International Journal of Scientific and Management Research
Volume 07 Issue 05 (May) 2024
ISSN: 2581-6888
Page: 37-56

Optimization of Solving the Vehicle Routing Problem with Time Windows in Multiple Product and Multiple Route Distribution (Case Study: PT Subang Mulya Sejahtera)

Hally Hanafiah[1], Prihantina Ardaniswarie[2], Fajar Ardhy Tri Susilo[3], & Dedi Rianto Rahadi[4]
[2,3] Institut Teknologi Sepuluh November, Surabaya, Jawa Timur
[1,4] Universitas Presiden, Cikarang, Kabupaten Bekasi, Jawa Barat, **Indonesia**
DOI - http://doi.org/10.37502/IJSMR.2024.7503

Abstract

The Fast-Moving Consumer Goods (FMCG) industry is faced with distribution complexity with a diversity of products and delivery routes (Multiple Products and Multiple Routes). PT Subang Mulya Sejahtera, part of the WINGS Group, is an FMCG company with distribution in Subang and Indramayu Regencies, serving 7,960 customers. To increase operational efficiency, companies need to optimize the resolution of Vehicle Routing Problem with Time Windows (VRPTW). Meeting needs on time requires significant costs in distribution. This research aims to develop an accurate mathematical model, considering vehicle capacity limitations, time windows, and variations in customer needs. In addition, the solution is integrated in the company's information technology system to support VRPTW implementation. The Sequential Insertion Algorithm methodology is used. The aim of this research is to achieve operational efficiency, especially in transport costs, and ensure delivery time targets to consumers are met.

Keywords: Fast-Moving Consumer Goods (FMCG), Vehicle Routing Problem with Time Windows (VRPTW), Sequential Insertion Algorithm, operational efficiency.

1. Introduction

Increasingly competitive market competition means companies must move quickly in terms of distributing goods. Implementing distribution requires companies to be able to meet customer needs on time. Inaccuracy in delivery times can cause customer dissatisfaction and reduce customer confidence in the company's services. This economic development also goes hand in hand with an increase in population and the development of consumer culture in society. This causes an increase in demand in terms of variations and quantities that cannot be predicted in advance.

The Fast-Moving Consumer Goods (FMCG) industry faces complex distribution challenges with a diversity of products and delivery routes (Multiple Products and Multiple Routes). PT Subang Mulya Sejahtera is part of the WINGS Group, as an FMCG company with a distribution coverage area in the Subang Regency area which has 7,960 customers, so it needs to optimize the resolution of the Vehicle Routing Problem with Time Windows (VRPTW) in order to increase its operational efficiency. Fulfilling needs in a timely manner requires quite large costs in distribution activities. Ballou stated that transportation costs range between one third or two thirds of total logistics costs so that increasing efficiency by maximizing the utility of transportation equipment and personnel is the main problem (Ballou, 1998). Accurate transport decisions can improve the company's service level and reduce transport costs. One of the transport decisions made in the distribution realm is the accuracy of determining the optimal configuration of vehicle visiting routes. The problem in transport decisions is determining or finding the optimal route.

This research is driven by the need to overcome delivery time constraints and optimal operational efficiency in the context of multiple product and multiple route distribution. Effective solutions can provide competitive advantages for PT Subang Mulya Sejahtera in a competitive market. This research will apply the Sequential Insertion Algorithm in forming distribution routes which are expected to provide feasible solutions to company distribution problems by minimizing distribution distance and travel time as well as costs incurred in distribution activities. The sequential insertion algorithm method that will be used is adapted from previous research conducted by Dita Ayu Pratama by applying it to land transportation routes in the distribution of bottled drinking water (AMDK) and adapted to the criteria and limitations contained in the company's distribution system.

Formulation of the problem

Distribution problems are one of the main problems in the FMCG industry, as experienced by PT Subang Mulya Sejahtera in distributing its products. Transportation costs contribute around 5% of total revenue (Tompkins & Ferrell, 2011). Creating more efficient transportation models allows costs to be reduced.

PT Subang Mulya Sejahtera as an FMCG company has a very wide distribution coverage area, namely throughout Subang Regency, up to Lembang with 7,960 customers and there are approximately 1,620 active Stock Keeping Units (SKU), so there are a number of problems that are the focus. study. The distribution of multiple products and multiple routes creates its own complexity in determining the optimal route for a vehicle fleet.

Much research has been carried out to determine goods delivery routes and is usually referred to as the Vehicle Routing Problem (VRP). This research has been developed to consider backhaul and time windows with the term VRPBTW (Gupta, 2013). VRPBTW determines the route for sending goods and picking up goods by considering operational constraints, namely time windows. Time windows describe the time limit in which vehicles must arrive at a location before the specified time. In VRPBTW there is a limitation that collection of goods can only be carried out if the delivery of goods has been completed by considering the feasibility in the field regarding the loading and unloading process.

Apart from that, VRPTW itself is a complex problem with many variables and obstacles. Factors such as vehicle capacity, time constraints for each customer, and the dynamics of changing customer needs are elements that need to be considered in designing effective solutions.

So, the problem in this research is how to optimize the resolution of the Vehicle Routing Problem with Time Windows (VRPTW) at PT Subang Mulya Sejahtera with several aspects of the problem identified including:

1. Product Variability: PT Subang Mulya Sejahtera manages a number of FMCG products with varying distribution characteristics. The optimal solution must be able to handle these variations efficiently.
2. Number and Type of Vehicles: Determining the right number and type of vehicles to send products to a number of customers by paying attention to delivery time constraints.
3. Limited Delivery Time: Having delivery time limits for each customer requires route planning that minimizes total travel time while adhering to established time constraints.
4. Operational Efficiency: Look for solutions that not only reduce logistics costs but also improve overall operational efficiency.
5. Implementation of the Sequential Insertion Algorithm: How to implement the Sequential Insertion Algorithm optimally, considering the peculiarities of product distribution in the Company.

