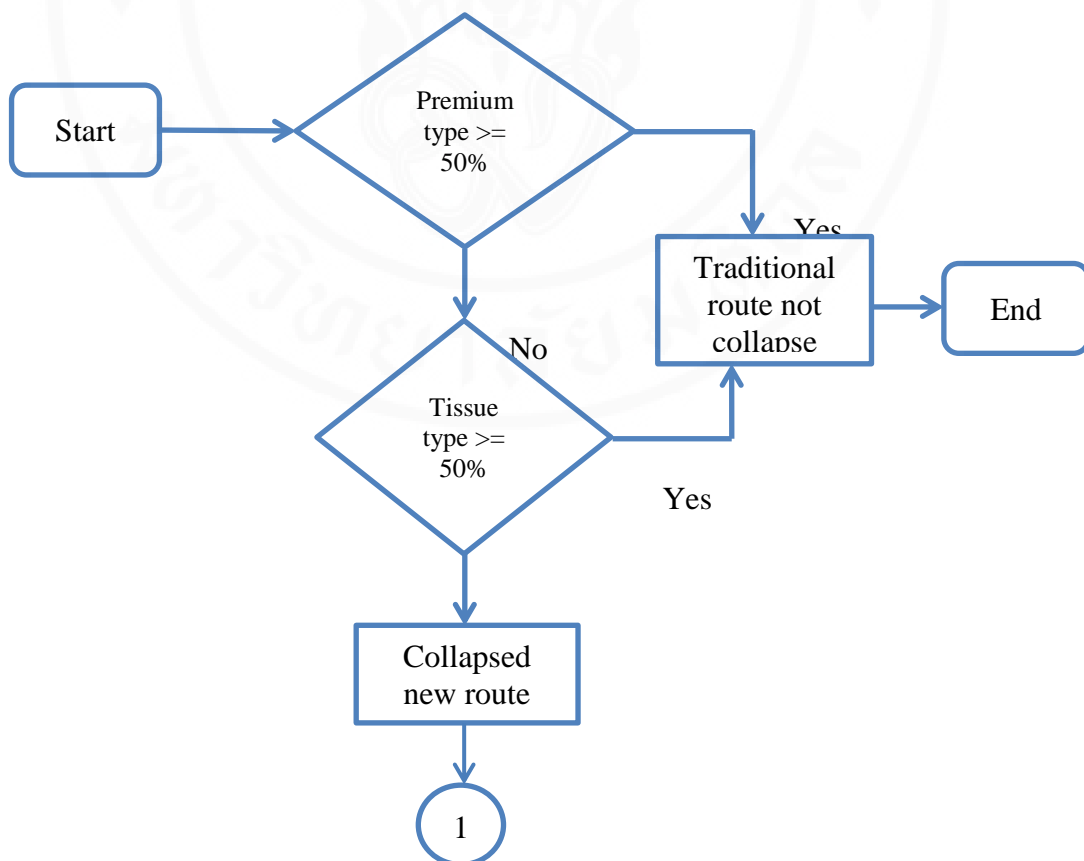


Figure 3.2 Step of considering route to collapsed

3.1.4.1 For customer's place, they have separated by three criteria are duration of customer to service (years), revenue from each customer

(bath/month) and proportion of payment. Type of customer's place are divide four groups; premium A, premium B, normal and fair.

3.1.4.2 Analysis of each routes are separate by two types.

- 1) We consider to route by types of customer
- 2) Number group of customer is premium type more than or equal 50% per each route
- 3) Quantities type of specimen (tissue) are more than or equal 50% per each route. Tissue is one type of specimen is more than expensive other type of specimen.

3.1.5 Quick solution method

We plan for routing to without traditional route and by two criteria is following. We consider nearest distance from center to customer's place and Then, we consider travel time departs of center and back to center relate 180 minute. Flow chart is showed in figure 3.3.

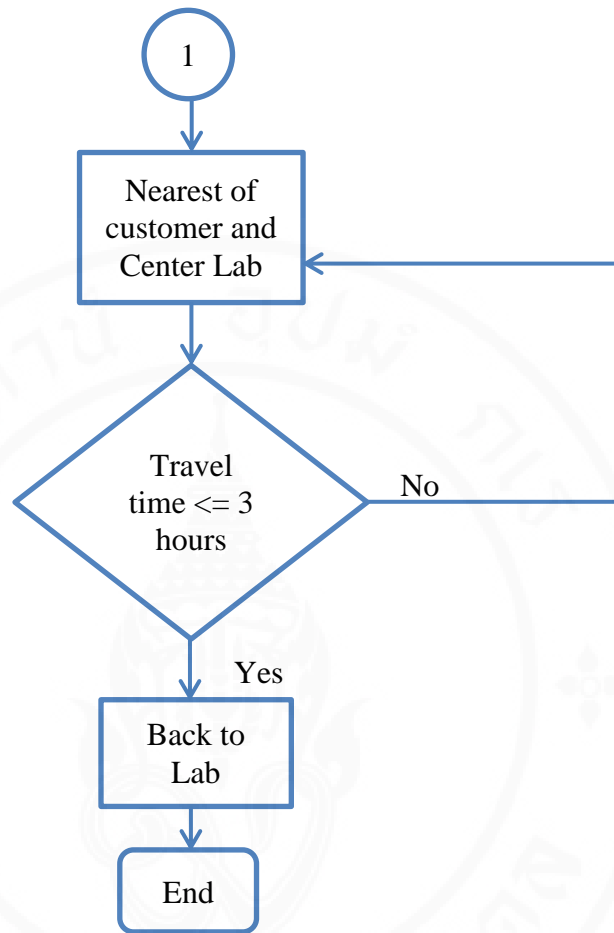


Figure 3.3 Step of quick solution method

3.1.3 Mathematic Model

From the above problem, the central laboratory has to send the vehicle to customer's places which in Bangkok. Every vehicle has to start at the central laboratory, visit the customer's place to pick up specimen, and return to central laboratory. Moreover, the central laboratory may have the limitation of travel time to finish in 3 hours. Since the each vehicles have enough capacity to support specimen from each customer's places.

We formulate the mathematical models that can be used for vehicle routing problem for transportation specimen. Our mathematical models aim to find a route or sequence of place to pick up specimen which minimizes the total cost of transport.

In this thesis, we construct the mathematical models for transportation specimen in that many vehicles are used to pick up specimen in each customer's places. Therefore, in each route many vehicles can be used to serve the customer's places at the same time. This model considers the case that more than one vehicle can be used in each region. However, it is not necessary to use all of the vehicles. We assume that each vehicle will leave the central laboratory to provide the service at most once in the whole 3 hours. The assumptions of mathematical model are shown as the following.

3.1.3.1) For each region, there are m available vehicles.

3.1.3.2) All vehicles may not be utilized and each of them can be used at most once.

3.1.3.3) All used vehicles must start and end at the central laboratory.

3.1.3.4) Each used vehicle has to serve some or all of the customer's places in the region with one tour.

3.1.3.5) Each visiting place must be visited once by a vehicle.

3.1.3.6) The service at each visiting place takes one day to complete and the whole services of each region can be finished in time.

3.1.4 Compare and Result

In this step, a dispatching plan which is derived from a new mathematical programming model will be compare with the ranking algorithm.

3.1.5 Conclusion and Suggestion

This step will consider some address question about the transportation specimen. After analyze the address questions, we will conclude and make complete report as well.

3.2 Research Time

Table 3.1 research time

| Activities | Month | | | | | | |
|--|-------|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 1. State and study problem. | | | | | | | |
| 2. Study related theory and literature. | | | | | | | |
| 3. Study process transportation specimen and grouping customer and collapse route with basic criteria. | | | | | | | |
| 4. Develop mathematical model and quick solution method. | | | | | | | |
| 5. Compare of method to improve specimen transportation. | | | | | | | |
| 6. Analysis result and discussion | | | | | | | |
| 7. Conclusion | | | | | | | |

CHAPTER IV

RESULT AND DISCUSSION

In this chapter, information gathering consisted of overview of case study in section: data collection in section, grouping of customer, result of quick solution method routing, result of mathematical model and compare between two methods will be discussed.

4.1 Data collection

In this chapter, data collection consisted of overview of operation type of customer, route for receive specimen, cost of transportation and demand of customer per route will be discuss.

4.1.1 Overview of operation

In this section, Overview of operation can be divided into two categories: external operation and internal operation will be discussed.

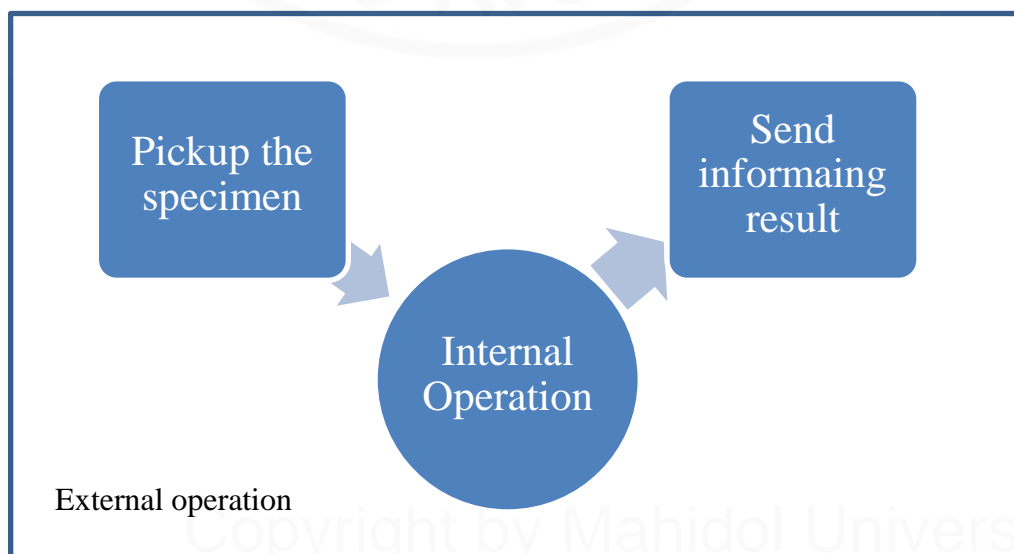


Figure 4.1 Overview of operation

4.1.1.1 External operation

External operation is processing of vehicles to receive the specimen, and informing results of diagnosis to the customer. Processing of vehicle to receive the specimen into two types: receive specimen of customer in Bangkok area by motorcycles and receive specimen of customer outside Bangkok (province) by car or post.

Receiving specimen from customer in Bangkok area used motorcycles. Fix the path in all 17 routes and one motorcycles per one route. Divide two rounds to receiving specimen are regular round (Monday – Friday, morning: 8.00 – 12.00 and evening: 13.00 – 16.00)

4.1.1.2 Internal operation

Start employees transfer the specimens to the center laboratory then. Staff will install a barcode registration and screening process, checking the customer's need. This internal process is the following diagram as showed in Figure 4.1.

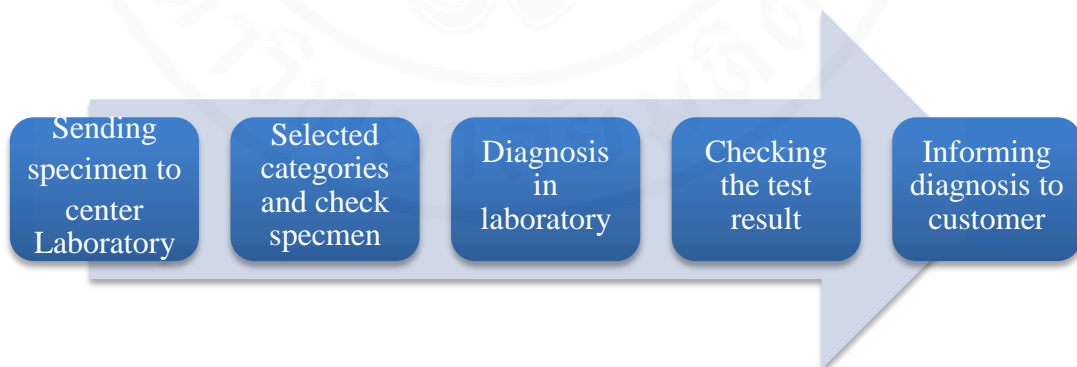


Figure 4.2 Internal operation

Classification of the specimen and will be sent to laboratory for analysis as following.

- Immunology : 4 operators
- Culture : 4 operators
- Pathology : 5 operators
- Toxicology : 3 operators

Analysis of the specimens is not certain the diagnosis, such as toxins made 80% will able to diagnosis because just open new laboratory and chemical solution not enough. Analysis of Serum or check in immunology, which are 20%, the company cannot be analyzed to check send it to the center cytology specimens outside (Outside lab) as the Rama/Siriraj hospital or outside laboratory center. The nature of the specimen examination testing divided by type of analysis is showed Table 4.1.

Laboratory center will have messenger or medical checker will always check the results with the standard should be after that will affect the investigation and will be sent immediately upon completion of inspection. To send a document that will be displayed in check. The documentation of inspection results is the administration. The staffs in the examination and issuance of six operators.

Overview of internal operation can be summarized as a swim lane chart of the specimen as showed Figure 4.2.

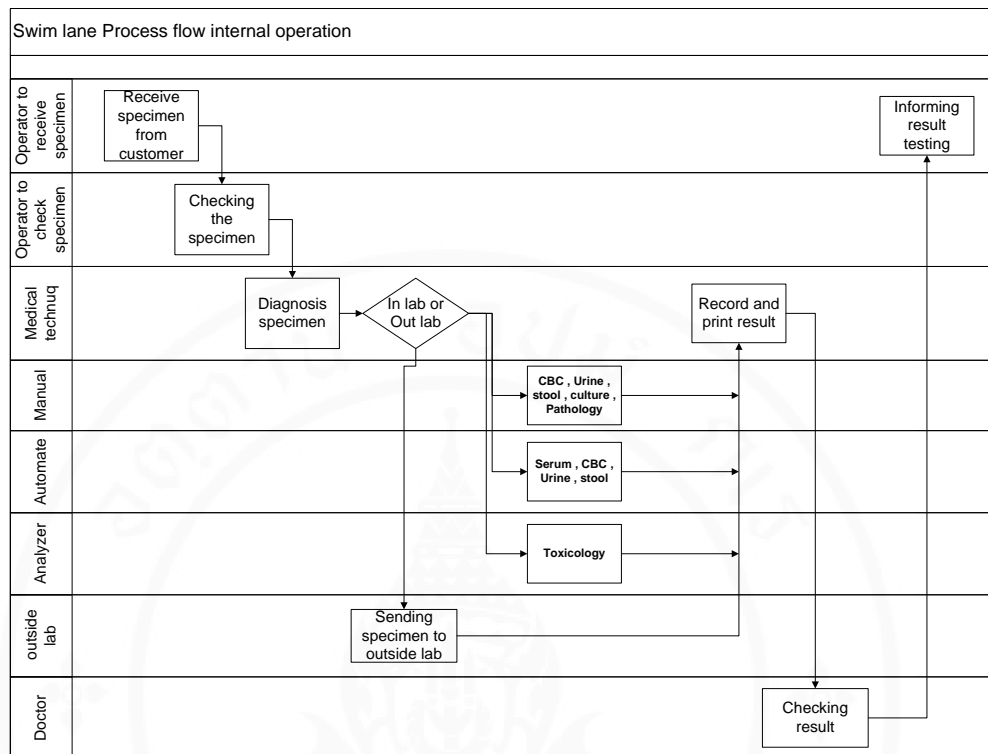


Figure 4.3 Swim lane of process flow internal operation

4.1.2 Type of customers

Type of customers can be divided into three categories: style of customer into service at center laboratory, organizational characteristics that service and type of customer in marketing department.

4.1.2.1 Style of customer into service at center laboratory

Style of customers into service at center laboratory can be divided into three categories: regular customers, temporary customers and walk in customers

4.1.2.1.1 Regular customers

Their regular customers have committed to the center laboratory, they must enter the specimen every day. Regular customers are only in the area near center lab. Which has a limitation is the need for specimen every day while no specimen by without advance notice.

4.1.2.1.2 Temporary customers

Their temporary customers that haven't committed to the center laboratory. If customers have specimen, they will call to center laboratory give arrange to receive specimen. So, Receiving specimen of temporary customer have exact quantity of specimen.

4.1.2.1.3 Walk in customers

Their walks in customers are access to the service center laboratory directly. Receiving specimen from customer directly and not transport occurs.

4.1.2.2 Organizational characteristics that service

Organizational characteristics that service have three types: hospital represents 45.43% of all customers, clinic represents 36.43% of all customers and laboratory represents 17.62% of all customer as shown in Figure 4.3

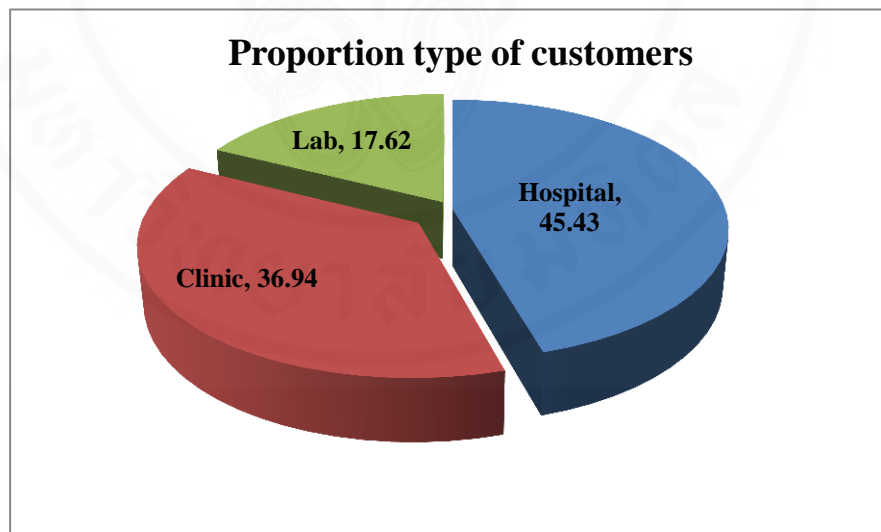


Figure 4.4 Proportion types of customers

4.1.3 Route for receive specimen

Vehicle route get into two types: route in Bangkok area 17 routes (In case study) and outside Bangkok area (province) 8 routes. Each route have number of point to receive and sending testing result are not equal. The distances and number of pick up point is depended on different routes. In the pickup specimen has used one vehicle per one route. Number of route to pickup specimen is same number of vehicle and messenger is show in table 4.1.

Table 4.1 Number of route and number of vehicle used to transportation each period

| Number | Period | Morning | Afternoon |
|---------|--------|---------|-----------|
| | Route | | 17 |
| Vehicle | | 17 | 17 |

In this case study , there are total 152 customers which located in Bangkok and nearby. The 17 transport truck are serve to transport the specimen from these customer by 17 routing as figure 4.5.

