Faculty of Computer Science and Information Technology

Variable Neighbourhood Search Algorithm for Vehicle Routing Problem with Backhaul

Doreen Sek Siaw Ying

Master of Science
2023

Variable Neighbourhood Search Algorithm for Vehicle Routing Problem with Backhaul

Doreen Sek Siaw Ying

A thesis submitted

In fulfillment of the requirements for the degree of Master of Science

(Computational Mathematics)

Faculty of Computer Science and Information Technology
UNIVERSITI MALAYSIA SARAWAK

2023

DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. Except where due acknowledgements have been made, the work is that of the author alone. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

………………………………………

Signature

Name: Doreen Sek Siaw Ying

Matric No.: 16020135

Faculty of Computer Science and Information Technology

Universiti Malaysia Sarawak

Date : April 2023

ACKNOWLEDGEMENT

First of all, I would like to express my profound gratitude and great appreciation to my supervisor, Associate Professor Dr. Sze San Nah for her valuable and constructive guidance and suggestions throughout this research project. A great appreciation for her patience, motivation, and willingness to share her knowledge throughout this research project which impressively assisted in this research project. Besides that, many thanks to my co-supervisors, Associate Professor Dr. Chiew Kang Leng and Dr. Sze Jeeu Fong for their encouragement and valuable time throughout the research planning and development process.

Apart from that, I also appreciate Faculty of Computer Science and Information Technology, Universiti Malaysia Sarawak for providing a comfortable learning environment and facilities. Moreover, I would like to thanks to all my friends for lending their precious time in giving their views, advices, ideas and supports throughout the completion of this research.

Last but not least, thanks to my family for their unconditional love, words of encouragement and the strength they gave me. This project would be impossible to be completed without them.

ABSTRACT

This research focuses on the Vehicle Routing Problem with Backhaul (VRPB). VRPB is one of the extended problems related to the usual Vehicle Routing Problem (VRP). VRPB consists of both linehaul customers and backhaul customers with known demand. There is only a single depot that can receive and supply the loads. The vehicles can only visit each customer once and serve all customers simultaneously by delivering or picking up the loads within a limited capacity. VRPB is a Non-deterministic Polynomial-time hard (NP-hard) problem. The huge data size has increased the difficulty of solving it using mathematical programming or combinatorial optimisation. Past literature showed that heuristic-based solutions could offer feasible solutions that are approximately accurate to the exact solution. It is one of the most popular solutions to solve a complex problem. Thus, a heuristic approach based on the Variable Neighbourhood Search (VNS) is proposed. In this research, 22 sets of benchmark instances introduced by Goetschalckx and Jacobs-Blecha are used to test the efficiency and effectiveness of the proposed algorithm. The proposed algorithm solution consists of two main phases. A simple priority heuristic rule is developed in the first phase to generate the initial dataset solution for each benchmark instance. The VNS algorithm is used to improve the obtained solutions in the improvement phase. A set of local search approaches and random shaking methods are proposed to conduct a list of neighbourhood solutions. Then, the most optimum solution among the neighbourhood solution in the improvement phase is selected as the final outcome of this research. The result is then compared with the best-known solution that can be found in past literature research. The relative percentage deviation shows a total of 14 out of 22 sets of datasets can achieve the same result as the best-known solution. The computational result shows that the proposed

heuristic algorithm is favourable in solving VRPB, and the generated solution is able to comply with VRPB constraints.

Keywords: Vehicle routing problem with backhaul, linehaul and backhaul customers, benchmark dataset, heuristic algorithm, variable neighbourhood search