Research Questions

1. How to develop an accurate mathematical model to overcome the complexity of VRPTW by considering vehicle capacity constraints, time windows, and variations in customer needs.
2. How to integrate solutions in the existing information technology system at PT Subang Mulya Sejahtera to support the implementation of VRPTW for operational efficiency.

By solving these problems, it is hoped that this research will be able to make a significant contribution to the operational efficiency of PT Subang Mulya Sejahtera in the field of FMCG product distribution.

Research Objective

The main objective of this research is to provide strategic recommendations based on research results to support decision making at the management level of PT Subang Mulya Sejahtera. This objective involves presenting practical recommendations that can be implemented to improve the Company's operational efficiency and competitiveness as follows:

1. Develop an accurate Mathematical Model to overcome VRPTW by considering vehicle capacity limitations, time windows, and variations in customer needs.
2. Integrating solutions in the existing information technology system at PT Subang Mulya Sejahtera to support the implementation of VRPTW for operational efficiency.

Benefits of research

This research is expected to provide significant benefits, both for the FMCG industry in general and specifically for PT Subang Mulya Sejahtera. The detailed benefits of research are:

Increased Operational Efficiency

It is hoped that this research can contribute to increasing the operational efficiency of PT Subang Mulya Sejahtera by optimizing the resolution of the Vehicle Routing Problem with Time Windows (VRPTW). By scheduling more efficient routes, companies can reduce logistics costs and increase vehicle fleet utilization.

Reduction of Logistics Costs

The solutions resulting from this research can help PT Subang Mulya Sejahtera to identify and implement distribution strategies that can reduce logistics costs. This can include optimizing vehicle usage, more efficient route scheduling and delivery time management.

Improved Timeliness of Delivery

By optimizing VRPTW completion, this research can increase the timeliness of product delivery to customers. This will have a positive impact on customer satisfaction, strengthen the company's image and help maintain market share in the highly competitive FMCG industry.

Competitive Advantage

Implementation of optimal solutions resulting from this research can provide a competitive advantage for PT Subang Mulya Sejahtera in the FMCG industrial market. This advantage can create differentiation for the company from its competitors, both in terms of operational efficiency and customer service quality.

Contribution to Knowledge Development

This research is also expected to contribute to the development of knowledge in the field of distribution optimization, especially in the context of VRPTW with multiple product and multiple route distribution. The research results can be a reference for further research in a similar domain.

The scope of research

This research focuses on optimizing the resolution of the Vehicle Routing Problem with Time Windows (VRPTW) in the context of product distribution at PT Subang Mulya Sejahtera, a Fast-Moving Consumer Goods (FMCG) company. The scope of the research covers several main aspects:

- Multiple Product Distribution: This research considers the variety of FMCG products managed by PT Subang Mulya Sejahtera, covering various types and characteristics of products with 1,620 active Stock Keeping Units (SKU).
- Multiple Route Distribution: This research pays attention to the diversity of distribution routes that can be taken by PT Subang Mulya Sejahtera's vehicle fleet to reach customers, here there are 121 routes.

Algoritma Sequential Insertion: The application of the Sequential Insertion Algorithm is the main focus as an optimization method for solving VRPTW.

Scope Consideration

The basis of the scope of this research refers to the need for PT Subang Mulya Sejahtera to increase operational efficiency in managing the distribution of FMCG products. On this basis, research will include:

- Algorithm adjustments: Make adjustments to the Sequential Insertion Algorithm to overcome challenges in the distribution of multiple products and multiple routes.
- Mathematical Model: Development of an accurate and relevant mathematical model to represent distribution problems at PT Subang Mulya Sejahtera.

- Number and Type of Vehicles: The research will consider determining the optimal number and type of vehicles for product distribution. The following are the number and types of delivery vehicles/fleet used by PT Subang Mulya Sejahtera in making deliveries to customers totaling 63 Delivery Fleet Units.

Type of Fleet	Amount
Small Truck	6
Four Wheel Standard	15
Four Wheel Long	10
Six Wheel Standard	22
Six Wheel Long	10
Grand Total	63

Table 1. Type and Number of Delivery Fleet

- Delivery Time: Scheduling delivery times that minimize total travel time while complying with time constraints for each customer, the following is the customer opening and closing schedule based on area/customer request Attached in Table 2. Customer Opening and Closing Schedule.
- Delivery Routes: Customer routes in the PT Subang Mulya Sejahtera delivery area are divided into 115 delivery routes which have been divided according to the delivery day schedule. Attached in Table 3. Delivery Routes based on Area, Mileage and Travel Time.
- Technology Integration: Integrating the resulting solutions into the existing information technology system at PT Subang Mulya Sejahtera here using the SAP system in daily operational processes.

Market	Operating Hours
Ps Ampera	07:00 sd 16:00
Ps Bobos	09:00 sd 16:00
Ps Bojong Keding	07:00 sd 19:00
Ps Bugis	06:00 sd16:30
Ps Ciasem	05:00 sd 15:00
Ps Cipunegara	07:00 sd 14:00
Ps Cisalak	06:30 sd 15:00
Ps Compreng	08:00 sd 16:00
Ps Haurgeulis	10:00 sd 16:00
Ps Kalijati	06:00 sd 14:00
Ps Kaso Malang	05:00 sd 14:00
Ps Pagaden	08:00 sd 16:00
Ps Palasari	07:00 sd 16:00
Ps Pamanukan	03:00 sd 12:00
Ps Panjang	10:00 sd 17:00
Ps Pilang	08:00 sd 16:00
Ps Pujasera	09:00 sd 17:00
Ps Purwadadi	07:00 sd 13:00
Ps Pusaka Ratu	02:00 sd 15:00
Ps Sanca	08:00 sd 16:00
Ps Sukra	07:00 sd 16:00
Ps Tanjung Siang	08:00 sd 16:00
Ps Terminal	03:00 sd 08:00
Ps Wates	05:00 sd 15:00

Table 2. Delivery Routes based on Area, Distance and Travel Time.

