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DEVELOPING MODEL OF FLEXIBLE PERIODIC VEHICLE ROUTING PROBLEM (FPVRP) CONSIDERING COLOR COMBINATION REQUIREMENTS FOR A PAINT DISTRIBUTION SYSTEM

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DEVELOPING MODEL OF FLEXIBLE PERIODIC VEHICLE ROUTING PROBLEM (FPVRP) CONSIDERING COLOR COMBINATION REQUIREMENTS FOR A PAINT DISTRIBUTION SYSTEM

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ABSTRACT

Managing a distribution system is compulsory in creating an effective supply chain. Moreover, distribution system in paint product sector does have some unique complexities. Within a developing technology, paint products are now wider in color range, faster in manufacturing, and even now it is possible to create a desired color instantly using on-spot paint tinting machine technology (One thousand color policy) Hence, paint distributor nowadays should consider the new way of distributing paints by not looking it as a single product only, but also as multi-product varieties

Periodic Vehicle Routing Problem (PVRP) is a tool chosen in planning the paint distribution system. Paint distributor will be able to plan the deliveries in a weekly planing horizon. This periodic routing principle assumes that the route schedule will repeat for the next week.

However, this research adds some flexibility features to classic PVRP method in order to face this complexity. Hence, the tool used in this research is upgraded into a term called “Flexible Periodic Vehicle Routing Problem” (FPVRP) with considering the flexibility features as mentioned above. The model is developed from previous research by adding the multi product criteria (weighted bill of color consideration) as well as multi capacity vehicle criteria to help paint distributors in making better decision of routing. In this research, the computerized model is created using Visual Basic Application (VBA) in Microsoft Excel.

The benefits obtained from FPVRP decision tools is the increasing flexibility of routing options considering the visit frequency, routing sequence and also the selection of the vehicle used, which save cost up to 59.85% compared to the normal Vehicle Routing Problem (VRP). Nevertheless, as a drawback, this model requires a very long computational time and some unexpected shut down often occurred especially during calculations for bigger data size.

Keywords: Flexible Periodic Vehicle Routing Problem, Visit Frequency Optimization Procedure, Weighted Bill of Colors, Multi Capacity Vehicle.

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As the completion of this research, author hopes this research is able to help and give insights for any paint distributors, logistics practitioners, academics and students who are interested in advanced vehicle routing problems.

Surabaya, January 2019

Author

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CHAPTER I
INTRODUCTION

1.1. Background of Problem

Vehicle routing has become one of the most concerned issues in distribution management nowadays. Supported by new and developing technologies, distribution systems are going to the whole new level. It does occur to the construction material distribution over the world, starting from main materials (wood, steel, etc.) up to the supporting materials. As the demands for construction materials always exist from year to year, many companies in the building construction field are racing to win the market through their distribution and logistics strategies.

One of the important components in constructing a building is paint product. It is a very substantial material that protects wall, wood material, steel, or any other surfaces while also adding color to the surfaces. This type of construction materials specifically will be discussed in this research.However, distribution system for paint products is still considered as challenging since it has some particular complexities. Due to more building activities, the sales of paint products will always exist in the future and even showing a linear increasing trend. The chart below represents annual global sales of a Japanese multinational paint company:

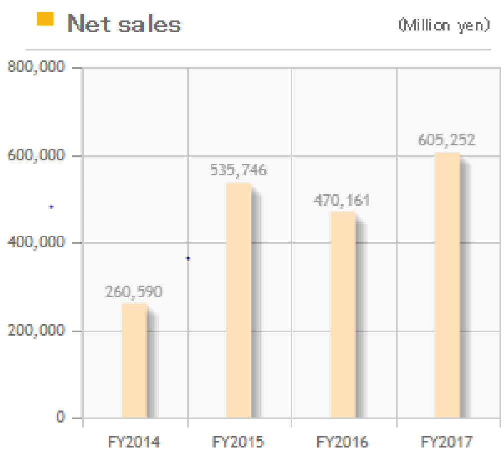

Figure 1. 1 Net Sales of Nippon Paint holdings for paint products

(source: https://www.nipponpaint-holdings.com)

In developing country itself, the trend is also increasing as well. In Indonesia, the market trend for paint is forecasted to increase by 5% by the end of 2018 from previous year (*industri.kontan.co.id*, 2018). The other characteristic of this product is that the trend of sales in most developing countries like Indonesia, holidays significantly impact on the sales of paint (especially for religious and national holidays). It is caused by the behaviors of Indonesian people who tend to renovate their houses during those holidays. Within these periods, most of them usually get holiday allowances and have more time to do renovations. Thus, the impact toward the paint's sales exponentially increases. According to historical data, the sales of paint in Cirebon, one city of Indonesia increased up to 100% in *Ramadhan* month compared to usual month. But yet, in low seasons, the demand of paint itself can be significantly much lower than usual. This reason makes media & press stating that the fluctuation of paint product's demand is considered as very proactive. This phenomenon will surely imply on the increasing need of logistics and distribution forces to fulfill the customers' demands.

A complicated problem about paint business is about the color required by the customers. The color requests tend to change dynamically depending on the needs of the customers. Below are some of the examples:

Figure 1. 2 Color Option Index

A very wide options of paint colors will strongly influence the inventory, availability and responsiveness of paint distributors and retailers. Preparing stocks of paints and forecasting the color demand of the customers surely become a challenge of any paint distributors. This problem will also become the issues of this research, even though to know the most used color and how to control the color demand are not the main focus in this research.

Another emerging problem that occurs in this modern era is a color combination requirement. Conventionally, paint manufacturers do the color mixing processes in their production floors. Nevertheless, some modern practices are now already doing the color mixing or tinting in the customer or retailer's place. These practices are purposed to increase the color options for customers (some companies' use a term called "1000 colors policy") which will increase the service level as well. This strategy is now possible due to machinery technology development called paint tinting machines. Customers now are able to combine two or more colors using this machine to produce various colors in minutes. Within this policy, the demands of color are no longer considered as a single product such as in Figure 1.2, but multiple dependent products as represented into color spectrum below:

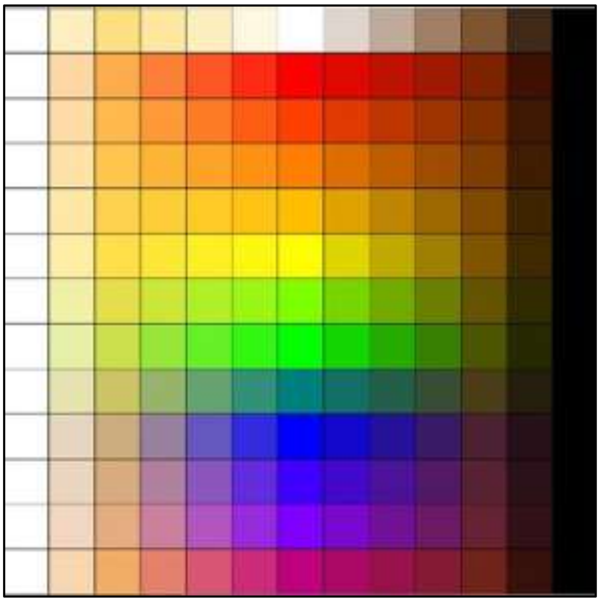

Figure 1. 3 Color Tinting spectrum

If viewed in supply chain, the distributor needs to order paint products from manufacturers, consolidate the demand to serve multiple retailers at once. As the consequences, planning and scheduling of each distribution are essential to be constructed. Besides, due to the characteristics of the paint sales itself, paint distributor need to supply paints of each retailer in weekly or monthly basis. Hence, information of quantity that needs to be delivered constantly is very crucial in paint distributor's point of view to perform a scheduled replenishment. Vendor Managed Inventory (VMI) is also crucial to be used in order to obtain an accurate information of inventory level for each retailer.

As the solution of problems above, there are actually some options of strategies that can be used to manage those problems while also coordinating the distribution activities. One of the famous method used recently is called Vehicle Routing Problem (VRP). Vehicle Routing Problem (VRP) is a technique firstly introduced by *Dantzig* and *Ramzer* (1959) as a method for managing available vehicles or fleets to perform or fulfill all delivery requests at minimum cost (*Toth and Vigo*, 2014). More specifically, it is a decision supporting tool that help user in determining which vehicles doing which route to achieve a feasible transportation system. To perform a scheduled replenishment strategy, this research uses Periodic Vehicle Routing Problem (PVRP) method. PVRP is a generalization of a classic VRP whereas the vehicle routes are constructed over multiple days (*Beltrami* and *Bodin*, 1974). Results of PVRP will represent the schedule as well as the routes for each demand or request in multiple days or weeks basis. The advancements of this tool seems to be more appropriate to apply for this research -or the distribution system for construction material products-, since the demands for this typical products are quite scheduled in term of demand frequencies and quantities.

However, a classic PVRP is not enough to solve the complexities existing in paint distribution practices. Some features and flexibilities need to be added to this method. This research develops a method called Flexible Periodic Vehicle Routing Problem (FPVRP). The flexibilities are constructed to satisfy and accommodate the particular needs of company and customers. It is considered as an appropriate tool to analyze and help for decision making of the paint material distribution business type. Since the demand of this product is not so that frequent or uncertain, hence the fulfillment processes can be well-scheduled but it also needs flexible options since some circumstances do exist. This research used visit frequency, multi-product criteria and multi-vehicle capacity as its flexible features. Through the whole planning horizon, the frequency of delivery for each retailer will become one of the main features in this model. The second one is due to color combination requirement, this model also provides a feature to route a set of multi-dependent product demands. This research also considers multi vehicle type as options to choose which vehicle is more appropriately used.

Finally, implementing the model into automated decision supporting system tool is something very crucial for company. This DSS also gives users more insights and analysis of the existing distribution network condition, which later help those users in choosing more appropriate strategies. This paper will observe the implementation of FPVRP model as a decision support tool for paint distributors to accommodate the needs of companies to advance in this new business era.

1.2. Problem Formulation

The problem that becomes the main subject in this report is how to develop previous distribution system, which adapts Periodic Vehicle Routing Problem by adding flexibility of multi-product (color combination requirement) and multi-capacity vehicle considerations, specifically for Paint distribution sector.

1.3. Objectives

The objectives of this report are listed as below:

1. To develop the recent distribution model of Flexible Periodic Vehicle Routing Problem (FPVRP) using heuristics for paint distribution's Decision Support System (DSS).
2. To analyze FPVRP model's benefits in term of costs, efficiency and utility compared with previous distribution model.

1.4. Benefit

The benefits of this report are listed as follow:

1. To learn how to develop the model of FPVRP for paint distribution system implementations
2. To understand the difference between FPVRP methods with previous model in benefits, costs, efficiency and utility.

1.5. Limitations and Assumptions

Below are the limitations and assumptions used for this research:

1.5.1. Limitations

1. The type of the products in this research is paints, which are uniform in size, functions and quality.
2. This research only uses 5 primary colors (blue, red, yellow, white and black - which later will be combined-) as the basis of color combination requirement considerations.
3. The observed processes are only the process from receiving order until fulfilling order using scheduling and routing procedures by considering color combination requirements.
4. The data used are dummy data randomly selected to represent the distribution system (both in size number and location).
5. This distribution system adopts single depot network.
6. The dummy data of demand is limited to 1-week planning horizon.

1.5.2. Assumption

1. The dummy data: number of retailers, location of retailers, depot location, number of fleets, type of fleets and demand rate for each retailer are assumed constant during model running.
2. Ceteris Paribus, all external factors outside of the system are assumed as neglected.

1.6. Report Outline

This sub chapter will consist of the outline and brief explanation for each chapter in this research report or observation. It is figured as follow:

Chapter I, “Introduction”

This chapter will discuss about the background of the problem, problem formulation, objectives, benefit, limitation and assumptions of the research. It consists of the reason for the research on Flexible Periodic Vehicle Routing Planning (FPVRP) on paint industries, while it has color combination complexity.

Chapter II, “Literature Review”

This chapter will consist of theoretical foundations used in the whole observation, starting from: the basic of distribution management; the concept of vehicle routing problem, periodic VRP, flexible PVRP, heuristics algorithm, VBA basic and this research position. All of those knowledge and theories will become the foundation of the research.

Chapter III, “Research Methodology”

Research methodology is a chapter of the complete framework of the observation. It consists of the processes and flows used from the beginning to the end of the research. These steps will be the basic of the research workflow.

Chapter IV, “Model Development”

This chapter will respectively consist of the model of the research according to the literature study and the field study. The model will be in form of mathematical formulations, heuristics iterations and the VBA model. This model then will also be validated and verified to ensure the accuracy of the model as well.

Chapter V, “Numerical Experiments and Analysis”

After the model has already finished to be developed in the previous chapter, numerical experiments will be conducted furthermore. Then, the results obtained from the model running will be analyzed and interpreted starting from the pattern of the results, the best solution conditions for the model, and the improvements that will be foreseen.

Chapter VI, “Conclusion and Suggestion”

This last chapter will be the conclusion of the whole observation by answering the formulated problems and the objectives of the research, after that, suggestions can be made for this research or the further research in the future.

CHAPTER II
LITERATURE REVIEW

This chapter will consist of all literatures and information that will become the basics of the entire research. The literatures will include the basic of the distribution knowledge, product information, supporting theories of the research methods until the position of the research.

2.1. Paint Product

Paint is defined as a coloring substance composed from solid coloring matters. Paint products considered in this research are those which packaged into a cylindrical tin for each a particular color. There are several characteristics, classifications and applications for paint products. Whereas due to the advancement of the technology, on-spot color tinting / combination is applicable and useable for this research. It is described as follows:

2.1.1. Paint characteristics, classifications and application's procedures

Paint is made of four basic ingredients: pigment, resin, solvent and additives. Pigment is the color substance that determines the color of the paint. Resin is functioning as "glue" or the binder in the whole paint substances. Solvent is a carrier material that makes liquid evaporates when the paint dries, while additives are the addition substances that give more specific performance characteristics to the paint.

There are several types of paint existing in the market. Several factors or categories make each paint to have different functions. Some of those are as follow:

1. Based on the surface type, paint products can be defined as:
    a. Interior paints (for interior concrete walls, etc.)
    b. Exterior paints (for exterior concrete walls, roofs)
    c. Wood and steel paints
    d. Other paints, such as for: automotive exterior, roadways, etc.
2. Based on the materials of the paint:

    a. Water-based (Latex)
    b. Acrylic
    c. Oil based (Alkyd)
    d. Other materials: hybrid
3. Based on the paint result characteristic (sheen, after-appliance-criteria, etc.):
    a. Matte or flat: least sheen (less shiny result) velvety surface result, difficult to wash.
    b. Eggshell: moderate sheen with little glare
    c. Satin: it is similar with eggshell but slightly glossier.
    d. Semi-gloss: moderate gloss, good for areas with high wash ability and need moisture resistance features.
    e. Gloss: high gloss, or type of paint that is able to reflect a lot of light. It is very durable and good for surfaces that need to be washed easily.

The paint itself is applied on a surface with many processes. The processes above can be defined as following:

1. Preparation stage: Preparing the paints and equipment, cleaning the surface from undesired objects.
2. Primary stage: smooth the surface using rough sandpaper (180) then soft sandpaper (360). After that, prepare the primary paint as the color foundation by mixing thinner to the paint materials within 10% composition to the overall mixture. Apply the primary paint. Let the primary paint dries, and then re-smooth the surface using soft sandpaper (360).
3. Finishing stage: Prepare the secondary paint by mixing it with thinner (10% rule), then apply it to the surface. For better quality and accent, it is recommended to apply or layer the surface twice. Let it dries.

2.1.2. Paint Color Combination Requirement

Another paint's characteristics is that most of the paint colors are combinable one each other. This combination process was commonly done only in the paint manufacturing stage. However, trends in paint sales and distribution nowadays involve paint color combination processes in the retailer places, as mentioned in the introduction chapter. Whereas this strategy is done to increase customer service by providing more options of color using paint-tinting machines.:

The processes of tinting itself require computerized system to input which color is used as the tinting paint. Based on figure above, the *tinter* or tinting paints are stored in the canisters. Then, we set any paint which later will be combined with the tinters into the shaker machine. The next step is by pressing the button or computerized module to start mixing. The mixing process is done also by shaking those mixtures to ensure perfect color combinations. The lead time for all of these processes is around 5 minutes only.

The color combination itself has specific configurations for each color composition. Hence, the range of the colors is very wide. Tinting those paints will be able to change the tone of the color itself. Below are the examples of pain tinting processes using white and dark complementary tinter colors:

According to the figure above,, Another factor which is able create more various colors is the composition of each color. The color combination is not always done within 50:50 composition. A slight difference in composition for each color will affect the color created. Color combination itself also allows more than 2 colors combination, which makes the variations of color are unimaginably wide.
To manage the combination options, this research limits the combinatorial colors into 5 primary colors. The colors are figured as following

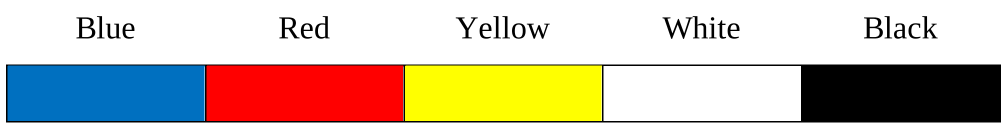

Figure 2. 1 Five colors used as basic colors in this research

In literature, blue, red and yellow color are also stated as the primary color (it has different meaning with the primary color in procedure section or sub chapter 2.1.1). White and black are also considered as the primary one but has functions more in brightening or darkening the colors. The combinations of those colors are called as secondary and tertiary colors. The combinations used in this research are also limited as table below:

Table 2. 1 Combination of Paint colors

	Blue	**Yellow**	**Red**	**Black**	**White**
Blue					
Yellow					
Red					
Black					
White					

The chart table above is a small part of the color spectrum above. The results above actually vary depends on the color composition (as mentioned previously, this policy is popular with 1000 colors policy). However, this research will use colors consisted in table above as a representation of color combination procedure.

2.2. Paint Distribution System

There is a lot of possible distribution system adopted for Paint distribution system. It depends on the policy of the respective companies or also is influenced by the customer condition and segments.

Based on the example above, the distribution network used in this research is considering a single depot distribution. It means that all distribution activities start from a single fixed facility or warehouse. The destination nodes of distribution are the retailers who sell paint and other building construction materials to the end customers. Number and position of those destination nodes is also considered as constant. However, since this model is developed using dummy data, the initial plotting of each node position is placed randomly. The transportation mode used is heterogeneous trucks in type, capacity and conditions.

The demand rate of paint replenishment requires constant frequency in daily weekly planning horizon. For example, in day 1 there are 6 retailers that need to be replenished by using Truck 1 as above. Important to notice that in a single day, more than 1 truck can be assigned to deliver those products. The delivery system itself also requires the trucks to return in the same day (no multiple days delivery is allowed).

In this research, a single distribution warehouse averagely need to replenish around 60-75 retailers weekly. (based on interview with a local distributor during field study). While each retailer can be visited more than once in a week. This demand pattern will be managed using Periodic Vehicle Routing Problem (PVRP). Nevertheless, the color requirements need a special treatment towards the PVRP. Hence, the replenishment planning becomes more complex in paint distribution system.

2.3. Transportation Management

As the part of distribution management, transportation management considers how to transport the goods or items from one place to another. The parameters of transportation strategy are described into 7R, which are: Right Product, Right place, Right customer, Right price, Right time, Right condition or quality and Right quantity. In Transportation strategy, costs involved are significant, starting from vehicle/asset cost and operational costs. Transportation is also the core of distribution activities, as the goal is to increase service level of customers and reduce the costs of all distribution activities. A well-managed distribution network and transportation itself will lead into a significant competitive advantage in the market (*Pujawan*, 2017). However, tradeoff occurs if it is related to responsiveness required by customers.

There are several types of transportation mode. In this research, the used transportation mode is by using trucks. Below is the comparison of truck mode with other transportation modes:

Table 2. 2 Comparisons between Transportation Modes

Transportation mode	**Truck**	**Train**	**Ship**	**Plane**	**Pipeline**	**Parcel**	**Inter modal**
Delivery volume capacity	Medium	Very high	Very high	High	Very High	Very low	Medium
Time Flexibility	High	Low	Low	Low	Very high	Very high	High
Routing Flexibility	High	Very low	Very low	Very low	Very low	High	Very high
Speed of Delivery	Medium	Medium	Low	Very high	Very high	Very high	Very High
Cost	Medium	Low	Low	High	Low	Very high	Low
Inventory (in transit)	Low	High	Very High	Low	Very low	Very low	Depends

(Source: Supply Chain Management edisi 3, Pujawan, 2017)

To manage those transportation activities, there are some strategies developed to increase transportation's effectivness, efficiency, utility and responsiveness. Below consists of popular techniques used to assess the transportation delivery problems:

- Travelling Salesman Problem (TSP)

  TSP is defined as a combinatorial optimization method which is used to find routes for a salesman from a home location, visiting all the prescribed destination and then coming back to the original location within a minimum total distance and each destination is visited exactly once *(Punnen. 2004).* This method is following Hamiltonian rule in optimizing the route.
- Chinese Postmen Problem (CPP)

Similar but slightly different from TSP, CPP is inspired by the Chinese postmen who works by finding a minimum traveling distance and visiting all nodes at least once.

- Vehicle Routing Problem (VRP)

  VRP is also a combinatorial optimization method famously used. But as a difference among the other method, VRP considers capacity in the algorithm. It will be more explained in sub chapter 2.3

2.4. Concept of VRP

Vehicle Routing Problem, based on *Toth* and *Vigo* (2014) is defined as "a planning method to determine a set of vehicle routes to perform all (or some) transportation requests with given vehicle fleets with minimum cost." In the other word, it is a strategy of decision to determine which vehicle serves which set of requests with costs as low as possible. The costs considered here are starting from the distance, time and other costs may be included.

There are several type of Vehicle Routing Problem according to *Toth* and *Vigo* (2014), as follow:

- Classic Vehicle Routing Problem (VRP)
- Vehicle Routing Problem with Time Windows (VRPTW)
- Pickup and Delivery Problem (PDP)
- Vehicle Routing Problem with Mixed Load (VRPM)
- Heterogeneous or Mixed Fleet Vehicle Routing Problem (HFVRP)
- Vehicle Routing Problem with Backhaul (VRPB)
- Periodic Vehicle Routing Problem (PVRP)
- Split Delivery Vehicle Routing Problem (SDVRP)
- Vehicle Routing Problem with Profit (VRPP)
- Dynamic Vehicle Routing Problem (DVRP)
- Other Vehicle Routing Problem for special cases (natural disaster, green VRP, etc.)

Beside of the VRP type based on *Toth* and *Vigo* (2014), there are also some other VRP techniques that has been already used and developed, as follow:

- Location Routing Problem (LRP)
- Inventory Routing Problem (IRP)
- Flexible Periodic Vehicle Routing Problem (FPVRP)
- Other modified VRP, such as: Vehicle Routing Problem with Inventory Control (VRP-IC), Periodic Vehicle Routing Problem with Time Windows (PVRP-TW), etc.

