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Heterogeneous Fleet Green Vehicle Routing Problem: A Literature Review

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ABSTRACT

Transportation, as a part of the supply chain process, contributes to carbon emission which leads to climate change and global warming. This environmental issue gives an impact to decisions regarding the supply chain of a company. One way to deal with this issue is by analyzing their vehicle routing problem. In this study, the issue about routing problems in green supply chain by considering the heterogeneous fleet is being discussed. One variant of Green Vehicle Routing Problem (GVRP) reviewed in this paper is about Heterogeneous Alternative Fuel Vehicles for Green Vehicle Routing Problem (HAFVGVRP). The purpose of this study is to review the development of GVRP with heterogeneous alternative fuel vehicles and the gap or state-of-the-art on existing researches. The review was classified according to the objectives, type of fleet, and solution used. Moreover, this study also presents the trend and direction of further research.
Keywords: Green Vehicle Routing Problem, Heterogeneous Fleet, Alternative Fuel Vehicles, Green Supply Chain, Literature Review

ABSTRAK

Transportasi yang merupakan bagian dari proses rantai pasok berkontribusi sebagai penghasil emisi karbon yang dapat menyebabkan perubahan iklim dan pemanasan global. Masalah lingkungan ini memberikan dampak terhadap pengambilan keputusan terkait rantai pasok dari suatu perusahaan. Salah satu cara untuk mengatasi masalah ini adalah dengan melakukan analisa pada masalah penentuan rute kendaraan dari perusahaan tersebut. Kajian ini membahas mengenai masalah penentuan rute dengan mempertimbangkan rantai pasok yang ramah lingkungan dengan mempertimbangkan armada yang heterogen. Salah satu varian dari Green Vehicle Routing Problem *(GVRP) yang dibahas dalam kajian ini adalah mengenai* Heterogeneous Alternative Fuel Vehicles for Green Vehicle Routing Problem *(HAFVGVRP). Tujuan dari kajian ini adalah mengkaji pengembangan GVRP dengan kendaraan heterogen berbahan bakar alternatif atau non-konvensional dan mengetahui celah penelitian atau kebaruan dan pengembangan dari penelitian-penelitian yang ada. Kajian dilakukan dengan melakukan klasifikasi berdasarkan tujuan, jenis armada, dan pendekatan untuk solusi yang digunakan. Selain itu, kajian ini juga memperlihatkan tren dan arah penelitian kedepannya.*
Kata Kunci: *Green Vehicle Routing Problem, Heterogeneous Fleet, Alternative Fuel Vehicles, Green Supply Chain, Literature Review*

1. INTRODUCTION

Transportation plays an important role in the supply chain process of a company. Transportation is becoming increasingly more dynamic in line with the demand from the customers or company growth. In order to face problems that might exist in transportation sector, the concept of Vehicle Routing Problem (VRP) was developed. VRP concept was firstly being proposed in 1959 [1] and is still being proceeded to be developed with various variants and focuses. These various variants of VRP have been developed for different applications.

Corban emission can be produced by supply chain activities especially transportation [2, 3]. Reducing carbon emission can be done by designing Vehicle Routing Problem (VRP), which then well known as Green Vehicle Routing Problem (GVRP). In GVRP, the concept of designing vehicle routes by considering the environmental problem is developed [4]. Research of GVRP has been conducted with various purposes. The purposes were to minimize carbon emission used in the routing [5, 6], minimize total travel distance [7, 8], and minimize total cost [6]. In order to achieve its environmental purposes, GVRP includes alternative fuel vehicles (AFVs) concept [9]. AFVs is one of the techniques that can be used to reduce the carbon which is one of the important aspects in GVRP theory.

Other than GVRP, Heterogeneous Fleet Vehicle Routing Problem (HFVRP) is also a classical variant of VRP. In homogeneous fleet, as a standard version of VRP, the capacity for all vehicles are same and usually based at a single depot [10]. Thus, HFVRP is more realistic because it considers the condition of transportation can used heterogeneous fleet or different types of vehicle. In HFVRP, there are several different types of

vehicles with various capacities, fixed cost, and variable cost [11]. This heterogeneous fleet condition also could help in increasing the flexibility of distribution planning [12]. Most transportation companies used heterogeneous fleets in order to give flexibility for servicing the customers in different locations or with different demands [13]. Due to the condition of different capacities in each vehicle or heterogeneous fleet, this study will discuss the research development by considering this issue in environmental perspective.