Scope Limitations

- Geographical Limitations: This research focuses on product distribution at PT Subang Mulya Sejahtera and does not consider geographical aspects that might influence routes.
- Certain Product Types: Focuses on the distribution of certain FMCG products managed by PT Subang Mulya Sejahtera without including product types that may have different distribution characteristics.
- Vehicle Fleet Limitations: Limitations on the type and capacity of the vehicle fleet available at the company.
- Technological Limitations: The research will consider the limitations of existing information technology at PT Subang Mulya Sejahtera in implementing solutions.

2. Research Methodology

This type of study is quantitative and descriptive qualitative data with data in the form of graph points as depots or customers, graph side weights as distance from depot to customer or between customers, number of vehicles, vehicle capacity, and time windows for each customer owned by PT Subang Mulya Prosperous. The procedure for solving this is by identifying VRPTW variants according to real problems and identifying the corresponding constraints. Next, model the real problem into a graph model and algorithm selection. Problem solving by implementing it into a computer program using Delphi by inputting data, processing the solution with an algorithm, and determining the optimal solution. The final step is to analyze the results of problem solving on the program display and interpret the results of real problem solving. A quantitative approach is used to develop mathematical models and apply the Sequential Insertion Algorithm. A qualitative approach was used to analyze and evaluate the implementation of solutions in a real context at PT Subang Mulya Sejahtera.

Research Approach

This research uses a combination of quantitative and qualitative approaches:

Quantitative Approach. First Mathematical Model Development: Building a VRPTW mathematical model based on literature studies and product distribution characteristics at PT Subang Mulya Sejahtera. Second Implementation of the Sequential Insertion Algorithm: Implementing the Sequential Insertion Algorithm in a company environment with adjustments for multiple product and multiple route distribution. Finally, Simulation and Testing: Perform simulations using historical data to test and evaluate solution performance.

Qualitative Approach. First Qualitative Solution Analysis: Conduct interviews and discussions with related parties at PT Subang Mulya Sejahtera to understand the qualitative aspects of the resulting solution. Second Implementation Validation: Validate the solution implementation by collecting feedback and observations from direct users.

Mathematical Model Development

In accordance with the characteristics of the distribution system contained in the system, a mathematical model is created which is adapted from the formulation of the model that will be used as the basis for forming the algorithm (Arvianto, 2014).

Implementation of the Sequential Insertion Algorithm

To complete the VRPTW variant in this study, the sequential insertion algorithm was used. The basic principle of the sequential insertion algorithm is initialization by selecting a vehicle, selecting the first customer (seed customer) to form an initial route, and then adding customers one by one to the route formed. The insertion process for each customer is required to provide the best criteria with the time window limits met with the total vehicle load not exceeding the vehicle capacity and the minimum total distance

Simulation and Testing

Performance testing in the Vehicle Routing Problem with Time Window (VRPTW) research at PT Subang Mulya Sejahtera was carried out using simulations based on historical product distribution data. The following are performance testing steps that can be implemented:

Historical Data

Data Collection is collect historical product distribution data that includes information such as number of customers, product type, service times, and delivery deadlines.

Data Preparation

Data Processing is prepare historical data to suit the format and structure required by mathematical models and Sequential Insertion Algorithms.

Simulation

- Simulation Input: Using historical data as simulation input, including number of customers, product demand, service time, delivery deadline, and vehicle capacity.
- Mathematical Model Execution: Executes the VRPTW mathematical model with the prepared input data.
- Implementation of the Sequential Insertion Algorithm: Applying the Sequential Insertion Algorithm to distribution data to obtain vehicle route solutions.
- Performance Criteria Measurement: Measure and record performance criteria such as total distance traveled, number of vehicles used, on time delivery, and logistics costs.

Performance Evaluation

- Comparison with Conventional Solutions: Compare the simulation results with conventional solutions that may have been used previously by PT Subang Mulya Sejahtera.
- Performance Criteria Analysis: Analyzing performance criteria to evaluate the effectiveness and efficiency of solutions produced by mathematical models and the Sequential Insertion Algorithm.

Decision Making

- Recommendations for Improvement: If differences in performance are found, provide recommendations for improvements or adjustments to the mathematical model or Sequential Insertion Algorithm.
- Validation of Results: Validating simulation results by involving related parties at PT Subang Mulya Sejahtera and collecting feedback.

Qualitative Analysis of Solutions

- Interviews and Discussions: Conduct interviews with related parties to gain qualitative views and understanding of the solution.
- Implementation Validation: Validate solution implementation by involving direct users and gathering feedback.

3. Literature Review

Supply Chain Management

Supply Chain Management as an approach used to achieve efficient integration of suppliers, manufacturers, distributors, retailers and customers. This means that goods are produced in the right quantity, at the right time, and in the right place with the aim of achieving a minimum cost of the system as a whole and also achieving the desired service level (Levi, et.al 2000). Pires, et.al. (2001) defines Supply Chain Management as a network of suppliers, manufacturing, distribution assembly, and logistics facilities that form the function of purchasing materials, transforming materials into semi-finished goods and finished products, and the distribution process of these products to consumers. Supply Chain Management as managing activities in order to obtain raw materials into goods in process or semi-finished goods and finished goods and then sending these products to consumers through a distribution system. These activities include traditional purchasing functions plus other important activities relating to suppliers and distributors (Heizer & Rander, 2004). Chow, et.al. (2008) defines Supply Chain Management as a holistic and strategic approach in terms of demand, operations, purchasing and logistics process management. Supply Chain Management is directly related to the complete process and cycle of raw materials from suppliers to production, warehouse and distribution then to consumers. Meanwhile, the Company increases its competitive capabilities through product customization, high quality, cost reduction, and speed to market.

Supply Chain Management Function

In general, Supply Chain Management has two functions, first Supply Chain Management physically changes raw material goods into finished products and delivers them to end users. This function is related to material costs, storage costs, production costs, transportation costs. Supply Chain Management as market mediation, namely ensuring that what is supplied by the supply chain reflects the aspirations of the customer or end user. This second function is related to market survey costs (Zabidi, 2001).

Goals of Supply Chain Management

- Ensuring a product is at the right place and time to meet consumer demand without creating excess or shortage of stock
- To ensure unity of movement of adequate quantity and quality of supplies which includes many things such as planning and communication
- To maximize the overall value produced (Chopra, 2001)
- Achieve activity and cost efficiency throughout the system, total system costs from transportation to distribution of raw material supplies, work processes and finished goods.