The basic mathematical formulation of traditional capacitated VRP is described as follows:

$$OF = MIN \sum_{(i,j)\in A} c_{ij}x_{ij} \tag{2.1}$$

Subject to:

$$\sum_{j\in\delta+(i)} x_{ij} = 1, \qquad \forall i \in N \tag{2.2}$$

$$\sum_{i\in\delta-(j)} x_{ij} = 1, \qquad \forall i \in N \tag{2.3}$$

$$\sum_{j\in\delta+(0)} x_{0j} = |K| \tag{2.4}$$

$$\sum_{(i,j)\in\delta+(S)} x_{ij} \geq r(S), \qquad \forall S \subseteq N, S \neq \emptyset \tag{2.5}$$

$$x_{ij} \in \{0,1\}, \qquad \forall (i,j) \in A \tag{2.6}$$

The notations above described VRP concept in mathematical or exact formulation based on *Toth* and *Vigo* (2014) literature. Notation (2.1) describes that the objective function of VRP is to minimize the total cost of all visitations from node I to node j. Notation (2.2) – Notation (2.6) are the constraints of the model. Constraints (2.2) and (2.3) state that each customer vertex us connected to a predecessor and a successor in a single route. Constraint (2.4) ensures that exactly |K| routes are constructed. Constraint (2.5) works as capacity constraints and Sub tour Elimination (SECs) to exclude infeasible routes. While Notation (2.6) simply states that numbers in *Xij* are integer.

2.5. Periodic Vehicle Routing Problem

Periodic Vehicle Routing Problem (PVRP) is a generalization of VRP when the customers require repetitive visits during the planning horizon (*Toth* and *Vigo*, 2014). In other reference, *Beltrami* and *Bodin* (1974) also stated Periodic Vehicle Routing Problem (PVRP) as a method in which vehicle routes must be constructed over multiple days. This method is for finding a constant schedule and route for pre-determined request each node. Just like the other VRP method, the goal of this formulation is to find the lowest cost as possible.

PVRP has become a long period research in distribution optimization research. PVRP is a firstly described as a generalization of VRP which is considering planning horizon extension from single day to m-days (*Gaur* & *Fisher*, in press). Some notable past researches of PVRP are such as *Beltrami* and *Bodin* (1974), *Russell* and *Igo* (1979), *Christofides* and *Beasley* (1984), *Tan* and *Beasley* (1984), *Russell* and *Gribbin* (1991), *Gaudioso* and *Paletta* (1992), *Chao, Golden*, and *Wasil* (1995), *Cordeau*, *Gendreau*, and *Laporte* (1997) *Baptista*, *Oliveira*, *Zu´quete* (2002), *Rusdiansyah* and *Tsao* (2005), *Francis et al* (2006 and 2007), *Francis* and *Smllowitz* (2006), *Hemmelmayr et al* (2009), *Pacheco et al* (2012), *Aksen et al* (2012) and *Archetti et al* (2015). These followings are the historical records of some PVRP research starting from the research of *Rusdiansyah* and *Tsao* (2004):

Reference	Application	Type of flexibility	Model and solution method	Objective (Min)
Rusdiansyah and Tsao (2005)	Vending-machine supply chains	Visit frequency is a decision variable	IRP model based on PVRPTW and five heuristics	Sum of the average inventory holding and travel costs
Francis et al. (2006)	Library deliveries	Visit frequency is a decision variable	PVRP-SC: exact algorithm and heuristic variation of the exact method	Total travel cost plus service benefit
Francis and Smilowitz (2006)	Periodic distribution with Service Choice	Visit frequency is a decision variable	Continuous PVRP-SC reduced by geographic decomposition and variable substitution	Total travel cost plus service benefit of each subregion
Francis et al. (2007)	Periodic distribution	Visit frequency, crew flexibility, schedule options, delivery strategy	PVRP embedded in a Tabu Search method	Total travel cost plus service benefit
Hemmelmayr et al. (2009b)	Blood product supplies	Routing decisions: regions/fixed routes and delivery regularity	IP formulation based on IRP, a basic heuristic and a Variable Neighborhood Search	Total traveling cost
Pacheco et al. (2012)	Bakery company	Dates of delivery	CVRP: metaheuristic (GRASP & Path Relinking)	Total distance traveled
Aksen et al. (2012)	Waste vegetable - oil collection	Visit frequency is not fixed nor a limited number of predetermined schedules is assumed	Two MILPs based on IRP and PVRP and partial linear relaxations to generate lower bounds	Total transportation costs, vehicle operation costs, holding costs, and purchasing costs
Archetti et al. (2015)	City logistics	Due date, crewsize, vehicle capacity	Three formulations reinforced with valid inequalities: Flow based formulation (FF), FF with assignment variables and load-based	Transportation costs, inventory costs and penalty costs for postponed service

Figure 2. 2 PVRP Research Timeline *(Source: Munoz, 2018)*

The PVRP is developing in variety and flexibility as well. Starting from *Rusdiansyah and Tsao* (2004) who developed the Inventory routing VRP based with Time windows (IPVRPTW) for vending machines supply chain; Francis et al (2005) developed the service choice modifications for PVRP; until *Archetti* et al (2015) PVRP development for city logistics. The newest development for PVRP so far was Munoz's (2018) research, which implements the Flexible Periodic Vehicle

Routing Problems (FPVRP) for vehicle index-based, load-based and inventory control-based.

2.6. Flexible Periodic Vehicle Routing Problem

The next generation of the Periodic Vehicle Routing Problem is called Flexible Periodic Vehicle Routing Problem (FPVRP). This model is inspired and developed to increase saving in routing cost of normal PVRP *(Francis et al, 2008)*, The main concern of this tool is how.to provide a mathematical and algorithm framework for PVRPs in which flexible distribution plans are allowed to improve the quality of the final solutions *(Munoz, 2018)*.

One of flexibility in PVRP used in this research is based on *Rusdiansyah and Tsao* (2004) research. *Rusdiansyah and Tsao* (2004) developed an Inventory Periodic Vehicle Routing Problem considering Time windows (IPVRPTW) for vending machine distribution problems. The basic reason of this research is due to high operational cost and out-of-stocks problem for vending machine replenishments. This research focuses on a PVRP method within visit frequency flexibility. One of the aims in this research is to turn the vending machine replenishment graph to follow stationary interval policy in reducing total cost as below:

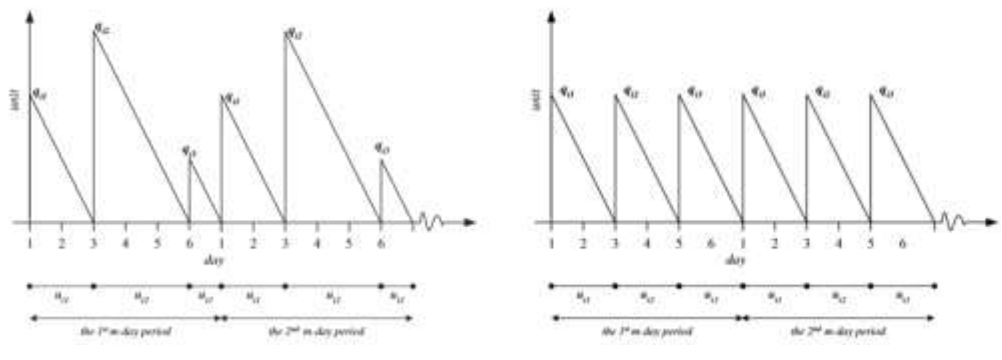

Figure 2. 3 Stationary Interval Policy, before –left- and after –right-

(Source: Rusdiansyah and Tsao, 2004)

This is able to be achieved by implementing VMI model for inventory routing. As in 6 work days, the combination of periodic replenishment is recapitulated as following table:

F	S					
	#1	#2	#3	#4	#5	#6
1	100000	010000	001000	000100	000010	000001
2	100100	010010	001001			
3	101010	010101				
6	111111					

Figure 2. 4 Visit Frequency periodic combinations
(Source: *Rusdiansyah and Tsao*, 2004)

The combinations above refer to the visit frequency that follows stationary interval property. There are 4 types, which are: once a week; twice a week; three times a week and everyday replenishments. The next thing to do is to find which interval with the lowest cost is. Below are the formulations of IPVRPTW:

2.6.1. Mathematical Function and Notation

The notations used in calculating IPVRPTW are listed as follow:

m	Period Length
c_{ij}	Travelling cost of traversing edge *(i,j)*
t_{ij}	Travelling time of traversing edge *(i,j)*
h	Inventory holding cost per unit of the goods held per day
$C_{inv(i)}$	Average period inventory holding cost of retailer i ∈ I
TC_{inv}	Average inventory holding cost for all retailers over the m-day period
TC_{trp}	Average traveling cost for all tours over the m-day period
TC	Average system-wide costs over the m-day period
D_i	Total demand of retailer i ∈ I over the m-day period
F	Set of allowable visit frequencies
S	Set of allowable visit-day combinations
q_i	The delivery size of retailer i ∈ I at any visit
b_i	The earliest possible departure time at vertex i $\in I_0$
e_i	The latest possible arrival time at vertex i $\in I_0$
s_{itk}	The start of service at vertex $i \in I_0$ by vehicle $k \in K$ on day $t \in T$
d_i	The service time required when a vehicle visits vertex $i \in I_0$

C Maximum capacity of any vehicle

R Maximum tour duration of any tour

h_{ik} The tour served by vehicle $k \in K$ on day $t \in T$

f_i Visit frequency of retailer $i \in I_0$ during the m-day period

$$x_{ijtk} \begin{cases} 1, If\ vehicle\ k\ \in\ K\ visits\ vertex\ j\ \in I_0\ just\ after\ vertex\ i\ \in I_0 \\ on\ day\ t\ \in\ T \\ \\ 0, Otherwise \end{cases}$$

$$y_{it} \begin{cases} 1, If\ vertex\ i\ \in I_0\ is\ visited\ by\ any\ vehicle\ on\ day\ t\ \in\ T \\ \\ 0, Otherwise \end{cases}$$

2.6.2. Objective Function

$$OF = MIN\left(\sum_{\forall i \in I} \frac{hD_i}{2f_i} + \frac{1}{m} \sum_{\forall i \in I_0} \sum_{\forall j \in I_0} \sum_{\forall t \in T} \sum_{\forall k \in K} c_{ij} x_{ijtk}\right) \tag{2.7}$$

The objective function of this model as described in the notation (2.7) above is to minimize the total cost consisting of the inventory and transportation visit costs (*TCinv* and *TCtrp*). It is actually quite different with the normal PVRP or PVRPTW, *fi* is in this model considered as decision variable.

2.6.3. Constraint Function

2.6.3.1. Stationary-Interval Property Constraints

$$\sum_{\forall t \in T} y_{it} = f_i, \qquad \forall i \in I;\ f_i \in F \tag{2.8}$$

$$\sum_{r=t+1}^{t+\frac{m}{f_i}} y_{ir} = 1, t = 0, \dots \dots \dots, \left(m - \frac{m}{f_i}\right), \qquad \forall i \in I;\ f_i \in F \tag{2.9}$$

The constraints above ensure the visitation criteria. Constraint (2.8) ensures that each retailer or destination node must be served as many as the assigned visit frequency. While Constraint (2.9) ensures that, each retailer is only visited only on the days that are already assigned previously.

2.6.3.2. Vehicle Capacity

$$\sum_{\forall i \in I_0} \sum_{\forall j \in I_0} q_i x_{ijtk} \leq C, \qquad \forall t \in T; \forall k \in K \tag{2.10}$$

Vehicle capacity constraints ensure that the quantity of all visits on that day is not exceeding the total capacity of the vehicle. It is described as Constraints (2.10) above.

2.6.3.3. Tour Duration

$$\sum_{\forall i \in I_0} \sum_{\forall j \in I_0} (t_{ij} + d_i) x_{ijtk} \leq R, \qquad \forall t \in T; \forall k \in K \tag{2.11}$$

The constraint above is focusing to ensure the schedule feasibility. It is stated on Constraint (2.11) that the duration of a tour must not more than the maximum tour duration R.

2.6.3.4. Periodic VRP standard constraints

$$\sum_{\forall i \in I_0} x_{irtk} - \sum_{\forall j \in I_0} x_{rjtk} = 0, \qquad \forall r \in I_0; \forall t \in T; \forall k \in K \tag{2.12}$$

$$\sum_{\forall j \in I_0} x_{rjtk} \leq 1, \qquad r = 0; \forall t \in T; \forall k \in K \tag{2.13}$$

$$\sum_{i \in B} \sum_{j \in B} x_{ijtk} \leq |B| - 1, \qquad \forall t \in T; \forall k \in K \tag{2.14}$$

$$B \subseteq I; \ |B| - 1, \qquad \forall t \in T; \forall k \in K \tag{2.15}$$

$$y_{it} \in \{0,1\}, \qquad \forall i \in I_0; \forall t \in T \tag{2.16}$$

Constraints above satisfy the standard PVRP constraints. Constraint (2.12) makes sure that each vehicle visits and leaves retailer on the same day. Equation (2.13) states that each vehicle can only be used once at any day (no multiple departures from depot in a single day). Constraint (2.14) is standard sub tour elimination, while equation (2.15) and (2.16) ensures that the solutions are in binary value.

2.6.3.5. Time-Windows Constraints

$$t_{ij} - e_j, 0 \}, \qquad i,j \in I_0 \tag{2.17}$$

$$s_{itk} + d_i + t_{ij} - s_{jtk} \leq \left(1 - x_{ij}\right) M_{ij}, \qquad \forall i,j \in I_0; \forall t \in T \tag{2.18}$$

$$b_i \leq s_{itk} \leq e_i, \qquad \forall i \in I_0; \forall t \in T; \forall k \in K \tag{2.19}$$

$$s_{0tk} = d_0 = 0, \qquad \forall t \in T; \forall k \in K \tag{2.20}$$

The constraints above simply state that a route is feasible only when the vehicle visit retailer in respect of time windows constraint per retailer.

Rusdiansyah and Tsao (2004) used some phases in developing model. The first phase is initialization phase, where the objective is to find the best visit frequency assignable to each retailer. The iteration algorithm used is cheapest insertion method and Visit Frequency Optimization Procedure. The concept of this procedure is by gradually increasing the visit frequency of each retailer until the highest allowable visit frequency so it will be able to reduce the current objective function value.

The basis of visit frequency optimization is on the costs. Before understanding the algorithm, there are some important cost equations considered In *Rusdiansyah and Tsao* (2004) research as following:

$$\Delta TC_{inv(i)} = \frac{hD_i}{2}\left(\frac{1}{\lambda} - \frac{1}{\mu}\right), \qquad i \in I; \ \lambda, \mu \in F \tag{2.21}$$

$$\Delta TC_{trp(i)} = \frac{VC_{I(i)}}{m}, \qquad i \in I \tag{2.22}$$

$$\Delta TC_{(i)} = \omega_{inv}\Delta TC_{inv(i)} - \omega_{trp}\Delta TC_{trp(i)}, \qquad i \in I \tag{2.23}$$

$$q'_j = \frac{\lambda}{\mu} q_j, \qquad j \in I;\ \lambda < \mu \in F \tag{2.24}$$

The cost equations above shows the difference between total cost when the visit frequency parameter is changed. The point is increasing visit frequency actually is also be linear with the increase of holding cost and transportation cost as well. Notation (2.21) is the difference of Inventory total cost between $f_i = \lambda$ (current visit frequencies) and $f_i = \mu$ (new visit frequency). Notation (2.22) is defined as the Transportation cost difference where $VC_{I(i)}$ refers to insertion cost of $M_{I(i)}$ between additions of frequency. Important to be noticed that adding frequency does not always mean that it will be followed by $\Delta TC_{trp(i)}$ increase, since the shortest tour principle is used here. Notation (2.23) is the combination between inventory holding and transportation costs. The notation of ω means that both inventory and transportation costs have proportions, where $\omega_{inv} + \omega_{trp} = 1$. While equation (2.24) is the adjustment for delivery-size of the new assigned visit frequency.

The algorithm procedure of Visit Frequency Optimization Procedure is formulated as below:

- Determine initial ω_{inv} and ω_{trp}
- For retailer $i \in I$:
  - Calculate $\Delta TC_{inv(i)}$
  - Choose the best feasible $M_{I(i)}$ or $VC_{I(i)}$
  - Calculate $\Delta TC_{trp(i)}$
  - Calculate $\Delta TC_{(i)}$
- Select retailer $j \in I$ whose $\Delta TC_{(j)} = max_{i \in I}\{\Delta TC_{(i)}\}$ and $\Delta TC_{(j)} > 0$
- Increase the visit frequency from $f_i = \lambda$ to $f_i = \mu$ and do move $M_{I(j)}$
- Update q_j by notation 2.36

- Let $n_\mu = n_\mu + 1$; $n_\lambda = n_\lambda - 1$ and $N = N + (\mu - \lambda)$
- Iterate these processes, and terminate when there is no more positive values of $\Delta TC_{(i)}$ produced. Otherwise, perform local optimization separately.

Second phase is called improvement. Researcher used Tabu search of *Glover* (1986) in visit-day combination interchange to find better solution from the previous algorithm. The other improvement algorithm done is Tour interchange algorithm. Then, those processes were used to develop 4 types of heuristics, which are: INC1, INC2, INC1-plus and INC2-plus. INC1 considers only the retailers whose current visit frequency equals to the immediate-lower possible number of the target visit frequency. INC2 considers similar as INC1 but the current visit frequency is not necessarily the immediate-lower possible number. While for INC1-plus and INC2-plus, the algorithm is added with visit frequency changes consideration by adding the visit frequency optimization procedure as stated previously.

2.7. Inventory Problem

Inventory, according to *Tersine* (1994), is any idle materials or goods, which are held before continuing to the next processes. Controlling inventory will also give significant impact since inventory's value can reach 25% or more for most companies (*Pujawan*, 2017). *Pujawan* also stated inventory occurs because of production and distribution planning or even because lack of information about the market demand or inventory itself. This lack of information will lead on costly inefficiency, especially for products with wide range of options and those products with high uncertainty. Therefore, understanding inventory management also equal with understanding demand of the customer and understanding all part of chains in the company's business processes. According to *Ballou* (2004), there are five distinct forms of inventory: (1) Transit inventory; (2) Stocks held for speculation; (3) Regular or cyclical stock; (4) Safety stock and (5) obsolete, dead or shrinkage inventory.

One of important notations in Inventory is the equation for determining the quantities of stocks need to be ordered. A famous technique used in determining the ordered quantity is by using EOQ or Economic of Quantity. This formula considers the annual demand, holding cost (variable cost) and the order cost (fixed cost). The notation is defined as below:

$$EOQ = \sqrt{\frac{2.A.S}{Ic}} \qquad (2.25)$$

Where:

A = Annual demand (quantity/year)

Ic = Inventory cost (Variable cost)

S = Cost of ordering (Fixed cost)

However, the final decision of ordering stocks in inventory actually depends on the total cost. The economic quantity just helps to determine the most cost-saving quantity for each product, but yet it does not concern about the transportation cost, assets cost, etc. Therefore, in the next chapter or model development, these criteria will be developed furthermore.

2.8. Vendor Managed Inventory

Vendor Managed Inventory or VMI is a modern principle of supply chain management, which involves the suppliers in advanced inventory decisions. It is quite different compared with the conventional model, where the customers decides how many to order, when to order, until how to order. VMI is a new concept for supply chain collaboration, whereas the suppliers/vendors are given access for accurate inventory information, and even vendor will be able to manage and decide the when and how the materials should be supplied. The objective of VMI is to align the business and supply chain between customers and vendors.

The implementation of VMI will enable distributors or vendors to coordinate, schedule and adjust their distribution activities more freely, such as advancing or delaying deliveries by considering the inventory situation and transportation (*Waller, Johnson, & Davis*, 1999). Besides of reducing costs in distributors' point of view, implementation of this principle will also increase the customer's service level due to better information obtained by distributor (*Kleywegt, Nori, & Savelsbergh*, 2004). Hence, the delivery reliability and products'availability are more able to be guaranteed and anticipated in the future. The other reason, VMI is more appropriate to be used since independent supply chain stakeholders often lead to inefficiency *(Pujawan,* 2017*)*. Firstly, information distortion between suppliers and factory/retailers. This thing often leads on ineffective inventory especially for suppliers (since its position is farther from customers, or Bullwhip effect). Second thing, schedule nervousness may occur if any change from retailers suddenly told to the suppliers. It is stated that suppliers often do not get the early signal from buyers or retailers about how many and what to order, while the order itself is very possible to change. The next thing, independency between suppliers and retailers is somehow disadvantagous for the retailer and also the customers due to averagely low customer service level.

In maximizing the functionality of this FPVRP method, VMI should be applied to improve the capability of suppliers to plan and execute the product stocking and replenishments. Moreover, the algorithm used in this model considers the visit frequency as the model input, hence the decision are obviously at distributor's hands. Practically, VMI is able to be done by also implementing advancing technologies, starting from equipping an online messaging devices in each retailer (*Ghiani, Laporte, & Musmanno,* 2004) up to implementing a powerful Enterprise Resource Planning (ERP) software to consolidate the inventory information from retailers and delivery schedules from distributors integrated-ly.

2.9. Heuristics method

Heuristics is an iterative algorithm approach to find solutions of problem, but in a much lower computational time compared to the exact or mathematical method. However, the quality of the heuristic approach is usually not optimum (worse than exact method) but somehow considered as acceptable solutions or very good solutions. There are some quite many heuristic methods already developed, hereby are some examples of heuristics that normally used in distribution management scope;

- Tour Construction Method
- Greedy algorithm heuristics
- Saving method
- Petal algorithm
- Nearest Neighbor (NN)
- Nearest Insertion (NI)
- Farthest Insertion (FI)
- Cheapest Insertion (CI)
- Priciest Insertion (PI)
- Random Insertion (RI)

A heuristic method used in this research is Nearest Neighbor (NN) algorithm. This method is one of the most commonly used algorithms in vehicle routing optimization. Concept of this heuristic is simply finding shortest distance destination node among overall nodes. Then, those nodes will be assigned as visited nodes and other shortest route will be generated. In the other side, if NN algorithm is transformed into costs instead of distance, hereby it is called as "Cheapest Neighbor" or "Cheapest Insertion" algorithm. These algorithms have their advantages and disadvantages. The most significant advantage is on the ease of usage. While the disadvantages are the results sometimes shown as quite far from the optimum result (as the goal for heuristics algorithm is to find a near optimum solutions) hence it will need a lot of improvement heuristics to make a good decision quality.

2.10. Improvement heuristics

Beside of normal heuristics, there are some heuristic methods used to improve the result of any method above called as Improvement Heuristics. Some of the classic improvement heuristics methods are as follow: 2-OPT swap, λ-OPT exchange, $O(n^2k^2)$ operation, b-cyclic, etc.

One of the popular improvement heuristics is Opt Swap Heuristics. This heuristics help increasing the quality of solutions by trying to randomly swap the orders of an existing route to develop a new tour that gives a better advantage. The swap is done until a certain amount of iterations is achieved. This method is also known as Local Search Algorithms. The concept of Opt swap is figured as:

Most of Opt-Swap cases are done to reduce the crossover in the overall routing. By doing so, the distance traveled is able to be minimized. But for more complex model, as this research is one of the examples, 2 Opt Swap also help increasing effiency in the holding cost and also in utilization.