Masalah Laluan Kenderaan Ambilan Balik dengan Cara Carian Kejiranan Berubah

ABSTRAK

Penyelidikan ini fokus kepada masalah laluan kenderaan ambilan balik (MLKB). MLKB adalah salah satu masalah lanjutan yang berkaitan dengan masalah laluan kenderaan. MLKB terdiri daripada pelanggan menerima dan pelanggan ambilan dengan permintaan yang diketahui. MLKB terdapat satu depoh yang boleh menerima dan membekalkan muatan. Kenderaan boleh melawat dan melayani setiap pelanggan dan memberikan khidmat kepada semua pelanggan secara serentak untuk menghantar atau mengambil muatan dalam kapasiti terhad. MLKB adalah masalah masa polinomial yang sukar dideterministik. Saiz data yang besar telah meningkatkan kesukaran untuk menyelesaikannya dengan menggunakan pengaturcaraan matematik atau cara pengoptimuman gabungan. Pengajian lepas telah menunjukkan bahawa penyelesaian berasaskan heuristik boleh menawarkan penyelesaian yang dekat dengan penyelesaian yang tepat. Ia adalah salah satu penyelesaian yang paling popular untuk menyelesaikan masalah ini. Oleh itu, pendekatan heuristik berdasarkan carian kejiranan berubah (CKB) telah dicadangkan. Dalam penyelidikan ini, 22 kombinasi contoh penanda aras yang diperkenalkan oleh Goetschalckx dan Jacobs-Blecha akan diguna untuk menguji kecekapan dan keberkesanan algoritma yang dicadangkan. Algoritma penyelesaian yang dicadangkan terdiri daripada dua fasa utama. Dalam fasa pertama, peraturan heuristik mudah dibangunkan untuk menjana penyelesaian bagi setiap kombinasi data. Algoritma CKB telah digunakan dekat fasa penambahbaikan untuk menambah baik penyelesaian. Senarai kaedah pendekatan carian tempatan dan kaedah goncangan rawak telah dicadangkan untuk menjalankan senarai penyelesaian kejiranan. Kemudian, penyelesaian yang paling baik antara penyelesaian kejiranan dalam fasa penambahbaikan akan dipilih sebagai hasil akhir dalam penyelidikan ini. Hasilnya *telah dibandingkan dengan penyelesaian yang paling terkenal yang didapati dalam penyelidikan literatur yang lalu. Sisihan peratusan relatif menunjukkan sejumlah 14 daripada 22 kombinasi data dapat mencapai hasil yang sama seperti penyelesaian yang paling terkenal. Keputusan tersebut menunjukkan bahawa algoritma heuristik yang dicadangkan adalah sesuai dalam menyelesaikan MKLB dan mampu mematuhi kekangan MKLB.*

Kata kunci: *Masalah laluan kenderaan ambilan balik, pelanggan penghantaran dan pelanggan menerima, kaedah heuristik, carian kejiranan berubah*

TABLE OF CONTENTS

		Page
DECLARATION		**i**
ACKNOWLEDGEMENT		**ii**
ABSTRACT		**iii**
ABSTRAK		**v**
TABLE OF CONTENTS		**vii**
LIST OF TABLES		**xi**
LIST OF FIGURES		**xii**
CHAPTER 1	**INTRODUCTION**	**1**
1.1	Background	1
1.2	Problem Statement	4
1.3	Research Objectives	6
1.4	Research Scope	6
1.5	Thesis Structure	6
CHAPTER 2	**LITERATURE REVIEW**	**8**
2.1	Overview of Vehicle Routing Problem	8
2.2	Vehicle Routing Problem with Backhaul	10
2.3	Existing Methods	12