Supply Chain Management Strategy

Many opportunities are available in supply chain management to increase product value at low costs. There are several strategies that can be used, including (Siagian, 2005):

- Postponement, namely a strategy to delay modifications or adjustments to the product as long as possible. With the help of design and the help of suppliers, a manufacturing company can maintain the generic characteristics of its products for as long as possible. Postpontment can be carried out in relation to technology and process characteristics, product characteristics, market characteristics.
- Drop ship, this strategy is often used on the distributor side. Initially, the stages for the product from the supplier to reach the consumer were quite long, as in Figure 1, but with the drop ship strategy, the supplier will send it directly to the consumer and not to the seller, in order to save time and transportation costs, as in Figure 2. Another thing that Cost savings include the use of special packaging, special labels and location.

Figure 1: Product Flow Source: (Siagian, 2005)

Figure 2: Dropship Strategy. Source: (Siagian, 2005)

In planning a Supply Chain Management strategy, several sources of decision making are needed. Below are several factors to consider in a Supply Chain Management strategy, including:

1. Competitive advantage that can be obtained from:
a. Differentiation, namely trying to create/make products that are unique, different or at least better than existing products.
b. Cost pioneering. Namely trying to minimize costs but without reducing the value or quality of the product which can be done through process innovation, correct product design and reducing manufacturing costs.
c. Fast response, characterized by flexibility, realiability, quick response to changes.
2. Demand flexibility, according to (Slack, 1990) is influenced by several factors, namely the product itself, product mix, volume and type of delivery
3. Process Capability, related to the extent to which the company can carry out the required activities, where there are many ways to meet these needs. If the process capabilities comply with industry standards, then benchmarking can be used effectively.
4. Process maturity is closely related to the level of process performance, how the process can be responsive in meeting market demand.
5. Strategic risk, which is the spread of risk, namely the risk that the company can accept due to leaks of information about its products and services. Risk can be high when the supplier has other customers so that competitors obtain the supplier's services and know the company's strategy.

Stages of Supply Chain Management

There are many chain models or paths in the supply chain stages, starting from the supplier to the manufacturer then continuing to the distributor and after that to the retailer and finally to the customer. Below are the stages or chain paths in the supply chain process.

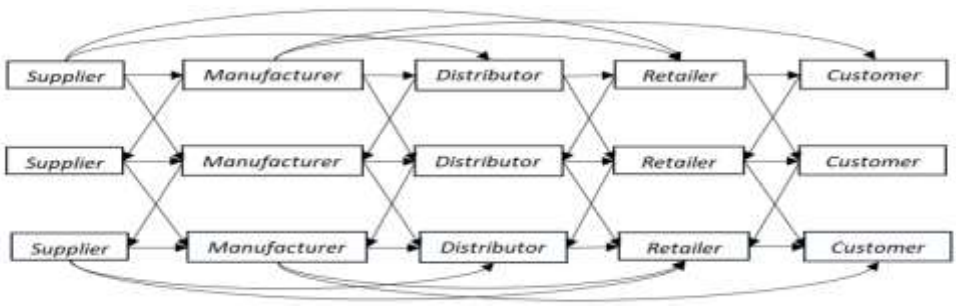

Figure 3: Supply Chain Path. Source: (Chopra, 2004)

Chain 1: Suppliers

This chain is the first stage in the cahin supply chain, where the supplier's activities are as a provider of production materials such as raw materials, raw materials, or auxiliary materials.

Chain 2: Supplier – Manufacturer

The first chain is connected to the second chain. In this chain, the manufacturer plays the role of making the work up to finishing. There can be savings in this chain, such as savings in inventory costs for raw materials, semi-finished materials and finished materials. Manufacturers can also collaborate with several suppliers.

Chain 3: Supplier – Manufacturer – Distributor

After passing through the manufacturer chain, the third chain is the distributor. In this chain, activities begin to occur in distributing semi-finished or finished materials to customers, where large distributors or wholesalers will distribute the goods to retailers or retailers or directly distribute the goods to consumers.

Chain 4: Supplier – Manufacturer – Distributor – Retailer

The fourth chain is a retailer or another name for a retailer. In general, large distributors have their own warehouses to store goods which will then be distributed to retailers whose role is to distribute goods to final consumers (end users). Retailers can be shops or roadside kiosks. The prices offered by retailers are usually more expensive compared to direct distributor prices, so the route may not go through the retailer, so it goes directly from the distributor to the final consumer, but in general the supply route goes through the retailer.

Chain 5: Supplier - Manufacturer - Distributor – Retailer – Customer

The aim of the Supply Chain is to distribute goods to consumers. Retailers directly offer their products to consumers. In fact, this chain is still not the last chain. Actually, there is still one more chain, namely buyers who do not use the product directly or better known as resellers.

Logistic

The types of goods in the logistics sector consist of physical objects which generally involve the integration of information flow, material handling, production, packaging, inventory, transportation, warehousing and security. Complexity in logistics can be analyzed, described into a model, visualized and optimized with existing simulation software (Li X., 2014). Logistics is the process of efficient planning, implementation and control, effective flow and storage of goods and services, and all related information from a point of origin to the point of consumption in order to meet customer needs. This definition includes inbound, outbound, internal and external movements, and returns of materials for environmental purposes (Bowersox, D.J., et al, 1996). Logistics plays an effective role in competition which is widely recognized as a superior customer service performance. Achieving logistics based on high quality service and cost control is an important dimension of a business focused on improving consumers. Logistics management functions are a series of processes consisting of planning, budgeting, procurement, storage and distribution, maintenance, erase and control function (Prihantono, C.R 2012).

Transportation

In the supply chain process, there are several transportation models that can be used to reach the target actor. The role of transportation is very significant in the supply chain process. Transportation is the movement of a product from one location to another location from the beginning of the supply chain process to the customer. Transportation plays an important role because a product is rarely produced and used in the same location. Transportation is a significant cost component in the supply chain process. There are several transportation models that can be used, including (Chopra, 2004).