The other method that is used to improve previous heuristics solution is by doing Metaheuristics. Metaheuristics is an approach to find a near-optimum solution with rather a low computational time by combining the searching method between local search procedure and global search procedure. *(Santosa, 2011).* This method is usually used to optimize the existing system by doing iterative stochastic solution computations to find those very good solutions not just in a local optimum solution, but also in global optimum solution.

2.11. VBA Implementation

According to *Walkenbach* (2007), VBA or stands for "Visual Basic for Applications" is a programming language created by Microsoft that let users give instructions and tasks to Microsoft applications. It is different function but yet has similar language with VB (Visual Basic), while VB is used to program a standalone executable program (, exe software). The instructions that are assigned to Microsoft program are summarized as follow:

- Inserting a bunch of text
- Automating a frequent task
- Automating repetitive operations
- Creating a custom command
- Creating a custom button
- Developing new worksheet functions
- Creating complete macro-driven applications
- Creating custom add-ins for Microsoft programs including Ms. Excel

VBA on Microsoft Excel also allows user to create instructions by using recording system. This feature is called Macro. It is done just by assigning Macro on a button or other objects, clicking record button, doing desired operations, and stop recording after finishing the wanted processes. However, there are some advantages and disadvantages of VBA implementation on Ms. Excel as follow:

- Advantages: Ms. Excel executes VBA consistently which refers on consistent result; VBA has a very fast and accurate operation performances; Macro feature really help users in assigning command; The formula or procedures used in Ms. Excel can be hidden for particular purposes; Very effective for repetitious actions.
- Disadvantages: VBA still needs debugging processes when error occurs; VBA is always updated if the Microsoft applications are updated; Excel is limited for a big data variable operations.

2.12. Research Position

The position of the research is the continuation of the PVRP development on sub chapter 2.5. As mentioned in the chapter, some of important researches in PVRP field are as follow: Some notable past researches of PVRP are such as *Beltrami* and *Bodin* (1974), *Russell* and *Igo* (1979), *Christofides* and *Beasley* (1984), *Tan* and *Beasley* (1984), *Russell* and *Gribbin* (1991), *Gaudioso* and *Paletta* (1992), *Chao*, *Golden*, and *Wasil* (1995), *Cordeau*, *Gendreau*, and *Laporte* (1997) *Baptista*, *Oliveira*, *Zu´quete* (2002), *Rusdiansyah* and *Tsao* (2005), *Francis et al* (2006 and 2007), *Francis* and *Smllowitz* (2006), *Hemmelmayr et al* (2009), *Pacheco et al* (2012), *Aksen et al* (2012) and *Archetti et al* (2015). The specific comparison of some researches related with flexible PVRP is defined as the table below:

Table 2. 3 Research Position Comparison

No	Observer	Method	Output	Application
1	*Rusdiansyah and Tsao* (2004)	Integrated Inventory Periodic Vehicle Routing Problem with	4 Heuristics Inventory Periodic VRPTW Planning (INC1, INC2, INC1-	Vending Machine Replenishment / supply chain

No	Observer	Method	Output	Application
		Time Windows (IPVRPTW)	plus, INC2-plus) considering visit frequency flexibility	
2	*Francis and Smilowitz (2006)*	Periodic Distribution with Service Choice	Continuous PVRP-SC reduced by geographical decomposition and variable substitution	Any periodic distribution system
3	*Francis et al (2006)*	Periodic Distribution considering visit frequency, schedule options and delivery strategy	PVRP embedded in a Tabu Search method	Any periodic distribution system
4	*Munoz (2018)*	Flexible Periodic Vehicle Routing Problem (FPVRP)	PVRP within 3 flexibilities embedded within: delivery schedule, delivery routing and amount of delivery quantity/size at each visit.	Any periodic distribution system
5	This Research (2018)	Flexible Periodic Vehicle Routing Problem (FPVRP) considering Color Combination Requirements within visit	Weekly horizon Periodic VRP planning with the cheapest routing set considering combinatorial color demand, visit	Paint Distribution System

No	Observer	Method	Output	Application
		frequency flexibility and multi-capacity vehicle flexibility	frequency for each retailer and which vehicles are used	

The first considered research is the beginning of PVRP as a vehicle routing method. Then, those approach is further developed by *Rusdiansyah* (2004) by implementing inventory based PVRP with time windows. This method is used since vending machine supply chain needs constant frequency visit with strict time windows. Continued in 2006, *Francis* and *Smilowits* did a research in the particular service choice flexibility by considering geographical and variable substitution factors. While the respective research is continued again in the same year by *Francis et al* (2006) by improving the recent PVRP model while adding visit frequency, schedule and delivery strategy options. Then, several years later *Munoz* (2018) introduced the PVRP modification from *Rusdiansyah* (2004) until her developments as Flexible PVRP. Her research introduced a much clearer concept and mathematical formulation for general use.

This research position is actually the implementation of PVRP by adapting *Rusdiansyah* (2004) flexibility, but focusing on Paint distribution system's complexity. The color requirements is defined as the Weighted Bill of Color (W-BOC) for each product, how frequent is a retailer need to be visited and which vehicle is used to ensure the lowest cost can be achieved. The planning horizon of FPVRP here is mapped for one week planning horizon in daily basis while assuming that this weekly schedule will repeat for the next period.

CHAPTER III
RESEARCH METHODOLOGY

This chapter will explain about the research methodologies used from the beginning period of the research until the result is obtained, complete with its explanations for each stage.

3.1. Research Flowchart

The flowchart of the whole research is presented as below:

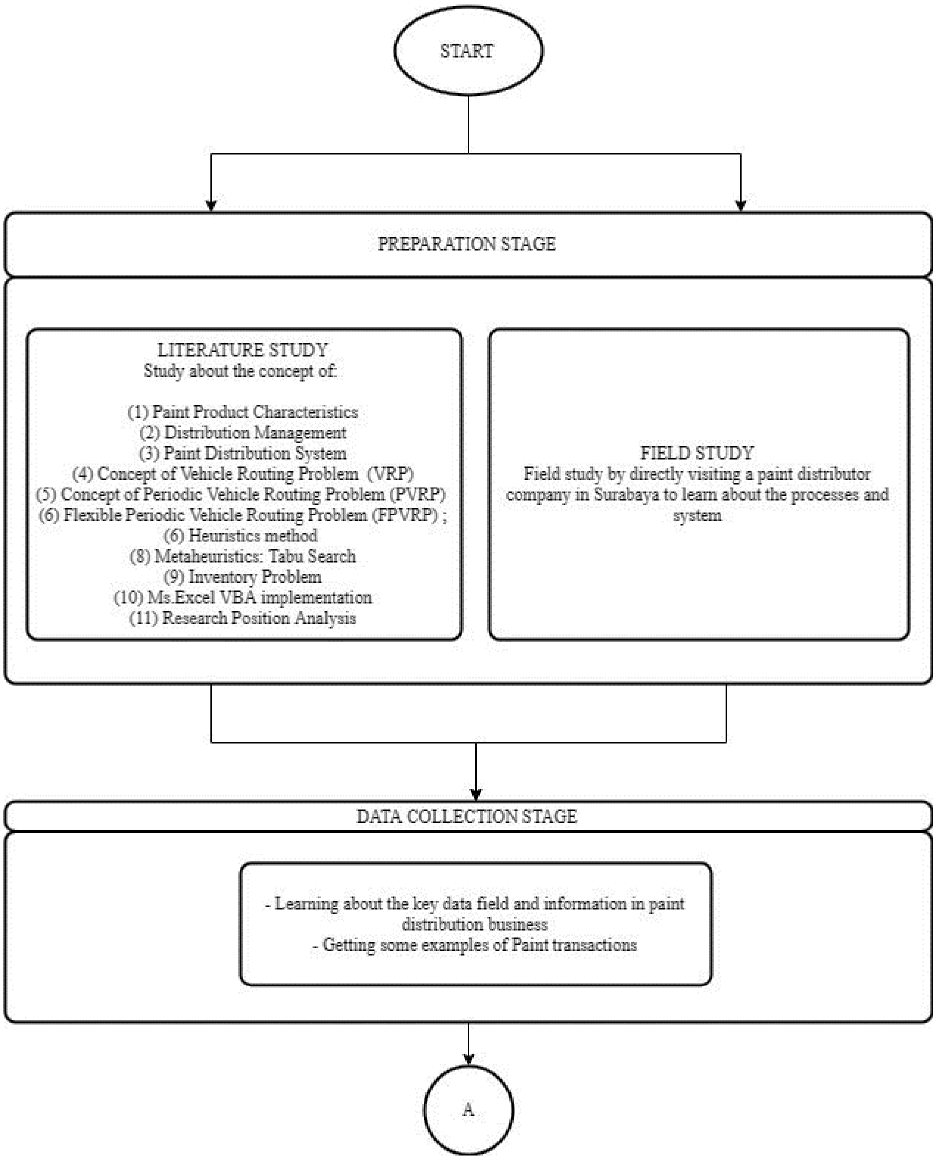

Figure 3. 1 Research Methodology Flowchart (part 1)

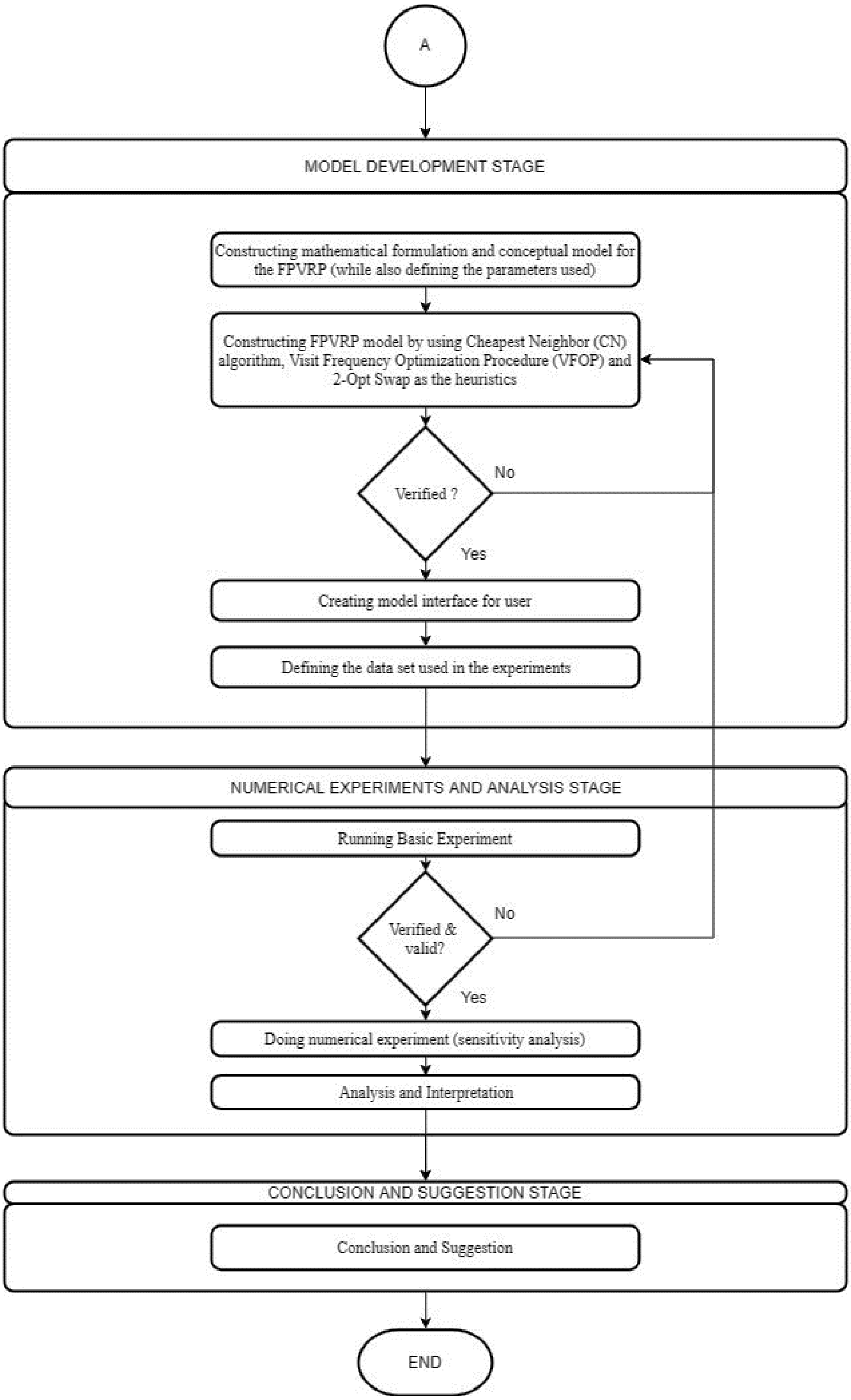

Figure 3. 2 Research Methodology Flowchart (part 2)

3.2. Flowchart Description

This sub chapter will explain the descriptions for each phase and process. Starting the research also means finding the topic of the research, finding research supervisor and pre-research discussion. After that, the processes are described as follow:

3.2.1. Preparation Stage

This stage is divided into 2 important parts done correspondingly, which are: literature study and field study. Literature study is done by collecting information, knowledge and theories from books, journals and online valid references, where the literatures complete recapitulation can be accessed in chapter 2 as well. Field study is done by visiting one of paint distributor companies. This direct visit is done to directly see and learn the business processes, direct practice, and the real problems that occur in the company.

3.2.2. Data Collection Stage

In this phase, observer obtained the information from the field study. However, since the real historical data were classified as confidential, hence observer only got the key information field and some examples of the transactions occur. The other important data were obtained by doing interview to the business actors in the company.

3.2.3. Model Development Stage

After studying the literature and the data were obtained, the model of FPVRP is constructed in form of mathematical formulation and conceptual model. Then the model will be further constructed by using Cheapest Neighbor (CN) algorithm for the PVRP calculation, while adding visit frequency optimization for the flexibility and 2-Opt Swap algorithm as the improvement heuristics. By using overall heuristics methods, the first results will be verified to test the model. If the result does not satisfy, then the model will be evaluated. If it is already verified, then the user interface is created as well as the dataset for further experiments.

3.2.4. Numerical experiment and analysis stage

This stage is done when the model is already well-established. Firstly, basic experiment is done by using the pre-constructed data sets. Then, the results will be checked whether it is verified & valid or not. If any improvements are necessary, then the model is repaired back in the model development stage. However, since this research is focusing to the model development and not focusing in the actual data processing, hence actually verification process is more dominant here compared to the validation process.

The next thing to do is executing some sensitivity analysis to the existing model. Some parameters are selected and used for this experiments. The aim of this stage is to learn about the impacts of changing variables to the system's behavior as well. Results of the experiments are further recapitulated, processed and analyzed.

3.2.5. Conclusion and suggestion stage

This last stage will consist of the conclusions of the whole observation by answering the objectives of the research. It will be about how the FPVRP is constructed and functioned for a real paint distribution system. Lastly, the suggestions were made both for this research and for the future research.

CHAPTER IV
MODEL DEVELOPMENT

This chapter consists of the development phase in creating a paint distribution model, starting from the model description, model formulation, algorithms, and the interfaces created for users to do the routing operations.

4.1. Model Description

FPVRP model is developed as a vehicle routing tools, which can be used for decision activities in the companies' operational stage, particularly for paint distributors. By adapting the on-spot color tinting and combination processes, distributors are responsible to deliver some certain number of colors but fulfilling various color needs of customers. It is described as the scheme below:

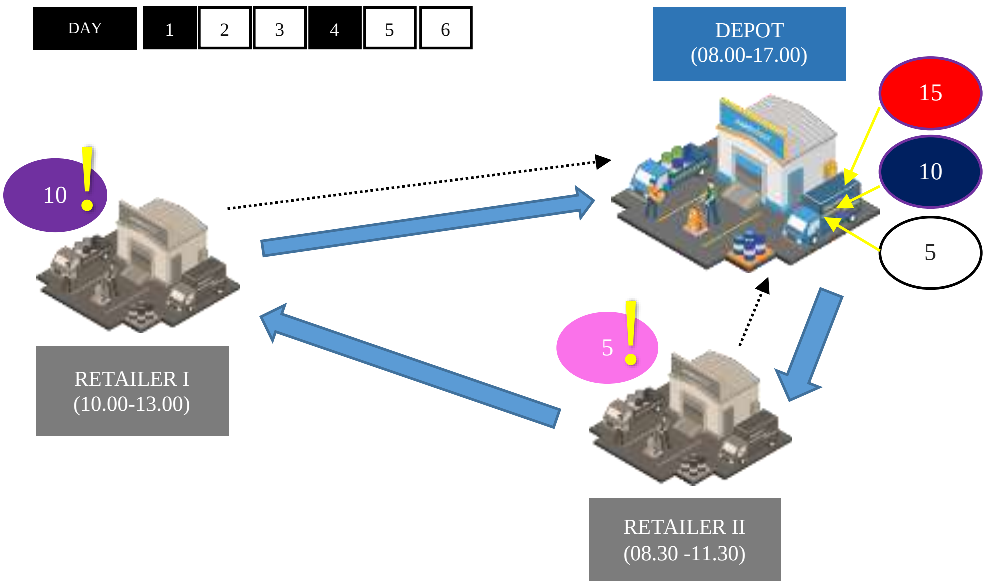

Figure 4. 1 FPVRP for Paint Distribution Scheme

This model involves particular bill of materials for the products. Hence, the scheme offered in this model is for multi dependent products. Within a VMI concept, distributor (or Depot) will schedule and route deliveries to its customers. Distributor will know the needs of each retailers. For as in the example above, Retailer I needs 10 purples and Retailer II needs 5 pinks (for period day 1 and 4, or in the binary scheduling value is notated as 100100). Since those colors are made by doing color combinations from primary colors, then distributors only need to prepare the constructing colors to fullfill the retailer needs. As for retailer 1, 10 purples are equal with 10 blue + 10 reds. While for Retailer 2, 5 Pinks are equal with 5 red and 5 white. After the demands are constructed, then for next step, a route will be established to deliver the products.

As a distributor that adopts VMI principle in supplying the retailers'demands, the distributor should also offer a routing schedule that help retailers in minimizing their holding cost also. Hence this model is developed to help users in calculating the best solution of minimized costs for all stakeholders.

However, FPVRP obviously has a significant tradeoff in determining the routing of each retailer. The cost tradeoff between traveling cost, holding cost and even vehicle fixed cost is very crucial to be managed. Therefore, a comprehensive decision tool is needed to find the best combination of costs in order to minimize the overall costs the distributor needs to spend. In addition, flexibility of capacity is given to the depot so they are able to find the cheapest vehicle and enhancing their utilitzation of assets with a wider vehicle options (or in Vehicle Routing Term, it is also be stated as: Multi-Capacity Vehicle Routing Problem).

In the other side, this research also considers time windows of each retailer and the distributor itself. It means that each retailer has their own opening and closing time as their time limitation of daily business. However, this research does not consider the deliveries which are outranged from the retailer's time windows as a reject. Nevertheless, distributor will be charged of additional costs: penalty cost for delivery lateness and waiting cost for premature arrivals. In real practice, these costs may be in form of imaginary costs or even real costs. But we use those variables in this model to help in route decision making, while it is also adding more complexity to make better decisions

.

4.2. Model Formulation

This section consists of model formulation before FPVRP is constructed into a decision tool. There are 2 parts of formulation, which are: mathematical and conceptual model as following.

4.2.1. Mathematical Model

In developing quantitative model, mathematical model is used to define the parameters, objectives and the constraints of the model. However, we implemented some modifications toward the formulations used in the research of *Rusdiansyah and Tsao.* (2004) due to the similarity of model's flexibility features. This research modifies the formulation by adding a multi-product variables and multi capacity vehicle features in both objective function and constraints.

4.2.1.1. FPVRP Objective Function

$$OF = MIN\left(\sum_{\forall i \in I}\frac{hD_{ic}}{2f_i} + \frac{1}{m}\sum_{\forall i \in I_0}\sum_{\forall j \in I_0}\sum_{\forall t \in T}\sum_{\forall k \in K} c_{ij}x_{ijtk} + FC_k\right) \tag{4.1}$$

This research divides the formulation above into 3 main parts consecutively: holding cost formulation, traveling cost formulation and the fixed cost formulation. The first cost component is the inventory or holding cost of each item. As a new modification, we change the demand variable into D_{ic}. It means that the holding cost is calculated by the amount of demand of retailer *i* for particularly color *c*. For each of color c, we consider a multi–dependent product consideration using weighted Bill of Color (BOC) concept as the bill of materials for each item. The formula is described as the equation below.

$$D_{ic} = a_1 D_{icolor1} + a_2 D_{icolor2} + \ldots + a_n D_{icolor\,n}, 0 \le a_n \le 1 \tag{4.2}$$

$$a_1 + a_2 + \cdots + a_n = 1 \tag{4.3}$$

The second cost that is tried to be minimized is traveling cost. this cost actually totally has the same concept from the previous formulation, which converts the traveled distances into cost by multiplying it with the fuel cost per km. But it is important to note that variable x_{ijtk} described as the node which is immediately visited by vehicle k. In this research, notation k is not only described as a vehicle number, but now also with its vehicle type that considers different vehicle characteristics or capacity attribute for each type.

The third major component of the objective function is the Fixed Cost (FC_k). This notation is able to be translated into the fixed cost of each vehicle k by considering its type and capacity. The fixed cost consists of 3 major sub components: Order Cost (C_o) or the cost taken by customers when setting or clarifying a delivery; Salary cost (C_s) for the daily truck drivers earnings; and the most significant one is the cost of trucks used per day (C_k), or the cost for charged to the distributor for owning vehicle k. The configuration is described as equation below:

$$FC_k = Co + Cs + C_k \ , \qquad \forall k \in K \tag{4.4}$$

It is important to be noticed that this research uses the vehicle cost in daily charges basis instead of the total investment cost. This research set this rule to make the cost calculation to be more equivalent with other costs which are also charged daily. Hence, we obtain the vehicle cost by dividing the capital cost of buying the vehicle with the vehicle lifetime in day (after it is reduced of certain assumed salvage value) or it is stated as depreciation value. Another way that is able to be used is by applying the daily leasing cost of the respective vehicle while assuming that the leasing profit is not significant. These two procedures are justified in this research in order to find the daily cost conversion for each vehicle type.