2.3.1 Overview for Exact Solution 13

2.3.2 Heuristic and Metaheuristic Algorithm 14

2.3.2.1 Insertion Heuristic Algorithm 15

2.3.2.2 Tabu Search Algorithm 16

2.3.2.3 Ant Colony Algorithm 17

2.3.2.4 Variable Neighbourhood Search 18

2.4 Conclusion 20

CHAPTER 3 PROBLEM FORMULATION 22

3.1 Introduction 22

3.2 Problem Statement 22

3.2.1 Customers 23

3.2.2 Depot 24

3.2.3 Vehicles 25

3.3 Constraints 25

3.4 Objective Function 26

3.5 Mathematical Model 26

3.5.1 Notation 26

3.6 Conclusion 28

CHAPTER 4 VEHICLE ROUTING PROBLEM WITH BACKHAUL **30**

4.1 Introduction 30

4.2 Benchmark Data 31

4.3 Data Pre-processing 33

4.3.1 Data Distance Calculation 34

4.4 Initial Solution 36

4.5 Variable Neighbourhood Search Algorithm 44

4.5.1 Local Search Techniques 49

4.5.1.1 Local 1-to-0 Swap 49

4.5.1.2 Local 2-to-1 Swap 51

4.5.1.3 Local 1-to-1 Swap 52

4.5.2 Shaking Methods 54

4.5.2.1 Random Multiple 1-to-0 Swap 54

4.5.2.2 Random Pick Solution 55

4.6 Result and Analysis 56

4.6.1 Computational Time 57

4.6.2 Computational Result 62

4.6.2.1 Analysis of the Final Solution 63

4.6.2.2 Analysis of Final Solution with Literature's Best-Known Solution 67

4.7 Conclusion 71

CHAPTER 5 MIXED VEHICLE ROUTING PROBLEM WITH BACKHAUL 72

5.1 Introduction 72

5.2 Model of m-VRPB 72

5.2.1 Initial Solution for m-VRPB 73

5.2.2 VNS for m-VRPB 79

5.2.2.1 Local Search Techniques for m-VRPB 80

5.2.2.2 Shaking Methods for m-VRPB 82

5.3 Result and Analysis for m-VRPB 83

5.3.1 Relaxed in Constraints 85

5.3.2 Minimise the Number of Vehicles 87

5.4 Conclusion 91

CHAPTER 6 CONCLUSION 93

6.1 Introduction 93

6.2 Conclusion of research 93

6.3 Research Contribution 94

6.4 Future Works 96

REFERENCES 97

APPENDICES 110

Appendix A Journal Publication 110

Appendix B Program Code 111

Appendix C Data output 117

LIST OF TABLES

		Page
Table 4.1:	Customer size of benchmark datasets	32
Table 4.2:	Lists of benchmark datasets	32
Table 4.3:	Differences between local search and random shaking method	56
Table 4.4:	Lists of compute time of VRPB	57
Table 4.5:	Characteristics of each sub-problem sets (customer ratio)	62
Table 4.6:	Initial and optimum solutions obtained for VRPB	64
Table 4.7:	Summary of journals for Best-Known solution	68
Table 4.8:	Lists of Best-Known result and final obtained result for VRPB	69
Table 5.1:	Lists of constraints of VRPB and m-VRPB	72
Table 5.2:	Benchmark dataset of m-VRPB	84
Table 5.3:	Lists of Best-Known solution and m-VRPB solution	85
Table 5.4:	Lists of Best-Known and m-VRPB (unfixed vehicle number) solution	89

LIST OF FIGURES

		Page
Figure 1.1:	VRP diagram	4
Figure 1.2:	VRPB diagram	5
Figure 3.1:	Transportation network of VRPB	24
Figure 4.1:	Distance matrix	34
Figure 4.2:	Data of Problem Set A	35
Figure 4.3:	Distance matrix of Problem Set A	36
Figure 4.4:	Sorting structure for each route in VRPB	37
Figure 4.5:	Vehicle travelling movement of VRPB	38
Figure 4.6:	Node assignation Process (second node)	39
Figure 4.7:	Node assignation (shortest travelled distance)	40
Figure 4.8:	Data flow diagram of VRPB linehaul customer	42
Figure 4.9:	Data flow diagram of VRPB backhaul customer	43
Figure 4.10:	Initial solution for Dataset A1	44
Figure 4.11:	Algorithm structure of VNS	45
Figure 4.12:	Local search algorithm of VNS	47
Figure 4.13:	Data flow diagram of VNS	48
Figure 4.14:	Local 1-to-0 Swap	49
Figure 4.15:	Lists of neighbourhood structure of node c_1	50
Figure 4.16:	Process flow when better feasible solution has found	51
Figure 4.17:	Local 2-to-1 Swap	52
Figure 4.18:	Local 1-to-1 Swap	53
Figure 4.19:	Lists of outcome for Dataset A1 by Local 1-to-1 Swap	53
Figure 4.20:	Random Multiple 1-to-0 Swap	54

Figure 4.21: Outcomes of 3 times Random Multiple 1-to-0 Swap 55

Figure 4.22: Time taken of initial solution 59

Figure 4.23: Time taken of VNS 60

Figure 4.24: Total compute time of VRPB 61

Figure 4.25: Total travelled distance of initial and optimum solution 65

Figure 4.26: Total travelled distance of Best-Known and final obtained solutions 70