Air (water) transportation is the fastest growing type of shipping because it offers speed and reliability for the movement of goods on a national and international scale and is light in weight. The use of this transportation is usually for high value products, not low value products because the shipping costs required for this mode are very high. Second, Delivery Services (package carriers), Package delivery companies carry small packages with a certain weight, these delivery services are more expensive and their prices cannot compete for sending large goods. Next Trucks, which have advantages in terms of delivery flexibility. Companies that adopt Just in Time (JIT) place increased emphasis on truck drivers to pick up and deliver on time, without damage, with good administrative work at low costs. Fourth Railways, with the growth of JIT, trains are lagging behind because manufacturing with small batches requires regular and smaller deliveries. This railway transportation tool has the ability to lift very large tonnage of goods, however this mode of transportation requires quite high fixed costs and quite high routine equipment costs too. Pipelines, usually used to transport liquid raw materials such as crude oil, natural gas, oil products and chemicals. The advantage of this mode of transportation is that the variable costs are relatively low, even though the fixed costs are still the highest. Meanwhile, the weakness of this mode of transportation is that the goods carried are very limited, because it really depends on the diameter of the pipe and the speed of the current being carried. Finally Water transportation, where the cargo sent is usually large and of low value. This system is chosen if delivery capability is considered more important than speed. The advantage of this mode is that it can carry large quantities of goods, while the disadvantage is in terms of delivery time or speed.

In this research, road transportation facilities using truck mode will be discussed with a diversity of products and routes (Multiple Products and Multiple Routes).

Vehicle Routing Problem with Time Window

Vehicle Routing Problem (VRP) defines the problem of determining distribution routes where a Salesman visits several cities and each city can only be visited by one Salesman where each salesman comes from a depot and must return to that depot at the end of his journey. VRP also defines a route problem where a city is associated as a demand or consumer, and each vehicle used for travel is assumed to have a certain capacity. The total amount of demand on a route must not exceed the capacity of the vehicles assigned to ply that route (Kallehauge, B., Larsen, J. and Madsen, O. 2006).

Vehicle Routing Problem with Time Windows is an extension of the VRP problem, where VRP adds time windows for each consumer. For VRPTW, apart from vehicle capacity constraints, there are additional constraints that require vehicles to serve each consumer in a certain time frame. Vehicles may arrive before opening time but these customers cannot be served until the time window opens. Distribution is not served when the time window has closed (Kallehauge, B., Larsen, J. and Madsen, O. 2006).

VRPTW is used to schedule a group of vehicles with limited capacity and travel time from a central depot to a group of consumers spread geographically with known demand in a certain time window. The time window is two sided, which means that each consumer must be served at or after the earliest time, and before the latest time of that consumer. If the vehicle arrives at the customer before the customer's earliest time, it will result in idle or waiting time. Vehicles that come to consumers after the latest time are tardy. There is also the service time required to serve each customer. The route cost of a vehicle is the total of travel time (proportional to distance), waiting time, and service time, required to visit a set of consumers (Thangiah, S. 1993).

The development of the VRPTW variant is adjusted to the additional constraints required. Below are several variants of VRPTW:

1) VRP with Backhauls and Time Windows (VRPBTW), this variant is a development of the VRP with Backhauls (VRPB) problem with additional time windows. In general, the case of VRP is delivery, in VRPB there is also collection of goods from customers. In each vehicle route, collection is carried out after all deliveries to customers have been completed and there is an additional time window for each customer to receive the goods.
2) Capacitated VRPTW (CVRPTW), this variant is a modification of the Capacitated Vehicle Routing Problem (CVRP) and VRPTW. This variant has the limitation that customer demand in one route is limited by vehicle capacity (according to CVRP characteristics) and there is an additional time window for each customer to be able to receive goods.
3) Split delivery VRPTW (SDVRPTW), this variant is a development of SDVRP, namely that demand exceeds vehicle capacity, so it can be divided into smaller units (split delivery) with additional time windows for each customer to receive the goods.
4) Multi Trip Split Delivery VRPTW (MT SDVRPTW), this variant is a development of Multi Trip VRP and SDVRPTW.
5) VRP with Simultaneous Pickups and Deliveries (VRPPDTW), this variant is a development of VRP with Simultaneous Delivery and Pickup (VRPSDP), namely carrying out delivery and pickup simultaneously and additional time windows for each customer to be able to receive the goods.
6) Multi-Depot Vehicle Routing Problem and Time Windows (MDVRPTW), this variant is a development of Multiple Depot VRP (MDVRP), namely that there is more than one depot to serve customers and there are additional time windows for each customer.
7) Vehicle routing problem with pick-up and delivery and time windows (VRPPDTW), this variant is a development of Vehicle routing problem with pick-up and delivery with additional time windows.
8) Multi-depot vehicle routing problem with pick-up and delivery and time windows (MDVRPPDTW), this variant is a development of multi-depot vehicle routing problem with pick-up and delivery (MDVRPPD) with additional time windows.

4. Research Model

Mathematical Formulation VRPTW

The mathematical formulation for the VRPTW problem which aims to minimize the total distance traveled or travel costs with a number of outlets is as follows:

Objective function:

$$\sum_{k\in V}\sum_{i\in N}\sum_{j\in N} c_{ij}\ x_{ij}^{k}$$

with:

$$x_{ij}^{k} = \begin{cases} 1, \text{if vehicle k is run from point i to j}, i \neq j \\ 0, for\ another \end{cases}$$

With the following limitations:

Limitations 1. Each outlet is only visited by one vehicle

$$\sum_{k\in V}\sum_{i\in N} x_{ij}^{k} = 1, \quad \forall j\ \in N\ \{0\}$$

Limitation 2. Total demand from each outlet on one route must not exceed vehicle capacity

$$\sum_{i\in N\backslash\{0\}}\sum_{j\in N} x_{ij}^{k} \leq Q, \quad \forall k\ \in V$$