4.2.1.2. FPVRP Constraints

As the limitations of the mathematical model, this research uses the constraints developed by *Rusdiansyah and Tsao* (2004). The constraints will give limitations toward the PVRP model in stationary-interval properties, vehicle capacity, tour duration constraints, periodic VRP constraints and time windows constraints. The complete formulations are figured within its modifications as below:

$$\sum_{\forall t \in T} y_{it} = f_i, \qquad \forall i \in I;\ f_i \in F \tag{4.5}$$

$$\sum_{r=t+1}^{t+\frac{m}{j_i}} y_{ir} = 1, t = 0, \dots \dots \dots, \left(m - \frac{m}{f_i}\right), \qquad \forall i \in I;\ f_i \in F \tag{4.6}$$

$$\sum_{\forall i \in I_0} \sum_{\forall j \in I_0} q_i x_{ijtk} \le C_k, \qquad \forall t \in T; \forall k \in K \tag{4.7}$$

$$\sum_{\forall i \in I_0} \sum_{\forall j \in I_0} (t_{ij} + d_i) x_{ijtk} \le R, \qquad \forall t \in T; \forall k \in K \tag{4.8}$$

$$\sum_{\forall i \in I_0} x_{irtk} - \sum_{\forall j \in I_0} x_{rjtk} = 0, \qquad \forall r \in I_0; \forall t \in T; \forall k \in K \tag{4.9}$$

$$\sum_{\forall j \in I_0} x_{rjtk} \le 1, \qquad r = 0; \forall t \in T; \forall k \in K \tag{4.10}$$

$$\sum_{i \in B} \sum_{j \in B} x_{ijtk} \le |B| - 1, \qquad \forall t \in T; \forall k \in K \tag{4.11}$$

$$B \subseteq I;\ |B| - 1, \qquad \forall t \in T; \forall k \in K \tag{4.12}$$

$$y_{it} \in \{0,1\}, \qquad \forall i \in I_0; \forall t \in T \tag{4.13}$$

$$t_{ij} - e_j, 0 \}, \qquad i, j \in I_0 \tag{4.14}$$

$$s_{itk} + d_i + t_{ij} - s_{jtk} \le (1 - x_{ij}) M_{ij}, \qquad \forall i, j \in I_0; \forall t \in T \tag{4.15}$$

$$b_i \le s_{itk} \le e_i, \qquad \forall i \in I_0; \forall t \in T; \forall k \in K \tag{4.16}$$

$$s_{0tk} = d_0 = 0, \qquad \forall t \in T; \forall k \in K \tag{4.17}$$

The constraints above are mostly similar with the original research *of Rusdiansyah and Tsao* (2004). Constraints (4.5) – Constraints (4.6) keeps the formulation to have stationary interval properties; Constraints (4.7) as the vehicle capacity constraints; Constraints (4.8) as Tour Duration Constraints; Constraints (4.9) - Constraints (4.13) as the basic Periodic VRP constraints and Constraints

(4.14) – Constraints (4.17) as the Time Windows constraints. However, there is a slight difference in the model, since this research involves Multi Capacity vehicles. Therefore, a slight change occurs in Equation (4.7) whereas the capacity of vehicle is stated as notation C_k or the capacity property for vehicle k. (different type of the vehicle will result on different capacity as well). It is also important to understand that there are 2 major considerations in managing the capacity. They are weight capacity constraints and cube capacity constraints. If one of those capacities is not satisfied, then adding more load will be considered as infeasible. In general practice of distribution, it is also known as Product density measurement.

4.2.2. Conceptual Model

We use conceptual model to develop the way of thinking in replicating how the real system works before it is converted into computerized model. This conceptual model is important moreover because of this research uses heuristics in addressing the research's solution. The conceptual model of this FPVRP is described into some explanation points as below:

- Model Objectives: Minimizing total cost for all retailer nodes
- Model Input: Customer data, demand Data, vehicle Data, cost Parameter, time windows parameter, product Bill of Color (BOC), other parameters
- Output: Routing Schedule for 6 days, within a set of complete data description of cost, distance, time, utilization and other supporting information.
- Process: routing determination based on constraints.

First of all, we assign all data and parameters. Then, it will be checked whether the operations are feasible or not. It is done by comparing the maximum vehicle capacity with the highest amount of demands splitter into 6 days. After it is proven as feasible, the next steps of calculation will be done immediately. Otherwise, in some extreme conditions, infeasible operations will not be calculated to avoid errors

Then, the next procedure is calculating the initial solution set. This solution is obtained by assigning the routing of the vehicles in immediate day (in this research, it is so called immediate routing). The next calculation is the Visit

Frequency Optimization Procedures. In this procedure, the initial weekly demand will be managed by the vendors or distributors (the concept of VMI) to be delivered in the most effective way through all the days in a week by the perspectives of day combinations. As mentioned before, the visit frequency also becomes the input variable, which will be combined by using a certain algorithm (which it will be explained in the next sections of this chapter). One other calculation that will be used in this research is 2 opt swap algorithm. We use this improvement heuristics to enhance the solution's quality from previous calculation results. It is also well-known as local search heuristics. This method is done by swapping 1 node with another node from current routing combination to get better routing solutions

Each of the calculation will be reported to the user. It is important to know that user actually is able to do the calculations either partially or completely. For example: user would like to improve the initial immediate solution by directly using 2-Opt swap. It is actually something executable by changing the setting parameter values. Finally, after this model is finished to be constructed, this model will thus be used for further analysis and interpretations.

4.3. FPVRP Algorithm

After developing the conceptual model of the FPVRP heuristics, this section will consist of the more detailed algorithm used for each part of calculation. It is divided into: basic PVRP heuristic algorithm; Visit Frequency Optimization procedure and also the 2-opt swap algorithm.

4.3.1. Periodic Vehicle Routing Problem Heuristics Algorithm

A PVPR process is the basic routing procedure, which will be used on all calculation methods. It makes PVRP heuristic algorithm as the basic sub-process for the whole calculation. The first phase of each PVRP calculation is the model setup by assigning all necessary parameters and data through model interface. Basically there are 2 general types of data used, which are: Master Data and Transactional Data.

After setting up the data, this research uses location data to construct a matrix of distance from a node to the rest of the nodes, including the depot itself. The product data and cost parameters are used to determine how many units of item needs to be prepared and scheduled by distributors. In this VMI model, an inventory principle used is EOQ (Economic Order Quantity) by computing the weekly demand for each products with holding and order cost.

Then all of those demands are converted into 5 basic colors (red, blue, yellow, white and black) by using weighted bill of colors (W-BOC) to be recapitulated as only 5 color demand types per retailer. Later on, the next thing to do is to construct a tour by tour using undetermined amount of fleets, targeting to fullfill all demands for each retailer.

The routing process is done by setting initial variable. Due to multi capacity vehicle options and flexibilities, then the cheapest vehicle is selected first (the largest capacity which the cost of Rp/kg or Rp/cm^3 is the lowest). After a tour is finished to construct, then vehicle adjustment is done to reduce cost and increase vehicle's utility.

The next step is by doing the Cheapest Algorithm Procedure to construct a tour. While the nearest neighbor concept since assuming that the smaller value of distance equals with smaller cost, cheapest neighbor (or also known as: cheapest insertion) considers which cost is the lowest to find which next neighbor should be visited. There are 3 key drivers that determine when a tour should be constructed more and when it needs to stop but change the vehicle, which are: Weight capacity, cube capacity and operational time windows of distributor (Depot).

After all nodes which need to be visited at that day are already satisfied, then stop the routing activities on that day and reset the vehicle usage to prepare for the next day activities. Then, redo the cheapest neighbor algorithm as explained previously. This algorithm is iterated until all retailers on the 6 days are already fullfilled and then reported to the distributor as a routing planning and analysis.

4.3.2. Visit Frequency Optimization Algorithm

As explained in previous section, this algorithm is developed by *Rusdiansyah and Tsao* (2004) to find the nearly optimum day combination for each customers to minimize overall total cost. This algorithm is essential since holding costs for each unit are significant to overall total cost. It means that a balancing between holding cost, travel cost and fixed cost need to be done. This algorithm consists of certain computation procedures to get results with reasonable computational time, which differs the result of exact method and even greedy heuristics that usually require a very long computational time.

However, this model assumed that holding cost originally is higher than the traveling cost due to the product characteristics. This is the main complexity of the PVRP model since traditional VRPs do not usually consider this cost. Another important thing that is required to be understood is that the frequency here is not stated as the output, but as the input of the model.

The results of the algorithm above are different with the exact methods. There are possibilities that the algorithms haven't explored some solution spaces yet. Therefore, improvement heuristics are important to help improving the solutions' quality.

4.3.3. 2-Opt Swap Improvement Heuristics Algorithm

As a local search heuristics, 2-opt swap is compulsory to improve the current result by looking for solution spaces which have not been explored yet. There are so many types of swap that are used in improving a heuristic result.

We start the hueristics by setting up the swap parameters. In this case, it is about how many iterations of swap that will be executed. Then, the next step of the algorithm is taking previous or initial result, either a result from visit frequency optimization procedure or from the immediate calculation. After everything has been set up, the swap algorithm can be executed. There are 2 types of swap method used in this algorithm:

4.3.3.1. Inter-Route Opt Swap

This type of Opt Swap allows any swap from any nodes (except the identical node or the nodes that already exists in the current route). However, due to the stationary-interval property existence, a pair of swap should also be followed by frequency-swap. Hence, the consistency of interval yet will be maintained. It is visualized as picture below:

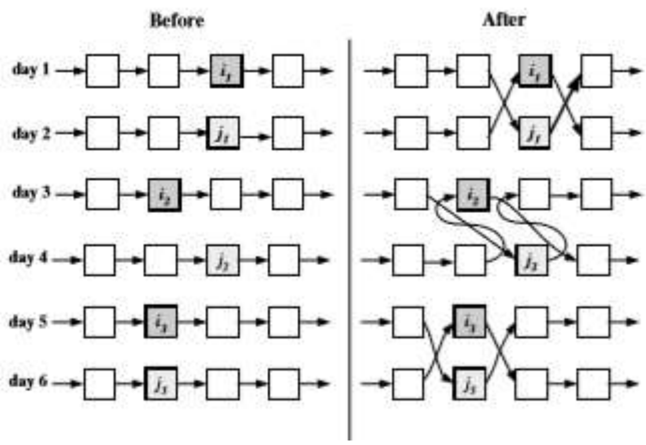

figure 4. 2 Example of inter-route swap

(source: Rusdiansyah and Tsao, 2004)

As an example, this algoritm randomly chooses node A (frequency = 1, within 100000 configuration) and node B (frequency = 3, within 101010 configuration). Therefore, if this swap is feasible to be done thus the node A will have frequency configuration of 101010 as well as the node B to have 100000 configuration. Then, this algorithm will recalculate the routes to obtain the cheapest delivery's sequences.

4.3.3.2. In-Day Opt Swap

In-day opt swap is quite different from previous swap. This heuristics only allows swaps within a same day deliveries, either it is in-route or inter-route swaps. For example: a swap is not allowed between node A in Monday and node B in Tuesday. It is regulated so to prevent any stationary-interval errors Different from previous swap, this type of swap will affect only to single interchange. It is also important to explore better solution spaces in a single day basis only to anticipate inefficiency of daily routing.

4.4. Interface of the Model

A tool to model the FPVRP Algorithm used is Visual Basic Applications (VBA), a programming language used in Microsoft software. We introduces the interface as COLO-ROUTING Application. The descriptions for each part will be explained as follow: HomePage, Main Interface, Input Data, Calculation Processor and Report of the tools.

Home page is the central access for all features in the whole system. The first picture below describes the main page of the application. It consists of the feature pages on the top right and also introduction in the page:

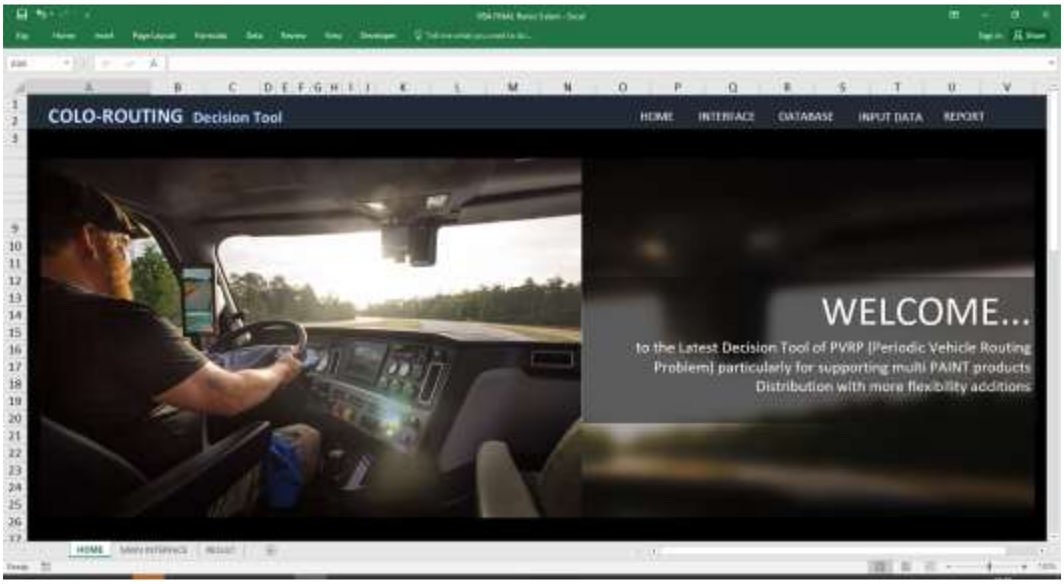

Figure 4. 3 Home Page Interface part 1

The interface below is the main guide for the FPVRP Calculating processes. The provess is started from inputing Data and parameter. Then, inputing transaction data (such as: demands, etc). Thus, calculation can be executed to obtain comprehensive report. While the command in the right side is Setting button for further model adjustment, starting from parameters, policies, etc

Figure 4. 4 Home Page Interface part 2

While home page helps guiding the user to operate the COLO-ROUTING, main interface is the central for all commands existing in the interface. Starting from New_Form to create new field; Randomize feature to help user in obtaining random data for simulation; Calculate_button is the main button to do a set of calculation procedures; and also other supporting features starting from Setting button, View button, About and Validation buttton.

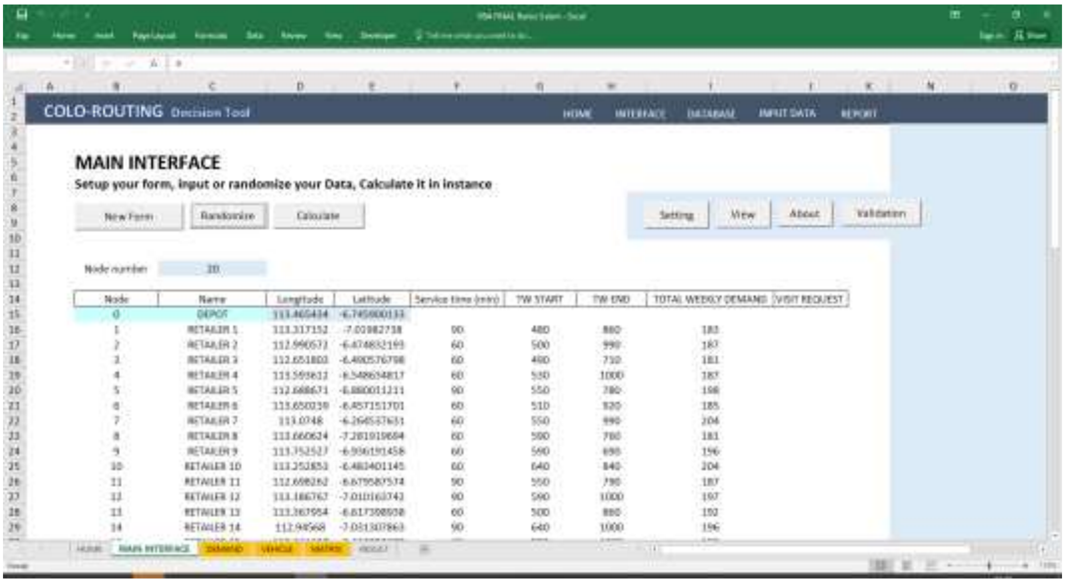

Figure 4. 5 Main Interface Page

The most important in the model interface is the Report page. Whereas all the data and calculations are recapitulated into a single page of report. Below is the sneakpeek of the report page:

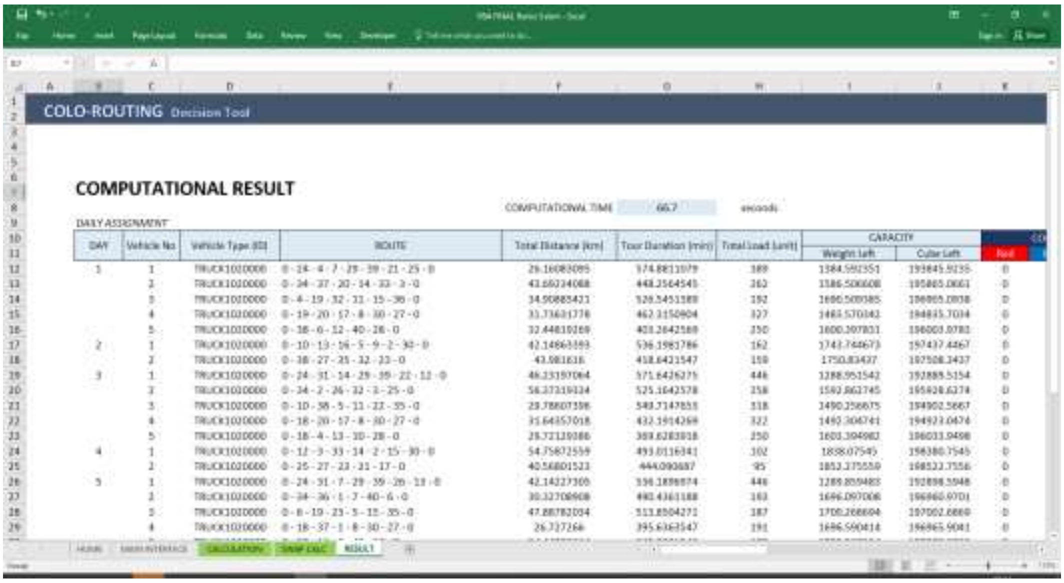

Figure 4. 6 Computational Result Page

As the goals for an interface is to connect the user with the system, the interfaces above were made to be as user-friendly as possible. However, the data and the calculation procedures should be noticed to prevent any error on calculation.

4.5. Datasets of Research

This section will consist of the data that will be used for the numerical experiments. The data's type is considered as dummy or random-obtained data. However, those dummy data are actually enough to represent FPVRP model and its scenarios.

Basically there are 5 data sets constructed in the model. The datasets are differed from the number of retailer served, which later will impact on the amount of demands are necessary to be delivered weekly. This state will also determine the vehicle type that might be appropriate to be used. Some of datasets uses real distance information obtained from online sources (GPS ./ Google Maps) for better data representation. However, for bigger data size, this action is quite infeasible due to data collection constraint. The datasets are figured as below:

Table 4. 1 Dataset List

Dataset	n	Distance origin	Total Demand	TW Min	TW Max
1	15	Real Data	3189	500	1000
2	30	Real Data	7061	480	1000
3	50	Euclidian	11052	480	1000
4	75	Euclidian	17021	490	1000
5	100	Euclidian	21994	480	1000

The next data used are the type of vehicle that can be used. In this FPVRP model, there are assumed 5 vehicle types that are allowed to be used in constructing a routing. Each vehicle type has their own capacity characteristics and also different cost per day. (The vehicle cost is assumed as the invenstment cost but converted into daily time buckets). Hence, which truck is more appropriate to be used will be strongly dependent with the characteristics of the routes themselves.

Table 4. 2 Vehicle List

#	Truck Type (ID)	Weight Capacity (kg)	Cube Capacity (cm^3)	Vehicle cost / day
1	L300BAK2000	2000	1104000	400,000.00
2	L300BOX1500	1500	3380000	500,000.00
3	COLTBOX5000	5000	13440000	1,200,000.00
4	FUSOBOX7000	7000	31464000	2,100,000.00
5	CDDLONGBOX14000	14000	41400000	4,750,000.00

The other data used is the Weighted Bill of Color (WBOC) for each paint product. As notated in the previous mathematical formulation, each color has a fraction or proportion of primary colors which cause the color changing. The data below represents the examples of the color combination. Due to the classified data, then the proportions for each color are assumed to be 70% base color : 30% addition color. The BOC Data will be figured in the Appendix-1

CHAPTER V
NUMERICAL EXPERIMENTS

This chapter will contain of all the experiments done to the constructed FPVRP model. This chapter will be divided into basic numerical experiments, model validation & verification, sensitivity analysis and also the further analysis of the model.