Figure 5.1: Route structure of m-VRPB 74

Figure 5.2: Vehicle travelling movement of m-VRPB 75

Figure 5.3: Sorting process of m-VRPB 76

Figure 5.4: Data flow diagram of initial solution of m-VRPB 78

Figure 5.5: Initial solution for Dataset A1 of m-VRPB 79

Figure 5.6: Local 1-to-1 Swap of m-VRPB 80

Figure 5.7: Local 2-to-1 Swap of m-VRPB 81

Figure 5.8: Local 1-to-Many Swap of m-VRPB 82

Figure 5.9: Random 1-to-0 Swap of m-VRPB 82

Figure 5.10: Random 2-to-2 Swap of m-VRPB 83

Figure 5.11: Random 1-to-1 Swap of m-VRPB 83

Figure 5.12: Total travelled distance of Best-Known and m-VRPB solution 86

Figure 5.13: Data flow diagram of initial solution (unfixed vehicle number) 88

Figure 5.14: Initial solution of Dataset A1 in m-VRPB (unfixed vehicle number) 89

Figure 5.15: Number of vehicles of Best-Known and final research outcomes 90

Figure 5.16: Total travelled distance of Best-Known, m-VRPB and m-VRPB (unfixed vehicle number) 91

CHAPTER 1

INTRODUCTION

1.1 Background

Logistic distribution is considered one of the core parts of our daily economy, production and transportation process. It plays an important role in global economic integration and information exchange operation. The logistic distribution has contributed a large portion of the total logistic costs (Crainic & Laporte, 1997). Among them, 85% of the logistic cost are transportation and stock costs (Zhao & Tang, 2009).

Logistic management is important not only at the firm level but also in the industry and globally economic competitiveness (Feng et al., 2012; Hwang et al., 2017). The study by Pishvaee and Basiri (2009) stated that logistics costs had compromised a large ratio of the total gross domestic product (GDP). Besides, Wantanakomol (2021) also mentioned that the global average ratio of logistic cost to GDP is 10.7%. Therefore, well-planned and cost-effective logistic management helps reduce costs and increases profitability in economic activities.

After the outbreak of the COVID-19 pandemic, people are opting for contactless services such as e-commerce, online shopping, online food ordering and goods delivery services. The pandemic has caused great competition between companies all over the world in order to survive.

The Minister in the Prime Minister’s Department (Economy) Datuk Seri Mustapa Mohamed has stated that the gross merchandise value (GMV) of Malaysia in the e-commerce and food delivery service showed a growth of RM29.28 billion in the year 2021

(“Tok Pa: E-commerce, Food Delivery Service Gross”,2022). In addition, food delivery services have expanded by 35% during that pandemic period. People are willing to pay for the online and delivery service to minimise their exposure to the virus and avoid the crowd and queues. As a result, the e-commerce and food delivery businesses such as, Grabfood, Foodpanda, fast food delivery services, Shopee, Lazada and Taobao were booming and accelerating globally.

Besides, this new normal has caused a rise in carriage volume and increased the demand for quality logistic service. Logistic service is said to be involved in the material transportation process, resources movement and goods distribution process (Laporte, 1992). Good transportation or logistic management can result in advantages over competitors and increase customer satisfaction (Sakhapov et al., 2018; Wantanakomol, 2021).

Based on the China Daily, the business volume of the express delivery companies in China has increased by over 70% with an increment of revenue of over 75% year on year in February 2022 (Yang, 2022). Moreover, Ninja Van, one of Malaysia’s courier and delivery services, has achieved 100 million parcel delivery as of July 2021 (Aufa, 2022). This parcel volume has shown the economic trends and the growth in e-commerce in Malaysia. According to the marketing forecast of Statista, the profit in the Platform-to-Consumer Delivery section is expected to show an annual growth rate of 7.78% with a market value of US$302.50 billion by 2027 (Statista, 2022). These statistics have reflected the consumption growth in the surging delivery business.