This study aims to conduct a systematic literature review of relevant literature on VRP new variant which is being widely researched is about Heterogeneous Fleet Green Vehicle Routing Problem (HGVRP). This study is conducted because there is a lack of research that serves the roadmap of study on the development and in the field of HGVRP. Thus, this study will analyse the presence of research about the use of heterogeneous fleets with alternative fuel vehicles that concern about environmental issues on vehicle routing problems. In this study, the literatures are classified based on the objectives, type of fleet, and solution used for the development of GVRP variants. The contribution of this study is to present a literature review and classification of GVRP with heterogeneous alternative fuel vehicles. By conducting a literature review and classification of existing researches will help to find a gap or state-of-the-art and point out the opportunities within this topic for further research.

The remainder of this paper is organized as follows. Section 2 describes the methodology of literature review process used in this study. Section 3 presents the review of existing research on GVRP. In Section 4, the evolution of GVRP research especially with heterogeneous alternative fuel vehicles is explained. The trend and future direction of HGVRP research is shown in Section 5. Moreover, the paper ends in Section 6 by presenting the conclusion of this study.

2. REVIEW METHODOLOGY

2.1. Source of Literature

In this study, there are some databases used to compile the literature related with heterogeneous alternative fuel vehicles for GVRP. The databases utilized in this study include Elsevier, ScienceDirect, Springer, and IEEE. Besides, the literature also obtained from Google and Google Scholar according to the relevancy with the objective of this study. In the literature collection process, we found some types of publication sources as depicted in Table 1.

Table 1. Main Source of Literature Based on Publication Year

Source	2009	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total
Annals of Operation Research								1			1
Arabian journal for Science and Engineering									1		1
Computers and Industrial Engineering							1		1		2
Computers and Operations Research							1	1	4		6
Electronics Notes in Discrete Mathematics								2			2
Energy Systems							1				1
Environmental Science and Pollution Research					1		1				2
European Journal of Industrial Engineering									1		1
European Journal of Operational Research							1		2		3
European Journal on Transportation and Logistics								1			1
Expert Systems with Applications								1	2	1	4
Flexible Services and Manufacturing Journal			1								1
International Journal of Production Economics					1			1			2
International Journal of Vehicle Design						1					1
Journal of Automatica Sinica									1		1
Journal of Business Economics									1		1
Journal of Cleaner Production							1	3	4	4	12
Journal of Industrial Engineering International						1					1
Logistics and Sustainable Transport									1		1
Mathematical Problems in Engineering									1		1
Optimization Letters							1				1
Soft Computing									1		1
Sustainability										1	1
Swarm and Evolutionary Computation									1	1	2
TOP									1		1
Transportation Research Part B									1	1	2
Transportation Research Part C						1			1		2
Transportation Research Part D							1				1
Transportation Research Part E						1	2				3
Others (Conference)	1	3	1	3	1	2	5	5	7	3	31

2.2. Literature Search and Selection Process

In the databases and other sources used to collect the existing literature, the searching process was conducted using a search phrase which are “green vehicle routing problem” and “heterogeneous fleet green vehicle routing problem”. This exact phrase was used in order to reduce the number of irrelevant literatures for

this study. By searching this phrase, there are around 133 literatures found from the academic databases and other sources.

After that, the literature selection was conducted. In the literature selection process, the literature must meet several criteria. The literature selection process for this study is confined to the literature that considered environmental issues and GVRP variants. In addition, the literature that would be selected is the literature that can be easily identified by its type of fleet and solution approach used. Besides, the literature must be written in English. The aim of this process is to help the review process for literatures that have been collected are easier to understand.

The process of literature selection began by reading the abstract of the literatures. The abstract of the literatures were read in order to determine its relevance with the objective of this study. Moreover, the literature that use languages other than English were eliminated. After reviewing all literatures, in the end there are 90 literatures found that contain the most relevant context with the objective in this study. These literatures are published between 2009 until 2020 as depicted in Figure 1. All of the literatures were recorded in a spreadsheet for further analysis and help in classifying processes.

2.3. Classification Schemes

One of the objectives in this study is to classify the literature related in GVRP. The literatures are classified based on the research objective, whether the literature has single-objective or multi-objective. After that, in each classification, the type of fleet and solution technique used for the literatures will be discussed.