5.1. Basic Numerical Experiment Results

The first numerical experiment is by doing normal experiment with normal data to know the behavior of the model. As an example, dataset 1 (number of retailer = 15) is taken. Within all parameters are set into default values, the data used in the calculation are figured as below:

Table 5. 1 Dataset 1 Basic Information

Node	Longitude	Latitude	Service (min)	TW START	TW END	DEMAND
0	112.7611547	-7.30487203				
1	112.7471085	-7.31949978	90	660	1000	213
2	112.6681538	-7.27316766	60	610	1000	186
3	112.6495615	-7.28862669	60	580	700	188
4	112.795232	-7.31286590	90	600	700	269
5	112.7739526	-7.29837510	90	500	640	216
6	112.6864553	-7.23173999	90	530	640	125
7	112.7468549	-7.26770801	60	550	770	271
8	112.7109613	-7.33301080	90	660	950	204
9	112.7343712	-7.25946690	60	510	660	214
10	112.7966424	-7.24216539	90	550	850	148
11	112.6393056	-7.27809907	90	540	950	216
12	112.7970743	-7.29204310	60	510	890	257
13	112.7550132	-7.28314245	60	560	1000	237
14	112.7260191	-7.28800919	60	620	880	166
15	112.6977216	-7.29517799	60	650	1000	279

Table 5. 2 Demand Recapitulation for Retailers in Dataset 1

Node	DEMAND	Red	Blue	Yellow	Black	White
1	213	50	36	32	37	58
2	186	34	44	33	41	34
3	188	31	30	46	34	47
4	269	51	80	36	49	53
5	216	58	39	36	45	38
6	125	31	19	7	25	43
7	271	53	58	56	53	51
8	204	60	34	48	36	26
9	214	67	46	38	31	32
10	148	31	27	29	10	51
11	216	60	42	37	28	49
12	257	60	85	46	37	29
13	237	49	41	31	50	66
14	166	56	39	41	28	2
15	279	58	69	54	28	70

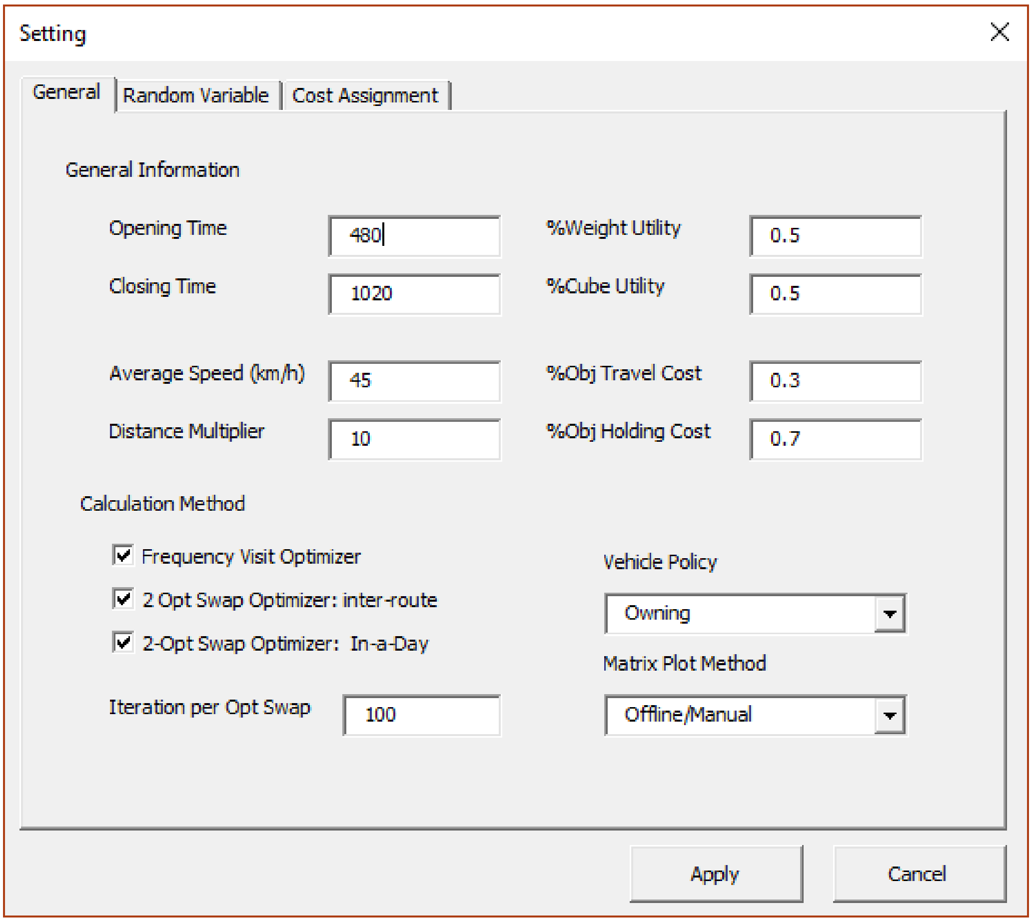

Figure 5. 1 General Configuration of Dataset 1

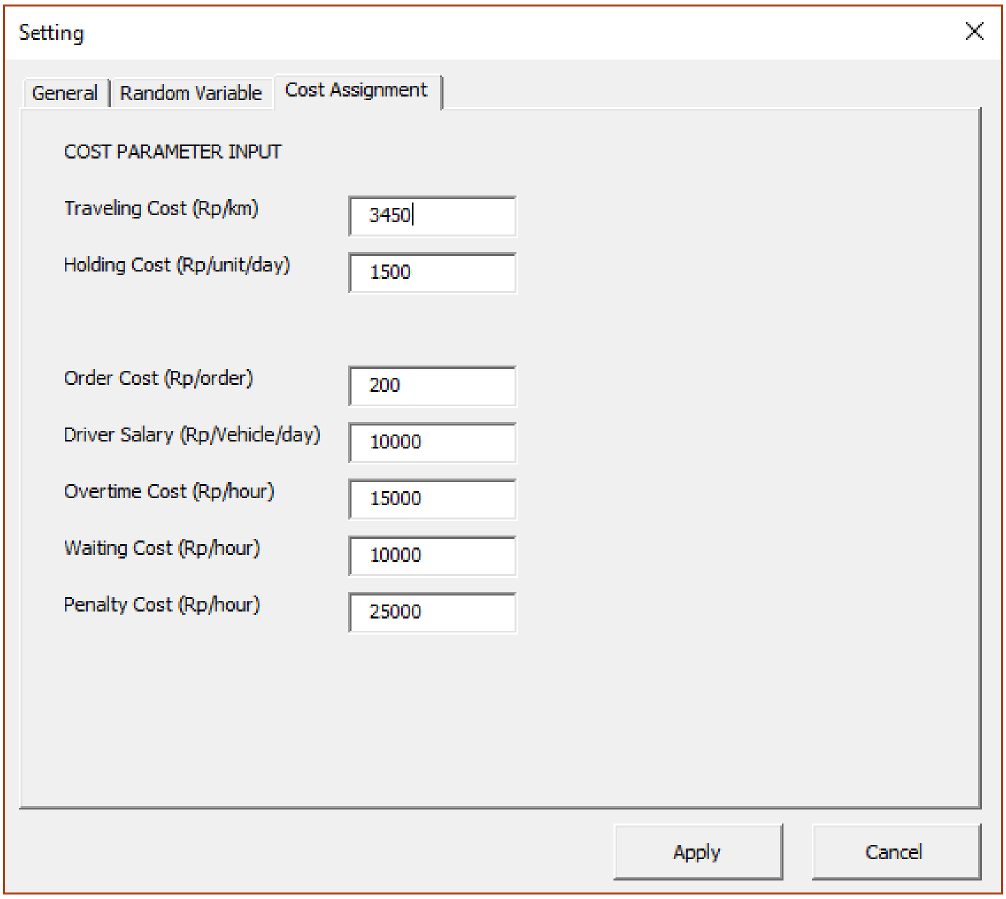

Figure 5. 2 Cost Parameters for Dataset 1

This research used Visual Basic Application (VBA) of Ms.Excel. The calculations were done firstly using immediate algorithm. It means that all deliveries for 15 retailers in dataset 1 are served as soon as possible. Since there is no frequency request does exist, hence all retailers are placed into the first day delivery. The results are obtained as below :

Table 5. 3 Routing Result of Dataset 1 for Immediate Delivery

DAY	Vehicle No	Vehicle Type (ID)	ROUTE
1	1	COLTBOX5000	0 - 5 - 12 - 13 - 7 - 14 - 15 - 2 - 11 - 0
	2	L300BOX1500	0 - 1 - 8 - 10 - 4 – 0
	3	L300BOX1500	0 - 9 - 6 - 3 – 0
2	1	L300BAK2000	0 – 0
3	1	L300BAK2000	0 – 0

DAY	Vehicle No	Vehicle Type (ID)	ROUTE
4	1	L300BAK2000	0 – 0
5	1	L300BAK2000	0 – 0
6	1	L300BAK2000	0 - 0

Next calculations were done by using Visit Frequency Optimization Procedure. As stated in the previous chapter, this algorithm is created to find the best visit frequency (as model's input) which will result on the lowest cost as possible by considering holding and travel cost ratio or fraction. The results then are obtained as below:

Table 5. 4 Routing results of Dataset 1 for Visit frequency Optimization Procedure

DAY	Vehicle No	Vehicle Type (ID)	ROUTE
1	1	L300BOX1500	0 - 13 - 7 - 14 - 15 - 2 - 11 - 8 - 0
	2	L300BOX1500	0 - 4 - 12 - 10 - 9 - 6 - 0
	3	L300BAK2000	0 - 3 - 0
2	1	L300BAK2000	0 - 0
3	1	L300BAK2000	0 - 5 - 1 - 0
4	1	L300BOX1500	0 - 13 - 7 - 9 - 8 - 15 - 2 - 11 - 0
	2	L300BAK2000	0 - 4 - 12 - 3 - 0
5	1	L300BAK2000	0 - 0
6	1	L300BAK2000	0 - 5 - 1 - 0

Based on the routing above, the research inferred that the frequency of each retailer is adjusted to minimize the holding cost. As explained before, holding cost is the significant cost and the main factor to reduce in this model. It is purposed to increase the frequency until the increase does not bring any saving to the grand total cost. if the increase of frequency is equal with increasing total cost, then there is a very high probability that the total cost will stay increasing after the next frequency addition (hence it needs to be terminated). The comparison of the visit frequency between the first and second algorithm is figured as follow:

Table 5. 5 Comparison of visit frequency between immediate and visit frequency optimization procedure

Frequency	IMMEDIATE		VISIT FREQ OPT	
	n	%	n	%
1	15	100%	3	20%
2	0	0%	12	80%
3	0	0%	0	0%
6	0	0%	0	0%

The comparison above shows that there is a significant shifting in the visit frequency. 80% of the retailers are cheaper to be visited twice a week rather than only once. It is due this model is considering holding cost and vehicle selection as the variables. The day of the delivery it is configured as written in Table 5.4.

While for the last heuristics algotithm, 2-Opt Swap is done by randomly local search to explore the new solution space. It is due to the previous algorithms are heuristics, which is done to find a very good solution but not optimum yet (it is probably local optimum or even local minimum results). Therefore, 2-Opt-Swap heuristics is used to improve the results as below:

Table 5. 6 Routing results of Dataset 1 after 2-opt Swap Algorithm

DAY	Vehicle No	Vehicle Type (ID)	ROUTE
1	1	L300BOX1500	0 - 5 - 12 - 7 - 1 - 14 - 15 - 2 - 0
	2	L300BOX1500	0 - 6 - 3 - 8 - 10 - 11 - 0
	3	L300BAK2000	0 - 4 - 0
2	1	L300BAK2000	0 - 0
3	1	L300BAK2000	0 - 9 - 13 - 0
4	1	L300BOX1500	0 - 5 - 12 - 4 - 1 - 8 - 15 - 0
	2	L300BAK2000	0 - 7 - 6 - 2 - 11 - 0
5	1	L300BAK2000	0 - 0
6	1	L300BAK2000	0 - 9 - 13 - 0

Those new routing is obtained by choosing 2 nodes to swap randomly. As described in model development chapter, the swap algorithm is divided into 2 types:

inter-route swap (or inter-day swap) and in-day swap. This swap algorithm is different from usual swap since it also considers the frequency swap to maintain the stationary interval property of all retailers. Historical swap of dataset 1 is figured in a table below:

Table 5. 7 Historical retailer swap of dataset 1 calculation

Swap	New Grand TC
In-Day 4 and 7	IDR 10,943,366.67
In-Day 6 and 7	IDR 10,947,143.33
In-Day 6 and 3	IDR 11,001,426.67
Inter-Day 6 and 9	IDR 11,019,111.67
Inter-Day 1 and 10	IDR 11,042,165.00
Inter-Day 10 and 3	IDR 11,147,436.67
Inter-Day 1 and 6	IDR 11,156,850.00
Inter-Day 5 and 13	IDR 11,167,330.00
PREVIOUS ALGORITHM	IDR 11,180,655.00

The swap algorithm is done within 100 iterations of inter-day swap and another 100 iterations of in-day swap. Among those swaps, advantageous swaps which are applied to existing routes are noted from bottom to top in table 5.7. It can be inferred that there is better routing result, in which this 2-opt swap algorithm helps to explore new possibilities of solution outcomes. This algorithm is done randomly, hence if this algorithm is applied again to the same datasets can result into different solutions as well. However, the cost saving occurred in this algorithm is actually not as significant as visit frequency optimization procedure previously, but it does some cost savings.

As a summary, a comparison is done to know the significant differences between all the algorithms. It shows that each of the calculation procedures will result on different routing results with different grand total cost, utilization, distance travcled, customer frequencies and vehicles used. The results are compared as below:

Table 5. 8 Comparison for each procedures used in Dataset 1

	DISTANCE	UTILIZATION	TOTAL COST	
Immediate Algorithm	146	8.59%	IDR	16,314,450
Visit Frequency Opt	277.9	17.80%	IDR	11,180,655
2-Opt Swap	306.5	16.81%	IDR	10,943,367

Table 5. 9 Total Cost Savings Recapitulation

SAVING COMPARISON OF DATASET 1					
	TOTAL COST				
Immediate Algorithm	IDR	16,314,450			
Visit Frequency Opt	IDR	11,180,655	Saving 1	IDR	5,133,795
2-Opt Swap	IDR	10,943,367	Saving 2	IDR	237,288

Table 5. 10 Customer Frequency Proportions of Dataset 1

Frequency	IMMEDIATE		VISIT FREQ OPT		2-OPT SWAP	
	n	%	n	%	n	%
1	15	100%	3	20%	3	20%
2	0	0%	12	80%	12	80%
3	0	0%	0	0%	0	0%
6	0	0%	0	0%	0	0%

Table 5. 11 Vehicle used for Dataset 1

#Truck	Truck Type (ID)	Weight Capacity	Cube Capacity	Vehicle cost per day	Amount
1	L300BAK2000	2000	1104000	400,000.00	1
2	L300BOX1500	1500	3380000	500,000.00	2
3	COLTBOX5000	5000	13440000	1,200,000.00	0
4	FUSOBOX7000	7000	31464000	2,100,000.00	0
5	CDDLONGBOX 14000	14000	41400000	4,750,000.00	0

The calculation above is an example of the FPVRP calculation for quite small node sizes within average parameter values. It is important to be noted that the calculation above used holding : travel cost fraction $(\omega_{inv} : \omega_{trp})$ by 0.7:0.3. It means that holding cost values are considered as significant compared to travel cost, hence it is emphasized to be reduced more than the travel cost itself.

5.2. Model Verification and Validation

This section will consist of the proofs in determining whether the model is already appropriate or not. It's appropriaty will be checked toward the conceptual model in Verification activities; while it is also checked toward the real system in through validation. It necessarily needs to be done before proceeding to the sensitivity analysis and further experiments.

5.2.1. Verification

The verification processes in this model will include some areas. The important verifications described in this model are: the vehicle routing problem procedure, the visit frequency optimization procedure, the impacts of frequency to traveling & holding cost; and impacts of frequency toward each cost. Each verification is analyzed as below:

5.2.1.1. Vehicle Routing Problem (VRP) verification

This verification is done to check whether the calculations of VRP computation using Microsoft Excel VBA does already match with algorithm's procedures. It is done by doing a manual calculation comparison, which then will be compared to the computerized heuristics' result. A dataset consists of 5 retailers is used for easier comparison as below:

Table 5. 12 Manual computation for 5 retailers' distribution

Truck				1	Arrival	875
ROUTE	0-4-1-2-3-5-0				Departure	946
Type	COLTBOX5000		Weight Load	1816	Cube Load	4812400
Tij (min)	0	1	2	3	4	5
0	0	4.153147	7.290439	11.370025	3.136686	10.510076
1	4.153147	0	8.471385	11.335659	7.284106	8.584618
2	7.290439	8.471385	0	4.521801	8.100525	6.737155
3	11.37002	11.335659	4.521801	0	12.58129	5.215676

4	3.136686	7.284106	8.100525	12.581296	0	12.849415
5	10.510076	8.584618	6.737155	5.215676	12.849415	0
TW Start		620	640	550	490	530
TW End		900	760	910	880	930
Service		90	90	90	90	60
Waiting		32.715894	0	0	0	0
Penalty		0	0	0	0	0
Travel Cost		18847.623	21919.7079	11700.15	0	13495.560
Waiting Cost		5452.6490	0	0	0	0
Penalty Cost		0	0	0	0	0
TOTAL		24300.272	21919.707	11700.15	0	13495.56

It can be inferred that within 5 retailers' distribution, a route of "0-4-1-2-3-5-0" is able to be constructed. The result is obtained by using cheapest neighbor concept by considering the travel cost, waiting cost and penalty cost. Hence, the sequences of retailer visitation is the nearest neighboring retailer from previous visit while also considering the operational hours / time windows of those respective retailer. While the result of the computerized calculation is seen as following:

Table 5. 13 Computerized calculation of 5 retailers' distribution

DAY	Vehicle No	Vehicle Type (ID)	ROUTE
1	1	COLTBOX5000	0 - 4 - 1 - 2 - 3 - 5 - 0
2	1	L300BAK2000	0 - 0
3	1	L300BAK2000	0 - 0
4	1	L300BAK2000	0 - 0
5	1	L300BAK2000	0 - 0
6	1	L300BAK2000	0 - 0

The result of the computerized calculation also shows the route of "0-4-1-2-3-5-0" using the same algorithmic procedures. It can be seen that the results between manual computation and computerized computation are identical. Therefore, the VRP calculation is concluded as verified.

5.2.1.2. Visit frequency optimization procedure verification

The next verification procedure is toward the visit frequency optimization procedure. Similar with previous verification, a manual computation for small data size is done and thus compared to computerized heuristics. Taking the route "0-4-1-2-3-5-0" result, the visit frequency of each retailer is found by following calculation:

Table 5. 14 Increasing frequency of retailer 1

Node	Frequency	Split Demand (any color/mix)						GRAND TOTAL COST
		MON	TUE	WED	THU	FRI	SAT	
1	1	368	0	0	0	0	0	10,041,774.05
	1	0	368	0	0	0	0	12,456,626.03
	1	0	0	368	0	0	0	12,456,626.03
	1	0	0	0	368	0	0	12,456,626.03
	1	0	0	0	0	368	0	12,456,626.03
	1	0	0	0	0	0	368	12,456,626.03
	2	184	0	0	184	0	0	12,197,466.58
	2	0	184	0	0	184	0	12,212,318.56
	2	0	0	184	0	0	184	10,041,774.05

Retailer 1 is taken as the example of the verification process. The visit frequency is initially set into 1 (once a week visitation). While also calculating the routing and total cost of overall routes, the frequency of Retailer 1 is increased into 2 (twice a week visitation). Then, the cheapest results of each frequency are compared. Since the result of $f = 1$ is cheaper, then stop the frequency addition and used the frequency as the best solution of visit. The next thing to do is to find which alternatives of frequency is the cheapest, as it is known that there are 6 possible alternatives for $f = 1$. Hence, the retailer 1 is placed into Monday delivery due that it has the cheapest cost among all alternatives.

All retailers thus are computed similarly with the Retailer 1. Then, it is found that each retailer has configuration of $f = 1$ during this algorithm. The configurations are as below:

Table 5. 15 Manual visit frequency optimization procedure for all 5 retailers

Node	Frequency	Split Demand (any color/mix)						ΔTC
		MON	TUE	WED	THU	FRI	SAT	
1	1	368	0	0	0	0	0	356,017.79
2	1	359	0	0	0	0	0	346,567.79
3	1	360	0	0	0	0	0	347,617.79
4	1	362	0	0	0	0	0	349,717.79
5	1	367	0	0	0	0	0	354,967.79

The following algorithm is used to calculate the ΔTC for each retailer. It is done by using $\Delta TC = \omega_{inv}\Delta TC_{Holding} - \omega_{trp}\Delta TC_{Traveling}$ formula, whereas $\omega_{inv}: \omega_{trp} = 0.7: 0.3$. If the result of ΔTC still shows positive results, hence the frequency needs to be added. This procedure is terminated if there is no positive value anymore or all retailers have already achieved the highest frequency values. Due to the positive values above, then the frequency of those retailers must be added. As the results, it is figured as follow:

Table 5. 16 Final visit frequency optimization using manual calculation

Node	Frequency	Split Demand (any color/mix)						ΔTC
		MON	TUE	WED	THU	FRI	SAT	
1	6	62	62	61	61	61	61	34,017.79
2	6	60	60	60	60	60	59	32,442.79
3	6	60	60	60	60	60	60	32,617.79
4	6	61	61	60	60	60	60	32,967.79
5	6	62	61	61	61	61	61	33,842.79

From the results above, it indicates that all the values of ΔTC are still positive but yet the frequency of those retailers has achieved its maximum value. Thus, the procedure ends with the frequency of all retailers are equal to 6.

The computerized calculation is figured as below:

Table 5. 17 visit frequency optimization using computerized calculation

DAY	Vehicle No	Vehicle Type (ID)	ROUTE
1	1	L300BAK2000	0 - 4 - 1 - 2 - 3 - 5 - 0
2	1	L300BAK2000	0 - 4 - 1 - 2 - 3 - 5 - 0
3	1	L300BAK2000	0 - 4 - 1 - 2 - 3 - 5 - 0
4	1	L300BAK2000	0 - 4 - 1 - 2 - 3 - 5 - 0
5	1	L300BAK2000	0 - 4 - 1 - 2 - 3 - 5 - 0
6	1	L300BAK2000	0 - 4 - 1 - 2 - 3 - 5 - 0

The results between manual operations and computerized operations are indicating the same frequency results. All retailers are set into f = 6 within route is "0-4-1-2-3-5-0". Hence, it is concluded that the VBA operations are verified.

5.2.1.3. Holding and Travel cost toward visit frequency

As mentioned previously, this model used frequency as the input of the formulation. However, setting or changing a frequency value will have different impacts on traveling and holding cost. An increase or high value of frequency will obviously press the holding cost, but it will obviously increase the traveling cost and also the vehicle fixed cost. This theory occurs in this model as well, and yet it is proven by the charts below:

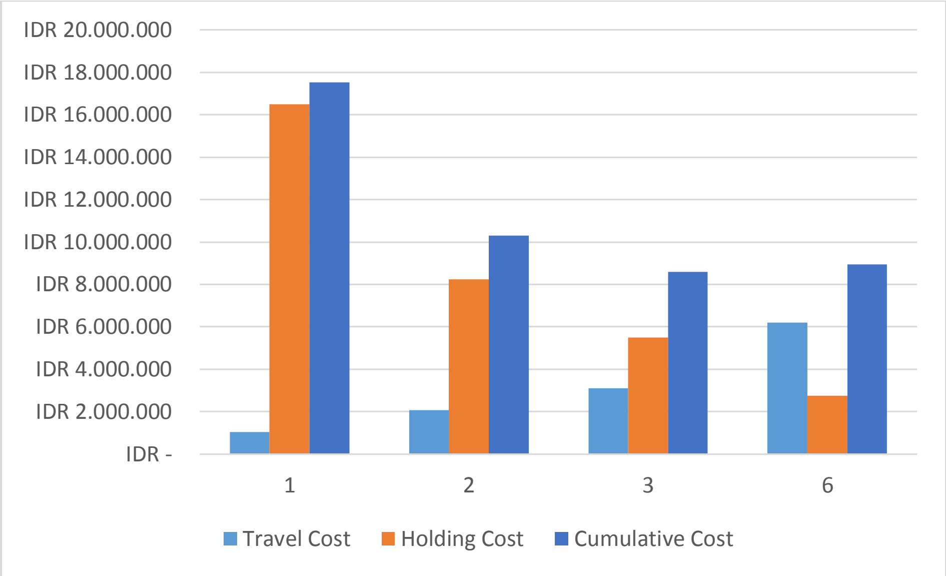

Figure 5. 3 Holding cost and Travel Cost Proportion Chart

From the experiments by using 4 types of frequency in dataset 5 as above (n = 100), the results are obtained typically as above which prove the theory. Holding Cost is very high and dominant in the routing where frequency is equal to 1. Then it will gradually decrease as the frequency increase. In the other hand, it also happens in the traveling cost, which it starts in a very low value but yet gradually increasing. The change increments for holding cost are much larger than the travel cost, which indicating that holding cost is superiorly significant if compared to other costs (it is followed also with significantly reducing Total cost),. In the most of occasions, in a highly frequent deliveries, finally traveling cost is more expensive than the holding cost itself. It is due that more distributing activities are done, more distance travelled and also more resources are used starting from vehicles, drivers, etc. Based on the pattern above, this FPVRP algorithm tries to find the most effective combination in saving the cost as much as possible.