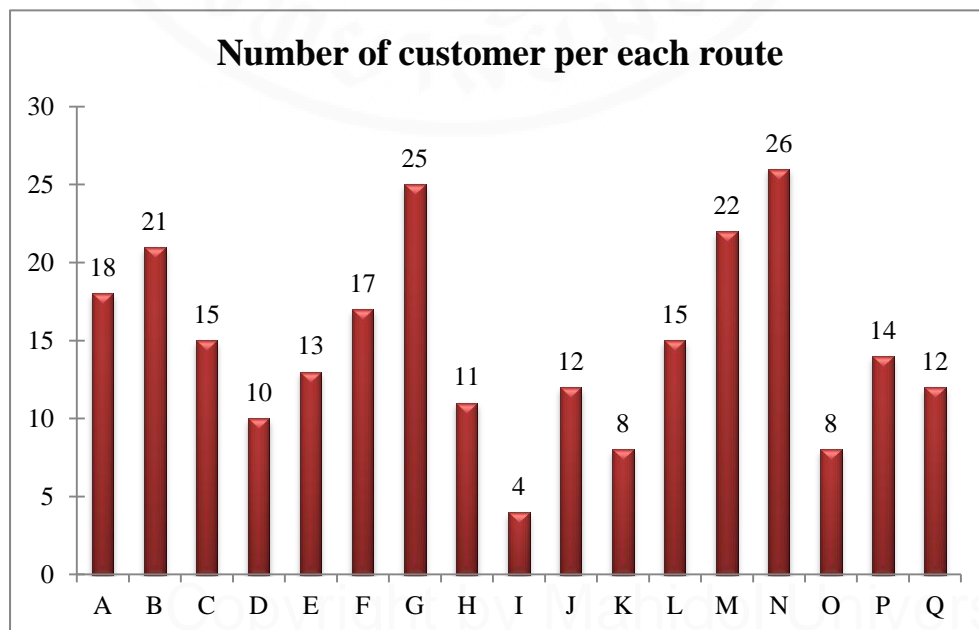


Figure 4.5 Number of customer's place per each route

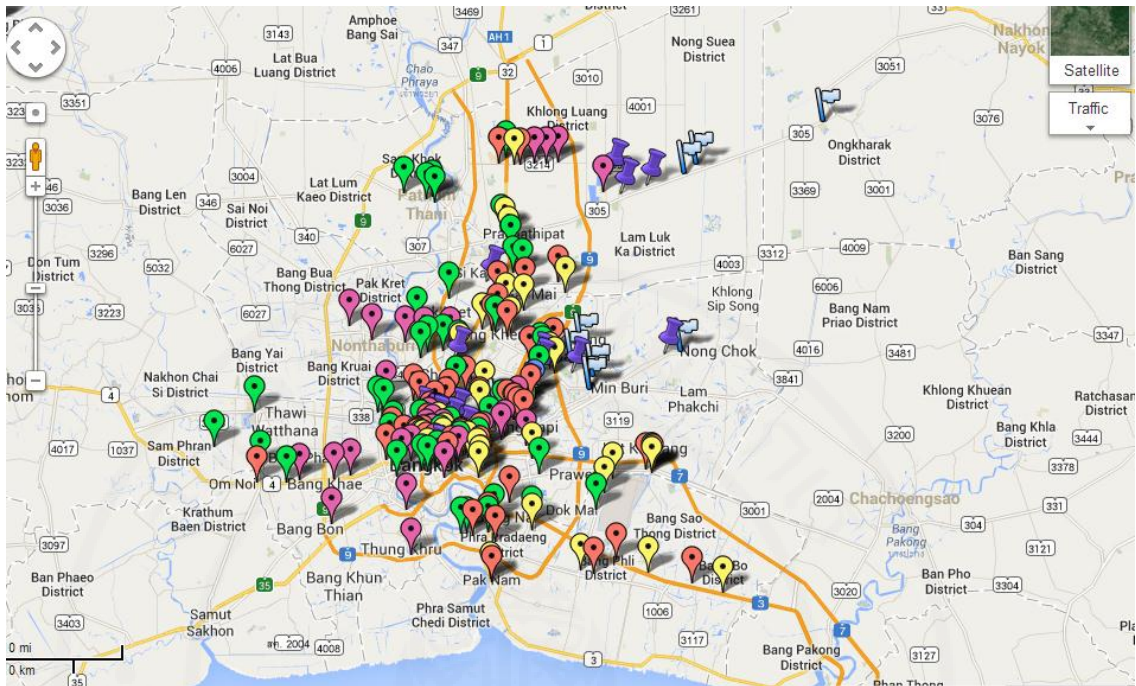


Figure 4.6 Number of customer on google map

From the figure 4.6, the transporter started at the company and travel to pick up the specimen from each customer and return to company again such as Sukhumwit route, the staff will begin at the company and go to customer's place and final back to company as figure 4.7.

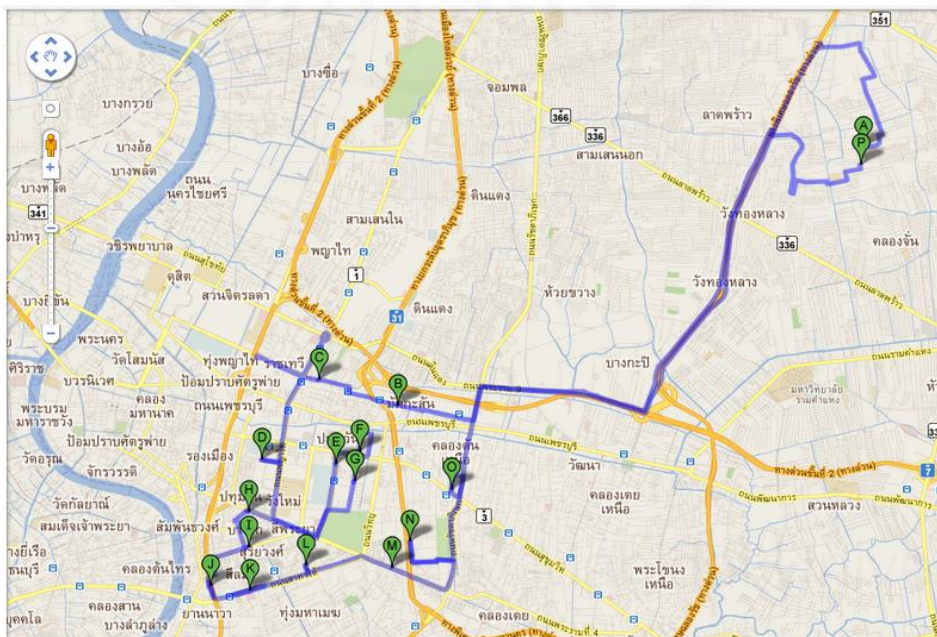


Figure 4.7 Example of Sukhumwit route

4.1.4 Distance and Traveling time of transportation

Distance transports of specimen are transformed of positioning google map clients to be able to measure the distance. Using the position of the laboratory center and location of customer's place and location of the customer's place with each customer's place. For example into a table 4.2 for seven customer's place and show distance matrix full version in Appendix A.

Table 4.2 Distance matrix from laboratory center to customer's place and customer's place to customer's place.

| Distance Metric (Km.) | Laboratory center | C1 | C2 | C3 | C4 | C5 | C6 | C7 |
|-----------------------|-------------------|------|------|------|------|------|------|------|
| Laboratory center | 0 | 0.3 | 1.5 | 8.9 | 10.1 | 18.4 | 21.2 | 22.8 |
| C1 | 0.3 | 0 | 1.3 | 9.2 | 10.3 | 18.2 | 21.7 | 23.3 |
| C2 | 1.5 | 1.3 | 0 | 8.3 | 9.8 | 18.1 | 21.4 | 23 |
| C3 | 8.9 | 9.2 | 8.3 | 0 | 2.1 | 10 | 14 | 15.1 |
| C4 | 10.1 | 10.3 | 9.8 | 2.1 | 0 | 8.6 | 13 | 13.2 |
| C5 | 18.4 | 18.2 | 18.1 | 10 | 8.6 | 0 | 6.4 | 6.8 |
| C6 | 21.2 | 21.7 | 21.4 | 14 | 13 | 6.4 | 0 | 2.5 |
| C7 | 22.8 | 23.3 | 23 | 15.1 | 13.2 | 6.8 | 2.5 | 0 |

Traveling time to pickup specimens are calculated by traveling speed. The laboratory center will use the analysis traveling speed of 40 km / 60 minutes, and average service time is 10 minutes per customer's place. For example, which is out on the table 4.3 by seven customer's place and full version of traveling time matrix is showed in the Appendix B.

Table 4.3 Traveling time from laboratory center to customer's place and customer's place to customer's place

| Travel time (min) | Laboratory center | C1 | C2 | C3 | C4 | C5 | C6 | C7 |
|-------------------|-------------------|-------|-------|-------|-------|-------|-------|-------|
| Laboratory center | 0 | 15.3 | 15.9 | 19.35 | 16.95 | 18.75 | 19.35 | 18.45 |
| C1 | 15.3 | 0 | 15.75 | 19.05 | 16.65 | 18.3 | 18.9 | 18.45 |
| C2 | 15.9 | 15.75 | 0 | 18.75 | 16.35 | 18.45 | 19.05 | 18.75 |
| C3 | 19.35 | 19.05 | 18.75 | 0 | 17.4 | 17.55 | 17.1 | 18 |
| C4 | 16.95 | 16.65 | 16.35 | 17.4 | 0 | 17.7 | 18 | 18.45 |
| C5 | 18.75 | 18.3 | 18.45 | 17.55 | 17.7 | 0 | 15.6 | 15.6 |
| C6 | 19.35 | 18.9 | 19.05 | 17.1 | 18 | 15.6 | 0 | 15.75 |
| C7 | 18.45 | 18.45 | 18.75 | 18 | 18.45 | 15.6 | 15.75 | 0 |

4.1.5 Cost of transportation

In this section, cost of transportation will be discussed two types: fix cost and variable cost. Fixed cost expend to be paid regularly every month. For example: messenger salary and degradation cost. Variable cost is a cost premium to be more paid. For example: fuel cost and service to pickup specimens each customer's place as showed Table 4.4.

Table 4.4 Type cost of transportation

| Fix cost | Variable cost |
|--|--|
| Messenger salary (Messenger to receive specimen/Manager of transportation) (12,000 Bath/month) | Fuel cost (1.12 Bath/km) |
| Degradation cost (10.95 Bath/day) | Service cost (3 Bath/customer's place) |

Messenger salary per month are 12,000 Bath/month and calculated 545.45 Bath/ 22 days and degradation cost are calculated from average cost of vehicle 20,000 Bath/1vehicle and duration to use vehicle is five years are 10.95 Bath/day. Fuel cost is variable for one vehicle is travel at 34 km / liter calculated as 38 baht / liter for use 1 tank of fuel in each vehicle, which is equal to 1.12 baht / km. And service cost are waiting time and pickup specimen.

4.1.5 Demand of customer

This section, demand of customer will be discussed three categories: type of human specimen demand, work load of human specimen with time period and quantities of specimen and tissue per route.

4.1.5.1 Type of human specimen demand

Demand of customer to service in diagnosis human specimen will be sent human specimen into two types: specimen and tissue. Specimen testing is based on the routine work and very fast testing with automate machine. Type of specimens are blood, urine, stool etc. Tissue testing is extra testing need to long time of diagnosis for example: culture of tissue or diagnosis toxic of tissue. Quantities of specimen testing have more than quantity of tissue testing because specimens testing use shorter time to diagnosis than tissue testing. And transportation of human specimen Proportion of quantity human specimen as showed Figure 4.8.

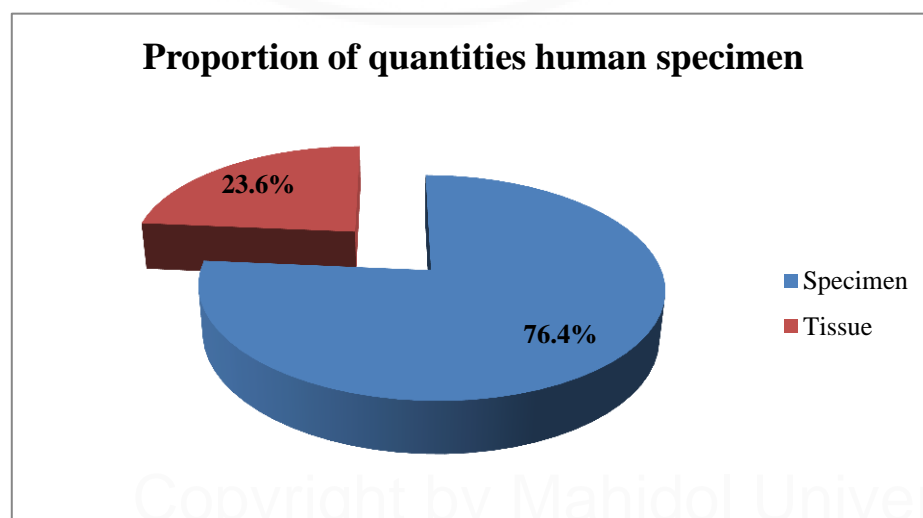


Figure 4.8 Proportion of quantity human specimen

4.1.5.2 Work load of human specimen with time period

There are three period to receive specimen of Bangkok area: morning (8 o'clock – 12 o'clock), afternoon (13 o'clock – 16 o'clock) and evening (17 o'clock – 20 o'clock) and all time period of outside Bangkok area. Quantity of receive human specimen are different from three time period in Bangkok area and outside Bangkok area as showed in Figure 4.9.

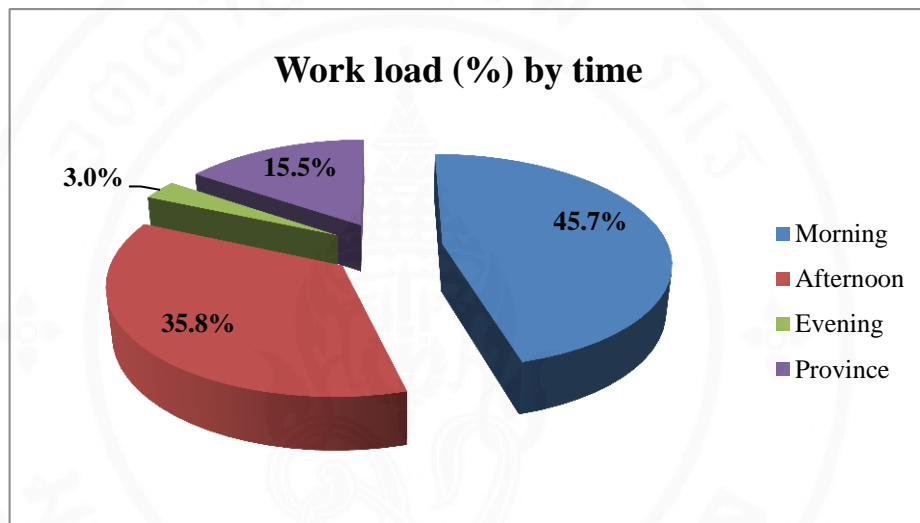


Figure 4.9 Work load (%) by time to receive human specimen

Figure 4.5 is showed quantities work load human specimen in the morning period is the highest quantities and the lowest quantities of human specimen in evening period. Which evening period is overtime period affect to high cost of transportation but Necessary to receive specimen because this period are customers of the evening clinic

4.2 Group of customer

4.2.1 Criteria of grouping customer type

The marketing department has divided customers into four main types. Customer in Premium (A, B), regular clients (Normal) and customer low level (Fair). Then, the basis criteria for separating the four customer types are following.

- Duration of customer to service (years).
- Revenue from each customer (Bath/month).
- The proportion of payment. The proportion of payment is finding proportion of duration of each customer to payment / Due time of payment each customer.
- If proportion of payment > 1 , Customers paying over due time.
- If proportion of payment = 1, Customer paying on time.
- If proportion of payment < 1 , Customer paying before due time.

Criteria of separate type of customer by marketing department are shown in table 4.5.

Table 4.5 Criteria of separate type of customer by marketing department

| Type of customer | Duration of customer service (Years) | | Revenue from each customer (Bath/month) | | | Proportion of payment | |
|------------------|--------------------------------------|-------|---|-----------------|------------|-----------------------|-------|
| | ≥ 5 | < 5 | $\geq 40,001$ | 10,000 – 40,000 | $< 10,000$ | ≥ 1 | < 1 |
| Premium A | X | | X | | | X | |
| | | X | X | | | X | |
| Premium B | X | | X | | | | X |
| | X | | | X | | X | |
| | | X | X | | | | X |
| Normal | X | | | X | | | X |
| | X | | | | | X | |
| | | X | | X | | X | |
| | | X | | X | | | X |
| Fair | X | | | X | | | X |
| | | X | | | X | X | |
| | | X | | | X | | X |

Type of customer has separated by marketing department are different by revenue from each customer. Premium (A,B) type have revenue more than 10,000 bath/month, normal type have revenue between 10,000 – 40,000 bath/month and Fair type have revenue less than 10,000 bath/month.

4.2.2 Result group of customers type

For 152 customer's place were grouped on the basis four criteria is preliminary are duration of customer to service (years), revenue from each customer (Bath/month) and the proportion of payment for four types of customer are Premium A, Premium B, Normal and Fair. Each type of customer have different number of customer are shown in figure 4.10.

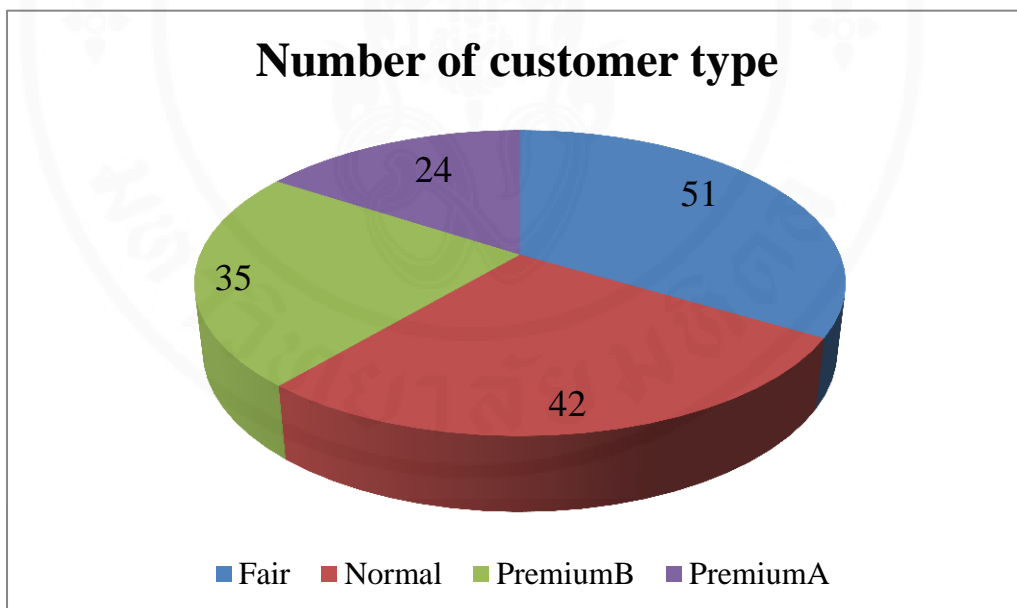


Figure 4.10 Number of customer type

In figure 4.10, each group number of customers is derived from the screening criteria to the three types: Premium A, Premium B is a group of customers who do not provide the facilities to perform high revenue. Type of normal and fair group give the revenue of less than the laboratory determined. So the group of route with a number of customers, Premium type amounts will be the vehicle that ran on the

same route and considering the number of customers of premium route with less than 50% and in the case of biopsy specimens. Tissue specimen's type makes to analysis of many types and it is kind of expensive due to the need for a medical diagnosis.

4.3 Consider route to collapse

4.3.1 Criteria to considering route to collapsed

After the section 4.2, analysis of traditional route to collapsed. Each route is the route by which the number of each mixes type of customer well. So in considering traditional route analysis using a group customer, which is considered to be the two main criteria.

4.2.2.1 Determination the percent of premium types of customers with more than 50% per each route. Shown in the figure 4.11.