However, Los Angeles Times has stated that the demand for grocery delivery has dropped 10.5% compared to its highest during the pandemic when the prices for the delivery service rose (Dee-Ann, 2022). One of the factors is that online prices are higher compared to in-store prices, which include the extra charge to cover labour and transportation costs. This issue has raised pressure on logistics companies to provide better services at a much lower cost. The same tendency has happened in Malaysia; according to Soh Thian Lai, the president of the Federation of Malaysian Manufacturers (FMM), the price of daily goods is estimated to increase by 10% due to the increase in logistics costs, and the labour shortage (Reshna, 2022). Based on the survey conducted by FMM, most companies are expected to pass the increase in costs of between 1 to 10% to consumers. The increase in the prices would cause a multiplier impact on the economy unless proactive action was taken to control the rise in prices of the products.

Furthermore, according to Anbuudayasankar (2012), inefficient delivery management will cause a serious decline in service quality, a decrease in order volume and a loss of the loyalty of customers. Thus, additional attention needs to drag to the improvement of the logistic planning as well as the efficiency and service quality of the service (Yang, 2022).

In short, a well-planned logistic route can produce a cost-effective flow for the goods supply chain and a great customer experience. It is the main connecting link between the consumers and producers in the whole industry supply chain (Zhang et al., 2022) and the business network that joins the product producers and service providers associated globally (Farahani, 2011). Therefore, logistic distribution issues have been generalised to the linear optimisation issues and then transformed and modelled to the Vehicle Routing Problem (VRP) (Clarke & Wright, 1964). The main objective of VRP is to generate the optimal solution to serve a group of customers with a list of homogeneous vehicles under certain constraints (Raff, 1983; Laporte & Nobert, 1987; Laporte, 1992). Therefore, VRP has become one of the popular topics among operation researchers in the past decade.

1.2 Problem Statement

In general, VRP is the flow of optimal routing routes between the initial point and a group of destination points under certain conditions. In a basic VRP, each customer can only be visited once and served by one vehicle. A vehicle should depart from an initial point, either a depot or warehouse and return to the same point after completing the tasks. Figure 1.1 represents a basic VRP routing diagram which involves a depot, a group of customers and the movement of a fleet of vehicles.

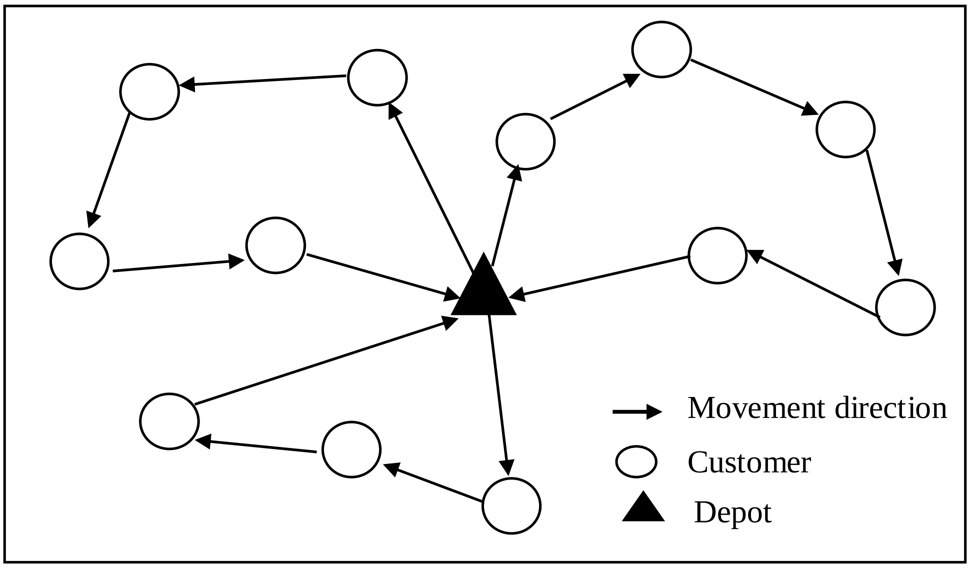

Figure 1.1: VRP diagram

In the past few years, VRP has widely extended with various constraints. Vehicle Routing Problem with Backhaul (VRPB) is one of the extension problems from the classical VRP (Goetschalckx & Jacobs-Blecha, 1989; Cuervo et al., 2014; Toth & Vigo, 1996; Nagy & Salhi, 2005).