5.2.1.4. Overall cost components compared to the frequency

Besides of traveling cost and holding cost, there are other costs involved as well in this model. However, each cost also has patterns for most calculations in the model. The visualizations of the comparison are figured as the chart below:

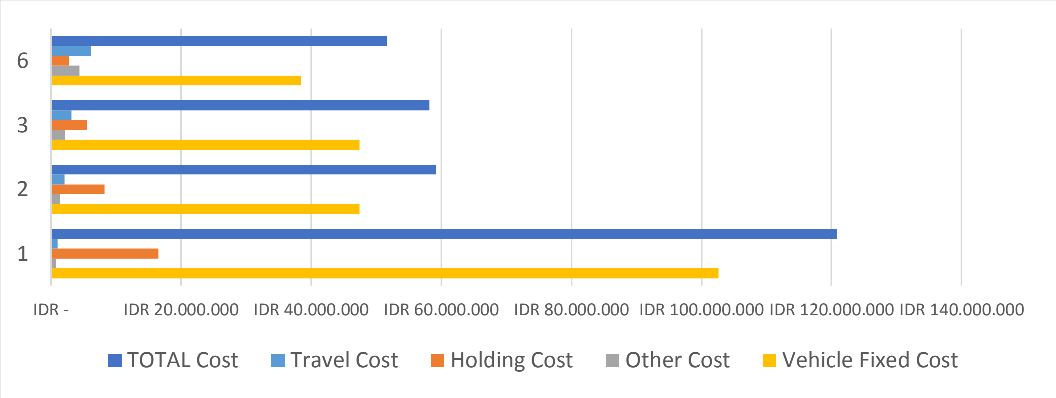

Figure 5. 4 Cost Comparison verification for each Frequency

Similar with previous sub-section, this verification compares the cost with frequency. Nevertheless, in the chart above, it can be learnt that besides of traveling and holding cost, fixed vehicle cost is also a significant variable, even more than both of those. It is because the vehicle policy used here is “owning” not leasing. Hence, the algorithm will calculate the vehicle cost as cumulative owned cost (even though the vehicle is not used that day, the cost of the vehicle is still charged daily to the owners). While for other costs which consists of order cost, penalty cost, waiting cost and overtime costs are not considered as significant.

5.2.2. Validation

Since the focus of this research is to develop a distribution model, hence there is not much thing to be validated (due to validation is a comparison between the computerized model with the real system). Some of the data used in this research is dummy data , and some others are supporting secondary data which functions as parameters. For example: the vehicle capacity, product’s basic information and the real distance using Google Maps for some datasets.

5.3. Sensitivity Analysis

In this section, we will apply some scenarios to the model to know the behavior, patterns and routing results of the system itself. There are some scenario types used in this research, which are: holding-travel cost fraction, number of retailers, retailers’ location, demand size, demand uniformity and time windows scenarios. The reason these scenarios are taken is because these parameters are suspected to be the significant factors which influence how the routing process will be done.

5.3.1. Holding and travel cost fraction sensitivity analysis

The first sensitivity analysis is the comparison between $\omega_{inv}: \omega_{trp}$ or the subjective fraction parameters between holding cost and traveling cost emphasize. The higher the fraction, it means that the cost needs more significant reduce compared to other cost. These subjective parameters are determined first to find which emphasize values are the best to be used for all experiments. By using 5 types of fraction combination, the result of sensitivity analysis is figured as below:

The results above indicate that 80% of the datasets are using $\omega_{trp}: \omega_{inv} = 0.3: 0.7$ as the best value of fractions. Except for dataset 3 which is using $\omega_{trp}: \omega_{inv} = 0.4: 0.6$ as its best fraction values. From this sensitivity, it is actually can be inferred that holding cost is significant in the calculation, hence it needs to be reduced at most compared to the travel cost.

5.3.2. Dataset size and location sensitivity analysis

In this scenario, all 5 datasets mentioned in sub chapter 4.5. are used to depict different nodes number and different node locations condition. There 5 types of node numbers used, which are: 15 nodes (small, dataset 1), 30 nodes (medium, dataset 2), 50 nodes (medium, dataset 3), 75 nodes (large, dataset 4) and 100 nodes (very large, dataset 5). Whereas each of the dataset has differenr combinations of node locations. However, node locations used are randomized in Surabaya region, Indonesia. Nodes in dataset 1 and 2 are plotted using real data with real distances through Google Maps GPS system, while the others are obtained randomly using random number formula within euclidian distance calculation.

Experiments conducted were done by using all of three procedures / algorithms, starting from immediate visit procedure, visit frequency optimization procedure and 2-Opt Swap algorithms. The overall experiments results are recapitulated into charts below:

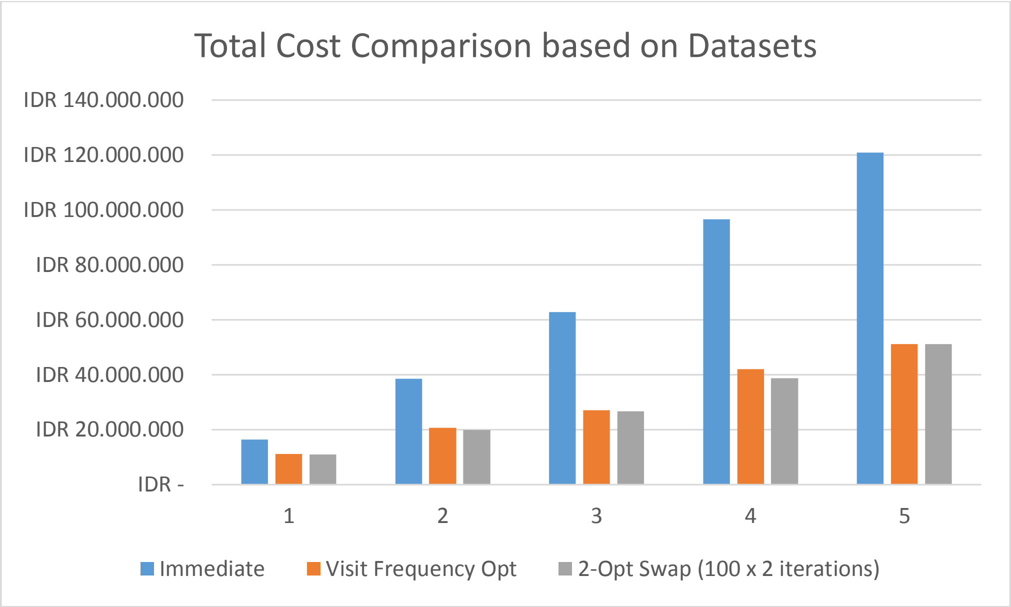

Figure 5. 5 Grand Total Cost Comparison for all Datasets

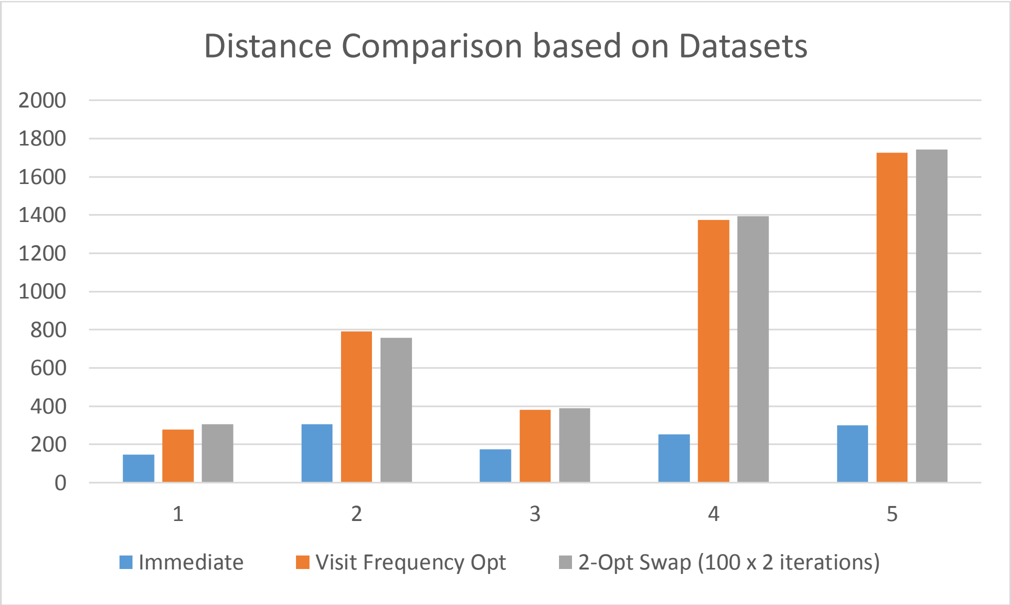

Figure 5. 6 Distance Comparison for all Datasets

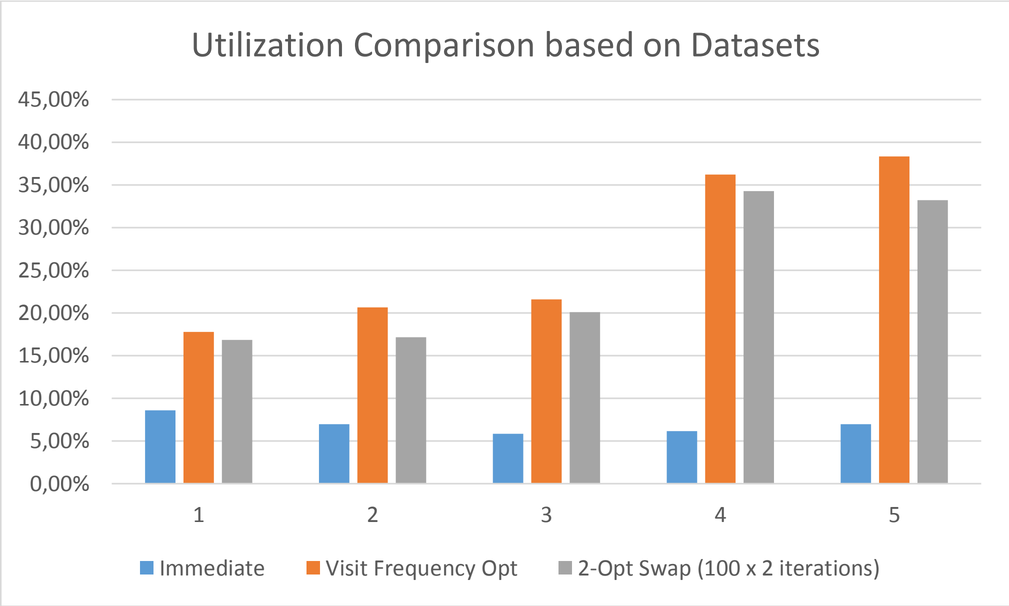

Figure 5. 7 Utilization Comparison for all Datasets

Based on the data above, it is inferred that all of immediate processes are ineffective. The immediate algorithm has the highest cost and lowest utilitization even though the distance is very low (it is very obvious, since immediate algorithm do the least frequent routing). In the other side, the result of Visit frequency Optimization procedure (VFOP) is proven to very effectively reduce the total cost. Within the last procedure, 2-opt swap improve the result but yet far less significant compared to VFOP.

Nevertheless, an unsuspected condition occurred in distance comparison. Whereas the total distance for dataset 3 (n=50) is much lower than dataset 2 (n=30). This state indicates that number of visited retailer is not the only factor influencing the amount of traveled distance, but also the retailer's location and distance between one each other. It can be analyzed that dataset 3 has a less distant retailers compared to dataset 2 conditions.

While 2-Opt Swap algorithm has issues in the utilization value, Based on data, all datasets show lesser utilization than previous. Even though the grand total cost is able to be reduced, it should be concerned carefully especially if the distributor want to buy vehicle (where usually distributor's purpose is to also increase the utilization). However, the 2-Opt Swap algorithm taken here is only by

100x2 iterations. Further value of iterations should be measured as well to learn behavior of this algorithm.

However, the objective function of the model is to minimize cost. Therefore, the cost savings of each algorithm are important to be compared. Hereby is the comparison of the saving in percentage for each algorithm of all datasets;

Table 5. 18 Cost saving comparison for all dataset

	DATASET				
	1	2	3	4	5
Saving of Immediate-VFOP	31.47%	46.54%	56.75%	56.54%	57.71%
Saving of VFOP – 2Opt Swap	1.45%	1.94%	0.86%	3.32%	0.02%
TOTAL SAVING	32.92%	48.48%	57.61%	59.85%	57.73%

According to the comparison table above, it is inferred that the cost saving produced by FPVRP algorithm achieves up to 59.85% saving compared to the normal or immediate vehicle routing problem. The saving for each dataset is dominated by the VFOP (Visit Frequency Optimization Procedure) while 2-Opt Swap is found to be not quite significant.

5.3.3. Demand size sensitivity analysis

This scenario is using demand size as the variables to know how the demand size will affect the routing decisions. To make it significant, hence this section will be divided into 2 parts: (1) when demand is 2x than initial demand; and (2) when demand is 0.5x than initial demand. The demand values are changed into those two states to learn how the model behaves through the change of the demands, both in fewer and more demand condition. For more demand condition, 2x demand is used since it is able to represent the excessing demand in real condition (such as: demand of paint in *Ramadhan* month which is noted to achieve 100% increase) while if the demand is increased more than this ratio is quite rarely to happen.

After the routing process is done using all the algorithms, the results of vehicles, customer frequency, cost, distance and utilization will be analyzed. However, due to the computation constraints, this scenario will only involve

Dataset 1- Dataset 3 to be experimented. The recapitulation of the demand size scenario from 0.5x, 1,0x and 2,0x for all of those three datasets can be figured as below:

Table 5. 19 Overall comparison of demand size scenario

Dataset	n	Demand	Distance	Util (%)	Total Cost
1	15	2x	663.20	36.34%	IDR 11,955,323
		1x	306.50	16.81%	IDR 10,943,367
		0,5x	163.30	12.80%	IDR 7,131,777
2	30	2x	1708.50	34.02%	IDR 24,405,675
		1x	756.50	17.14%	IDR 19,856,900
		0,5x	406.10	9.93%	IDR 18,442,753
3	50	2x	995.73	31.82%	IDR 32,076,466
		1x	390.20	20.07%	IDR 26,589,676
		0,5x	313.09	10.84%	IDR 25,778,293

Table 5. 20 Overall visit frequency comparison of demand size scenario

Dataset	n	Frequency	Demand proportion		
			0.5x	1x	2x
1	15	1	12	3	0
		2	3	12	1
		3	0	0	5
		6	0	0	9
2	30	1	25	0	0
		2	5	17	0
		3	0	13	4
		6	0	0	26
3	50	1	6	3	0
		2	44	41	0
		3	0	6	3
		6	0	0	47

Table 5. 21 Overall vehicle comparison of demand size scenario

Dataset	n	#Truck	Truck Type (ID)	Demand		
				0.5x	1x	2x
1	15	1	L300BAK2000	2	1	1
		2	L300BOX1500	1	2	1

Dataset	n	#Truck	Truck Type (ID)	Demand		
				0.5x	1x	2x
		3	COLTBOX5000	0	0	0
		4	FUSOBOX7000	0	0	0
		5	CDDLONGBOX14000	0	0	0
2	30	1	L300BAK2000	1	2	2
		2	L300BOX1500	4	4	4
		3	COLTBOX5000	0	0	0
		4	FUSOBOX7000	0	0	0
		5	CDDLONGBOX14000	0	0	0
3	50	1	L300BAK2000	6	1	2
		2	L300BOX1500	4	6	7
		3	COLTBOX5000	0	0	0
		4	FUSOBOX7000	0	0	0
		5	CDDLONGBOX14000	0	0	0

Based on the overall scenario above, it can be inferred that demand size change will change the visit frequency proportion. Those results indicate that the change of demand size will affect the visit frequency of each retailer linearly. In the other word, increasing demand of a retailer will imply to increasing visit frequency for the retailer. The reason is, the more products are ordered will result into the more products are stored in the retailer. As a consequent, the holding cost will increase significantly as well as the total cost, since holding cost has been proven as a key or main cost of the research. The same pattern applies when the demand is fewer than usual. Therefore this model tries to reduce cost by adjusting the visit frequency to reduce the holding cost. Following this decision, the values of distance is adjusted linearly as well. However, this scenario’s impacts did not quite show any pattern to the vehicle used decision. It is due that the vehicle decision is also affected by the specific demand of each retailer, the location of the retailer and also the time windows of each retailer.

5.3.4. Demand uniformity sensitivity analysis

Another scenario that can be experimented is the demand uniformity. Different from demand size scenario, demand uniformity change the pattern of the demand. Similar with demand size sensitivity analysis, this process will only involve dataset 1-3 due to computational drawback consideration.

After all calculations are already performed, the comparison table for all of 3 datasets is represented as tables below. This part will recapitulate the comparison of distance, utilization, grand total cost, visit frequency and the vehicle used data.

Table 5. 22 Overall comparison for uniformity scenario

Dataset	n	Demand	DISTANCE	UTIL(%)	TOTAL COST
1	15	Uniform	349.400	21.96%	IDR 11,412,663
		Normal	306.50	16.81%	IDR 10,943,367
		Skew	142.600	10.90%	IDR 6,792,320
2	30	Uniform	911.800	24.66%	IDR 20,727,460
		Normal	756.50	17.14%	IDR 19,856,900
		Skew	393.200	16.13%	IDR 13,325,582
3	50	Uniform	1060.741	45.32%	IDR 27,268,891
		Normal	390.20	20.07%	IDR 26,589,676
		Skew	337.418	14.10%	IDR 21,134,233

Table 5. 23 Overall visit frequency comparison for uniformity scenario

Dataset	n	Frequency	Proportion		
			Uniform	Normal	Skew
1	15	1	0	3	14
		2	13	12	1
		3	2	0	0
		6	0	0	0
2	30	1	0	0	19
		2	0	17	11
		3	30	13	0
		6	0	0	0
3	50	1	0	3	22
		2	0	41	27
		3	0	6	1
		6	50	0	0

Table 5. 24 Overall vehicle used comparison for uniformity scenario

Dataset	n	#Truck	Truck Type (ID)	Amount		
				Uniform	Normal	Skew
1	15	1	L300BAK2000	1	1	1
		2	L300BOX1500	2	2	1
		3	COLTBOX5000	0	0	0
		4	FUSOBOX7000	0	0	0
		5	CDDLONGBOX14000	0	0	0
2	30	1	L300BAK2000	1	2	3
		2	L300BOX1500	4	4	1
		3	COLTBOX5000	0	0	0
		4	FUSOBOX7000	0	0	0
		5	CDDLONGBOX14000	0	0	0
3	50	1	L300BAK2000	8	1	6
		2	L300BOX1500	0	6	1
		3	COLTBOX5000	0	0	0
		4	FUSOBOX7000	0	0	0
		5	CDDLONGBOX14000	0	0	0

Based on the table above, it can be seen that skewed demand actively and significantly change the routing decision. It is considered as the sensitive factors. Where 3 of 3 datasets are in influenced by the demand skewness which impact on significant change of frequency plan. The retailer visit for uniform demand state is more identical and frequent compared to the skew demand state. However, the total cost of the uniform demand state tend to be higher than normal, while the skewed demand scenario’s tend to be lower than normal (it is found to be linear also with the difference in the amount of the demand as well). While for the vehicle used analysis, it is similar with previous sensitivity analysis whereas the behavior is not clear enough due to the other factors.

5.3.5 Time windows sensitivity analysis

There are 2 types of changes in this scenario, which are restricted Time Windows and loosen time windows. Due to the initial sets are using mixed Time windows. Hence, in this scenario, the effect of a specified time windows for all retailers will be analyzed. In this sensitivity analysis, only dataset 1 until dataset 3 are used with similar reason as previous.

Once all calculations are finished, hence the results are recapitulated for further analysis as tables below. Similar with previous sensitivity analysis, this section will recapitulate the comparison of distance, utilization, grand total cost, visit frequency and the vehicle used data.

Table 5. 25 Overall comparison of time windows tests

Dataset	n	Time Windows	DISTANCE	UTIL(%)	TOTAL COST
1	15	Strict	327.700	16.91%	IDR 11,473,665
		Normal	306.50	16.81%	IDR 10,943,367
		Loose	328.200	16.45%	IDR 9,999,915
2	30	Strict	617.000	19.53%	IDR 20,772,325
		Normal	756.50	17.14%	IDR 19,856,900
		Loose	582.300	19.77%	IDR 19,237,835
3	50	Strict	493.787	19.09%	IDR 30,301,483
		Normal	390.20	20.07%	IDR 26,589,676
		Loose	485.203	18.78%	IDR 27,883,476

Table 5. 26 Overall visit frequency comparison of time windows tests

Dataset	n	Frequency	Proportion		
			Strict	Normal	Loose
1	15	1	2	3	0
		2	13	12	5
		3	0	0	10
		6	0	0	0
2	30	1	6	0	0
		2	24	17	28
		3	0	13	2
		6	0	0	0
3	50	1	0	3	0
		2	35	41	7
		3	15	6	40
		6	0	0	3

Table 5. 27 Overall vehicle used comparison of time windows tests

Dataset	n	#Truck	Truck Type (ID)	Amount		
				Strict	Normal	Loose
1	15	1	L300BAK2000	1	1	2
		2	L300BOX1500	2	2	1
		3	COLTBOX5000	0	0	0
		4	FUSOBOX7000	0	0	0
		5	CDDLONGBOX14000	0	0	0
2	30	1	L300BAK2000	1	2	1
		2	L300BOX1500	4	4	4
		3	COLTBOX5000	0	0	0
		4	FUSOBOX7000	0	0	0
		5	CDDLONGBOX14000	0	0	0
3	50	1	L300BAK2000	0	1	2
		2	L300BOX1500	7	6	6
		3	COLTBOX5000	0	0	0
		4	FUSOBOX7000	0	0	0
		5	CDDLONGBOX14000	0	0	0

In overall, strict time windows will mostly result into higher grand total cost. The reason is that stricter time windows scenario will have more penalty cost and less-frequent visit compared to normal and loose time windows state (except for the visit frequency of dataset 3, but yet the total cost for strict time windows is still higher). While the vehicle used remains showing no pattern in behavior.

5.4. Research interpretation

This section will consist of the analysis taken according to the model and sensitivity analysis. Some of aspects which will be further analyzed are: general analysis of FPVRP model, sensitivity analysis, real case implementation and research's drawbacks.

5.4.1. General analysis

FPVRP model is created to enhance the previous routing strategy. Whereas, in this research is by adding flexibility. After all numerical experiments have been done, some analyses are able to be conducted.

First, FPVRP decision is affected by various factors, which different combination of the factors may lead to different outcomes. As an example, adding the retailer nodes mostly will lead into increasing distance. Nevertheless, if the consideration is combined with the location of the retailers and the demand size, it can lead into different decisions. If the location of the nodes are close to each other or the demand size is not so that big, thus the distance traveled during a route is probably tend to be shorter. However, some of the significant factors that influence the routing decision are listed as: number of retailers, location of retailers (through longitude and latitude), distance between retailers, demand size (by considering the bill of color criteria), demand uniformity, time windows, capacity of vehicles (both in weight and cube), cost parameters up to the emphasize parameters denoted as ω_{trp} and ω_{inv} as the main parameters in determining the visit frequency. While there are also less significant factors that may influence such as: vehicle average speed and service time, which is not mainly measured and changed in this research as well.