Limitation 3. Every vehicle leaves the outlet that has been visited

$$\sum_{i\in N} x_{ih}^{k} - \sum_{j\in N} x_{hj}^{k} \leq 0, \quad \forall h\ \in N\backslash\{0\}, \forall k\ \in V$$

Limitation 4. Every vehicle that leaves the depot must return to the depot

$$\sum_{j\in N\backslash\{0\}} x_{0j}^{k}\ = 1, \qquad \forall k\ \in V$$

$$\sum_{j\in N\backslash\{0\}} x_{j0}^{k}\ = 1, \qquad \forall k\ \in V$$

Limitation 5. Vehicle k cannot arrive at customer j before the specified time

$s_{ik} + t_{ij} - K\,(1- x_{ijk}) \leq s_{jk}\,, \quad \forall i,j\ \in N, \quad \forall k\ \in V$

Limitation 6. The vehicle can only be with the customer within the specified time limit

$a_i\ \leq\ s_{ik}\ \leq b_i, \quad \forall i\ \in N, \quad \forall k\ \in V$

Information:

x_{ij}^{k} = binary variable equal to 1 if vehicle k travels from request location i to request location j, and 0 otherwise

d_{ij} = distance between points

tij = time between the locations of points i and j

s = service time required between locations

K = the number of vehicles available

c_{ij} = travel costs between customers

N = number of destination points

V = vehicle capacity

Sequential Insertion Algorithm

The sequential insertion algorithm is an exact algorithm that can be used to solve VRPTW variants. The basic principle of the sequential insertion algorithm is initialization by selecting a vehicle, selecting the first customer (seed customer) to form an initial route. Next add customers one by one to the route formed. The insertion process for each customer is required to provide the best criteria with the time window limits met with the total vehicle load not exceeding the vehicle capacity and the minimum total distance. This procedure continues to be repeated until all customers are included in the route.

Application Example

The data used for the application is standard test data from Solomon (http://www.vrp-rep.org/datasets/item/2014-0015.html), where each customer has demand, opening time, closing time, and all have service time. This problem will be resolved using the TSP-VRP application. As in the example in Figure 4.

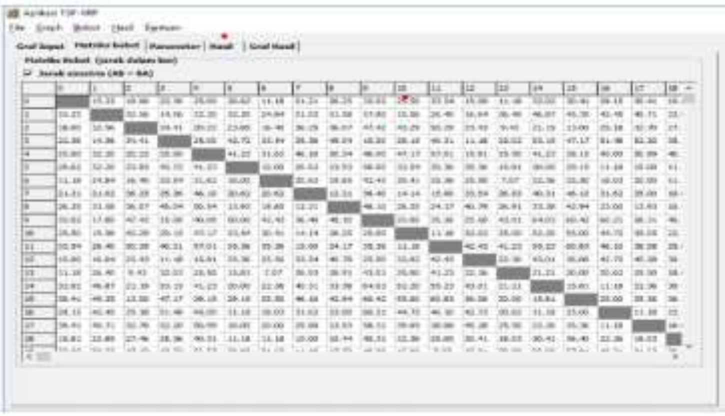

Figure 4: Example of a standard test using the application

Research Flow

The steps in the research are depicted in a flow chart as follows.

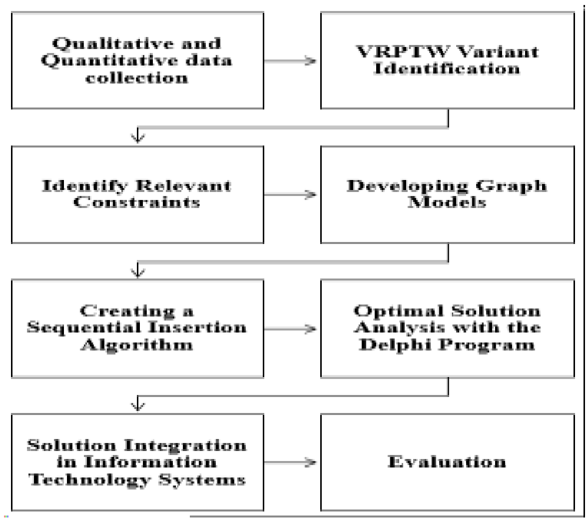

Figure 5. Research Flow Diagram

5. Conclusion

One of the measures of supply chain performance through the Supply Chain Operation Reference (SCOR) is measuring operational efficiency through route optimization. One of the techniques used is Vehicle Routing Problem with Time Windows (VRPTW) which is able to solve the complexity of shipping with many loading points and delivery points. This VRPTW measurement uses data on timeliness of delivery because it will affect distribution costs.

The calculation accuracy of the Vehicle Routing Problem with Time Windows (VRPTW) also uses a mathematical model that includes several parameters such as vehicle capacity limits, time windows and variations in customer needs. Apart from the integration process with the information system owned by the logistics service provider company, the Sequential Insertion Algorithm methodology was also used in this research. The supply chain target in achieving transport cost efficiency and ensuring timely delivery to consumers can be proven.

Vehicle Routing Problem with Time Windows (VRPTW) in this research is proven to originate from the development of the Vehicle Routing Problem (VRP). VRP itself is defined as the problem of determining distribution routes or salesmen visiting several locations and having to return to the initial location. The expansion is carried out by adding time window parameters other than vehicle capacity.

The VRPWT problem with the target of minimizing the total distance traveled or travel costs with a number of outlets in this study can also be solved using mathematical formulations. Many variants in the VRPWT calculation can be completed using the sequential insertion algorithm with initialization in selecting the vehicle, the first customer (seed customer) to form the initial route.

Through the development of the VRP concept into VRPWT which is strengthened by using integrated mathematical models and algorithms, several variants included in the calculations will be easier to carry out, one of which is in the fast-moving consumer goods industry.