4.2.2.2 Determination the percent of customers who send tissue specimens more than 50% per each route. Shown in the figure 4.12.

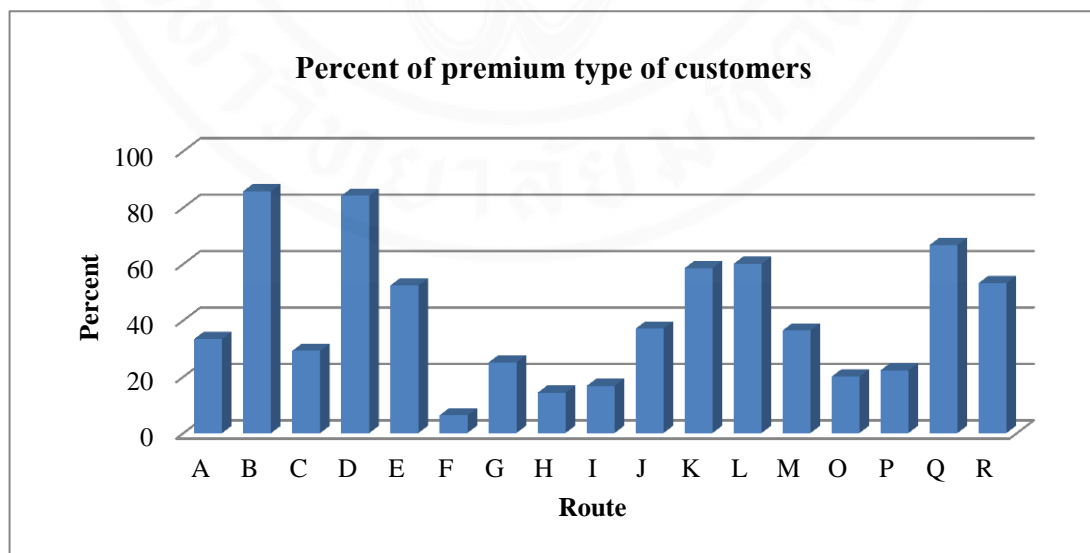


Figure 4.11 Percent of premium type of customer for each route (A – R)

From figure 4.11, which can be seen as a route with the premium customers more than 50% are 7 routes: B, D, E, K, L, Q and P. Route have the

premium customers below 50% would be considered the threshold of the number of submissions tissue specimens of more than 50% as shown in Figure 4.12.

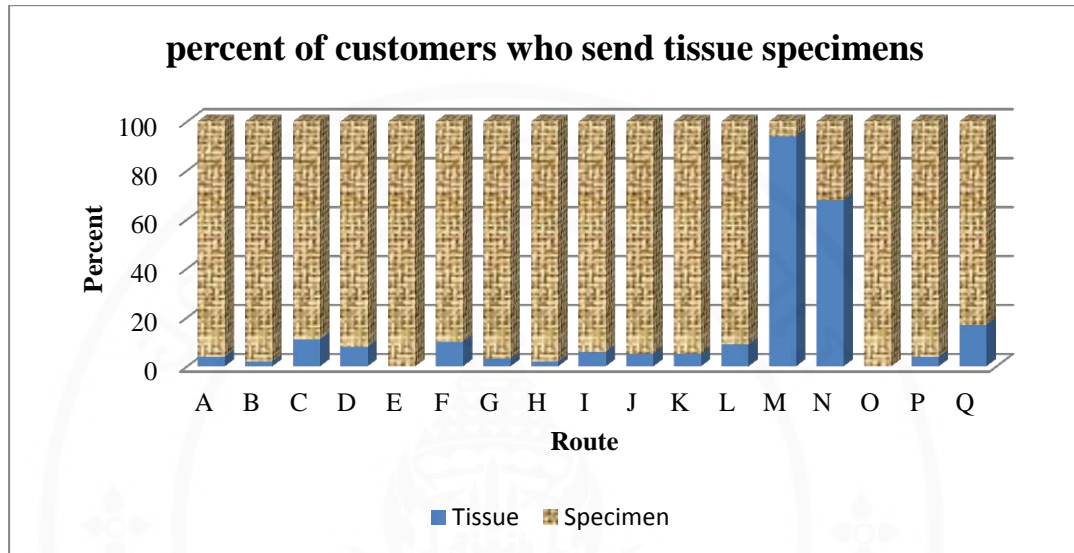


Figure 4.12 Percent of customers who send tissue specimens for each route (A – R)

From figure 4.12, the route amount to service the tissue specimen, with the M and N is the volume of specimens of more than 50 %, which when combined with the B, D, E , K , L, Q and P respectively. All nine routes a path give high revenue for laboratories. Therefore, the remaining eight routes, including the number of customers are 65 will take a new route regardless of the original route.

4.3.2 Zoning of customers

According to a scope of research, there are 65 customers have been grouped by direction between laboratory and different customer locations. In the zoning of total customer after customer and the criteria used to analyze the new route to collapse. With the 65 customers, all of which can be divided into 4 zone is shown in Figure 4.13. Basic of the criteria zoning is divided into 4 categories are following.

4.3.2.1 For those customers is Northern region (or measuring by X-Y graph, the laboratory as the center, those customers will be in between 45 degree to 125 degree), are defined as zone3 with in total are 15 customers.

4.3.2.2 For those customers is Western region (or measuring by X-Y graph, the laboratory as the center, those customers will be in between 125 degree to 215 degree), are defined as zone2 with in total are 20 customers.

4.3.2.3 For those customers is Eastern region (or measuring by X-Y graph, the laboratory as the center, those customers will be in between -45 degree to 45 degree), are defined as zone3 with in total are 16 customers.

4.3.2.4 For those customers is Southern region (or measuring by X-Y graph, the laboratory as the center, those customers will be in between 215 degree to 315 degree), are defined as zone4 with in total are 14 customers.

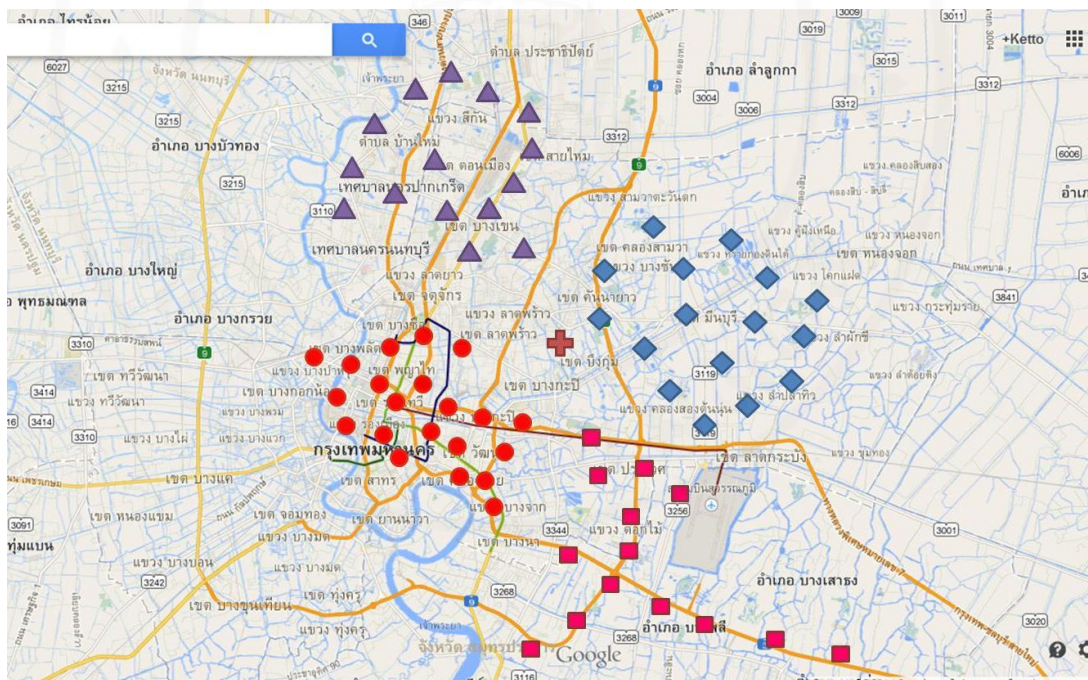


Figure 4.14 Zoning of 62 customers

From figure 4.14, 65 customers all of which can be divided into 4 zones are following: Zone 1 is Northern Bangkok, Zone 2 is Western Bangkok, Zone 3 is Eastern Bangkok and Zone 4 is Southern Bangkok respectively. Each zone has different number of customers. The number of customers and number of traditional route for each zone is shown in table 4.6.

Table 4.6 Number of customer of each zone

| Zone | Number of customer | Number of traditional route |
|--------|--------------------|-----------------------------|
| Zone 1 | 15 | 2 |
| Zone 2 | 20 | 2 |
| Zone 3 | 16 | 2 |
| Zone 4 | 14 | 2 |

4.4 Quick solution method

Routing of the remaining customers regardless of the original route are considered by customers located nearest to the laboratory and the nearest of the customer’s place to the customer’s place. The travelling time of depart form laboratory center to provide service in each customer’s place and returned to the laboratory center for up to 3 hours (180 minutes). Result of quick solution method is shown in each zone will be analyze a number of route, number of vehicle to use, distance and traveling time, sequence of transportation and cost of transport will be discussed in table 4.7.

Table 4.7 Result of quick solution method

| Zone | No. Vehicle (k) | No. Customer | Best Solution | | | Cost/Day | | |
|------|-----------------|--------------|---|---------------|-------------------|----------|---------------|------------|
| | | | Customer Sequence | Distance (km) | Travel time (min) | Fix cost | Variable cost | Total cost |
| 1 | k=1 | 15 | 0>1>8>7>9>6>5>4>3>2>10>11>12>13>14>15>0 | 40.7 | 136.2 | 556.41 | 90.584 | 646.994 |
| 2 | k=2 | 13 | 0>16>25>24>26>27>28>29>30>31>32>33>34>35>0 | 19.2 | 168.95 | 1112.82 | 111.52 | 1224.34 |
| | | 7 | 0>22>21>20>19>18>17>23>0 | 26.8 | 120.35 | | | |
| 3 | k=1 | 16 | 0>36>37>39>38>41>40>42>48>46>45>44>43>49>47>51>50>0 | 23.6 | 115.4 | 556.41 | 74.432 | 630.842 |
| 4 | k=1 | 14 | 0>52>53>54>55>56>64>62>57>59>58>60>61>63>65>0 | 85.5 | 128.1 | 556.41 | 137.76 | 694.17 |

Firstly, the routing zone 1 is the area Northern Bangkok. Which has a total number of 15 customer’s place and have two route with two vehicles to go after a specimen designated 0 is zero laboratory center conditions and 1 - 15 as a customer’s

place and 0>1 refer departure from the laboratory center to customer's place 1. From Table 4.7, result of the zone 1 can route has only one path, and the vehicle is only one to use by the customer 15 has an travel sequence as shown in Table 4.7 have a distance to travel 40.7 kilometers travel time 136.2 minutes which is sufficient to continue the one round, and the cost of transportation 646.994 baht per day.

Second, the routing zone 2 is the area Western Bangkok. Which has a total number of 20 customer's place and have two route with two vehicles to go after a specimen designated 0 is zero laboratory center conditions and 16 - 35 as a customer's place and 0>16 refer departure from the laboratory center to customer's place 16. From Table 4.7, result of the zone 2 can route has two paths, and the vehicle are two to use by the customer 20 has an travel sequence as shown in Table 4.7. Route 2.1 have thirteen customer's place have a distance to travel 19.2 kilometers travel time 168.95 minutes which is sufficient to continue the one round. Route 2.2 have seven customer's place have a distance to travel 26.8 kilometers travel time 120.35 minutes which is sufficient to continue the one round and the cost of transportation 1,224.34 baht per day in two routes.

The routing zone 3 is the area Eastern Bangkok. Which has a total number of 16 customer's place and have two route with two vehicles to go after a specimen designated 0 is zero laboratory center conditions and 35 - 51 as a customer's place and 0>36 refer departure from the laboratory center to customer's place 36. From Table 4.7, result of the zone 3 can route has only one path, and the vehicle is only one to use by the customer 16 has an travel sequence as shown in Table 4.7 have a distance to travel 23.6 kilometers travel time 115.4 minutes which is sufficient to continue the one round, and the cost of transportation 630.842 baht per day.

The finally, the routing zone 4 is the area Southern Bangkok. Which has a total number of 14 customer's place and have two route with two vehicles to go after a specimen designated 0 is zero laboratory center conditions and 52 - 65 as a customer's place and 0>52 refer departure from the laboratory center to customer's place 52. From Table 4.7, result of the zone 4 can route has only one path, and the vehicle is only one to use by the customer 14 has an travel sequence as shown in Table 4.7 have a distance to travel 85.5 kilometers travel time 128.1 minutes which is sufficient to continue the one round, and the cost of transportation 694.17 baht per day.

4.5 Mathematical model

This section presents information of mathematical model for the transportation specimen problem. To formulate mathematical model and result of use mathematical model.

4.5.1 Information of mathematical model

The center may have many vehicles for providing the services. Therefore, many vehicles can be used to serve the customer's places at the same time. This model considers the case that more than one vehicle can be used. However, it is not necessary to use all of the vehicles. We assume that each vehicle will leave the company to provide the service at most once in the whole period. The assumptions of Model are shown as the following.

4.5.1.1) m available vehicles.

4.5.1.2) All vehicles may not be utilized and each of them can be used at most once.

4.5.1.3) All used vehicles must start and end at the center.

4.5.1.4) Each used vehicle has to serve some or all of the customer's places with one tour.

4.5.1.5) Each customer's place must be visited once by a vehicle.

4.5.1.6) The service at each visiting place takes one day to complete and the whole services can be finished in time.

4.5.1.7) Capacity of each vehicle is not necessary.

The traveling salesman problem came from the real problem of a salesman who wants to find the route for traveling. He has to start at the origin, visit a prescribed set of cities and return to the original location in such a way that the total distance traveled is the minimum and each city is visited exactly once. In order to formulate the mathematical model for this problem, we define the notations as the following.

Let

c_{ij} be the cost of transportation from customer's place i to customer's place j

N be the number of customer's place or the number of customer's places for $i, j = 0, 1, 2, 3, \dots, N$, $i \neq j$ and 0 is the center

M set of number of vehicles to provide the service.

Index

i, j, p is number of customer's place or number of customer's place.

0 is laboratory center.

k is number of vehicles to provide the service.

Parameter

c_{0j} is cost of transportation from laboratory center to customer's place j .

c_{ij} is cost of transportation from customer's place i to customer's place j .

t_{0j} is travelling time from laboratory center to customer's place j .

t_{ij} is travelling time from customer's place i to customer's place j .

u_{ik} is sequence number in which customer's place i visit by vehicles k .

According to Assumption 4.3.1, the decision variable from the previous section is not appropriate for this model because it cannot identify which vehicle goes from visiting i to customer's place j . Therefore, we extend the decision variables in order to determine a sequence of customer's places visited by each vehicle. We define

$$x_{ijk} = \begin{cases} 1 & \text{if vehicle } k \text{ is goes form customer's place } i \text{ to customer's place } j \\ 0 & \text{otherwise} \end{cases}$$

for $i, j = 0, 1, 2, 3, \dots, N$ and $k = 1, 2, 3, \dots, m$

In this mathematical model is liked travelling salesman problem. We can be written mathematical model as the following.

$$\text{Min. } \sum_{i=0}^N \sum_{j=0}^N c_{ij} \sum_{k=1}^M x_{ijk} \quad (4.1)$$

Subject to

$$\sum_{i=0}^N \sum_{k=1}^M x_{ijk} = 1 \quad \text{for } j = 1, 2, 3, \dots, N \quad (4.2)$$

$$\sum_{j=1}^N x_{0,jk} \leq 1 \quad \text{for } k = 1, 2, 3, \dots, M \quad (4.3)$$

$$\sum_{\substack{i=0 \\ i \neq p}}^N x_{ipk} - \sum_{\substack{j=0 \\ j \neq p}}^N x_{pjk} = 0 \quad \text{for } p = 1, 2, 3, \dots, N$$

and $k = 1, 2, 3, \dots, M$ (4.4)

$$\sum_{i=0}^N \sum_{j=0}^N t_{ij} x_{ijk} \leq 180 \quad \text{for } k = 1, 2, 3, \dots, M \quad (4.5)$$

$$u_{ik} - u_{jk} + (N + 1)x_{ijk} \leq N \quad \text{for } i, j = 1, 2, 3, \dots, N; i \neq j$$

and $k = 1, 2, 3, \dots, M$ (4.6)

$$x_{ijk} \in \{0, 1\} \quad \text{for } i, j = 1, 2, 3, \dots, N; i \neq j$$

and $k = 1, 2, 3, \dots, M$ (4.6)

$$u_{ik} \geq 0 \quad \text{for } i = 1, 2, 3, \dots, N \quad (4.7)$$

The objective function (4.1) aim to minimize to the total cost of transportation human specimen. Therefore, the objective function is summation of distance traveled by all vehicles. We consider a pair of customer's place called customer's place i and customer's place j or laboratory center 0. If vehicle k used to provide service from customer's place i to customer's place j or laboratory center 0 to customer's place i or back to laboratory center, the total cost of transportation human specimen is equal to d_{ij} . And otherwise, the total cost of transportation human

specimen is equal to zero. Travelling distance relates to route or decision variables x_{ijk} .

Constraint 4.2 guarantee that for every customer's place there is only one vehicle arrived and leave it. If the vehicle is used to provide the service, it needs to leave the company and go to any customer's places. Nevertheless, each vehicle can go to only one customer's place each time. From the company or place 0, vehicle k can goes to customer place 1, visiting place 2, visiting place 3, ..., or visiting place N . All of the possible ways to travel of vehicle k from the company can be written as

$$x_{01k} + x_{02k} + x_{03k} + \dots + x_{0Nk}$$

Therefore, this term is equal to one if vehicle k is utilized. On the other hand, if vehicle k is not used, its value is equal to zero is following

$x_{01k} + x_{02k} + x_{03k} + \dots + x_{0Nk} = 1$ if vehicles k are provided to service.

$x_{01k} + x_{02k} + x_{03k} + \dots + x_{0Nk} = 0$ if vehicles k are not provided to service.