The objective of the FPVRP model is to minimize the total cost. Basically, the cost compositions are: travel cost, holding cost, vehicle cost and other costs (starting from: driver's daily salary, order cost, overtime cost, lateness penalty cost and waiting cost). Among of these costs, it is concluded that there are mainly 3 significant costs: holding cost, vehicle cost and travel cost. The relationship between holding cost and travel cost are obviously contrary one another. It is due to the visit frequency, whereas more frequent visit will result on increasing travel cost but in the same time decreasing holding cost, and vice versa. However, vehicle cost position is somehow uncertain. It is actually depending more in the demand load and the capacity. A frequent delivery results to lower vehicle cost if those vehicle is well utilized. In the other side, a non-frequent delivery will probably also result into lower vehicle cost either, if the number of the retailers is actually not that big (which resulting into smaller need to buy vehicle). Therefore, this complexities make a paint distribution system requires a computational tool.

Implementing FPVRP of this research will add more features and flexibility. It is because this decision support system tool depicts many variables and criteria that are actually applied in the real practice. Hence, this tool is guaranteed to be useful for paint distributors in making real decisions both directly and indirectly (such as: user can get more insights of distribution by applying this study)

5.4.2. Sensitivity analysis evaluation

According to the sensitivity results, it is concluded that each experiment affects different aspects. But in overall, the changing parameters will result mostly in grand total cost, total distance, utilization rate, visit frequency for each retailer and which vehicles are used. However, all of the scenarios used are proven as influencing to the routing decisions.

Based on the sensitivity result, the scenario of ω_{trp} and ω_{inv} affects directly to the visit frequency of each retailer. While different value of retailer's number and location influence influence the whole routing decisions (as it is one of the most complex sensitivity test) which actually can be indicated into the difference of total cost, distance and utilization rate. Demand size scenario is similar with number of retailer scenario but significantly affecting the visit frequency (bigger demand size will impact on more frequent delivery to reduce holding cost). Demand uniformity sensitivity uniquely affects the division of the colors need to be prepared. Finally, change in time windows is also resulting in different total cost since this model charges any lateness by using penalty cost (no forbidding in any late visitation except after the distributor's operational hours end).

Specifically, vehicle used in all of the scenario never exceeds the third type (COLTBOX5000). It is due to the load number and specifications that unnecessarily need bigger vehicle size. Besides, the cost of FUSOBOX7000 and CDDLONGBOX14000 are considered as very high compared to the lower level vehicles. It is actually cheaper to buy small amount of vehicle but with a very big capacity to serve more retailers. However, the condition in which time windows constraints must ensure all vehicle depart and return at the same day (in a range of operational hour time) makes that policy infeasible to be taken within the amount of the load.

5.4.3. Real implementation analysis

The FPVRP model is applicable to the real field processes. However, it is very important to be noted that this model involves some assumptions. In the real implementation, things happen differently. Many dynamic things and obstacles occur out of the assumptions made in this research.

One of the most important factor that exists in the real implementation is in the stochastic or dynamic condition (while the model in this research is deterministic). Some examples of stochastic condition meant here are when the demand can change anytime (order change); the visited node is suddenly unavailable to be visited; and other unpredictable things that may occur.

Facing this stochastic condition, this FPVRP model is actually still useable. However, the FPVRP parameters need to be changed while the model need to be recalculated each time a change occurs. As an example: if a certain retailer is unexpectedly closed during the operational time, hence distributor is able to change the route by inserting it into other day delivery. Yet, the processes taken to face this condition are considered as manual and repetitive. However, new model need to be applied to face this condition. One of the notable distribution model which is more appropriate is: DVRP (Dynamic Vehicle Routing Problem) within online technology implementation.

In the future, deterministic model as this research will no longer be used in practice. It is due to the improving technology which will result into a more real time and dynamic condition. But the result of this research will still be useful as the main basis and fundamentals for the future and present online models. Hence, it is very important to develop this model into a dynamic model in the future.

5.4.4. Research drawbacks

Similar with other research, this model also has some drawbacks. The most significant drawback occur in this research is in the computational time. In the other words, this model requires a quite long time to calculate a large number of retailers (despite of its heuristics algorithm). As additional information, a table below describes the computational time of each scenario of all datasets in second

Table 5. 28 Computational time recapitulation for all research processes

Dataset	n	Normal	Demand Size		Demand uniformity		Time Windows	
			0.5x	2x	Skew	Uniform	Strict	Loose
1	15	144.8	134.75	158.82	677.74	545.54	79.17	249.37
2	30	215.87	452.12	265.44	1023.54	199.75	121.92	194.63
3	50	443.25	414.2	312.56	2554.28	638.01	291.9	348.58
4	75	867.8	NR	NR	NR	NR	NR	NR
5	100	919.11	NR	NR	NR	NR	NR	NR

*) NR = Not responding (or the computation is infeasible)

All calculations in this research were done by using computer within Intel i7 processor and 8.00 GB RAM size. While the VBA used is in Microsoft Excel 2016. But yet for bigger data size, some computations result to not-responding state (VBA unexpectedly shut down due to a too big data processing). In the other side, some successful computations also have a very long computational time, especially in demand uniformity sensitivity analysis. Whereas dataset 3 within n = 50 took 2554.28 seconds or 42.57 minutes for a single calculation. This is suspected to be caused by some factors. The first one is in the coding language used. It is probably caused by too many “For-Next” and “While-Wend” commands; too many subs embedded within subs and the loop cases which can be terminated by very small options (especially in some 2-opt swap cases). The second reason is that VBA does not run only the codes but also spend memories to other excel functions as well. It is different from other language, such as: C language used by *Rusdiansyah and Tsao* (2004). Where C language is a more dedicated and reliable software to run the codes compared to VBA embedded in Microsoft Excel.

However, there are some suggestions offered to anticipate these drawbacks. The first suggestion is that to try other programming language, since this FPVRP model calculations are actually considered as heavy (it is also proven by some hardware indications which CPU cooling fan started to operate very much faster during computations). Nevertheless, if VBA is still used, thus the second suggestion that is essential is to find out how to simplify the code. This solution somehow needs to be consulted to the experts from informatics or computer engineering (for example: start to use more array in the model to reduce looping, etc.). The third solution is to add calculation breaks for few seconds for bigger data size if it is possible to be done (further consultation with the expert is also necessary). And the last solution is to upgrade the hardware and software used. It is believed to help a lot for harder calculation basis. For example: researcher should use Intel i9 computer instead or upgrade the Microsoft Excel to 2018 version.

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CHAPTER VI
CONCLUSION AND SUGGESTION

6.1. Conclusion

From this research, it is concluded that:

1. Researchers developed FPVRP model by constructing a Periodic Vehicle Routing Problem (PVRP) while also considering some flexiblity features. Those flexibilities used by this research are as following: visit frequenct optimization procedure for each retailer; multi products through weighted Bill of Colors (BOC) flexibility; and multi capacity vehicle flexibility. There are mainly 3 algorithm used to perform vehicle routing, starting from immediate algorithm, visit frequency optimization algorithm and 2-Opt Swap Improvements as a local search improvement heuristics. This research develops this model particularly for Paint distributors that need to consider how to deliver multi products at once based on various color demands (1000 demands policy)
2. The FPVRP model has proven to bring more flexibilities to the users as a Decision Support System (DSS). It is able to help user in analyzing how they should do their routing, since constructed FPVRP which considers time windows, multi capacity vehicle and multi-item products gives more insights to distributors. Compared to the normal vehicle routing problem, adding flexibility in the visit frequency save cost up to 59.85%. Besides of routing decision, this model also provide further information such as the Bill of Color (BOC) division for each vehicle, detailed costs information, traveled distance for each truck, etc. This research also did some experimentations for different conditions, starting from: the number of the retailers, demand size, demand uniformity, time windows, until the policy whether to emphasize holding cost or traveling cost as well. These experiments show that deciding a vehicle routing set yet is something complex but this model is able to flexibly operate the calculation. However, drawbacks occurred since this model took a very long computational time to do routing operations with huge amount of nodes.

It appeared due to the way of coding and the capability of the VBA language itself. Therefore, this research was not able to do the FPVRP calculations for retailers more than 100 for normal calculation; or more than 50 for sensitivity analysis due to “Not responding” problem and unexpected shutdown of the VBA itself.

6.2. Suggestion

From the research, it is suggested for the next researchers to:

1. Develop FPVRP using exact method (for example: Lingo Software) to enhance the optimality of the solution. It is due to the weakness of heuristic solutions whereas are incapable to find the most cost efficient solutions in achieving the objective function of the research.
2. Develop a more complex distribution system, which now is necesarily needed by modern companies: Online-based routing or Dynamic Vehicle Routing problem (DVRP) for products with multi bill-of-material, in order to anticipate any stochastic change from the retailers.
3. Develop FPVRP further by adding more policy options to the users. Such as: multi products PVRP with different dimension and delivery requirements (by considering loading constraints as well); FPVRP which considers combination of truck owning and truck leasing (third party logistics) in term of scheduling, cost and utilization or FPVRP with service choice strategy. Further research on FPVRP that considers real data especially on paint historical sales data is also important, hence the pattern of the data is also able to be analyzed further.
4. Develop FPVRP similar with this research, but using other programming language to obtain faster and more reliable results. (For example: R, Python, etc.)

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APPENDIX

APPENDIX 1 – WEIGTHED BILL OF COLOR INFORMATION

		Weighted Bill of Colors (BOC)							
Product ID	Color Description	Red	Blue	Yellow	Black	White	Product Weight	Product Cube	Total Product Value
RED	Red	1					1	10	IDR 30,000.00
BLU	Blue		1				1	10	IDR 30,000.00
YEL	Yellow			1			1	10	IDR 30,000.00
BLA	Black				1		1	10	IDR 30,000.00
WHI	White					1	1	10	IDR 30,000.00
PUR	Purple	0.3	0.7				2	20	IDR 60,000.00
ORG	Orange	0.7		0.3			2	20	IDR 60,000.00
GRE	Green		0.7	0.3			2	20	IDR 60,000.00
DRD	Dark Red	0.7			0.3		2	20	IDR 60,000.00
DBL	Dark Blue		0.7		0.3		2	20	IDR 60,000.00
BRO	Brown			0.7	0.3		2	20	IDR 60,000.00
PIN	Pink	0.7				0.3	2	20	IDR 60,000.00
CYA	Cyan		0.3			0.7	2	20	IDR 60,000.00
CRM	Cream			0.3		0.7	2	20	IDR 60,000.00
GRY	Gray				0.7	0.3	2	20	IDR 60,000.00

APPENDIX 2 – DATASET GENERAL INFORMATION

DATASET 1 (15 RETAILERS)

Node	Name	Longitude	Latitude	Service time (min)	TW START	TW END	TOTAL WEEKLY DEMAND
0	DEPOT	112.76115	-7.304872				
1	RETAILER 1	112.74711	-7.3194998	90	660	1000	213
2	RETAILER 2	112.66815	-7.2731677	60	610	1000	186
3	RETAILER 3	112.64956	-7.2886267	60	580	700	188
4	RETAILER 4	112.79523	-7.3128659	90	600	700	269
5	RETAILER 5	112.77395	-7.2983751	90	500	640	216
6	RETAILER 6	112.68646	-7.23174	90	530	640	125
7	RETAILER 7	112.74685	-7.267708	60	550	770	271
8	RETAILER 8	112.71096	-7.3330108	90	660	950	204
9	RETAILER 9	112.73437	-7.2594669	60	510	660	214
10	RETAILER 10	112.79664	-7.2421654	90	550	850	148
11	RETAILER 11	112.63931	-7.2780991	90	540	950	216
12	RETAILER 12	112.79707	-7.2920431	60	510	890	257
13	RETAILER 13	112.75501	-7.2831425	60	560	1000	237
14	RETAILER 14	112.72602	-7.2880092	60	620	880	166
15	RETAILER 15	112.69772	-7.295178	60	650	1000	279

DATASET 2 (30 RETAILERS)

Node	Name	Longitude	Latitude	Service time (min)	TW START	TW END	TOTAL WEEKLY DEMAND
0	DEPOT	112.7598864	-7.279324153				
1	RETAILER 1	112.7376339	-7.309389844	90	540	950	241
2	RETAILER 2	112.6886241	-7.249572293	60	510	890	221
3	RETAILER 3	112.6377851	-7.251300388	60	560	1000	161
4	RETAILER 4	112.7791221	-7.257672717	60	620	880	225
5	RETAILER 5	112.6433178	-7.294043909	60	650	1000	279
6	RETAILER 6	112.7876201	-7.247631719	90	560	700	282
7	RETAILER 7	112.7012642	-7.226490795	90	610	1000	286
8	RETAILER 8	112.7891786	-7.338156557	90	480	850	221
9	RETAILER 9	112.8029704	-7.300210137	90	560	1000	180
10	RETAILER 10	112.7279844	-7.250512804	60	570	880	189
11	RETAILER 11	112.6447571	-7.272045823	60	550	760	234
12	RETAILER 12	112.718067	-7.308329183	60	520	1000	254
13	RETAILER 13	112.7452577	-7.265220126	60	550	810	226
14	RETAILER 14	112.6818871	-7.310649918	60	510	830	226
15	RETAILER 15	112.7818256	-7.243424804	60	590	940	179
16	RETAILER 16	112.7393367	-7.223514574	60	650	1000	261
17	RETAILER 17	112.7961562	-7.31711969	60	550	670	283
18	RETAILER 18	112.7580445	-7.224265401	90	560	1000	284
19	RETAILER 19	112.6783802	-7.279268788	90	630	730	233
20	RETAILER 20	112.6540914	-7.221872179	60	490	610	211

Node	Name	Longitude	Latitude	Service time (min)	TW START	TW END	TOTAL WEEKLY DEMAND
21	RETAILER 21	112.7547003	-7.343153864	60	500	560	229
22	RETAILER 22	112.7368685	-7.33275456	90	600	970	246
23	RETAILER 23	112.6535004	-7.246595543	90	490	680	247
24	RETAILER 24	112.6855398	-7.339461914	90	560	830	231
25	RETAILER 25	112.6875337	-7.297991901	60	610	1000	296
26	RETAILER 26	112.6884515	-7.228140671	90	500	980	173
27	RETAILER 27	112.8083155	-7.295604558	60	560	890	224
28	RETAILER 28	112.6844451	-7.325309165	60	540	650	247
29	RETAILER 29	112.6640589	-7.265372272	90	510	1000	233
30	RETAILER 30	112.7077154	-7.294199979	60	560	770	259

DATASET 3 (50 RETAILERS)

Node	Name	Longitude	Latitude	Service time (min)	TW START	TW END	TOTAL WEEKLY DEMAND
0	DEPOT	113.52098	-6.6005788				
1	RETAILER 1	113.66883	-6.4107007	90	570	1000	239
2	RETAILER 2	113.64509	-7.2815804	60	620	1000	189
3	RETAILER 3	113.59606	-6.3237747	60	560	1000	256
4	RETAILER 4	112.87127	-6.7202843	90	550	640	216
5	RETAILER 5	113.79737	-6.6313225	60	520	750	201
6	RETAILER 6	113.28645	-7.1730748	90	580	1000	192
7	RETAILER 7	113.20053	-6.719525	90	610	1000	193

Node	Name	Longitude	Latitude	Service time (min)	TW START	TW END	TOTAL WEEKLY DEMAND
8	RETAILER 8	113.62364	-6.9066818	60	500	1000	211
9	RETAILER 9	113.49204	-7.1362463	90	590	1000	260
10	RETAILER 10	112.73651	-6.7799587	60	510	1000	232
11	RETAILER 11	112.73794	-7.0460808	90	530	1000	228
12	RETAILER 12	113.36807	-6.4352272	60	520	760	235
13	RETAILER 13	113.41753	-7.0210261	90	490	930	259
14	RETAILER 14	113.27125	-6.9485391	90	570	1000	243
15	RETAILER 15	113.10279	-7.0571742	30	490	650	190
16	RETAILER 16	113.09557	-6.459377	60	610	1000	266
17	RETAILER 17	113.08036	-6.5571602	60	560	760	181
18	RETAILER 18	112.80235	-6.7524308	60	640	890	176
19	RETAILER 19	113.14895	-6.2783686	60	650	1000	155
20	RETAILER 20	113.08018	-7.2023631	60	500	740	204
21	RETAILER 21	113.77025	-6.6304463	90	590	930	189
22	RETAILER 22	113.52498	-6.3007815	60	640	1000	210
23	RETAILER 23	113.80769	-6.8152842	30	510	610	225
24	RETAILER 24	113.46724	-6.272258	60	620	1000	254
25	RETAILER 25	113.26565	-7.0560459	60	520	770	212
26	RETAILER 26	113.09347	-7.299917	60	550	680	231
27	RETAILER 27	112.79308	-7.1755032	60	560	670	282
28	RETAILER 28	113.68513	-7.0866496	90	650	1000	151
29	RETAILER 29	113.48133	-7.1401301	60	600	690	263
30	RETAILER 30	113.44558	-6.8752461	90	600	1000	250
31	RETAILER 31	113.42629	-7.3233741	60	640	810	230

Node	Name	Longitude	Latitude	Service time (min)	TW START	TW END	TOTAL WEEKLY DEMAND
32	RETAILER 32	113.03354	-7.0780962	90	650	1000	236
33	RETAILER 33	112.82079	-6.2415242	60	590	1000	196
34	RETAILER 34	113.15485	-7.1192256	90	480	1000	218
35	RETAILER 35	113.45817	-6.9950774	90	640	760	229
36	RETAILER 36	113.62489	-7.2420916	60	630	750	283
37	RETAILER 37	112.64729	-6.5799324	60	510	610	218
38	RETAILER 38	112.72511	-6.666685	90	540	890	242
39	RETAILER 39	112.71693	-6.2602703	60	520	620	250
40	RETAILER 40	112.73664	-7.0822601	60	590	1000	135
41	RETAILER 41	113.16593	-7.0578435	60	500	1000	270
42	RETAILER 42	112.82565	-6.8729221	90	520	940	176
43	RETAILER 43	113.69647	-7.2070216	90	560	710	238
44	RETAILER 44	112.81213	-6.2952916	90	600	770	228
45	RETAILER 45	112.83534	-7.1920452	60	600	740	233
46	RETAILER 46	113.70293	-6.7588974	60	530	980	186
47	RETAILER 47	112.73208	-6.6404269	90	600	1000	221
48	RETAILER 48	112.63629	-6.4558761	60	620	1000	231
49	RETAILER 49	113.66224	-6.5519797	60	640	960	199
50	RETAILER 50	113.41572	-6.9427495	60	540	1000	240

DATASET 4 (75 RETAILERS)

Node	Name	Longitude	Latitude	Service time (min)	TW START	TW END	TOTAL WEEKLY DEMAND
0	DEPOT	113.59219	-6.4744844				

Node	Name	Longitude	Latitude	Service time (min)	TW START	TW END	TOTAL WEEKLY DEMAND
1	RETAILER 1	113.26499	-7.0575935	90	590	1000	193
2	RETAILER 2	112.96203	-7.2351379	90	530	650	235
3	RETAILER 3	113.42183	-6.4457729	60	490	610	196
4	RETAILER 4	112.70584	-6.4999926	60	620	990	219
5	RETAILER 5	113.75476	-6.8253453	60	550	910	246
6	RETAILER 6	113.56564	-6.6049622	90	510	1000	180
7	RETAILER 7	112.85317	-7.1749698	90	590	740	251
8	RETAILER 8	113.5822	-6.6422416	60	640	1000	221
9	RETAILER 9	113.23257	-6.485372	60	630	890	215
10	RETAILER 10	113.18732	-6.9359145	90	650	860	259
11	RETAILER 11	113.04344	-6.9712513	90	560	670	212
12	RETAILER 12	113.53092	-6.4970006	90	490	670	239
13	RETAILER 13	113.36964	-6.892756	90	610	1000	238
14	RETAILER 14	112.74912	-6.937418	90	600	850	257
15	RETAILER 15	112.87869	-6.5756157	90	590	920	246
16	RETAILER 16	113.11556	-7.1168055	90	500	810	211
17	RETAILER 17	113.35534	-6.2874205	60	520	720	149
18	RETAILER 18	113.1915	-6.4948401	60	640	1000	176
19	RETAILER 19	113.76356	-7.2029493	60	620	690	213
20	RETAILER 20	113.21225	-7.0794439	90	610	740	183
21	RETAILER 21	112.83866	-6.472224	90	490	820	223
22	RETAILER 22	113.70843	-7.2311374	90	600	750	197
23	RETAILER 23	113.15016	-6.6105117	60	570	1000	188
24	RETAILER 24	113.24475	-6.4194702	90	600	870	224

Node	Name	Longitude	Latitude	Service time (min)	TW START	TW END	TOTAL WEEKLY DEMAND
25	RETAILER 25	113.69304	-6.6348653	60	530	1000	301
26	RETAILER 26	113.5123	-6.3287606	90	560	900	210
27	RETAILER 27	113.36233	-6.3993201	90	590	1000	260
28	RETAILER 28	112.94938	-7.1898505	60	540	840	257
29	RETAILER 29	113.54523	-7.279399	90	540	880	278
30	RETAILER 30	113.59868	-7.2009098	60	520	620	197
31	RETAILER 31	112.77138	-6.9593448	60	630	1000	230
32	RETAILER 32	112.96324	-7.2838674	90	600	1000	180
33	RETAILER 33	113.423	-6.29472	90	600	820	270
34	RETAILER 34	113.80502	-6.5736993	60	650	1000	278
35	RETAILER 35	113.44376	-6.9078642	60	640	720	191
36	RETAILER 36	113.05943	-6.6132154	90	540	690	248
37	RETAILER 37	113.63715	-6.2559487	90	610	1000	211
38	RETAILER 38	113.39881	-6.2807026	60	580	880	200
39	RETAILER 39	113.4934	-7.0209794	60	540	1000	235
40	RETAILER 40	112.73524	-6.5463559	60	490	880	266
41	RETAILER 41	113.19324	-7.1230459	60	520	870	160
42	RETAILER 42	112.84254	-7.0848572	30	620	910	226
43	RETAILER 43	113.55283	-6.3020996	60	540	630	235
44	RETAILER 44	112.97709	-7.1002916	60	490	1000	271
45	RETAILER 45	112.73297	-6.802458	60	660	730	207
46	RETAILER 46	113.20533	-6.9935303	60	520	840	225
47	RETAILER 47	112.65516	-7.0367471	90	500	1000	213
48	RETAILER 48	113.31907	-6.3789223	60	510	610	274