VRPB consists of a group of customers, a depot and a fleet of homogeneous vehicles.

Unlike the basic VRP, VRPB consists of both delivery customers (linehaul customers) and pickup customers (backhaul customers). Delivery customers are the customers who require a delivery service, and the pickup customers are those who request a pickup service. The geometric location and the demand of each customer are different from each other. The vehicles need to move around the customers to either supply and collect sufficient loads for or from them.

In VRPB, a depot is a place that provides and stores stocks or goods. It can always supply a sufficient amount of the load to the delivery customers. Same as the basic VRP, in VRPB, the vehicle needs to depart and return to the depot in every logistic route. The vehicle will carry a certain amount of goods, depart from a depot, and distribute it to the delivery customers. It starts to approach the pickup customer along the way back to the depot after delivering all the goods to the customer. A feasible routing solution for a VRPB would be a list of transportation routes that can serve all the customer requirements under a fixed number fleet without violating the predefined capacity limit. Figure 1.2 below represents the vehicle movement in VRPB.

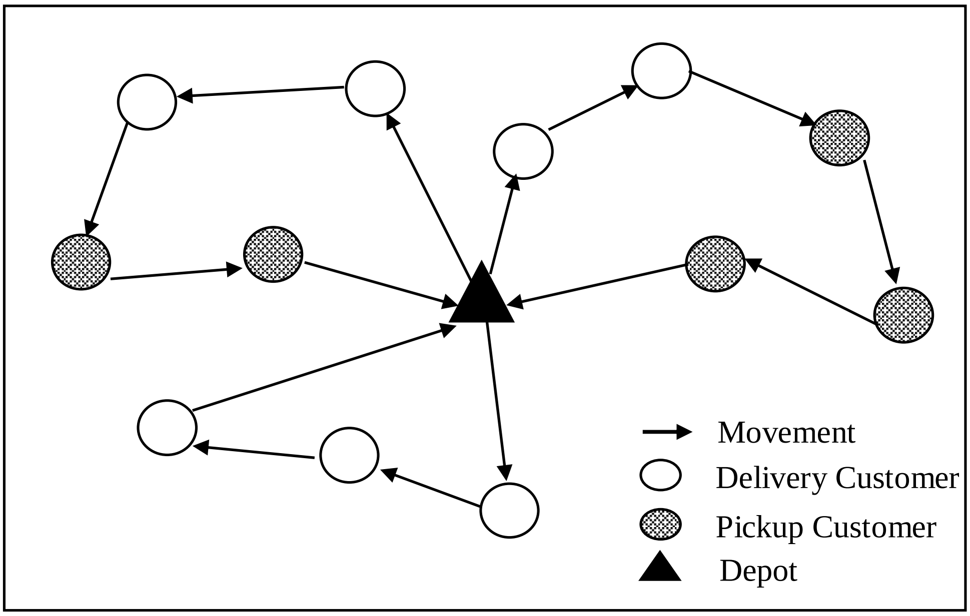

Figure 1.2: VRPB diagram

1.3 Research Objectives

The objectives of this research:

i. To model a VRPB with extra operational constraints consideration.

ii. To design and develop an effective Variable Neighbourhood Search (VNS) algorithm (Refer to Section 2.3.2.4) for the VRPB.

iii. To conduct an extensive computational study and analysis using the benchmark data proposed by Goetschalckx and Jacobs-Blecha (1989).

1.4 Research Scope

The scope of this research is defined as follow:

i. Focus on the metaheuristic Variable Neighbourhood Search (VNS) algorithm especially in algorithm development, to solve VRPB.

ii. Conduct the computational and comparison study based on the 22 sets of selected benchmark data with the size from 25 to 113 customers proposed by Goetschalckx and Jacobs-Blecha (1989).

1.5 Thesis Structure

In Chapter 2, literature reviews on the overview of VRP and VRPB are studied and elaborated on in detail. Besides, the popular methodology approaches that have been used to solve VRPB-related issues in the past decade were presented in this chapter.

Chapter 3 presents the background and the constraint of the case study of this research. It included a detailed explanation of the customer, depot, vehicle, and problem constraint of VRPB. A clear VRPB background condition and restriction are explained in this chapter.