Reference

1) Arvianto, A. H. Setiawan, and S. Saptadi, "Model Vehicle Routing Problem dengan Karakteristik Rute Majemuk, Multiple Time Windows, Multiple Products dan Heterogeneous Fleet untuk Depot Tunggal," Jurnal Teknik Industri, vol. 16, pp. 83-94, 2014
2) Anugerah Trisatryo, Muhammad Nashir A, Femi Yulianti. (2021). "Perancangan Vehicle Routing Problem Pick-Up and Delivery Menggunakan Algoritma Nearest Neighbor dan Multi-Start Adaptive Large Neighborhood Search (Msalns) Pada Trayek Sekunder Pos Logistic Distribution Center Tambun PT Pos Logistik Indonesia", Prodi S1 Teknik Industri, Fakultas Rekayasa Industri, Universitas Telkom, e-Proceeding of Engineering.
3) Ballou, Ronald H. (1992). Business Logistics Management, 4th edition, Prentice-Hall, Inc. New Jersey
4) Bowersox, D.J. (1996). Logistical Management: Integrated Supply Chain Process. Singapore: McGraw-Hill Companies, Inc.
5) Brain Slack (1990). Interrmodal Transportation in North America and The Development Of Inland Load Centers

6) Chopra, Sunil, and Peter Meindl. (2010). Supply Chain Management: Strategy, Planning, and Operation. Second Edition. Northwestern University: Prentice Hall.
7) Chow, Wing S. et al. (2008). Supply Chain Management in the US and Taiwan:An Empirical Study."
1) David Simchi-Levi (2000). Designing And Managing The Supply Chain, Mc Graw - Hill Companies Inc, United States of America
2) Dita Ayu Pratama (2016). Vehicle Routing Problem dengan Time Window untuk Multiple Product dan Multiple Route Menggunakan Algoritma Sequential Insertion.
3) Felix Arya Gunadi, J. Dharma Lesmono, Kinley Aritonang. (2020). A Routing Model for Hybrid Hub-and-Spoke With Time Windows. Jurnal Teknik Industri ISSN Vol. 21, No. 1, February 2020, pp. 22-33
4) Heizer, Jay dan Barry Render. (2004). Principles of Operations Management. Fifth Edition. Pearson Education, Inc. Upper Saddle River : New Jersey
5) Johannes Igl, Florian Kellner. (2017). Exploring greenhouse gas reduction opportunities for retailers in Fast Moving Consumer Goods distribution networks. Faculty of Business, Economics and Management Information Systems, University of Regensburg, Germany.
6) Johan Oscar Ong, Suprayogi. (2011).Vehicle Routing Problem with Backhaul, Multiple Trips and Time Window, Jurnal Teknik Industri, Vol. 13, No. 1, Juni 2011, 1-10 ISSN 1411-2485 print / ISSN 2087-7439 online
7) Kallehauge, B., Larsen, J. and Madsen, O. (2006). Lagrangian Duality Applied to The Vehicle Routing Problem with Time Windows. Computers & Operations Research.
8) Li, X., (2014). Operations Management of Logistics and Supply Chain: Issues and Directions Review, Discrete Dynamics in Nature and Society.
9) Pires, et al. (2001). Measuring Supply Chain Performance, Orlando.
10) Prihantono, C.R (2012). Konsep Pengendalian Mutu, Bandung: PT Remaja Rosdakarya
11) Putu Irvan Arya Purwadana, I Made Candiasa, I Nyoman Sukajaya. (2021). "Pengembangan Aplikasi Penentuan Rute Pengiriman Barang Berdasarkan Berat dan Time Windows Menggunakan Metode Nearest Neighbour dan Tabu Search" Majalah Ilmiah Teknologi Elektro, Vol. 20, No. 2, Juli - Desember 2021 DOI: https://doi.org/10.24843/MITE.2021.v20i02.P14
12) Sapti Wahyuningsih, Darmawan Satyananda, Lucky Tri Octoviana, Rini Nurhakiki, Vehicle Routing Problem with Time Windows Variants and its Application in Distribution Optimization, Jurusan Matematika FMIPA, Universitas Negeri Malang, Indonesia
13) Siagian, Yolanda M. (2005). Aplikasi Supply Chain Management Dalam Dunia Bisnis. Jakarta : Gramedian Widiasarana
14) Thangiah, S. (1993). Vehicle Routing With Time Windows Using Genetic Algoruthms, Universitas Slippery Rock.
15) Tompkins, B., Ferrell. C. (2011). Benchmarking & Best Practices. Supply Chain Consortium.
16) Zabidi, Yasrin. (2001). "Supply Chain Management". Institut Teknologi Semarang.

Appendix 1

Table 3. Delivery Routes based on Area, Distance (km) and Travel Time

Route	Description	Distance VV	Duration VV
170001	Subang - Ps.Haurgeulis (Indramayu)	50	4:00:00
170002	Subang - Ps.Patrol (Indramayu)	106	3:00:00
170003	Subang - Jln.Gantar (Indramayu)	100	4:30:00
170004	Subang - Jln.Ry.Patrol (Indramayu)	110	3:00:00
170005	Subang - Jln.Kandang Haur (Indramayu)	130	3:30:00
170006	Subang - Ps.Sukra (Indramayu)	88	2:30:00
170007	Subang - Ps.Wanguk (Indramayu)	65	3:30:00
170008	Subang - Bojong Keding (Subang)	56	2:00:00
170009	Subang - Jln.Gambar Sari (Subang)	18	0:40:00
170010	Subang - Ps.Wates (Subang)	36	1:00:00
170011	Subang - Jln.Pondok Bali (Subang)	78	2:30:00
170012	Subang - Ps.Pamanukan (Subang)	60	2:00:00
170013	Subang - Ps.Pusaka Ratu (Subang)	76	2:30:00
170014	Subang - Ps.Compreng (Subang)	50	3:00:00
170045	Subang - Ps. Ciasem	96	2:30:00
170056	Subang - PS PABUARAN	100	3:00:00
170046	Subang - Rancabango Sukamandi	104	3:00:00
170059	Subang - Jl Patok Beusi (Suba	145	2:30:00
170015	Subang - Ps.Pagaden (Subang)	10	0:30:00
170016	Subang - Ps.Purwadadi (Subang)	70	2:00:00
170017	Subang - Ps Ampera (Subang)	50	3:00:00
170018	Subang - Ps.Pegadungan (Subang)	50	0:30:00
170019	Subang - Ps.Cipunegara (Subang)	32	0:30:00
170020	Subang - Ps.Kalijati (Subang)	52	1:00:00
170021	Subang - Jln.Ry.Kalijati (Subang)	55	2:00:00
170114	Subang-Ps. Cilamaya (Blanakan)	120	3:00:00
170116	Subang-Tanjung Garut (PWK)	100	3:20:00
170022	Subang - Ps.Kaso Malang (Subang)	64	3:00:00
170023	Subang - Ps.Cisalak (Subang)	76	3:20:00
170024	Subang - Ps.Tanjung Siang (Subang)	96	4:00:00
170025	Subang - Ps.Cagak (Subang)	56	2:30:00
170026	Subang - Jln.Ciater (Subang)	76	3:00:00
170027	Subang - Ps.Baru Subang (Subang)	24	0:30:00
170028	Subang - Ps.Inpres Subang (Subang)	20	0:30:00
170029	Subang - Jln.Terminal Subang (Subang)	18	0:40:00
170065	Subang - Ps Wanayasa (Subang)	110	4:00:00
170030	Subang - Ps.Sagala Herang (Subang)	78	3:30:00
170031	Subang - Jln.Cinangsih (Subang)	32	1:00:00
170112	Subang-Bojong Sawit (PWK)	135	3:00:00
170118	Subang-Jl Cibungur	110	3:00:00
170120	Subang-Kapten Halim	135	4:00:00
170032	Subang - Ps.Cilege (Indramayu)	192	4:30:00