Constraint 4.3 guarantees all of the vehicles do not have to be used. For vehicles k the value of constraint 4.3 can be one or zero. Can be expressed as

$$x_{01k} + x_{02k} + x_{03k} + \dots + x_{0Nk} \leq 1$$

We can written this constrain and must be satisfied for every vehicles k . is following

$$\sum_{j=1}^N x_{0,jk} \leq 1 \quad \text{for } k = 1, 2, 3, \dots, M$$

Constraint 4.4 all vehicles k to requires the transport by start and back at the laboratory center. However, each vehicle need to visited to customer's place and the vehicle is cannot stay at customer's place all time. Then vehicle to leave that customer's place after finishing to service. Let's p is customer's place, it's to visited by vehicle. Then all possibilities that vehicle k travel from laboratory center or other customer's place to customer's place p can be written as

$$x_{0pk} + x_{1pk} + x_{2pk} + \dots + x_{Npk}$$

However, the vehicle travel to customer's place p and finish to provides service, the vehicle leave to another customer's place or back to laboratory center can be written as

$$x_{p0k} + x_{p1k} + x_{p2k} + \dots + x_{pNk}$$

In the reasonable, the vehicle k arrive to customer's place p and leave that customer's place p to another place or back to laboratory center. The possible ways the vehicle k arrives to customer's place must equal to the ways that vehicle k leave to customer's place p to another place or back to laboratory center. The left hand side of the equation is the arrival and right hand side represent the departure form customer's place p . We can written as

$$x_{0pk} + x_{1pk} + x_{2pk} + \dots + x_{Npk} = x_{p0k} + x_{p1k} + x_{p2k} + \dots + x_{pNk}$$

Or

$$\sum_{\substack{i=0 \\ i \neq p}}^N x_{ipk} = \sum_{\substack{j=0 \\ j \neq p}}^N x_{pjk} \quad \text{for } p = 1, 2, 3, \dots, N$$

Constrain 4.4 is can be written as

$$\sum_{\substack{i=0 \\ i \neq p}}^N x_{ipk} - \sum_{\substack{j=0 \\ j \neq p}}^N x_{pjk} = 0 \quad \text{for } p = 1, 2, 3, \dots, N \text{ and } k = 1, 2, 3, \dots, m$$

Constraints 4.5 all vehicles k depart laboratory center or customer's place to customer's place or back to laboratory center have travelling time on the tour. Consider t_{0j} is travelling time from laboratory center to customer's place j and t_{ij} is travelling time from customer's place to customer's place. Then, x_{ij} is decision variable which vehicle is used to provide service from i to j . Therefore, the vehicle k departs from laboratory center to customer's place j and uses travelling time t_{0j} , can be written as.

$$t_{01}x_{01k} + t_{02}x_{02k} + t_{03}x_{03k} + \dots + t_{0j}x_{0jk}$$

Similarity, the vehicle k departs from customer's place i to customer's place j or customer's place i, j to laboratory center and uses travelling time t_{ij} , can be written as.

$$t_{12}x_{12k} + t_{13}x_{13k} + t_{14}x_{14k} + \dots + t_{ij}x_{ijk}$$

Summation of travelling time is time to travel from laboratory center to customer's place or customer's place to customer's place and customer's place back to laboratory center less than or equal 180 minutes can be written as.

$$\sum_{i=0}^N \sum_{j=0}^N t_{ij} x_{ijk} \leq 180 \quad \text{for } k = 1, 2, 3, \dots, m$$

Constraint 4.6, each vehicle needs subtour elimination constraint as the previous section. This constraint prevents a cycle that starts and ends at some customer's place except customer's place 0 which is the laboratory center. The subtour elimination constraint by defining the variable that give the value like u_i for vehicle k is following below.

$$u_{ik} - u_{jk} + (N + 1)x_{ijk} \leq N \quad \text{for } i, j = 1, 2, 3, 4, \dots, N \quad k = 1, 2, 3, \dots, m, \\ i \neq j$$

and

$$u_{ik} \geq 0 \quad \text{for } i, j = 1, 2, 3, 4, \dots, N \quad k = 1, 2, 3, \dots, m$$

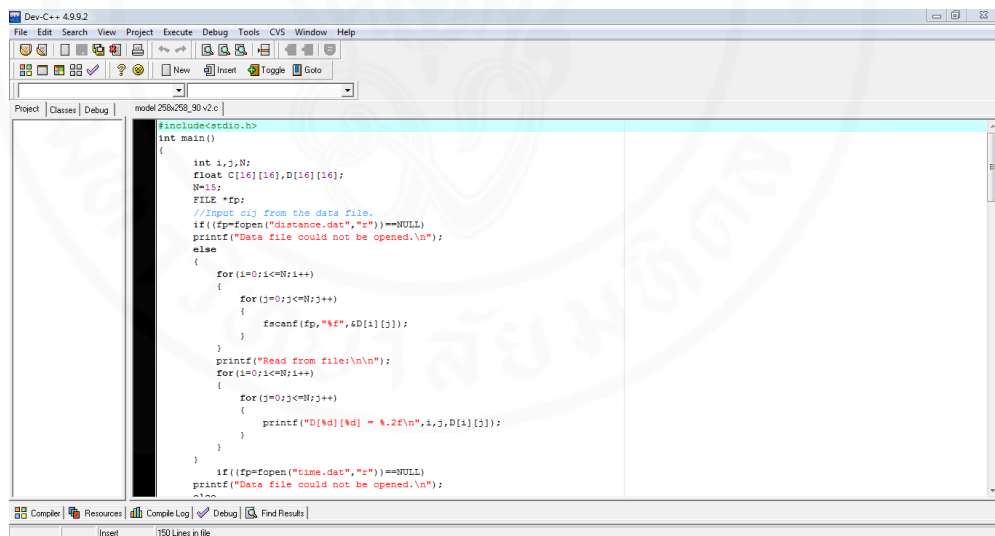
4.5.2 Result of Mathematical Model

After grouping of customers type in section 4.2 and consider the collapsed route by the criteria in section 4.3 We see that the route must have a total of eight new routes and the total numbers of customer's place are 65, which will be adopted for new route and regardless of the original route and which has led both to the coordinates in Google map. We can be seen that most of the customers are located in internal Bangkok and partially diffuse into external Bangkok is four zones in section 4.3.2.

Routing of the remaining 65 customer's place regardless of the original route are considered by time constraint (4.5) the travelling time of depart form laboratory center to provide service in each customer's place and returned to the laboratory center for up to 3 hours (180 minutes) including average service time as 10 minutes per each customer's place. Result of Mathematical model is shown in each zone will be analyze a number of route, number of vehicle to use, distance and traveling time, sequence of transportation and cost of transport will be discussed. The analysis of travelling salesman problem for decision making used Binary programming by Lindo which is called Branch and bound to identify optimization. The process of Branch and Bound starts from creating initial solution (LP Relaxation)

other comparable sub problem by different objectives e.g. Minimization of cost, distance and vehicle. When the program successfully identify more effective sub problem, it become a new main upper bound as well as the less effective upper bound will be deleted. The process would be continually determining until the optimization (integer solution) has been discovered. Hence, this method reduced ineffective sub problem and able to identify effective route in a short period of time.

Tool of analysis the minimize cost of transportation Lindo version 6.1 is used. Data of The cost of transportation of the customer's place to customer's place and travel time from laboratory center to customer's place and customer's place to customer's place. Which has created a table and a cost matrix, travelling time matrix, which represents the Appendix B. Cleaning to the routing of data, each Zone using the section 4.5.1 Mathematical model details to create Function code out into Lindo 6.1 applications using DEV-C++ program is shown Figure 4.15.



```

#include<stdio.h>
int main()
{
    int i,j,M;
    float c[16][16],D[16][16];
    N=15;
    FILE *fp;
    //Input c15 from the data file.
    if((fp=fopen("distance.dat","r"))==NULL)
        printf("Data file could not be opened.\n");
    else
    {
        for (i=0;i<N;i++)
        {
            for (j=0;j<N;j++)
            {
                fscanf(fp,"%f",&D[i][j]);
            }
        }
        printf("Read from file:\n\n");
        for (i=0;i<N;i++)
        {
            for (j=0;j<N;j++)
            {
                printf("D[%d][%d] = %.2f\n",i,j,D[i][j]);
            }
        }
    }
    if((fp=fopen("time.dat","r"))==NULL)
        printf("Data file could not be opened.\n");
}

```

Figure 4.15 DEV-C++ program to use construct function of mathematical model.

When the code function is complete will analyze the results and then can turn into the program Lindo 6.1 in Figure 4.16.

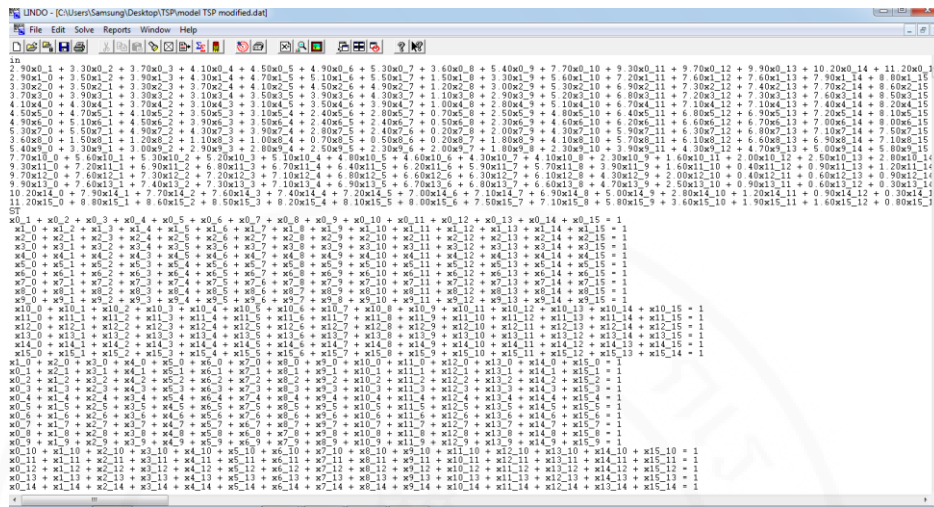


Figure 4.16 Lindo version 6.1 used to analyze the new routing.

After run model by Lindo version 6.1 programs already has the new route in each zone. Each zone will have to analyze a number of routes, number of messenger to pickup specimen, number of vehicles, total distance, total traveling time, and total cost of transportation. Which results is showed in the table 4.8.

Table 4.8 Result of Mathematical Model

| Zone | No. Vehicle (k) | No. Customer | Optimal Solution | | | Cost/Day | | |
|------|-----------------|--------------|---|---------------|-------------------|----------|---------------|------------|
| | | | Customer Sequence | Distance (km) | Travel time (min) | Fix cost | Variable cost | Total cost |
| 1 | k=1 | 15 | 0>3>4>5>6>9>2>10>11>12 >13>14>15>7>8>1>0 | 36.4 | 137.75 | 556.41 | 85.768 | 642.178 |
| | | 9 | 0>27>28>29>30>31> 32>33>34>35>0 | 11.3 | 128.2 | | | |
| 2 | k=2 | 11 | 0>16>17>18>19>20>21 >22>23>24>25>26>0 | 24 | 156 | 1112.82 | 99.536 | 1212.356 |
| | | 16 | 0>36>43>44>45>46>48>49>47> 51>50>42>41>40>38>39>37>0 | 18.9 | 113.35 | 556.41 | 69.168 | 625.578 |
| 4 | k=1 | 14 | 0>52>53>54>55>64>56>62>57 >59>58>60>61>63>65>0 | 82.9 | 127.35 | 556.41 | 134.848 | 691.258 |

Firstly, the routing zone 1 is the area Northern Bangkok. Which has a total number of 15 customer’s place and have two route with two vehicles to go after a specimen designated 0 is zero laboratory center conditions and 1 - 15 as a customer’s place and 0>3 refer departure from the laboratory center to customer’s place 3, so differ from result zone 1 in quick solution method has start 0 to customer’s place 1.

From Table 4.8, result of the zone 1 can route has only one path, and the vehicle is only one to use by the customer 15 has an travel sequence as shown in Table 4.6 have a distance to travel 36.4 kilometers less than quick solution method travel time 137.75 minutes which is sufficient to continue the one round, and the cost of transportation 642.178 baht per day is less than quick solution method 4.816 baht per day.

Second, the routing zone 2 is the area Western Bangkok. Which has a total number of 20 customer's place and have two route with two vehicles to go after a specimen designated 0 is zero laboratory center conditions and 16 - 35 as a customer's place and 0>27 refer departure from the laboratory center to customer's place 27, so differ from result zone 1 in quick solution method has start 0 to customer's place 16. From Table 4.6, result of the zone 2 can route has two paths, and the vehicle are two to use same the transportation plan by the customer 20 has an travel sequence as shown in Table 4.6. Route 2.1 have nine customer's place have a distance to travel 11.3 kilometers, travel time 128.2 minutes which is sufficient to continue the one round. Route 2.2 have eleven customer's place have a distance to travel 24 kilometers travel time 156 minutes which is sufficient to continue the one round and the cost of transportation 1,213.49 baht per day in two routes less than quick solution method 10.85 baht per day.

The routing zone 3 is the area Eastern Bangkok. Which has a total number of 16 customer's place and have two route with two vehicles to go after a specimen designated 0 is zero laboratory center conditions and 35 - 51 as a customer's place and 0>36 refer departure from the laboratory center to customer's place 36 as same as quick solution method. From Table 4.6, result of the zone 3 can route has only one path, and the vehicle is only one to use by the customer 16 has an travel sequence as shown in Table 4.6 have a distance to travel 18.9 kilometers travel time 113.35 minutes which is sufficient to continue the one round, and the cost of transportation 625.578 baht per day less than quick solution method 5.564 baht per day.

The finally, the routing zone 4 is the area Southern Bangkok. Which has a total number of 14 customer's place and have two route with two vehicles to go after a specimen designated 0 is zero laboratory center conditions and 52 - 65 as a customer's place and 0>52 refer departure from the laboratory center to customer's place 52 as same as quick solution method. From Table 4.6, result of the zone 4 can route has only

one path, and the vehicle is only one to use by the customer 14 has an travel sequence as shown in Table 4.6 have a distance to travel 82.9 kilometers travel time 133.2 minutes which is sufficient to continue the one round, and the cost of transportation 691.258 baht per day less than quick solution method 2.912 baht per day.

The results of each zone by mathematical model, the number of routes is an important factor that makes the cost of transportation increases. If the number of routes can be reduced effect to reducing the cost of the salary messenger and degradation cost of vehicles. The mathematical model can be used to reduce the total distance per route more than quick solution method, thus making the cost of goods sold decreased from the original as well.

4.5.3 Sensitivity analysis

In this section, the sensitivity analysis which is analyzed to find the value of the parameter is changed witch traveling time to transportation. Mathematical model is using Traveling Salesman Problem (TSP) with a time constraint. This analysis divided into three sections: 1) the reduction in the total traveling time of the trip 2) increase the total traveling time and 3) traffic jam by the traveling time to transportation from customer's place to customer's place is raising respectively.

4.5.3.1 The reduction in the total traveling time of the trip

Transportation costs will be higher due to the number of routes. It must be added to the messenger on the trip and added number of vehicle. The duration of one round trip is 180 minutes but has reduced the traveling time per 1 round will result in the number of trip. So, in this section will reduce traveling time to consider: How traveling time need to increase the number of round trips which the cost will be increased? The analysis of all 4 scenarios per each zone are showed below.

4.5.3.1.1 Base case (180 minutes)

4.5.3.1.2 Scenario 1: reduce traveling time 10% (162 minutes)

4.5.3.1.3 Scenario 2: reduce traveling time 20% (144 minutes)

4.5.3.1.4 Scenario 3: reduce traveling time 30% (126 minutes)

4.5.3.1.5 Scenario 4: reduce traveling time 40% (108 minutes)

Sensitivity analysis of zone 1 (Northern Bangkok) is showed in the Table 4.9 and have to analyze a number of routes, number of messenger to pickup specimen, number of vehicles, total distance, total traveling time, and total cost of transportation.

Table 4.9 Sensitivity analysis with reduce total traveling time of zone 1

| Zone | Scenario | No. Vehicle (k) | No. Customer | Optimal Solution | | | Cost/Day | | |
|------|-----------|-----------------|--------------|---|---------------|-------------------|----------|---------------|------------|
| | | | | Customer Sequence | Distance (km) | Travel time (min) | Fix cost | Variable cost | Total cost |
| 1 | Base case | k=1 | 15 | 0>3>4>5>6>9>10>11>12>13>14>15>7>8>1>2>0 | 36.4 | 137.75 | 556.41 | 85.768 | 642.178 |
| | 1 | k=1 | 15 | 0>3>4>5>6>9>10>11>12>13>14>15>7>8>1>2>0 | 36.4 | 137.75 | 556.41 | 85.768 | 642.178 |
| | 2 | | | 0>3>4>5>6>9>10>11>12>13>14>15>7>8>1>2>0 | 36.4 | 137.75 | 556.41 | 85.768 | 642.178 |
| | 3 | k=2 | 13 | 0>5>6>9>10>11>12>13>14>15>7>8>3>4>0 | 31 | 116.5 | 1112.82 | 90.584 | 1203.404 |
| | 4 | | 2 | 0>1>2>0 | 9.7 | 29.55 | | | |

From the Table 4.9, sensitivity analysis of zone 1, Base case is optimal solution from Mathematical model in section 4.5.2. This routing is one route by a customer 1-15 a total distance is 36.4 kilometers and is the travel time 137.75 min, which was 645.18 baht per day. If you reduce traveling time by 10 % (168 minutes) and 20 % (144 minutes) can travel using just one vehicle and the cost of transportation same Base case. If reduction of more than 30 % (126 minutes) and 40 % (108 minutes) to travel less than Base case in case it is necessary to increase the travel. Which can travel up to 2 routes: Route 1 has a number of customer’s place are 13 with total distance 31 kilometers and total traveling time 116.5 minutes and Route 2, have customer’s place only 2 people, with total distance 9.7 kilometers and total traveling time of 29.55 minutes, which was the total cost 1209.41 baht per day due to the increasing number of messenger and number of vehicles.

Sensitivity analysis of zone 2 (Western Bangkok) is showed in the Table 4.10 and have to analyze a number of routes, number of messenger to pickup

specimen, number of vehicles, total distance, total traveling time, and total cost of transportation.

Table 4.10 Sensitivity analysis with reduce total traveling time of zone 2

| Zone | Scenario | No. Vehicle (k) | No. Customer | Optimal Solution | | | Cost/Day | | |
|------|-----------|-----------------|--------------|--------------------------------------|---------------|-------------------|----------|---------------|------------|
| | | | | Customer Sequence | Distance (km) | Travel time (min) | Fix cost | Variable cost | Total cost |
| 2 | Base case | k=2 | 9 | 0>27>28>29>30>31>32>33>34>35>0 | 11.3 | 128.2 | 1112.82 | 99.536 | 1212.356 |
| | | | 11 | 0>16>17>18>19>20>21>22>23>24>25>26>0 | 24 | 156 | | | |
| | 1 | k=2 | 9 | 0>27>28>29>30>31>32>33>34>35>0 | 11.3 | 128.2 | 1112.82 | 99.536 | 1212.356 |
| | 2 | | 11 | 0>16>17>18>19>20>21>22>23>24>25>26>0 | 24 | 156 | | | |
| | 3 | k=3 | 8 | 0>16>17>18>19>20>21>22>23>0 | 24.7 | 120.05 | 1669.23 | 112.64 | 1781.87 |
| | 4 | | 3 | 0>24>25>26>0 | 11 | 56.5 | | | |
| | | | 9 | 0>27>28>29>30>31>32>33>34>35>0 | 11.3 | 121.2 | | | |

From the Table 4.10, sensitivity analysis of zone 2, Base case is optimal solution from Mathematical model in section 4.5.2. This routing is two routes by a customer 16-35. Number of customer's place are 9 person, a total distance is 11.3 kilometers and the travel time 128.2 minutes in route number 1 and number of customer's place are 11 persons a total distance is 24 kilometers and the travel time 156 minutes in route number 2 which was 1,218.27 baht per day. If you reduce traveling time by 10 % (168 minutes) and 20 % (144 minutes) can travel using just one vehicle and the cost of transportation same Base case. If reduction of more than 30 % (126 minutes) and 40 % (108 minutes) to travel less than Base case in case it is necessary to increase the travel. Which can travel up to 3 routes: Route 1 has a number of customer's place are 8 with total distance 24.7 kilometers and total traveling time 127.05 minutes, Route 2, have customer's place only 3 people, with total distance 11 kilometers and total traveling time of 56.5 minutes and Route 3 have

customer’s place only 9 people, with total distance 11.3 kilometers and total traveling time of 127.2 minutes which was the total cost 1,790.78 baht per day due to the increasing number of messenger and number of vehicles.