In Chapter 4, the methodology to solve the VRPB of this research is discussed. The methodology included the data pre-processing steps used to prepare the input data, a simple priority rules heuristic algorithm used to generate the initial solution and the VNS heuristic algorithm used to produce an optimum solution. The proposed VNS algorithm with a set of local search techniques and random shaking methods is described in detail. The data analysis and result of the proposed algorithm on VRPB are discussed in this chapter.

In Chapter 5, a mixed Vehicle Routing Problem with Backhaul (m-VRPB) is proposed to examine the impact of the priority of the type of customer on the performance of the proposed algorithm. Note that m-VRPB is investigated using the same benchmark data but slight differences in the problem restriction. Two constraints are relaxed to simulate the real practical environment by removing some of the restrictions from the VRPB. The proposed VNS algorithm is transformed to cope with the new constraints. The new result obtained by m-VRPB is analysed and discussed in this chapter.

Lastly, Chapter 6 contains the conclusion remarks, the contribution of the project and some ideas for future works.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview of Vehicle Routing Problem

Vehicle Routing Problem (VRP) is a significant and widely studied logistics problem with a wide range of applicability. VRP is described as obtaining the optimal solution for transportation movement, which involves both delivery and collection processes from one or several depots to multiple geographical customer points under certain constraints (Raff, 1983; Laporte & Nobert, 1987; Laporte, 1992). It aims to develop suitable routes for a fleet of homogeneous vehicles that can serve a group of customers that start and end at a depot by minimising the travelling distance and transportation cost.

The first logistic issue, the "Truck Dispatching Problem", was introduced by Dantzig and Ramser in 1959. Modelling of how a fleet of homogeneous gasoline delivery trucks travelled between a list of terminals with various supplier points has been conducted. It is targeted to obtain an optimum routing solution with minimum travel distance. However, the problem has been generalised to the linear optimisation issues commonly occurring in logistics and transport. Thus, the VRP was introduced (Clarke & Wright, 1964). Clarke and Wright (1964) were the first to have multiple corporate vehicles in VRP and also the first to introduce a new variant of VRP. It has begun to be applied in solving various kinds of real-life logistics problems.

Moreover, a study has started applying or combining VRP with different constraints and parameters in order to incorporate real-life situations. Researchers have simulated the transportation problem by varying the operational conditions, such as consideration of different circumstances, different modes of serving, and various vehicle conditions (Clarke & Wright, 1964; Toth & Vigo, 1996; Nagy & Salhi, 2005; Braekers et al., 2016). Routing issues such as Capacitated Vehicle Routing Problem (CVRP) (Uchoa et al., 2017), Vehicle Routing Problem with Time Window (VRPTW) (Errico et al., 2016), Vehicle Routing Problem with Backhauls (VRPB) (Pinto et al., 2017; Wassan et al., 2017), Vehicle Routing Problem with Simultaneous Delivery and Pickup (VRPSDP) (Bianchessi & Righini, 2007; Wang et al.,2016), Green Vehicle Routing Problem (GVRP) (Koç & Karaoglan, 2016; Xiao & Konak, 2017), Open Vehicle Routing Problem (OVRP) (Lalla-Ruiz et al., 2016) and Split Delivery Vehicle Routing Problem (SDVRP) (Chen et al., 2017) are some of the common research topics of VRP that conducted in the past few years.

Furthermore, VRP software and applications development showed rapid growth in the industry and logistics fields. More and more companies have started to implement this technology into the logistics management process, for example, the support system used by an oil downstream company (Gayialis & Tatsiopoulos, 2004) and the scheduling model used by a sales company for flight tickets to arranging their free pickup and delivery services (Dong et al., 2011).

The study of Xiao and Konak (2017) has untaken that an optimised routing solution is able to reduce transportation costs and the number of resources required. Besides that, good routing management can cut down fuel consumption (Norouzi et al., 2017) and reduce greenhouse gas emissions, such as carbon dioxide, especially in urban areas (Ehmke et al., 2016; Tian et al., 2018).

In short, a well-planned logistic route can produce a cost-effective flow for the goods supply chain, a great customer experience and a better optimisation plan within the limited