Node	Name	Longitude	Latitude	Service time (min)	TW START	TW END	TOTAL WEEKLY DEMAND
49	RETAILER 49	112.76938	-7.3252117	90	520	880	248
50	RETAILER 50	113.22157	-6.3133228	90	510	1000	244
51	RETAILER 51	113.52868	-6.3678821	90	490	620	236
52	RETAILER 52	113.60778	-6.7511392	90	620	880	229
53	RETAILER 53	113.0985	-6.4222393	90	510	1000	198
54	RETAILER 54	113.40889	-7.0884251	60	490	1000	236
55	RETAILER 55	113.77258	-6.9671575	90	590	1000	295
56	RETAILER 56	113.41407	-6.4261506	90	520	640	269
57	RETAILER 57	113.38772	-7.0723435	90	630	810	177
58	RETAILER 58	113.12672	-6.9225217	90	600	1000	258
59	RETAILER 59	113.50461	-6.3636645	60	650	1000	237
60	RETAILER 60	113.79789	-6.7548661	60	570	1000	220
61	RETAILER 61	113.76399	-6.8309426	60	660	840	223
62	RETAILER 62	113.51774	-6.2801766	90	500	770	223
63	RETAILER 63	113.5963	-6.4918973	60	590	1000	290
64	RETAILER 64	113.1903	-7.1750924	90	640	810	221
65	RETAILER 65	113.04902	-6.2547452	90	600	730	253
66	RETAILER 66	113.38986	-6.8018976	60	580	980	208
67	RETAILER 67	112.73148	-6.3903677	90	530	770	227
68	RETAILER 68	112.688	-6.8964675	60	540	940	211
69	RETAILER 69	112.87726	-7.2168154	90	550	880	212
70	RETAILER 70	113.33424	-6.249332	60	620	1000	246
71	RETAILER 71	112.70083	-7.2564108	90	500	720	196
72	RETAILER 72	113.11195	-6.5853966	90	600	870	205

Node	Name	Longitude	Latitude	Service time (min)	TW START	TW END	TOTAL WEEKLY DEMAND
73	RETAILER 73	113.57789	-6.7284778	60	540	1000	205
74	RETAILER 74	112.78385	-6.9299412	90	530	990	224
75	RETAILER 75	113.1074	-6.2680895	90	500	890	236

DATASET 5 (100 RETAILERS)

Node	Name	Longitude	Latitude	Service time (min)	TW START	TW END	TOTAL WEEKLY DEMAND
0	DEPOT	113.46543	-6.7459001				
1	RETAILER 1	113.31715	-7.0198274	90	510	820	230
2	RETAILER 2	112.99057	-6.4748322	90	630	1000	195
3	RETAILER 3	112.6518	-6.4905768	60	570	750	203
4	RETAILER 4	113.59361	-6.5486348	90	570	1000	285
5	RETAILER 5	112.68867	-6.8800112	90	550	790	215
6	RETAILER 6	113.65024	-6.4571517	60	510	860	210
7	RETAILER 7	113.0748	-6.2645376	60	590	850	182
8	RETAILER 8	113.66062	-7.2819197	90	570	760	210
9	RETAILER 9	113.75253	-6.9361915	90	610	1000	219
10	RETAILER 10	113.25285	-6.4834011	90	510	1000	192
11	RETAILER 11	112.69826	-6.6795876	60	650	750	200
12	RETAILER 12	113.18677	-7.0101637	60	620	880	231
13	RETAILER 13	113.36795	-6.6173989	60	500	620	224
14	RETAILER 14	112.94568	-7.0313079	60	490	940	199
15	RETAILER 15	113.61163	-6.4188227	90	580	780	204
16	RETAILER 16	113.3285	-6.2374214	60	610	1000	258

Node	Name	Longitude	Latitude	Service time (min)	TW START	TW END	TOTAL WEEKLY DEMAND
17	RETAILER 17	113.70712	-7.0902537	60	640	1000	188
18	RETAILER 18	113.45316	-6.2442622	60	590	1000	219
19	RETAILER 19	112.92231	-6.7453957	60	560	840	203
20	RETAILER 20	112.76046	-6.2224576	60	660	1000	143
21	RETAILER 21	113.43088	-7.3274499	90	560	1000	216
22	RETAILER 22	113.31205	-7.2327023	60	540	830	234
23	RETAILER 23	112.75652	-6.4477112	90	500	920	260
24	RETAILER 24	112.97002	-7.2938127	60	500	660	236
25	RETAILER 25	112.98331	-6.9159812	60	560	1000	220
26	RETAILER 26	112.98942	-6.2795696	90	570	1000	229
27	RETAILER 27	113.78814	-6.8942302	60	550	820	214
28	RETAILER 28	112.96273	-7.1648676	60	570	700	266
29	RETAILER 29	112.82688	-6.6187851	90	650	1000	190
30	RETAILER 30	113.11779	-6.8814332	90	600	910	180
31	RETAILER 31	113.47389	-6.9786658	90	490	970	225
32	RETAILER 32	113.38029	-7.1119387	90	570	740	283
33	RETAILER 33	112.85417	-6.6898087	60	540	1000	214
34	RETAILER 34	112.73028	-6.8306552	60	570	1000	187
35	RETAILER 35	113.70096	-7.0514976	90	540	1000	245
36	RETAILER 36	113.55916	-6.9194725	90	600	1000	201
37	RETAILER 37	112.97612	-6.3123629	90	550	700	277
38	RETAILER 38	113.3786	-6.640066	90	620	1000	205
39	RETAILER 39	113.13942	-7.235037	60	480	630	200
40	RETAILER 40	113.29541	-6.5649816	60	570	850	205

Node	Name	Longitude	Latitude	Service time (min)	TW START	TW END	TOTAL WEEKLY DEMAND
41	RETAILER 41	113.71036	-6.4073482	60	530	940	139
42	RETAILER 42	112.66193	-6.7347385	90	570	760	230
43	RETAILER 43	113.71324	-6.861782	90	550	810	211
44	RETAILER 44	113.43296	-6.7806885	90	520	840	233
45	RETAILER 45	113.23976	-6.8250292	60	640	1000	225
46	RETAILER 46	113.05119	-6.8903438	60	550	1000	210
47	RETAILER 47	112.95267	-7.2826424	90	650	1000	205
48	RETAILER 48	112.92221	-6.2453015	60	640	840	253
49	RETAILER 49	112.70698	-6.9066795	60	510	760	211
50	RETAILER 50	113.06475	-6.7947961	30	610	1000	194
51	RETAILER 51	112.81846	-6.8121348	60	610	890	169
52	RETAILER 52	112.938	-6.6388193	90	610	920	133
53	RETAILER 53	113.27309	-7.1695173	60	550	790	223
54	RETAILER 54	113.73957	-6.6098974	90	540	1000	267
55	RETAILER 55	113.23076	-6.9064773	60	590	1000	247
56	RETAILER 56	112.76164	-6.464436	60	650	770	216
57	RETAILER 57	113.17611	-6.4984797	90	590	990	178
58	RETAILER 58	113.33666	-6.4096925	90	580	800	200
59	RETAILER 59	112.65738	-7.108785	90	490	800	235
60	RETAILER 60	112.72232	-7.2266361	90	520	800	244
61	RETAILER 61	113.02557	-7.2010282	60	570	780	253
62	RETAILER 62	112.63559	-6.7421146	90	520	650	221
63	RETAILER 63	113.40838	-6.7340045	90	500	920	292
64	RETAILER 64	113.60882	-7.2530998	90	520	1000	183

Node	Name	Longitude	Latitude	Service time (min)	TW START	TW END	TOTAL WEEKLY DEMAND
65	RETAILER 65	112.86112	-6.5824734	90	560	900	240
66	RETAILER 66	113.16972	-6.9440495	90	630	920	259
67	RETAILER 67	112.81177	-6.5538493	60	540	820	188
68	RETAILER 68	113.72809	-6.7495076	60	590	700	216
69	RETAILER 69	112.74078	-6.4939403	60	600	930	308
70	RETAILER 70	113.1081	-6.8262711	60	660	970	224
71	RETAILER 71	113.21438	-7.1118643	30	560	750	257
72	RETAILER 72	113.02327	-7.2378955	90	640	1000	197
73	RETAILER 73	113.32924	-7.1542728	60	500	570	200
74	RETAILER 74	113.72671	-7.2350864	60	550	710	191
75	RETAILER 75	113.15754	-7.0384916	90	640	1000	228
76	RETAILER 76	113.66192	-6.50185	90	510	730	214
77	RETAILER 77	112.95644	-6.5883894	60	630	1000	245
78	RETAILER 78	112.93725	-7.2441101	90	540	860	188
79	RETAILER 79	112.67173	-6.9825845	90	620	1000	205
80	RETAILER 80	113.56495	-7.011183	60	520	780	206
81	RETAILER 81	112.91214	-6.8053776	90	540	900	200
82	RETAILER 82	112.93487	-6.96249	60	580	670	141
83	RETAILER 83	112.68818	-6.8031834	90	520	1000	251
84	RETAILER 84	112.8777	-6.373967	90	660	1000	259
85	RETAILER 85	113.32787	-6.497109	60	620	1000	224
86	RETAILER 86	113.72703	-6.973262	60	510	950	214
87	RETAILER 87	113.27412	-7.2544502	60	540	970	242
88	RETAILER 88	113.38169	-6.8844999	60	500	720	210

Node	Name	Longitude	Latitude	Service time (min)	TW START	TW END	TOTAL WEEKLY DEMAND
89	RETAILER 89	113.76531	-7.2163348	60	580	810	238
90	RETAILER 90	113.72181	-6.6484148	60	630	860	247
91	RETAILER 91	113.04443	-7.1774438	60	550	1000	283
92	RETAILER 92	113.20004	-7.0986299	60	610	1000	214
93	RETAILER 93	113.8045	-7.19859	60	650	1000	232
94	RETAILER 94	112.6693	-6.957115	90	520	910	234
95	RETAILER 95	113.27968	-6.3083444	90	560	1000	205
96	RETAILER 96	113.26859	-6.888561	60	600	1000	207
97	RETAILER 97	113.63215	-6.4169991	60	550	620	270
98	RETAILER 98	113.42647	-6.5341925	60	660	1000	251
99	RETAILER 99	113.80808	-6.9633892	90	590	820	219
100	RETAILER 100	113.21796	-6.8812074	60	620	1000	218

APPENDIX 3 - DISTANCE MATRIX (FOR REAL DATA ONLY)

DATASET 1 (15x15, REAL DATA)

Dij	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	0	3.8	16	19	5.6	2.5	17.3	7.2	12	7.9	11.5	18.8	6.6	3.4	7.1	17
1	2.8	0	26.6	16.1	7.8	4.7	28.4	9.7	9.9	11	13.6	17.8	8.8	5.8	9.5	14.9
2	15.8	25.5	0	3.6	20	16.5	16.3	15.6	19.8	15	21.5	4.7	24.2	13.3	10.9	9.7
3	15.8	21.7	3.6	0	19.8	16.5	19.2	15.3	14.8	15.2	24.4	2.3	19.3	14.1	10.5	9.3
4	5.8	8	21.9	30.1	0	5.5	22	12.8	16.2	14.3	12.8	31.2	7.8	8.8	12.5	20.7
5	3.6	5.8	16.9	19.1	4.7	0	17.2	7.8	14	9.3	8.8	20.4	3.8	3.9	8.7	19
6	16.9	24.6	7.1	10.1	22.2	17.7	0	10.9	18.9	10.2	16.9	11.3	19.5	14.2	14.6	13.1
7	6.7	9.5	12.9	15.9	11.6	7.5	11.3	0	10.1	3	11.2	16	8.8	4.2	4.3	8.6
8	7.9	5.3	19	14.3	12.9	9.7	20.8	11.8	0	11.4	18.7	16.1	13.9	9.6	8.4	7.3
9	8.8	11.5	12.6	19.2	14.1	9.6	8.6	2.7	10.8	0	10	16.8	11.3	6.1	4.7	11.7
10	12.2	14	21.5	24.3	12	8.8	16.5	9.3	22.2	10.8	0	24.8	6.6	9.9	13.1	17.1
11	16.7	23.4	4.7	2.5	21.5	17.6	20.5	16.4	17.7	16.2	26.4	0	20.4	15.2	11.8	10.6
12	7.1	9.4	18.9	22.4	7	3.8	18.6	9.2	17.6	10.7	8.4	22.3	0	5.5	10.6	14.9
13	3.6	6.4	13.1	16.6	8.3	4.3	13.9	4	10.9	5.6	10.7	16.5	5.7	0	4.8	9.1
14	7.1	8.6	11.2	11.7	11.8	7.9	12.3	5.2	11.6	5	14.9	11.9	10.6	5.5	0	4.5
15	9.8	15.4	7.4	7.8	14	10.7	13.6	12.8	9.7	12.2	21.5	8.1	13.4	8.3	4.6	0

DATASET 2 (30x30, REAL DATA)

Dij	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
0	0	6	12	15.7	5.7	20	7.6	15.4	10.3	7.7	7.2	15.5	7.5	3.5	11.7	8.8	8.8	9.2
1	6.8	0	14	17.2	11.9	15.7	13.8	17.7	9.5	9.3	9.2	16.5	3.7	7.8	8.3	15	13.2	8.4
2	14.1	12.4	0	7.6	16.4	12.9	17.5	6.4	20.1	19.8	10	8.2	15	12.7	10.5	17.4	13.6	19
3	17.3	15.7	11.9	0	20.9	7.6	22	10.9	23.3	23.1	14.5	3.8	18.2	14.2	12	21.9	18.1	22.2
4	5.5	10.3	13	19.7	0	24.2	2.5	16.6	10.5	7.8	7.8	20.3	11.4	5	15.6	3.7	7.9	9.4
5	19.2	16.2	17.3	7.5	24.3	0	25.7	16.3	23.8	23.6	19.9	5.7	12.1	18.8	7.2	26.3	26	22.7
6	6.6	12.3	13.6	20.3	2.9	26.5	0	17.2	11.6	7.4	8.2	20.9	13.4	7	18.2	3.2	7.5	10.5
7	12.2	12.7	9	15.7	12.9	21	11.9	0	20.3	18	5.8	16.3	15.2	8.5	17.5	11.7	7.2	19.2
8	9.9	10	31.2	25.9	10.4	26.3	12.3	31.9	0	7.7	17.1	28.6	11.6	13.3	17.8	13.5	17.7	7.2
9	7	10	18.9	22.7	7.5	24.9	9.4	22.3	7.9	0	14.1	22.5	12	10.4	17.5	10.6	14.8	6.8
10	7.2	7.5	5.8	14.1	8.8	19.5	9	11	15.1	13.9	0	14.7	8.2	3.3	12.4	8.8	5.2	14
11	16.5	14.5	12.5	3.7	21.4	5.6	22.6	11.4	22.1	21.9	15	0	13.8	17.7	9.6	22.4	18.6	21
12	8	5	16.6	17.6	13.2	12.2	14.5	17.4	12.7	12.4	9	14.1	0	7.7	4.8	15.2	16.8	11.6
13	3.7	5.3	8.4	14.5	7.3	19.2	10.4	13.4	12.9	10.5	3.6	15	6.4	0	10.6	9.3	7.1	11.8
14	12	9	18.7	11.5	17.2	7.4	18.5	19.5	16.7	16.4	12.9	8.6	5	11.6	0	19.2	18.9	15.6
15	7.7	12.1	13.4	20.1	4	25.4	3	17	12.6	10	8	20.7	13.2	6.8	17.4	0	7.3	11.5
16	9.1	11.4	9.3	16.8	9.2	24.6	8.2	10.9	17.9	14.4	6.1	17.3	16	6.1	18.2	8.1	0	16.8
17	9.3	9.4	21	24.2	9.8	24.3	11.7	24.6	6	7.1	16.1	23.5	11.4	12.6	16.9	12.9	17.1	0
18	7.7	11.6	14.5	19.1	7.3	27.2	6.3	13.5	16	13.3	6.7	19.9	18.6	6.3	20.8	6.2	2.6	14.9
19	13.3	11.2	10.8	9.8	18.1	9.7	23.2	9.7	18.9	18.6	11.6	6.2	10.5	12.6	5.7	23	18.8	17.8
20	17.8	17.5	8.9	12.7	17.7	18	17.7	6.5	25.2	24.7	11.6	13.3	19	14.1	16.1	17.5	13	24.1
21	14.9	17.4	32.1	33.1	15.4	32.1	17.3	32.9	10	12.8	22.3	29.6	19.4	21	21.4	18.5	32.3	12.9
22	8.8	8.9	24.6	25.5	13.4	24.5	15.3	25.3	8.2	11.4	13.8	22	8.3	12.5	13.8	16.5	17.8	11
23	15.6	13.9	10.2	2.5	19.1	8.3	20.3	9.2	21.6	21.3	12.7	3.1	16.5	12.4	12.6	20.2	16.2	20.5

Dij	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
24	30.2	26.9	37.6	20.5	34.8	17	36.6	38.4	33.2	32.8	34.6	18.7	24.9	30.5	18.7	42	37.8	32.6
25	14.4	11.4	15	12.1	18.8	10.1	23.8	14	19	18.8	12.3	7.8	8.9	13.2	4	23.6	19.4	17.9
26	13.9	14.4	5.5	9.4	13.6	14.7	13.6	2.4	22	20.6	7.5	9.9	15.7	10.2	12.3	13.4	8.9	20.9
27	6.9	11.2	19.6	22.6	7.4	26.1	7.7	22.3	9.1	1.3	14	22.4	13.2	10.3	18.6	10.5	14.7	8
28	13.1	10.1	19.8	14.3	18.3	10.8	19.6	20.5	17.7	17.5	14	10.8	6.1	12.7	2.2	20.3	20	16.7
29	14.6	13	9.3	5.3	18.2	8.1	19.4	8.2	20.6	20.4	11.8	3.1	15.5	12.2	8.6	19.3	15.4	19.5
30	10.2	7.2	14.4	12.5	15.4	13.8	19	15.2	14.8	14.6	7.7	9.9	3.1	9.8	6.3	18.8	14.6	13.7

Dij	18	19	20	21	22	23	24	25	26	27	28	29	30
0	8.3	11.8	16.4	10.8	9.1	13.2	15.2	11.7	13.9	7.6	12.5	12.3	8.1
1	13.5	12.2	18.7	7.3	3.5	15.5	9.6	12.1	15.9	10.4	10.8	14.6	8.4
2	15.4	6.2	7.4	22.4	15.5	5.9	21.2	10.4	4.8	19.5	13	5	9.7
3	19.9	9.9	11.9	25.7	18.7	2.5	24.5	11.8	9.3	23.5	14.4	5.3	13
4	7	16.1	17.7	13.3	13.4	18	19.5	16	13.3	7.8	16.5	17.1	12.3
5	27.9	9.8	17.3	23.8	23.9	8.4	19.4	10	14.7	24.4	9.6	8.2	13.6
6	6.6	18.3	18.3	14.4	14.8	18.6	21.4	18.3	14.6	7.3	19.1	17.6	14.3
7	9	15.7	11.6	22.7	15.7	14	21.5	15.6	6.8	18	18.4	13	13.1
8	16.8	19.8	32.9	6.3	7.7	23.4	14.2	20	23.9	8.9	17.7	22.5	16.4
9	13.9	18.7	23.4	10.8	11.6	20.2	17.8	18.7	20.9	1.3	18.3	19.2	15
10	6.8	14.1	12.1	14.3	10.5	12.4	16.7	10.9	7.8	13.8	13.3	11.5	7.2
11	20.5	6.2	12.5	21.3	21.7	3.1	20	8.8	9.9	21.7	11.4	3.1	10.1
12	13.3	9.8	18.4	11.1	6.5	15.9	9.9	7.1	15.8	13.6	5.6	14.9	4
13	7.4	11	14.4	12.1	8.3	12.7	14.5	11	10.5	10.4	11.5	11.8	7.3
14	20.7	5.3	20.5	13.5	13.9	12.6	12.3	4	17.9	17.5	2.5	8.3	7.7
15	6.4	17.8	18.1	15.5	15.1	18.4	21.3	17.8	14.4	9.9	18.3	17.5	14.1

Dij	18	19	20	21	22	23	24	25	26	27	28	29	30
16	3	16.4	11.9	23.5	14.4	15	22.2	16.3	7.1	15.2	19.1	14.1	13.8
17	16.2	19.2	25.7	8.9	11	22.5	16.7	19.1	22.9	8.3	17.7	21.6	15.4
18	0	19	14.5	26.1	14.6	17.6	24.8	18.9	9.7	12.4	21.7	15.7	16.4
19	20.6	0	10.7	18	14.3	6.2	16.8	5.6	8.1	18.4	8.2	4	6.8
20	15.5	11.3	0	26.5	26.9	11	25.3	16	4.9	24.6	22.2	10	14.8
21	21.9	25.2	33.9	0	12.4	31.3	15.1	25.2	31.3	13.9	18.6	30.4	22.7
22	18.2	17.7	26.3	5.2	0	23.8	7.6	17.6	23.7	12.6	11.1	22.9	13.1
23	18.2	6.2	10.2	23.9	17	0	22.7	12.4	7.6	21	14.5	3.6	11.2
24	39.6	22.2	39.4	23.3	23.3	21.4	0	20.9	36.8	34.8	20.2	21.8	28.2
25	21.2	4.5	15	15.9	16.3	10.6	14.6	0	12.4	19.6	6.4	7.5	7.5
26	11.4	8	5.6	23.2	17.4	7.6	22	12.1	0	20.5	18.9	6.7	11.5
27	13.8	18.7	23.3	11.9	12.8	20.1	19	18.6	19.9	0	19.5	19.2	14.9
28	21.8	7.6	21.6	11.4	11.5	19	9.5	6.3	19	18.3	0	10.5	8.8
29	17.2	4	9.2	23	16	3.6	21.8	8.4	6.6	20	11	0	9.7
30	16.4	5.6	16.2	12.6	10.2	10.7	11.4	5.5	13.6	15.4	7.1	8.9	0

AUTHOR'S BIOGRAPHY

Alexander Billy Widjaja was born in Surabaya, 24th of January 1998. Author is the first son among 3 children of Antonius Widjaja and Maria Agustina. Author started his education in Gracia Kindergarten (finished in 2003). Then, he continued his study in Kartika National Plus elementary school, Surabaya (Graduated on June 2009); Petra 3 Christian Junior High School (Graduated on June 2012) and Petra 2 Christian Senior High School (Graduated on June 2015). Recently, author is taking an undergraduate program at Industrial Engineering department of *Institut Teknologi Sepuluh Nopember* (ITS), Surabaya in 2015 and planning to graduate in the seventh semester of his program (in 2019).

During his college program, author was actively involved in all learning processes of the department, more particularly in international class (Class Q) of batch 2015. This class required the students to do all academic processes in english. Author also participated actively as a class captain / representative during his education. Besides, author took other organizational activities. He has experiences in joining Christian student assembly organization (PMK ITS), specifically in NaPas (*Natal Paskah*) division as staff, event coordinator and steering commitee; joining Industrial Engineering Student Association (HMTI ITS) as the staff and head of AKATARA talent department; and also participating in seminars and trainings (For example: LKMM Pra TD, LKMM TD, etc). Author has also ever joined internship program in PT. Adicitra Bhirawa (June - July 2018) as an intern in Production Department. While finally author decided to conduct his final research in Logistics and Supply Chain field, which is recapitulated in this report. For further information, author is able to be contacted via email in alexander.billy15@mhs.ie.its.ac.id, or also in alexanderbilly98@gmail.com.