Sensitivity analysis of zone 3 (Eastern Bangkok) is showed in the Table 4.11 and have to analyze a number of routes, number of messenger to pickup specimen, number of vehicles, total distance, total traveling time, and total cost of transportation.

Table 4.11 Sensitivity analysis with reduce total traveling time of zone 3

| Zone | Scenario | No. Vehicle (k) | No. Customer | Optimal Solution | | | Cost/Day | | |
|------|-----------|-----------------|--|---|---------------|-------------------|----------|---------------|------------|
| | | | | Customer Sequence | Distance (km) | Travel time (min) | Fix cost | Variable cost | Total cost |
| 3 | Base case | k=1 | 16 | 0>36>43>44>45>46>48>49>47 >51>50>42>41>40>38>39>37>0 | 18.9 | 113.35 | 556.41 | 69.168 | 625.578 |
| | 1 | k=1 | 16 | 0>36>43>44>45>46>48>49>47 >51>50>42>41>40>38>39>37>0 | 18.9 | 113.35 | 556.41 | 69.168 | 625.578 |
| | 2 | | | | | | | | |
| | 3 | | | | | | | | |
| | 4 | k=2 | 1 | 0>36>0 | 0.4 | 10.6 | 1112.82 | 69.504 | 1182.324 |
| | 15 | | 0>43>44>45>46>48>49>47 >51>50>42>41>40>38>39>37>0 | 18.8 | 108.2 | | | | |

From the Table 4.11, sensitivity analysis of zone 3, Base case is optimal solution from Mathematical model in section 4.5.2. This routing is one route by a customer 36-51 a total distance is 18.9 kilometers and total traveling time 113.35 minute, which was 628.57 baht per day. If you reduce traveling time by 10 % (168 minutes), 20 % (144 minutes) and 30% (126 minutes) can travel using just one vehicle and the cost of transportation same Base case. If reduction of more than 40 % (108 minutes) to travel less than Base case in case it is necessary to increase the travel. Which can travel up to 2 routes: Route 1 has a number of customer’s place are only one with total distance 0.4 kilometers and total traveling time 10.6 minutes and Route 2, have customer’s place are 15 people, with total distance 18.8 kilometers and total traveling time of 105.2 minutes, which was the total cost 1,188.32 baht per day due to the increasing number of messenger and number of vehicles.

Finally, sensitivity analysis of zone 4 (Southern Bangkok) is showed in the Table 4.12 and have to analyze a number of routes, number of

messenger to pickup specimen, number of vehicles, total distance, total traveling time, and total cost of transportation.

Table 4.12 Sensitivity analysis with reduce total traveling time of zone 4

| Zone | Scenario | No. Vehicle (k) | No. Customer | Optimal Solution | | | Cost/Day | | |
|------|-----------|-----------------|-----------------|---|---------------|-------------------|----------|---------------|------------|
| | | | | Customer Sequence | Distance (km) | Travel time (min) | Fix cost | Variable cost | Total cost |
| 4 | Base case | k=1 | 14 | 0>52>53>54>55>64>56>62>57>59>58>60>61>63>65>0 | 82.9 | 127.35 | 556.41 | 134.848 | 691.258 |
| | 1 | k=1 | 14 | 0>52>53>54>55>64>56>62>57>59>58>60>61>63>65>0 | 82.9 | 127.35 | 556.41 | 134.848 | 691.258 |
| | 2 | | | | | | | | |
| | 3 | | | | | | | | |
| | 4 | k=2 | 10 | 0>64>56>62>57>59>58>60>61>63>65>1 | 62.8 | 104.2 | 1112.82 | 123.872 | 1236.692 |
| | 4 | | 0>52>53>54>55>0 | 10.3 | 32.9 | | | | |

From the Table 4.12, sensitivity analysis of zone 4, Base case is optimal solution from Mathematical model in section 4.5.2. This routing is one route by a customer 52-65 a total distance is 82.9 kilometers and total traveling time 127.35 minutes, which was 694.258 baht per day. If you reduce traveling time by 10 % (168 minutes), 20 % (144 minutes) and 30% (126 minutes) can travel using just one vehicle and the cost of transportation same Base case. If reduction of more than 40 % (108 minutes) to travel less than Base case in case it is necessary to increase the travel. Which can travel up to 2 routes: Route 1 has a number of customer's place are 10 persons with total distance 62.8 kilometers and total traveling time 104.2 minutes and Route 2, have customer's place are 4 people, with total distance 10.3 kilometers and total traveling time of 32.9 minutes, which was the total cost 1,254.228 baht per day due to the increasing number of messenger and number of vehicles.

From Table 4.11 to 4.14 we can see that the cost of transport will increase when the number of round trips increased. Which in Zone 1 and 2 will be added to 2 rounds trip, when reduce traveling travel time by 30% (126 minutes) and Zone 3 and 4 will be added to 2 rounds trip, when reduce traveling travel time by 40% (108 minutes) is shown figure 4.17 below.

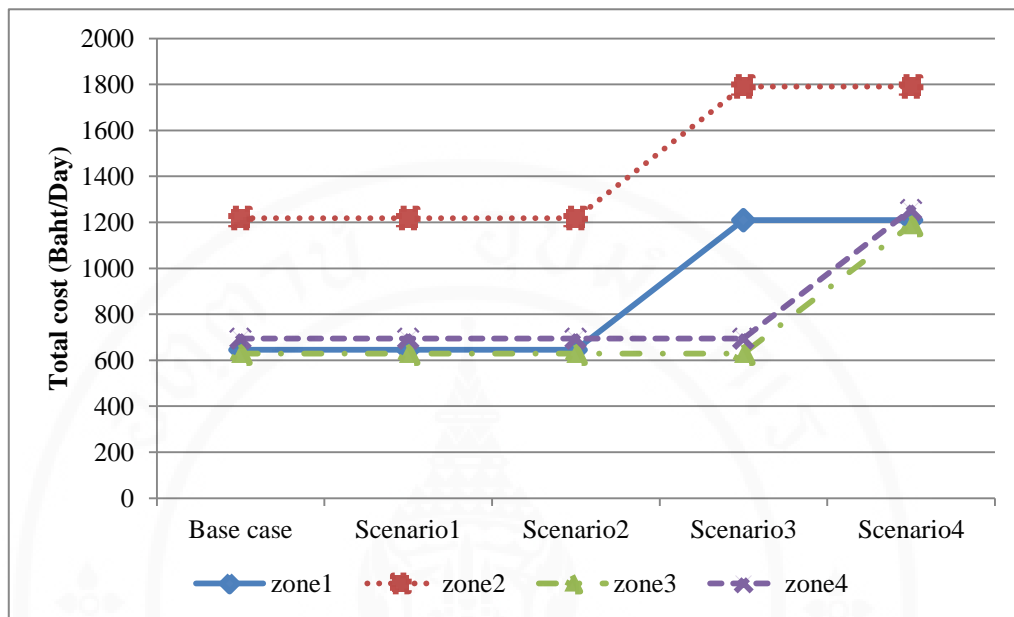


Figure 4.17 Comparison of total cost of transport with reduce traveling time

4.5.3.2 Increase the total traveling time

If the improve the box packaging of human specimen that can lengthen the time it takes to transport the collected specimen can be extended to more than 180 minutes travel time due to problems in the traffic jam or the highway by using the indirect route. So in this section are presented in increasing the traveling time it has to reduce costs of transport. Set the duration is divided into 4 categories of scenario are following.

4.5.3.2.1 Base case (180 minutes)

4.5.3.2.2 Scenario 1: increasing traveling time 10% (198 minutes)

4.5.3.2.3 Scenario 2: increasing traveling time 20% (216 minutes)

4.5.3.2.4 Scenario 3: increasing traveling time 30% (234 minutes)

4.5.3.2.5 Scenario 4: increasing traveling time 40% (252 minutes)

Sensitivity analysis results of the analysis by increasing the duration of the trip using Lindo version 6.1 program is shown in Figure 4.18.

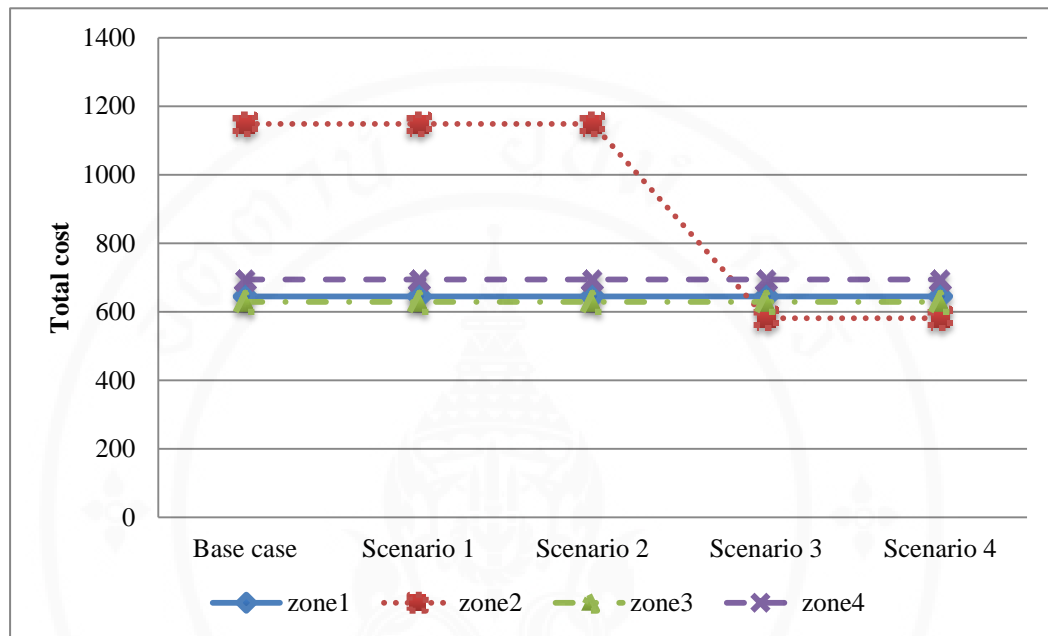


Figure 4.18 Comparison of total cost of transport with increasing traveling time

Figure 4.18 zone 1, 3 and 4 have the optimal solution is the only one vehicle was used in the transport human specimen. Thus, if the increasing traveling time of the trip, it takes only one vehicle like the base case. The zone 2 has optimal solution is 2 vehicles were used to transport human specimen can be seen that Scenario 1 (198 minutes), Scenario 2 (216 minutes) and Scenario 3 (234 minutes) will continue to use only 2 vehicles like the Base case, but if we increase the traveling time of the trip is Scenario 4 (252 minutes) traveling time will be sufficient to route 1 vehicle. Therefore, the system to improve the packaging of human specimens as well, it can extend the traveling time of the trip and reduce the cost of transportation as well. The cost of transportation increases in travel time each Scenario shown in Table 4.13. In scenario 4, zone 2 can be reduced total cost of transport up to 581.71 baht per day or reduce 18.176%.

Table 4.13 Total cost per day of transport with increasing traveling time

| Case Zone | Base case | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|--------------|-----------|------------|------------|------------|------------|
| zone1 | 642.178 | 642.178 | 642.178 | 642.178 | 642.178 |
| zone2 | 1213.49 | 1213.49 | 1213.49 | 581.71 | 581.71 |
| zone3 | 625.578 | 625.578 | 625.578 | 625.578 | 625.578 |
| zone4 | 691.258 | 691.258 | 691.258 | 691.258 | 691.258 |

4.5.3.3 Increasing traveling time of customer’s place to customer’s place

In case of traffic jam traveling time of Laboratory center to customer’s place or customer’s place to customer’s place the period of traveling time of vehicle is higher. So in this section will be to increase the travel time of each customer’s place to customer’s place divided into the following 4 scenarios bellow.

4.5.3.3.1 Base case (180 minutes)

4.5.3.3.2 Scenario1: increasing traveling time per customer’s place 10%

4.5.3.3.3 Scenario2: increasing traveling time per customer’s place 20%

4.5.3.3.4 Scenario3: increasing traveling time per customer’s place 30%

4.5.3.3.5 Scenario4: increasing traveling time per customer’s place 40%

4.5.3.3.6 Scenario5: increasing traveling time per customer’s place 50%

Sensitivity analysis with traveling time per customer’s place of zone 1 (Northern Bangkok) is showed in the Table 4.14 and have to analyze a number of routes, number of messenger to pickup specimen, number of vehicles, total distance, total traveling time, and total cost of transportation.

Table 4.14 Sensitivity analysis with traveling time per customer's place of zone 1

| Zone | Scenario | No. Vehicle (k) | No. Customer | Optimal Solution | | | Cost/Day | | |
|------|-----------|-----------------|--------------|---|---------------|-------------------|----------|---------------|------------|
| | | | | Customer Sequence | Distance (km) | Travel time (min) | Fix cost | Variable cost | Total cost |
| 1 | Base case | k=1 | 15 | 0>3>4>5>6>9>10>11>12> 13>14>15>7>8>1>2>0 | 36.4 | 137.75 | 556.41 | 85.768 | 642.178 |
| | 1 | k=1 | 15 | 0>3>4>5>6>9>10>11>12> 13>14>15>7>8>1>2>1 | 36.4 | 151.525 | 556.41 | 85.768 | 642.178 |
| | 2 | | | 0>3>4>5>6>9>10>11>12> 13>14>15>7>8>1>2>2 | | | | | |
| | 3 | | | 0>3>4>5>6>9>10>11>12> 13>14>15>7>8>1>2>3 | | | | | |
| | 4 | k=2 | 3 | 0>1>2>0 | 31.7 | 172.76 | 1,112.82 | 64.368 | 1,177.19 |
| | | | 12 | 0>5>6>9>10>11>12> 13>14>15>7>8>3>4>0 | | | | | |
| | 5 | | 12 | 0>5>6>9>10>11>12> 13>14>15>7>8>3>4>1 | 9.7 | 44.33 | | | |

From the Table 4.14, sensitivity analysis with traveling time per customer's place of zone 1, Base case is optimal solution from Mathematical model in section 4.5.2. This routing is one route by a customer 1-15 a total distance is 36.4 kilometers and is the travel time 137.75 min, which was 645.18 baht per day. If you increasing traveling time per customer's place by 10%, 20% and 30% can travel using just one vehicle and the cost of transportation same Base case but traveling time are differ from base case: 151.525 minutes, 165.3 minutes and 179.075 minutes are increase traveling time per customer's place 10%, 20% and 30% respectively. If increase of more than 40% and 50% to travel less than Base case in case it is necessary to increase the travel. Which can travel up to 2 routes: Route 1 has a number of customer's place are 3 with total distance 9.7 kilometers and total traveling time 41.37 minutes by increase traveling time per customer's place 40% and Route 2, have customer's place are 12 people, with total distance 31.7 kilometers and total traveling time of 172.76 minutes by increase traveling time per customer's place 50%, which was the total cost 1209.41 baht per day due to the increasing number of messenger and number of vehicles.

Sensitivity analysis with traveling time per customer's place of zone 2 (Western Bangkok) is showed in the Table 4.15 and have to analyze a number of routes, number of messenger to pickup specimen, number of vehicles, total distance, total traveling time, and total cost of transportation.

Table 4.15 Sensitivity analysis with traveling time per customer’s place of zone 2

| Zone | Scenario | No. Vehicle (k) | No. Customer | Optimal Solution | | | Cost/Day | | |
|------|-----------|-----------------|--------------|--------------------------------------|---------------|-------------------|----------|---------------|------------|
| | | | | Customer Sequence | Distance (km) | Travel time (min) | Fix cost | Variable cost | Total cost |
| 2 | Base case | k=2 | 9 | 0>27>28>29>30>31>32>33>34>35>0 | 11.3 | 128.2 | 1,112.82 | 99.536 | 1,212.36 |
| | | | 11 | 0>16>17>18>19>20>21>22>23>24>25>26>0 | 24 | 156 | | | |
| | 1 | k=2 | 9 | 0>27>28>29>30>31>32>33>34>35>0 | 11.3 | 141.02 | 1,112.82 | 99.536 | 1,212.36 |
| | | | 11 | 0>16>17>18>19>20>21>22>23>24>25>26>0 | 24 | 171.6 | | | |
| | 2 | k=3 | 3 | 0>24>25>26>0 | 11 | 67.8 | 1,669.23 | 112.64 | 1,781.87 |
| | | | 8 | 0>16>17>18>19>20>21>22>23>0 | 24.7 | 152.48 | | | |
| | | | 9 | 0>12>13>14>15>16>17>18>19>20>0 | 11.3 | 153.48 | | | |
| | 3 | k=3 | 3 | 0>24>25>26>0 | 11 | 73.45 | | | |
| | | | 8 | 0>16>17>18>19>20>21>22>23>0 | 24.7 | 165.17 | | | |
| | | | 9 | 0>12>13>14>15>16>17>18>19>20>0 | 11.3 | 166.67 | | | |
| | 4 | k=3 | 3 | 0>24>25>26>0 | 11 | 79.1 | | | |
| | | | 8 | 0>16>17>18>19>20>21>22>23>0 | 24.7 | 178.61 | | | |
| | | | 9 | 0>12>13>14>15>16>17>18>19>20>0 | 11.3 | 179.48 | | | |
| | 5 | k=4 | 6 | 0>30>31>32>33>34>35>0 | 11.3 | 147.3 | 2,225.64 | 127.536 | 2,353.18 |
| | | | 5 | 0>16>17>18>19>20>0 | 21.5 | 138.38 | | | |

From the Table 4.14, sensitivity analysis with traveling time per customer’s place of zone 2, Base case is optimal solution from Mathematical model in section 4.5.2. This routing is two routes by a customer 16-35. Number of customer’s place are 9 person, a total distance is 11.3 kilometers and the travel time 128.2 minutes in route number 1 and number of customer’s place are 11 persons a total distance is 24 kilometers and the travel time 156 minutes in route number 2 which was 1,218.27 baht per day. If we increasing traveling time per customer’s place by 10% can travel using just one vehicle and the cost of transportation same base case but traveling time are differ from base case 141.02 minutes and 171.6 minutes in route 1 and 2 respectively. If increase traveling time per customer’s place of between 20% and 40% to travel less than Base case in case it is necessary to increase the travel. Which can travel up to 3 routes: Route 1 has a number of customer’s place are 3 with total distance 11 kilometers and total traveling time 67.8 minutes, 73.45 minutes, 79.1 minutes by a scenario 2, 3 and 4 respectively. Route 2 have customer’s place are 8

people, with total distance 24.7 kilometers and total traveling time of 152.48 minutes, 165.17 minutes, 178.61 minutes by a scenario 2, 3 and 4 respectively. Route 3 have customer's place only 9 people, with total distance 11.3 kilometers and total traveling time of 153.84 minutes, 166.67 minutes, 179.48 minutes by a scenario 2, 3 and 4 respectively. which was the total cost 1,790.78 baht per day due to the increasing number of messenger and number of vehicles. Scenario 5 is increase 50% traveling time per customer's place, which can travel up to 4 routes, route 1 has a number of customer's place are 6 with total distance 11.3 kilometers and total traveling time 147.3 minutes, route 2 has a number of customer's place are 5 with total distance 21.1 kilometers and total traveling time 138.38 minutes, route 3 has a number of customer's place are 6 with total distance 16.5 kilometers and total traveling time 142.13 minutes and route 4 has a number of customer's place are 3 with total distance 11 kilometers and total traveling time 84.75 minutes, which was the total cost 2,365.17 baht per day due to the increasing number of messenger and number of vehicles.

Sensitivity analysis of zone 3 (Eastern Bangkok) is showed in the Table 4.16 and have to analyze a number of routes, number of messenger to pickup specimen, number of vehicles, total distance, total traveling time, and total cost of transportation.