170039	Subang - Sirap (Tanjung Siang)	102	4:30:00
170040	Subang - Panaruban	84	3:30:00
170041	Subang - Jl Wanayasa	96	4:00:00
170042	Subang - Jl Raya Ciasem	90	3:00:00
170043	Subang - Ps Cipeundeuy (Subang)	86	3:00:00
170113	Subang-PS Anyar Sukatani (PWK)	130	2:30:00
170044	Subang - Bongas	90	3:00:00
170111	Subang-Sawit Cileunca (PWK)	150	3:30:00
170047	Subang - Salamjaya Pringkasap	106	3:00:00
170115	Subang-Jl Raya Cilamaya Blanakan	130	3:00:00
170056	Subang - PS PABUARAN	100	3:00:00
170057	Subang - PRINGKASAP	90	4:00:00
170058	Subang - PASAS SUKAMANDI	135	2:00:00
170060	Subang - BLANAKAN	90	3:30:00
170119	Subang-Pondoksalam	150	4:00:00
170121	Subang-Tanjung tiga Ciasem	100	2:30:00
170064	Subang-Cibatu	110	4:00:00
170036	Subang - Serang	180	6:00:00
170048	Subang - Genteng	98	3:30:00
170049	Subang - Patimban	92	3:30:00
170050	Subang - Cigarugak	66	2:30:00
170037	Subang - Batu Ceper	160	5:00:00
170061	Subang-Cileunyi	278	6:00:00
170038	Subang - Cibitung	210	4:00:00
170110	Subang-Bandung Utama Mandiri	244	3:30:00
170062	Subang-Cikalong Sari	130	4:00:00
170063	Subang-Wanayasa	120	4:00:00
170067	Subang-Wates Kihiang	42	1:30:00
170068	Subang-Tanjung Tiga Ciasem	95	3:00:00
170069	Subang-Anggasari Ciasem	85	3:00:00
170070	Subang-Wanajaya	75	1:30:00
170071	Subang-Batang Ciasem	85	2:00:00
170072	Subang-Mundusari Pamanukan	78	1:30:00
170073	Subang-Jatiroke Ciasem	75	1:30:00
170074	Subang-Jl Ry Tambak Dahan	70	1:15:00
170075	Subang-Wanareja Subang	30	0:45:00
170076	Subang-Jl Raya Pabuaran	95	2:00:00
170077	Subang-Sukaresmi Pabuaran	140	2:20:00
170078	Subang-Kp Siluman Ciparay	120	2:30:00
170079	Subang-Tanjung Sari Cikaum	65	1:00:00
170080	Subang-Sumur Sapi	90	1:45:00
170081	Subang-Cipedang	94	1:30:00
170082	Subang-Anjatan	80	2:00:00
170083	Subang-Hambaro Ciasem	88	1:30:00
170084	Subang-Muara Ciasem	107	2:00:00
170085	Subang-Jalan Raya Bugel	170	2:30:00
170087	Subang-Jatibarang	192	5:00:00
170088	Subang-Banggala	65	1:30:00

170091	Subang-Bugis	50	1:00:00
170092	Subang-Pasar Pujasera	21	0:50:00
170093	Subang-Ranca Bango	71	1:20:00
170094	Subang-Kebondanas	78	2:00:00
170095	Subang-Kaliangsana	47	1:00:00
170096	Subang-Bojong Loa	65	2:00:00
170097	Subang-Kertanegara	43	1:15:00
170098	Subang-Baleraja	53	2:00:00
170099	Subang-Pasar Panjang	20	1:00:00
170100	Subang-Cerelek	26	0:40:00
170101	Subang-Jl. Sanca	65	2:00:00
170102	Subang-Jl. Ciater	73	2:00:00
170103	Subang-Jl. Cagak	59	2:00:00
170104	Subang-Parung	37	1:10:00
170105	Subang-Jl. Raya Cijambe	44	1:30:00
170106	Subang-Jl. Raya Sukamandi	74	2:00:00
170107	Subang-Pasar Sukaseneng	50	2:00:00
170108	Subang-Pasar Jatireja	35	1:30:00
170109	Subang-Bojong Jaya	60	2:00:00
170122	Subang-Jl. Raya Darangdan (purwakarta)	135	3:00:00
170123	Subang-Jl Raya Cikamurang (indramayu)	90	2:00:00
170126	Subang-Bukanegara	110	3:30:00
170127	Subang-Surian	70	2:00:00
170128	Subang-Cimenteng	77	3:00:00
170066	Subang - Desa Ujung Gebang	110	1:40:00