Table 4.16 Sensitivity analysis with traveling time per customer's place of zone 3

| Scenario | No. Vehicle (k) | No. Customer | Optimal Solution | | | Cost/Day | | |
|-----------|-----------------|--------------|---|---------------|-------------------|----------|---------------|------------|
| | | | Customer Sequence | Distance (km) | Travel time (min) | Fix cost | Variable cost | Total cost |
| Base case | k=1 | 16 | 0>36>43>44>45>46>48>49>47>51>50>42>41>40>38>39>37>0 | 18.9 | 113.35 | 556.41 | 69.168 | 625.578 |
| 1 | k=1 | 16 | 0>36>43>44>45>46>48>49>47>51>50>42>41>40>38>39>37>0 | 18.9 | 124.685 | 556.41 | 69.168 | 625.578 |
| 2 | | | | | 136.02 | | | |
| 3 | | | | | 147.355 | | | |
| 4 | | | | | 158.69 | | | |
| 5 | | | | | 170.025 | | | |

From the Table 4.16, sensitivity analysis with traveling time per customer's place of zone 3, Base case is optimal solution from Mathematical model in section 4.5.2. This routing is one route by a customer 36-51 a total distance is

36.4 kilometers and is the travel time 137.75 min, which was 645.18 baht per day. If you increasing traveling time per customer’s place by all scenario 10%, 20%, 30%, 40% and 50% can travel using just one vehicle and the cost of transportation same Base case but traveling time are differ from base case: 124.685 minutes, 136.02 minutes, 147.355 minutes, 158.69 minutes and 170.025 minutes are increase traveling time per customer’s place 10%, 20%, 30%, 40% and 50% respectively. In scenario 5 total traveling time is 170.025 minutes are enough to travel for one round but if increase traveling time more than 50% number of route more than 1 route.

Sensitivity analysis of zone 4 (Southern Bangkok) is showed in the Table 4.17 and have to analyze a number of routes, number of messenger to pickup specimen, number of vehicles, total distance, total traveling time, and total cost of transportation.

Table 4.17 Sensitivity analysis with traveling time per customer’s place of zone 4

| Scenario | No. Vehicle (k) | No. Customer | Optimal Solution | | | Cost/Day | | |
|-----------|-----------------|--------------|---|---------------|-------------------|----------|---------------|------------|
| | | | Customer Sequence | Distance (km) | Travel time (min) | Fix cost | Variable cost | Total cost |
| Base case | k=1 | 14 | 0>52>53>54>55>64>56>62>57>59>58>60>61>63>65>0 | 82.9 | 127.35 | 556.41 | 134.848 | 691.258 |
| 1 | k=1 | 14 | 0>52>53>54>55>64>56>62>57>59>58>60>61>63>65>0 | 82.9 | 140.085 | 556.41 | 134.848 | 691.258 |
| 2 | | | 0>52>53>54>55>64>56>62>57>59>58>60>61>63>65>0 | | 152.82 | | | |
| 3 | | | 0>52>53>54>55>64>56>62>57>59>58>60>61>63>65>0 | | 165.555 | | | |
| 4 | | | 0>52>53>54>55>64>56>62>57>59>58>60>61>63>65>0 | | 178.29 | | | |
| 5 | k=2 | 10 | 0>64>56>62>57>59>58>60>61>63>65>1 | 62.8 | 156.3 | 1112.82 | 123.872 | 1236.692 |
| | | 4 | 0>52>53>54>55>0 | 10.3 | 49.35 | | | |

From the Table 4.17, sensitivity analysis with traveling time per customer’s place of zone 4, Base case is optimal solution from Mathematical model in section 4.5.2. This routing is one route by a customer 52-65 a total distance is 82.9 kilometers and is the travel time 127.35 minutes, which was 694.258 baht per day. If you increasing traveling time per customer’s place by 10%, 20%, 30% and 40% can travel using just one vehicle and the cost of transportation same Base case but traveling time are differ from base case: 140.085 minutes, 152.82 minutes 165.555 minutes and 178.29 minutes are increase traveling time per customer’s place 10%, 20%, 30% and 40% respectively. If increase of more than 50% to travel less than Base

case in case it is necessary to increase the travel. Which can travel up to 2 routes: Route 1 has a number of customer's place are 10 with total distance 62.8 kilometers and total traveling time 156.3 minutes and Route 2, have customer's place are 4 people, with total distance 10.3 kilometers and total traveling time of 49.35 minutes, which was the total cost 1254.23 baht per day due to the increasing number of messenger and number of vehicles.

4.6 Comparison of quick solution method and Mathematical model

This section we compare the results of the two methods, which between Quick solution method and Mathematical model. The analysis is a comparison of three parts: the distance and traveling time, the number of messenger and vehicles and the cost of transportation. The results of the analysis of section 4.4 and 4.5 as a result of the way the quick solution method and Mathematical model respectively, the results are shown in Table 4.18.

Table 4.18 Comparison result between Quick solution method and Mathematical model

| Method | Number of trip / zone | | | | Total distance | Total travel time | Cost of transport | % Saving |
|--------------------|-----------------------|--------|--------|--------|----------------|-------------------|-------------------|----------|
| | Zone 1 | Zone 2 | Zone 3 | Zone 4 | | | | |
| Base case | 2 | 2 | 2 | 2 | 570 | 855 | 5,248.08 | - |
| Quick solution | 1 | 2 | 1 | 1 | 195.8 | 681 | 3,196.35 | 39.09% |
| Mathematical model | 1 | 2 | 1 | 1 | 173.5 | 669 | 3,172.5 | 39.54% |

From Table 4.18 we can be seen that the number of trips in base case per each zone to use 2 vehicles and 8 messengers. The number of vehicles used to transport human specimens depends on which one route per 1 vehicle and 1 messenger, with no basis in the routing clearly by making the distance to travel to 570

kilometers and total traveling time (including 4 zone) is 855 minutes. Therefore, the number of messenger and much more distances used in traveling. So, the cost of transporting up to 5248.08 baht per day.

Quick solution method are initial routing with basic criteria, the distance nearest laboratory center to customer's place, and the customer's place to the customer's place and total traveling time equal 180 minutes. We can be seen that each zone has a number of routes that is zone 1, 3, 4 have only one route and the zone 2 have two routes and the messenger in all five people, which reduced the number of messenger from the base case with 3 people. From the historical distance of the nearest laboratory center to the customer's place, and the customer's place to the customer's place are making the distance is equal 195.8 kilometers, which can reduce the distance of up to 65.64% from base case and resulted in a traveling time of reduced travel with up to 681 minutes, reducing the base case 20.35%. The Quick solution method reduction in number of messenger, vehicles and total distance traveled as a result transportation costs fell as well down to 3,196.35 baht per day equivalent to 39.09 %.

Mathematical model are constructed by Traveling Salesman Problem model (TSP) and adding time constraint, total traveling time equal 180 minutes. We can be seen that each zone has a number of routes that is zone 1, 3, 4 have only one route and the zone 2 have two routes and the messenger in all five people, which reduced the number of messenger from the base case with 3 people as same as quick solution method. From the historical distance of the nearest laboratory center to the customer's place, and the customer's place to the customer's place are making the distance is equal 173.5 kilometers, which can reduce the distance of up to 69.56% from base case and resulted in a traveling time of reduced travel with up to 669 minutes, reducing the base case 21.75%. The mathematical model reduction in number of messenger, vehicles and total distance traveled as a result transportation costs fell as well down to 3,172.5 baht per day equivalent to 39.54 %.

According to the number of trip is equal to 2 methods but total distance and total traveling time are difference. Mathematical model can be result of total distance and total traveling time greater than quick solution method. Mathematical model can be find optimal solution and find limit of traveling time in case traffic jam

and save total cost of transportation greater than quick solution method equal 0.45%. Cost saving percentage of transporting are same 2 methods, and effect to objective function is calculated by fix cost and add variable cost (which changes with distance) in each zone of the same parameters C_{ij} . So, cost saving percentage of the two methods is similar.

An advantage of Quick solution is faster to find out the best solution because it is simply use and does not require a complicated computing application; MS Excel is applicable. The result of quick solution is able to replace a new cost-saving solution.

Considering on mathematical model, it requires understanding on creating model, setting up conditions and related software. To create a mathematical model, it requires more computation time since all possible solutions will be restructured in order to find out optimal solution. However, the purpose of this research is to explore a sub-problem for 65 customers. A further study of 152 customers would be result of better cost saving solution. Hence, the use of Mathematical model is more effective than Quick Solution because it is able to analyze all possible solution and flexibility to adjust constrains.

Adjustment in zoning of customers would be resulted to change of optimal solution in mathematical model since all of customers will be visited (i,j). Therefore, changing in customer zoning, would be affected logistic management because of optimal solution determined highest cost-saving and optimized travelling period. The other solution would be lower effective.

To reorganize new route, some direction would be able to pick up human specimen and return to laboratory within travelling condition; e.g. the route of 90 minutes is under travelling condition of 180 minutes which is able to implement a second route by a same vehicle. If a combination of two routes spends total travelling time within 180 minutes with only one vehicle, it results to reduce management cost and investment cost; a number of vehicles and messengers but effect to flexibility of laboratory center; time delay in human specimen testing because human specimen into laboratory center is not simultaneously.

CHAPTER V

CONCLUSION

This chapter has divided into two sections: 5.1 will be presented the conclusion of this research and the recommendations for future will be presented in section 5.2.

5.1 Conclusions

In the present, the laboratory center provides service for diagnosis and treatment, specimen testing too many hospitals, clinics, companies and also people which decrease in every year. In addition, the center need to provide transportation services which transport the specimen from the customer to the center and on the other hand delivery the result to the customer. For this business, transportation of specimen is more challenge than the other because the specimen is very delicate and easy to contaminate, damage within the time period and need to storage in specific temperature , so the transportation need to achieve the customer satisfaction beneath the time constrain . In the past, the center managed and designed route by using experience and the location of customer. When a number of customers decrease, the new route occurs and the center have to bear higher cost. Without a systematic routing, many customers are on more than one route because of the route overlap. Thus, the systematic routing can solve this problem and reduce the cost of service for laboratory center.

In this study, the quick solution method and mathematical model were used to decide the route for laboratory center. The quick solution method begin with classify the group of customer's place and design the route by using shortest distance for each node. For mathematical modeling, the travelling salesman problem was adapted to fit for this business by adding time constrain. The result show that both of models have better result from as is operation. The quick solution method can be able

to service all customers by using 5 vehicles for 5 routes – one car per route which is less than the base case. The mathematical modeling services all customers by using 5 vehicles for 5 routes. Moreover, the cost from routing by quick solution method and mathematical modeling is reduced equal to 39.09% and 39.58% respectively or around 3,196.35 baht per day for heuristics and 3,172.5 baht per day for mathematical modeling.

For the laboratory center business, the systematic routing can increase the utilization of resource such as transport service within the same condition and also reduce the cost of company. The heuristics model is easy to use for routing because the criteria is selected from experience and the model is not complex, but the routing from these criteria is not always the best or optimal solution. The mathematical modeling has the better result than the quick solution because it calculates the entire possible route and compares each other to find the optimal solution. Moreover mathematical model can adjust the constraint or criteria according to the characteristics of problem. So, the mathematical modeling can imitate and find the answers close to the real problem.

5.2 Recommendation

If the improve the box packaging of human specimen that can lengthen the traveling time. It takes to transport the pickup human specimen can be extended to more than 180 minutes travel time due to problems in the traffic jam or the highway by using the indirect route, which can be reduced travel trip and transportation cost.

A new routing by only group of customers (sub problem) is that the response time using the shorter route. Easy to administer on increasing and decreasing the number of customers. Which have an impact on the zone, which is easier to manage the entire path. If in the future, to study new routes. Without breaking zone may improve the delivery of the company's more powerful than this . But take a longer route .

For the future research, the constraint which is exclude from this research may add to the model for the better result and closer to the real operation such as capacity of truck, the rush service or the time schedule for some customer. Moreover,

the establishment of hub in each area instead of routing may increase efficiency for transportation service and may reduce costs even more.

Since many of the human specimens are more every year therefore, there are many more customers in each zone to construction medical hub for pickup human specimen in each zone. Medical hub are constructed, it can be reduce a number of trip to pickup human specimen but laboratory center have invested a lot to build medical hub.

To reorganize new route, some direction would be able to pick up human specimen and return to laboratory within travelling time condition; e.g. the route of 90 minutes is under travelling condition of 180 minutes which is able to implement a second route by a same vehicle. If a combination of two routes spends total travelling time within 180 minutes with only one vehicle, it results to reduce management cost and investment cost; a number of vehicles and messengers but effect to flexibility of laboratory center; time delay in human specimen testing because human specimen into laboratory center is not simultaneously.

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APPENDIX A DISTANCE MATRIC

Table A.1 Distance matric of customer zone 1

| Distance (Km.) | Laboratory center | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 | C10 | C11 | C12 | C13 | C14 | C15 |
|-------------------|-------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------|
| Laboratory center | 0 | 2.9 | 3.3 | 3.7 | 4.1 | 4.5 | 4.9 | 5.3 | 3.6 | 5.4 | 7.7 | 9.3 | 9.7 | 9.9 | 10.2 | 11.2 |
| C1 | 2.9 | 0 | 3.5 | 3.9 | 4.3 | 4.7 | 5.1 | 5.5 | 1.5 | 3.3 | 5.6 | 7.2 | 7.6 | 7.6 | 7.9 | 8.8 |
| C2 | 3.3 | 3.5 | 0 | 3.3 | 3.7 | 4.1 | 4.5 | 4.9 | 1.2 | 3 | 5.3 | 6.9 | 7.3 | 7.4 | 7.7 | 8.6 |
| C3 | 3.7 | 3.9 | 3.3 | 0 | 3.1 | 3.5 | 3.9 | 4.3 | 1.1 | 2.9 | 5.2 | 6.8 | 7.2 | 7.3 | 7.6 | 8.5 |
| C4 | 4.1 | 4.3 | 3.7 | 3.1 | 0 | 3.1 | 3.5 | 3.9 | 1 | 2.8 | 5.1 | 6.7 | 7.1 | 7.1 | 7.4 | 8.2 |
| C5 | 4.5 | 4.7 | 4.1 | 3.5 | 3.1 | 0 | 2.4 | 2.8 | 0.7 | 2.5 | 4.8 | 6.4 | 6.8 | 6.9 | 7.2 | 8.1 |
| C6 | 4.9 | 5.1 | 4.5 | 3.9 | 3.5 | 2.4 | 0 | 2.4 | 0.5 | 2.3 | 4.6 | 6.2 | 6.6 | 6.7 | 7 | 8 |
| C7 | 5.3 | 5.5 | 4.9 | 4.3 | 3.9 | 2.8 | 2.4 | 0 | 0.2 | 2 | 4.3 | 5.9 | 6.3 | 6.8 | 7.1 | 7.5 |
| C8 | 3.6 | 1.5 | 1.2 | 1.1 | 1 | 0.7 | 0.5 | 0.2 | 0 | 1.8 | 4.1 | 5.7 | 6.1 | 6.6 | 6.9 | 7.1 |
| C9 | 5.4 | 3.3 | 3 | 2.9 | 2.8 | 2.5 | 2.3 | 2 | 1.8 | 0 | 2.3 | 3.9 | 4.3 | 4.7 | 5 | 5.8 |
| C10 | 7.7 | 5.6 | 5.3 | 5.2 | 5.1 | 4.8 | 4.6 | 4.3 | 4.1 | 2.3 | 0 | 1.6 | 2 | 2.5 | 2.8 | 3.6 |
| C11 | 9.3 | 7.2 | 6.9 | 6.8 | 6.7 | 6.4 | 6.2 | 5.9 | 5.7 | 3.9 | 1.6 | 0 | 0.4 | 0.9 | 1.2 | 1.9 |
| C12 | 9.7 | 7.6 | 7.3 | 7.2 | 7.1 | 6.8 | 6.6 | 6.3 | 6.1 | 4.3 | 2 | 0.4 | 0 | 0.6 | 0.9 | 1.6 |
| C13 | 9.9 | 7.6 | 7.4 | 7.3 | 7.1 | 6.9 | 6.7 | 6.8 | 6.6 | 4.7 | 2.5 | 0.9 | 0.6 | 0 | 0.3 | 0.8 |
| C14 | 10.2 | 7.9 | 7.7 | 7.6 | 7.4 | 7.2 | 7 | 7.1 | 6.9 | 5 | 2.8 | 1.2 | 0.9 | 0.3 | 0 | 0.6 |
| C15 | 11.2 | 8.8 | 8.6 | 8.5 | 8.2 | 8.1 | 8 | 7.5 | 7.1 | 5.8 | 3.6 | 1.9 | 1.6 | 0.8 | 0.6 | 0 |

Table A.2 Distance matric of customer zone 2.

| Distance (Km.) | Laboratory Center | C16 | C17 | C18 | C19 | C20 | C21 | C22 | C23 | C24 | C25 | C26 | C27 | C28 | C29 | C30 | C31 | C32 | C33 | C34 | C35 |
|-------------------|-------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------|------|
| Laboratory Center | 0 | 1.3 | 7.1 | 7.9 | 8.9 | 8 | 6.9 | 6 | 7.1 | 5.6 | 4.9 | 5 | 5.1 | 5.2 | 5.8 | 6.2 | 6.5 | 7.4 | 7.8 | 7.7 | 7.6 |
| C16 | 1.3 | 0 | 7.8 | 8.1 | 9 | 8.1 | 6.7 | 5.2 | 5.4 | 4.6 | 3.9 | 4 | 4.1 | 4.2 | 4.8 | 5.2 | 5.5 | 6.4 | 6.5 | 6.4 | 6.3 |
| C17 | 7.1 | 7.8 | 0 | 2.4 | 3.7 | 3.5 | 4.4 | 3.5 | 6.9 | 7.5 | 6.8 | 6.9 | 7 | 7.1 | 7.7 | 8.1 | 8.4 | 9.3 | 10.8 | 10.7 | 10.6 |
| C18 | 7.9 | 8.1 | 2.4 | 0 | 1.3 | 1.1 | 2.5 | 3.7 | 5 | 6 | 5.3 | 5.4 | 5.5 | 5.6 | 6.2 | 6.6 | 6.9 | 7.8 | 9.5 | 9.4 | 9.3 |
| C19 | 8.9 | 9 | 3.7 | 1.3 | 0 | 0.7 | 2.7 | 2.7 | 4.9 | 6.1 | 5.4 | 5.5 | 5.6 | 5.7 | 6.3 | 6.7 | 7 | 7.9 | 9.6 | 9.5 | 9.4 |
| C20 | 8 | 8.1 | 3.5 | 1.1 | 0.7 | 0 | 1.6 | 1.5 | 4.1 | 5.2 | 4.5 | 4.6 | 4.7 | 4.8 | 5.4 | 5.8 | 6.1 | 7 | 8.8 | 8.7 | 8.6 |
| C21 | 6.9 | 6.7 | 4.4 | 2.5 | 2.7 | 1.6 | 0 | 0.9 | 2.5 | 3.5 | 2.8 | 2.9 | 3 | 3.1 | 3.7 | 4.1 | 4.4 | 5.3 | 7.1 | 7 | 6.9 |
| C22 | 6 | 5.2 | 3.5 | 3.7 | 2.7 | 1.5 | 0.9 | 0 | 1.6 | 2.4 | 1.7 | 1.8 | 1.9 | 2 | 2.6 | 3 | 3.3 | 4.2 | 6 | 5.9 | 5.8 |
| C23 | 7.1 | 5.4 | 6.9 | 5 | 4.9 | 4.1 | 2.5 | 1.6 | 0 | 1 | 0.3 | 0.4 | 0.5 | 0.6 | 1.2 | 1.6 | 1.9 | 2.8 | 4.9 | 4.8 | 4.7 |
| C24 | 5.6 | 4.6 | 7.5 | 6 | 6.1 | 5.2 | 3.5 | 2.4 | 1 | 0 | 0.2 | 0.1 | 0.2 | 0.3 | 0.6 | 0.4 | 0.7 | 1.6 | 4.1 | 4 | 3.9 |
| C25 | 4.9 | 3.9 | 6.8 | 5.3 | 5.4 | 4.5 | 2.8 | 1.7 | 0.3 | 0.2 | 0 | 0.2 | 0.3 | 0.4 | 0.4 | 0.8 | 1.1 | 2 | 3.5 | 3.4 | 3.3 |
| C26 | 5 | 4 | 6.9 | 5.4 | 5.5 | 4.6 | 2.9 | 1.8 | 0.4 | 0.1 | 0.2 | 0 | 0.1 | 0.1 | 0.7 | 1.1 | 1.4 | 2.3 | 3.4 | 3.3 | 3.2 |
| C27 | 5.1 | 4.1 | 7 | 5.5 | 5.6 | 4.7 | 3 | 1.9 | 0.5 | 0.2 | 0.3 | 0.1 | 0 | 0.2 | 0.8 | 1.2 | 1.5 | 2.4 | 3.3 | 3.2 | 3.1 |
| C28 | 5.2 | 4.2 | 7.1 | 5.6 | 5.7 | 4.8 | 3.1 | 2 | 0.6 | 0.3 | 0.4 | 0.1 | 0.2 | 0 | 0.6 | 1 | 1.3 | 2.2 | 3.6 | 3.5 | 3.4 |
| C29 | 5.8 | 4.8 | 7.7 | 6.2 | 6.3 | 5.4 | 3.7 | 2.6 | 1.2 | 0.6 | 0.4 | 0.7 | 0.8 | 0.6 | 0 | 0.3 | 0.6 | 1.5 | 3.8 | 3.7 | 3.6 |
| C30 | 6.2 | 5.2 | 8.1 | 6.6 | 6.7 | 5.8 | 4.1 | 3 | 1.6 | 0.4 | 0.8 | 1.1 | 1.2 | 1 | 0.3 | 0 | 0.3 | 1.2 | 3.6 | 3.5 | 3.4 |
| C31 | 6.5 | 5.5 | 8.4 | 6.9 | 7 | 6.1 | 4.4 | 3.3 | 1.9 | 0.7 | 1.1 | 1.4 | 1.5 | 1.3 | 0.6 | 0.3 | 0 | 0.9 | 3.1 | 3 | 2.9 |
| C32 | 7.4 | 6.4 | 9.3 | 7.8 | 7.9 | 7 | 5.3 | 4.2 | 2.8 | 1.6 | 2 | 2.3 | 2.4 | 2.2 | 1.5 | 1.2 | 0.9 | 0 | 3.4 | 3.3 | 3.2 |
| C33 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0 | 0.2 | 0.3 |
| C34 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0 | 0.2 |
| C35 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.3 | 0.2 | 0 |

Table A.3 Distance matrix of customer zone 3.

| Distance (Km.) | Laboratory Center | C36 | C37 | C38 | C39 | C40 | C41 | C42 | C43 | C44 | C45 | C46 | C47 | C48 | C49 | C50 | C51 |
|-------------------|-------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Laboratory Center | 0 | 0.2 | 0.6 | 2.9 | 1.3 | 2.5 | 2.9 | 2.3 | 0.8 | 3.2 | 3.9 | 2.6 | 4.8 | 1.9 | 3.7 | 7 | 4.7 |
| C36 | 0.2 | 0 | 0.5 | 2.7 | 1.1 | 2.2 | 2.6 | 2.3 | 0.7 | 2.6 | 3.3 | 2 | 4.5 | 2.1 | 3.5 | 6.9 | 4.6 |
| C37 | 0.6 | 0.5 | 0 | 2.5 | 0.9 | 2.3 | 2.7 | 2.5 | 1.2 | 3.1 | 3.8 | 2.5 | 4.4 | 2.3 | 3.7 | 6.6 | 4.3 |
| C38 | 2.9 | 2.7 | 2.5 | 0 | 1.6 | 1.7 | 1.4 | 2 | 2.8 | 4.2 | 4.9 | 3.6 | 3.5 | 2.9 | 3.9 | 5.4 | 3.1 |
| C39 | 1.3 | 1.1 | 0.9 | 1.6 | 0 | 1.8 | 2 | 2.3 | 1.6 | 3.5 | 4.2 | 2.9 | 4.3 | 2.3 | 3.8 | 6.5 | 4.2 |
| C40 | 2.5 | 2.2 | 2.3 | 1.7 | 1.8 | 0 | 0.4 | 0.4 | 1.8 | 2.6 | 3.3 | 2 | 2.5 | 1.3 | 2.2 | 4.7 | 2.4 |
| C41 | 2.9 | 2.6 | 2.7 | 1.4 | 2 | 0.4 | 0 | 0.5 | 2.4 | 3 | 3.7 | 2.4 | 2.2 | 1.8 | 2.6 | 4.4 | 2.1 |
| C42 | 2.3 | 2.3 | 2.5 | 2 | 2.3 | 0.4 | 0.5 | 0 | 2.2 | 2.5 | 3.2 | 1.9 | 2 | 1.3 | 1.8 | 4.2 | 1.9 |
| C43 | 0.8 | 0.7 | 1.2 | 2.8 | 1.6 | 1.8 | 2.4 | 2.2 | 0 | 0.8 | 1.5 | 1.7 | 4 | 1.3 | 2.9 | 6.5 | 4.2 |
| C44 | 3.2 | 2.6 | 3.1 | 4.2 | 3.5 | 2.6 | 3 | 2.5 | 0.8 | 0 | 0.7 | 1.9 | 4.9 | 2.1 | 3.3 | 7.4 | 5.1 |
| C45 | 3.9 | 3.3 | 3.8 | 4.9 | 4.2 | 3.3 | 3.7 | 3.2 | 1.5 | 0.7 | 0 | 1.3 | 4.3 | 1.7 | 2.5 | 6.9 | 4.6 |
| C46 | 2.6 | 2 | 2.5 | 3.6 | 2.9 | 2 | 2.4 | 1.9 | 1.7 | 1.9 | 1.3 | 0 | 3 | 0.6 | 1.3 | 5.7 | 3.4 |
| C47 | 4.8 | 4.5 | 4.4 | 3.5 | 4.3 | 2.5 | 2.2 | 2 | 4 | 4.9 | 4.3 | 3 | 0 | 2.8 | 1.9 | 2.5 | 0.2 |
| C48 | 1.9 | 2.1 | 2.3 | 2.9 | 2.3 | 1.3 | 1.8 | 1.3 | 1.3 | 2.1 | 1.7 | 0.6 | 2.8 | 0 | 1.5 | 5.3 | 3 |
| C49 | 3.7 | 3.5 | 3.7 | 3.9 | 3.8 | 2.2 | 2.6 | 1.8 | 2.9 | 3.3 | 2.5 | 1.3 | 1.9 | 1.5 | 0 | 4.5 | 2.2 |
| C50 | 7 | 6.9 | 6.6 | 5.4 | 6.5 | 4.7 | 4.4 | 4.2 | 6.5 | 7.4 | 6.9 | 5.7 | 2.5 | 5.3 | 4.5 | 0 | 1.5 |
| C51 | 4.7 | 4.6 | 4.3 | 3.1 | 4.2 | 2.4 | 2.1 | 1.9 | 4.2 | 5.1 | 4.6 | 3.4 | 0.2 | 3 | 2.2 | 1.5 | 0 |

Table A.4 Distance matrix of customer zone 4.

| Distance (Km.) | Laboratory Center | C52 | C53 | C54 | C55 | C56 | C57 | C58 | C59 | C60 | C61 | C62 | C63 | C64 | C65 |
|-------------------|-------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Laboratory Center | 0 | 0.3 | 1.5 | 8.9 | 10.1 | 18.4 | 21.2 | 22.8 | 22.3 | 22.4 | 23.2 | 21 | 36.1 | 18.3 | 15.5 |
| C52 | 0.3 | 0 | 1.3 | 9.2 | 10.3 | 18.2 | 21.7 | 23.3 | 22.8 | 22.9 | 23.7 | 24.2 | 36.8 | 17.9 | 15.7 |
| C53 | 1.5 | 1.3 | 0 | 8.3 | 9.8 | 18.1 | 21.4 | 23 | 22.5 | 22.6 | 23.4 | 20.7 | 37.1 | 18.1 | 16.9 |
| C54 | 8.9 | 9.2 | 8.3 | 0 | 2.1 | 10 | 14 | 15.1 | 15.2 | 15.6 | 15.7 | 12.1 | 29.1 | 10.2 | 15.4 |
| C55 | 10.1 | 10.3 | 9.8 | 2.1 | 0 | 8.6 | 13 | 13.2 | 13.9 | 13.7 | 14.1 | 10.8 | 27.4 | 8.5 | 13.4 |
| C56 | 18.4 | 18.2 | 18.1 | 10 | 8.6 | 0 | 6.4 | 6.8 | 6.9 | 7.1 | 7.4 | 4.3 | 19.8 | 2.3 | 17.3 |
| C57 | 21.2 | 21.7 | 21.4 | 14 | 13 | 6.4 | 0 | 2.5 | 2 | 3.2 | 3.5 | 4 | 18 | 8 | 23.2 |
| C58 | 22.8 | 23.3 | 23 | 15.1 | 13.2 | 6.8 | 2.5 | 0 | 0.6 | 0.5 | 0.7 | 4.5 | 17.9 | 8.2 | 23.4 |
| C59 | 22.3 | 22.8 | 22.5 | 15.2 | 13.9 | 6.9 | 2 | 0.6 | 0 | 0.7 | 1.2 | 5.1 | 18 | 8.2 | 24.1 |
| C60 | 22.4 | 22.9 | 22.6 | 15.6 | 13.7 | 7.1 | 3.2 | 0.5 | 0.7 | 0 | 0.6 | 5.5 | 19 | 7.2 | 25.4 |
| C61 | 23.2 | 23.7 | 23.4 | 15.7 | 14.1 | 7.4 | 3.5 | 0.7 | 1.2 | 0.6 | 0 | 4.4 | 17 | 7.5 | 23.1 |
| C62 | 21 | 24.2 | 20.7 | 12.1 | 10.8 | 4.3 | 4 | 4.5 | 5.1 | 5.5 | 4.4 | 0 | 16.2 | 6.5 | 21.1 |
| C63 | 36.1 | 36.8 | 37.1 | 29.1 | 27.4 | 19.8 | 18 | 17.9 | 18 | 19 | 17 | 16.2 | 0 | 19 | 15.6 |
| C64 | 18.3 | 17.9 | 18.1 | 10.2 | 8.5 | 2.3 | 8 | 8.2 | 8.2 | 7.2 | 7.5 | 6.5 | 19 | 0 | 15.6 |
| C65 | 15.5 | 15.7 | 16.9 | 15.4 | 13.4 | 17.3 | 23.2 | 23.4 | 24.1 | 25.4 | 23.1 | 21.1 | 15.6 | 15.6 | 0 |

APPENDIX B

TRAVELING TIME MATRIC

Table B.1 Traveling time matric of customer zone 1

| Traveling time (Min.) | Laboratory Center | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 | C10 | C11 | C12 | C13 | C14 | C15 |
|-----------------------|-------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Laboratory Center | 0 | 9.35 | 9.95 | 10.6 | 11.2 | 11.8 | 12.4 | 13 | 10.4 | 13.1 | 16.6 | 19 | 19.6 | 19.9 | 20.3 | 21.8 |
| C1 | 9.35 | 0 | 10.3 | 10.9 | 11.5 | 12.1 | 12.7 | 13.3 | 7.25 | 9.95 | 13.4 | 15.8 | 16.4 | 16.4 | 16.9 | 18.2 |
| C2 | 9.95 | 10.3 | 0 | 9.95 | 10.6 | 11.2 | 11.8 | 12.4 | 6.8 | 9.5 | 13 | 15.4 | 16 | 16.1 | 16.6 | 17.9 |
| C3 | 10.6 | 10.9 | 9.95 | 0 | 9.65 | 10.3 | 10.9 | 11.5 | 6.65 | 9.35 | 12.8 | 15.2 | 15.8 | 16 | 16.4 | 17.8 |
| C4 | 11.2 | 11.5 | 10.6 | 9.65 | 0 | 9.65 | 10.3 | 10.9 | 6.5 | 9.2 | 12.7 | 15.1 | 15.7 | 15.7 | 16.1 | 17.3 |
| C5 | 11.8 | 12.1 | 11.2 | 10.3 | 9.65 | 0 | 8.6 | 9.2 | 6.05 | 8.75 | 12.2 | 14.6 | 15.2 | 15.4 | 15.8 | 17.2 |
| C6 | 12.4 | 12.7 | 11.8 | 10.9 | 10.3 | 8.6 | 0 | 8.6 | 5.75 | 8.45 | 11.9 | 14.3 | 14.9 | 15.1 | 15.5 | 17 |
| C7 | 13 | 13.3 | 12.4 | 11.5 | 10.9 | 9.2 | 8.6 | 0 | 5.3 | 8 | 11.5 | 13.9 | 14.5 | 15.2 | 15.7 | 16.3 |
| C8 | 10.4 | 7.25 | 6.8 | 6.65 | 6.5 | 6.05 | 5.75 | 5.3 | 0 | 7.7 | 11.2 | 13.6 | 14.2 | 14.9 | 15.4 | 15.7 |
| C9 | 13.1 | 9.95 | 9.5 | 9.35 | 9.2 | 8.75 | 8.45 | 8 | 7.7 | 0 | 8.45 | 10.9 | 11.5 | 12.1 | 12.5 | 13.7 |
| C10 | 16.6 | 13.4 | 13 | 12.8 | 12.7 | 12.2 | 11.9 | 11.5 | 11.2 | 8.45 | 0 | 7.4 | 8 | 8.75 | 9.2 | 10.4 |
| C11 | 19 | 15.8 | 15.4 | 15.2 | 15.1 | 14.6 | 14.3 | 13.9 | 13.6 | 10.9 | 7.4 | 0 | 5.6 | 6.35 | 6.8 | 7.85 |
| C12 | 19.6 | 16.4 | 16 | 15.8 | 15.7 | 15.2 | 14.9 | 14.5 | 14.2 | 11.5 | 8 | 5.6 | 0 | 5.9 | 6.35 | 7.4 |
| C13 | 19.9 | 16.4 | 16.1 | 16 | 15.7 | 15.4 | 15.1 | 15.2 | 14.9 | 12.1 | 8.75 | 6.35 | 5.9 | 0 | 5.45 | 6.2 |
| C14 | 20.3 | 16.9 | 16.6 | 16.4 | 16.1 | 15.8 | 15.5 | 15.7 | 15.4 | 12.5 | 9.2 | 6.8 | 6.35 | 5.45 | 0 | 5.9 |
| C15 | 21.8 | 18.2 | 17.9 | 17.8 | 17.3 | 17.2 | 17 | 16.3 | 15.7 | 13.7 | 10.4 | 7.85 | 7.4 | 6.2 | 5.9 | 0 |

Table B.2 Traveling time matric of customer zone 2.

| Travel time (min) | Laboratory Center | C16 | C17 | C18 | C19 | C20 | C21 | C22 | C23 | C24 | C25 | C26 | C27 | C28 | C29 | C30 | C31 | C32 | C33 | C34 | C35 |
|-------------------|-------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Laboratory Center | 0 | 11.95 | 20.65 | 21.85 | 23.35 | 22 | 20.35 | 19 | 20.65 | 18.4 | 17.35 | 17.5 | 17.65 | 17.8 | 18.7 | 19.3 | 19.75 | 21.1 | 21.7 | 21.55 | 21.4 |
| C16 | 11.95 | 0 | 21.7 | 22.15 | 23.5 | 22.15 | 20.05 | 17.8 | 18.1 | 16.9 | 15.85 | 16 | 16.15 | 16.3 | 17.2 | 17.8 | 18.25 | 19.6 | 19.75 | 19.6 | 19.45 |
| C17 | 20.65 | 21.7 | 0 | 13.6 | 15.55 | 15.25 | 16.6 | 15.25 | 20.35 | 21.25 | 20.2 | 20.35 | 20.5 | 20.65 | 21.55 | 22.15 | 22.6 | 23.95 | 26.2 | 26.05 | 25.9 |
| C18 | 21.85 | 22.15 | 13.6 | 0 | 11.95 | 11.65 | 13.75 | 15.55 | 17.5 | 19 | 17.95 | 18.1 | 18.25 | 18.4 | 19.3 | 19.9 | 20.35 | 21.7 | 24.25 | 24.1 | 23.95 |
| C19 | 23.35 | 23.5 | 15.55 | 11.95 | 0 | 11.05 | 14.05 | 14.05 | 17.35 | 19.15 | 18.1 | 18.25 | 18.4 | 18.55 | 19.45 | 20.05 | 20.5 | 21.85 | 24.4 | 24.25 | 24.1 |
| C20 | 22 | 22.15 | 15.25 | 11.65 | 11.05 | 0 | 12.4 | 12.25 | 16.15 | 17.8 | 16.75 | 16.9 | 17.05 | 17.2 | 18.1 | 18.7 | 19.15 | 20.5 | 23.2 | 23.05 | 22.9 |
| C21 | 20.35 | 20.05 | 16.6 | 13.75 | 14.05 | 12.4 | 0 | 11.35 | 13.75 | 15.25 | 14.2 | 14.35 | 14.5 | 14.65 | 15.55 | 16.15 | 16.6 | 17.95 | 20.65 | 20.5 | 20.35 |
| C22 | 19 | 17.8 | 15.25 | 15.55 | 14.05 | 12.25 | 11.35 | 0 | 12.4 | 13.6 | 12.55 | 12.7 | 12.85 | 13 | 13.9 | 14.5 | 14.95 | 16.3 | 19 | 18.85 | 18.7 |
| C23 | 20.65 | 18.1 | 20.35 | 17.5 | 17.35 | 16.15 | 13.75 | 12.4 | 0 | 11.5 | 10.45 | 10.6 | 10.75 | 10.9 | 11.8 | 12.4 | 12.85 | 14.2 | 17.35 | 17.2 | 17.05 |
| C24 | 18.4 | 16.9 | 21.25 | 19 | 19.15 | 17.8 | 15.25 | 13.6 | 11.5 | 0 | 10.3 | 10.15 | 10.3 | 10.45 | 10.9 | 10.6 | 11.05 | 12.4 | 16.15 | 16 | 15.85 |
| C25 | 17.35 | 15.85 | 20.2 | 17.95 | 18.1 | 16.75 | 14.2 | 12.55 | 10.45 | 10.3 | 0 | 10.3 | 10.45 | 10.6 | 10.6 | 11.2 | 11.65 | 13 | 15.25 | 15.1 | 14.95 |
| C26 | 17.5 | 16 | 20.35 | 18.1 | 18.25 | 16.9 | 14.35 | 12.7 | 10.6 | 10.15 | 10.3 | 0 | 10.15 | 10.15 | 11.05 | 11.65 | 12.1 | 13.45 | 15.1 | 14.95 | 14.8 |
| C27 | 17.65 | 16.15 | 20.5 | 18.25 | 18.4 | 17.05 | 14.5 | 12.85 | 10.75 | 10.3 | 10.45 | 10.15 | 0 | 10.3 | 11.2 | 11.8 | 12.25 | 13.6 | 14.95 | 14.8 | 14.65 |
| C28 | 17.8 | 16.3 | 20.65 | 18.4 | 18.55 | 17.2 | 14.65 | 13 | 10.9 | 10.45 | 10.6 | 10.15 | 10.3 | 0 | 10.9 | 11.5 | 11.95 | 13.3 | 15.4 | 15.25 | 15.1 |
| C29 | 18.7 | 17.2 | 21.55 | 19.3 | 19.45 | 18.1 | 15.55 | 13.9 | 11.8 | 10.9 | 10.6 | 11.05 | 11.2 | 10.9 | 0 | 10.45 | 10.9 | 12.25 | 15.7 | 15.55 | 15.4 |
| C30 | 19.3 | 17.8 | 22.15 | 19.9 | 20.05 | 18.7 | 16.15 | 14.5 | 12.4 | 10.6 | 11.2 | 11.65 | 11.8 | 11.5 | 10.45 | 0 | 10.45 | 11.8 | 15.4 | 15.25 | 15.1 |
| C31 | 19.75 | 18.25 | 22.6 | 20.35 | 20.5 | 19.15 | 16.6 | 14.95 | 12.85 | 11.05 | 11.65 | 12.1 | 12.25 | 11.95 | 10.9 | 10.45 | 0 | 11.35 | 14.65 | 14.5 | 14.35 |
| C32 | 21.1 | 19.6 | 23.95 | 21.7 | 21.85 | 20.5 | 17.95 | 16.3 | 14.2 | 12.4 | 13 | 13.45 | 13.6 | 13.3 | 12.25 | 11.8 | 11.35 | 0 | 15.1 | 14.95 | 14.8 |
| C33 | 21.7 | 19.75 | 26.2 | 24.25 | 24.4 | 23.2 | 20.65 | 19 | 17.35 | 16.15 | 15.25 | 15.1 | 14.95 | 15.4 | 15.7 | 15.4 | 14.65 | 15.1 | 0 | 10.3 | 10.45 |
| C34 | 21.55 | 19.6 | 26.05 | 24.1 | 24.25 | 23.05 | 20.5 | 18.85 | 17.2 | 16 | 15.1 | 14.95 | 14.8 | 15.25 | 15.55 | 15.25 | 14.5 | 14.95 | 10.3 | 0 | 10.3 |
| C35 | 21.4 | 19.45 | 25.9 | 23.95 | 24.1 | 22.9 | 20.35 | 18.7 | 17.05 | 15.85 | 14.95 | 14.8 | 14.65 | 15.1 | 15.4 | 15.1 | 14.35 | 14.8 | 10.45 | 10.3 | 0 |

Table B.3 Traveling time matrix of customer zone 3.

| Travel time (min) | Laboratory Center | C36 | C37 | C38 | C39 | C40 | C41 | C42 | C43 | C44 | C45 | C46 | C47 | C48 | C49 | C50 | C51 |
|-------------------|-------------------|-------|-------|-------|-------|-------|-------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Laboratory Center | 0 | 5.3 | 5.9 | 9.35 | 6.95 | 8.75 | 9.35 | 8.45 | 6.2 | 9.8 | 10.85 | 8.9 | 12.2 | 7.85 | 10.55 | 15.5 | 12.05 |
| C36 | 5.3 | 0 | 5.75 | 9.05 | 6.65 | 8.3 | 8.9 | 8.45 | 6.05 | 8.9 | 9.95 | 8 | 11.75 | 8.15 | 10.25 | 15.35 | 11.9 |
| C37 | 5.9 | 5.75 | 0 | 8.75 | 6.35 | 8.45 | 9.05 | 8.75 | 6.8 | 9.65 | 10.7 | 8.75 | 11.6 | 8.45 | 10.55 | 14.9 | 11.45 |
| C38 | 9.35 | 9.05 | 8.75 | 0 | 7.4 | 7.55 | 7.1 | 8 | 9.2 | 11.3 | 12.35 | 10.4 | 10.25 | 9.35 | 10.85 | 13.1 | 9.65 |
| C39 | 6.95 | 6.65 | 6.35 | 7.4 | 0 | 7.7 | 8 | 8.45 | 7.4 | 10.25 | 11.3 | 9.35 | 11.45 | 8.45 | 10.7 | 14.75 | 11.3 |
| C40 | 8.75 | 8.3 | 8.45 | 7.55 | 7.7 | 0 | 5.6 | 5.6 | 7.7 | 8.9 | 9.95 | 8 | 8.75 | 6.95 | 8.3 | 12.05 | 8.6 |
| C41 | 9.35 | 8.9 | 9.05 | 7.1 | 8 | 5.6 | 0 | 5.75 | 8.6 | 9.5 | 10.55 | 8.6 | 8.3 | 7.7 | 8.9 | 11.6 | 8.15 |
| C42 | 8.45 | 8.45 | 8.75 | 8 | 8.45 | 5.6 | 5.75 | 0 | 8.3 | 8.75 | 9.8 | 7.85 | 8 | 6.95 | 7.7 | 11.3 | 7.85 |
| C43 | 6.2 | 6.05 | 6.8 | 9.2 | 7.4 | 7.7 | 8.6 | 8.3 | 0 | 6.2 | 7.25 | 7.55 | 11 | 6.95 | 9.35 | 14.75 | 11.3 |
| C44 | 9.8 | 8.9 | 9.65 | 11.3 | 10.25 | 8.9 | 9.5 | 8.75 | 6.2 | 0 | 6.05 | 7.85 | 12.35 | 8.15 | 9.95 | 16.1 | 12.65 |
| C45 | 10.85 | 9.95 | 10.7 | 12.35 | 11.3 | 9.95 | 10.55 | 9.8 | 7.25 | 6.05 | 0 | 6.95 | 11.45 | 7.55 | 8.75 | 15.35 | 11.9 |
| C46 | 8.9 | 8 | 8.75 | 10.4 | 9.35 | 8 | 8.6 | 7.85 | 7.55 | 7.85 | 6.95 | 0 | 9.5 | 5.9 | 6.95 | 13.55 | 10.1 |
| C47 | 12.2 | 11.75 | 11.6 | 10.25 | 11.45 | 8.75 | 8.3 | 8 | 11 | 12.35 | 11.45 | 9.5 | 0 | 9.2 | 7.85 | 8.75 | 5.3 |
| C48 | 7.85 | 8.15 | 8.45 | 9.35 | 8.45 | 6.95 | 7.7 | 6.95 | 6.95 | 8.15 | 7.55 | 5.9 | 9.2 | 0 | 7.25 | 12.95 | 9.5 |
| C49 | 10.55 | 10.25 | 10.55 | 10.85 | 10.7 | 8.3 | 8.9 | 7.7 | 9.35 | 9.95 | 8.75 | 6.95 | 7.85 | 7.25 | 0 | 11.75 | 8.3 |
| C50 | 15.5 | 15.35 | 14.9 | 13.1 | 14.75 | 12.05 | 11.6 | 11.3 | 14.75 | 16.1 | 15.35 | 13.55 | 8.75 | 12.95 | 11.75 | 0 | 7.25 |
| C51 | 12.05 | 11.9 | 11.45 | 9.65 | 11.3 | 8.6 | 8.15 | 7.85 | 11.3 | 12.65 | 11.9 | 10.1 | 5.3 | 9.5 | 8.3 | 7.25 | 0 |

Table B.4 Traveling time matrix of customer zone 4.

| Travel time (min) | Laboratory Center | C52 | C53 | C54 | C55 | C56 | C57 | C58 | C59 | C60 | C61 | C62 | C63 | C64 | C65 |
|-------------------|-------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Laboratory Center | 0 | 5.45 | 7.25 | 18.35 | 20.15 | 32.6 | 36.8 | 39.2 | 38.45 | 38.6 | 39.8 | 36.5 | 59.15 | 32.45 | 28.25 |
| C52 | 5.45 | 0 | 6.95 | 18.8 | 20.45 | 32.3 | 37.55 | 39.95 | 39.2 | 39.35 | 40.55 | 41.3 | 60.2 | 31.85 | 28.55 |
| C53 | 7.25 | 6.95 | 0 | 17.45 | 19.7 | 32.15 | 37.1 | 39.5 | 38.75 | 38.9 | 40.1 | 36.05 | 60.65 | 32.15 | 30.35 |
| C54 | 18.35 | 18.8 | 17.45 | 0 | 8.15 | 20 | 26 | 27.65 | 27.8 | 28.4 | 28.55 | 23.15 | 48.65 | 20.3 | 28.1 |
| C55 | 20.15 | 20.45 | 19.7 | 8.15 | 0 | 17.9 | 24.5 | 24.8 | 25.85 | 25.55 | 26.15 | 21.2 | 46.1 | 17.75 | 25.1 |
| C56 | 32.6 | 32.3 | 32.15 | 20 | 17.9 | 0 | 14.6 | 15.2 | 15.35 | 15.65 | 16.1 | 11.45 | 34.7 | 8.45 | 30.95 |
| C57 | 36.8 | 37.55 | 37.1 | 26 | 24.5 | 14.6 | 0 | 8.75 | 8 | 9.8 | 10.25 | 11 | 32 | 17 | 39.8 |
| C58 | 39.2 | 39.95 | 39.5 | 27.65 | 24.8 | 15.2 | 8.75 | 0 | 5.9 | 5.75 | 6.05 | 11.75 | 31.85 | 17.3 | 40.1 |
| C59 | 38.45 | 39.2 | 38.75 | 27.8 | 25.85 | 15.35 | 8 | 5.9 | 0 | 6.05 | 6.8 | 12.65 | 32 | 17.3 | 41.15 |
| C60 | 38.6 | 39.35 | 38.9 | 28.4 | 25.55 | 15.65 | 9.8 | 5.75 | 6.05 | 0 | 5.9 | 13.25 | 33.5 | 15.8 | 43.1 |
| C61 | 39.8 | 40.55 | 40.1 | 28.55 | 26.15 | 16.1 | 10.25 | 6.05 | 6.8 | 5.9 | 0 | 11.6 | 30.5 | 16.25 | 39.65 |
| C62 | 36.5 | 41.3 | 36.05 | 23.15 | 21.2 | 11.45 | 11 | 11.75 | 12.65 | 13.25 | 11.6 | 0 | 29.3 | 14.75 | 36.65 |
| C63 | 59.15 | 60.2 | 60.65 | 48.65 | 46.1 | 34.7 | 32 | 31.85 | 32 | 33.5 | 30.5 | 29.3 | 0 | 33.5 | 28.4 |
| C64 | 32.45 | 31.85 | 32.15 | 20.3 | 17.75 | 8.45 | 17 | 17.3 | 17.3 | 15.8 | 16.25 | 14.75 | 33.5 | 0 | 28.4 |
| C65 | 28.25 | 28.55 | 30.35 | 28.1 | 25.1 | 30.95 | 39.8 | 40.1 | 41.15 | 43.1 | 39.65 | 36.65 | 28.4 | 28.4 | 0 |

Table C.3 Cost of transport matrix of customer zone 3.

| Cost (Bath/day) | Laboratory Center | C36 | C37 | C38 | C39 | C40 | C41 | C42 | C43 | C44 | C45 | C46 | C47 | C48 | C49 | C50 | C51 |
|-------------------|-------------------|-------|-------|------|-------|------|------|------|-------|-------|-------|------|------|------|------|-------|------|
| Laboratory Center | 0.00 | 3.22 | 3.67 | 6.25 | 4.46 | 5.80 | 6.25 | 5.58 | 3.90 | 6.58 | 7.37 | 5.91 | 8.38 | 5.13 | 7.14 | 10.84 | 8.26 |
| C36 | 3.22 | 0.00 | 3.56 | 6.02 | 4.23 | 5.46 | 5.91 | 5.58 | 3.78 | 5.91 | 6.70 | 5.24 | 8.04 | 5.35 | 6.92 | 10.73 | 8.15 |
| C37 | 3.67 | 3.56 | 0.00 | 5.80 | 4.01 | 5.58 | 6.02 | 5.80 | 4.34 | 6.47 | 7.26 | 5.80 | 7.93 | 5.58 | 7.14 | 10.39 | 7.82 |
| C38 | 6.25 | 6.02 | 5.80 | 0.00 | 4.79 | 4.90 | 4.57 | 5.24 | 6.14 | 7.70 | 8.49 | 7.03 | 6.92 | 6.25 | 7.37 | 9.05 | 6.47 |
| C39 | 4.46 | 4.23 | 4.01 | 4.79 | 0.00 | 5.02 | 5.24 | 5.58 | 4.79 | 6.92 | 7.70 | 6.25 | 7.82 | 5.58 | 7.26 | 10.28 | 7.70 |
| C40 | 5.80 | 5.46 | 5.58 | 4.90 | 5.02 | 0.00 | 3.45 | 3.45 | 5.02 | 5.91 | 6.70 | 5.24 | 5.80 | 4.46 | 5.46 | 8.26 | 5.69 |
| C41 | 6.25 | 5.91 | 6.02 | 4.57 | 5.24 | 3.45 | 0.00 | 3.56 | 5.69 | 6.36 | 7.14 | 5.69 | 5.46 | 5.02 | 5.91 | 7.93 | 5.35 |
| C42 | 5.58 | 5.58 | 5.80 | 5.24 | 5.58 | 3.45 | 3.56 | 0.00 | 5.46 | 5.80 | 6.58 | 5.13 | 5.24 | 4.46 | 5.02 | 7.70 | 5.13 |
| C43 | 3.90 | 3.78 | 4.34 | 6.14 | 4.79 | 5.02 | 5.69 | 5.46 | 0.00 | 3.90 | 4.68 | 4.90 | 7.48 | 4.46 | 6.25 | 10.28 | 7.70 |
| C44 | 6.58 | 5.91 | 6.47 | 7.70 | 6.92 | 5.91 | 6.36 | 5.80 | 3.90 | 0.00 | 3.78 | 5.13 | 8.49 | 5.35 | 6.70 | 11.29 | 8.71 |
| C45 | 7.37 | 6.70 | 7.26 | 8.49 | 7.70 | 6.70 | 7.14 | 6.58 | 4.68 | 3.78 | 0.00 | 4.46 | 7.82 | 4.90 | 5.80 | 10.73 | 8.15 |
| C46 | 5.91 | 5.24 | 5.80 | 7.03 | 6.25 | 5.24 | 5.69 | 5.13 | 4.90 | 5.13 | 4.46 | 0.00 | 6.36 | 3.67 | 4.46 | 9.38 | 6.81 |
| C47 | 8.38 | 8.04 | 7.93 | 6.92 | 7.82 | 5.80 | 5.46 | 5.24 | 7.48 | 8.49 | 7.82 | 6.36 | 0.00 | 6.14 | 5.13 | 5.80 | 3.22 |
| C48 | 5.13 | 5.35 | 5.58 | 6.25 | 5.58 | 4.46 | 5.02 | 4.46 | 4.46 | 5.35 | 4.90 | 3.67 | 6.14 | 0.00 | 4.68 | 8.94 | 6.36 |
| C49 | 7.14 | 6.92 | 7.14 | 7.37 | 7.26 | 5.46 | 5.91 | 5.02 | 6.25 | 6.70 | 5.80 | 4.46 | 5.13 | 4.68 | 0.00 | 8.04 | 5.46 |
| C50 | 10.84 | 10.73 | 10.39 | 9.05 | 10.28 | 8.26 | 7.93 | 7.70 | 10.28 | 11.29 | 10.73 | 9.38 | 5.80 | 8.94 | 8.04 | 0.00 | 4.68 |
| C51 | 8.26 | 8.15 | 7.82 | 6.47 | 7.70 | 5.69 | 5.35 | 5.13 | 7.70 | 8.71 | 8.15 | 6.81 | 3.22 | 6.36 | 5.46 | 4.68 | 0.00 |

Table C.4 Cost of transport matrix of customer zone 4.

| Cost (Baht/Day) | Laboratory Center | C52 | C53 | C54 | C55 | C56 | C57 | C58 | C59 | C60 | C61 | C62 | C63 | C64 | C65 |
|-------------------|-------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Laboratory Center | 0 | 3.336 | 4.68 | 12.968 | 14.312 | 23.608 | 26.744 | 28.536 | 27.976 | 28.088 | 28.984 | 26.52 | 43.432 | 23.496 | 20.36 |
| C52 | 3.336 | 0 | 4.456 | 13.304 | 14.536 | 23.384 | 27.304 | 29.096 | 28.536 | 28.648 | 29.544 | 30.104 | 44.216 | 23.048 | 20.584 |
| C53 | 4.68 | 4.456 | 0 | 12.296 | 13.976 | 23.272 | 26.968 | 28.76 | 28.2 | 28.312 | 29.208 | 26.184 | 44.552 | 23.272 | 21.928 |
| C54 | 12.968 | 13.304 | 12.296 | 0 | 5.352 | 14.2 | 18.68 | 19.912 | 20.024 | 20.472 | 20.584 | 16.552 | 35.592 | 14.424 | 20.248 |
| C55 | 14.312 | 14.536 | 13.976 | 5.352 | 0 | 12.632 | 17.56 | 17.784 | 18.568 | 18.344 | 18.792 | 15.096 | 33.688 | 12.52 | 18.008 |
| C56 | 23.608 | 23.384 | 23.272 | 14.2 | 12.632 | 0 | 10.168 | 10.616 | 10.728 | 10.952 | 11.288 | 7.816 | 25.176 | 5.576 | 22.376 |
| C57 | 26.744 | 27.304 | 26.968 | 18.68 | 17.56 | 10.168 | 0 | 5.8 | 5.24 | 6.584 | 6.92 | 7.48 | 23.16 | 11.96 | 28.984 |
| C58 | 28.536 | 29.096 | 28.76 | 19.912 | 17.784 | 10.616 | 5.8 | 0 | 3.672 | 3.56 | 3.784 | 8.04 | 23.048 | 12.184 | 29.208 |
| C59 | 27.976 | 28.536 | 28.2 | 20.024 | 18.568 | 10.728 | 5.24 | 3.672 | 0 | 3.784 | 4.344 | 8.712 | 23.16 | 12.184 | 29.992 |
| C60 | 28.088 | 28.648 | 28.312 | 20.472 | 18.344 | 10.952 | 6.584 | 3.56 | 3.784 | 0 | 3.672 | 9.16 | 24.28 | 11.064 | 31.448 |
| C61 | 28.984 | 29.544 | 29.208 | 20.584 | 18.792 | 11.288 | 6.92 | 3.784 | 4.344 | 3.672 | 0 | 7.928 | 22.04 | 11.4 | 28.872 |
| C62 | 26.52 | 30.104 | 26.184 | 16.552 | 15.096 | 7.816 | 7.48 | 8.04 | 8.712 | 9.16 | 7.928 | 0 | 21.144 | 10.28 | 26.632 |
| C63 | 43.432 | 44.216 | 44.552 | 35.592 | 33.688 | 25.176 | 23.16 | 23.048 | 23.16 | 24.28 | 22.04 | 21.144 | 0 | 24.28 | 20.472 |
| C64 | 23.496 | 23.048 | 23.272 | 14.424 | 12.52 | 5.576 | 11.96 | 12.184 | 12.184 | 11.064 | 11.4 | 10.28 | 24.28 | 0 | 20.472 |
| C65 | 20.36 | 20.584 | 21.928 | 20.248 | 18.008 | 22.376 | 28.984 | 29.208 | 29.992 | 31.448 | 28.872 | 26.632 | 20.472 | 20.472 | 0 |

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