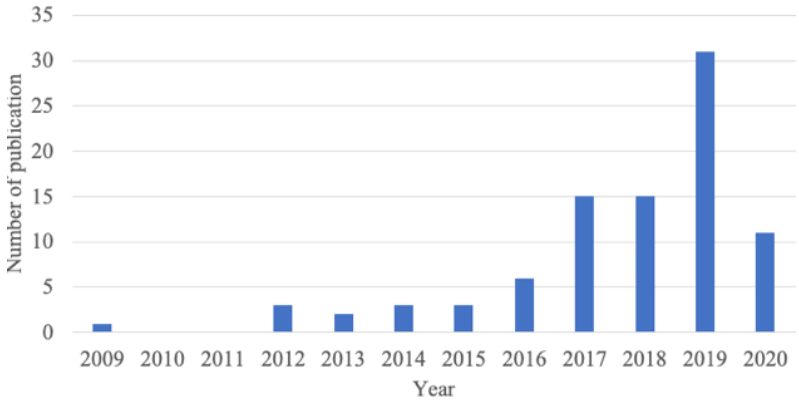

Figure 1. Distribution of literature based on publication year

3. GREEN VEHICLE ROUTING PROBLEM

Research about GVRP has been conducted by some researchers [14, 15, 16]. In GVRP, usually there are a set of customers, a set of refueling stations, and a fleet of AFVs to be analyzed [8]. Moreover, GVRP also can be applied in many sectors. One of the implementations for GVRP is solving routing problems for perishable products. The concept of GVRP is important for perishable products because this type of product must be transported as quickly as possible before they spoil [17]. Another implementation for GVRP concept is for vehicle scheduling and routing problems of airline ticketing companies [18]. In this condition, the company provides free services of picking customers up and taking the customers to airports. By considering the facilities provided by this company, the company needs to consider and optimize the emission footprint that produced and fuel consumption for their activities.

In GVRP, economic profit is not a primary objective [19]. The main concern is introducing vehicle transportation and routing models for alternative fuel vehicles (AFVs) which already consider environmental issues. The example of AFVs could be hybrid, electrical, and fuel cell vehicles [19]. GVRP is related with alternative fuel vehicles (AFVs) which by using AFVs can help in reducing carbon emission and fuel consumption. This condition will lead to minimizing fuel cost. However, using AFVs will lead to another problem. The problem is AFVs have limited tank capacity [20], and AFVs are required to visit alternative fuel stations (AFSs) for refueling [21]. On the other hand, since AFVs started to operate recently, the AFSs are still very few. Therefore, this condition makes routing decisions for AFVs getting more difficult to do [9].

There is some research that already tried to develop a concept in order to response AFVs problem. One of the examples is for electrical vehicles. Electrical vehicles that usually use batteries usually have a limited autonomy of battery, thus the possibility of recharging partially at available stations have been considered [22, 23]. However, a long charging time at station can give an impact to the route planning. This condition needs to be considered when short delivery time windows is becoming one of the constraints [24]. Thus, another solution that have been generated is by conducting battery swapping that helps in minimizing

total travel time [25, 26]. This solution has higher potential to reduce recharging times that leads to reduce overall cost [24].

The basic concept of GVRP only has a single depot. So that, the other variants of GVRP concept development is having a multi depot or known as multi-depot green vehicle routing problem (MDGVRP) [27, 28, 29, 30]. Satisfactory-GVRP (SGVRP) is also another concept that has been developed. In this concept, maximizing customer satisfaction is also becoming one of the main objectives [31, 32]. GVRP can also be combined with scheduling problems in order to get a balanced environmental and economic costs by implementing effective vehicle routing and scheduling. This concept is known as green vehicle routing and scheduling problem (GVRSP) [33, 34, 35].

Concept of HFGVRP has been examined by some researchers. A comprehensive mixed integer linear programming model to formulate HFGVRP and scheduling problems by focusing on minimization of CO_2 emission has been generated [33]. In that study, some considerations such as customer-vehicle assignment, route selection, and travel time scheduling have been analyzed. Other than that, the variant of HFGVRP has been developed using a fixed number of heterogeneous fleets with the purposes were to minimize distribution cost, fixed and variable fuel costs, the carbon emitted by the vehicles, total delivery tardiness, and customer dissatisfaction [34].

4. GROWTH OF GVRP RESEARCH

4.1. GVRP with single-objective

There are some variants of GVRP that have been developed by some researchers with single-objective. One of the variants is green vehicle routing and scheduling problem (GVRSP) [5, 33]. In this concept, the scheduling for routing is also being considered, thus the output could be the minimization of carbon emission cost. Other than that, there is a research that tries to focus on capacitated AFS, in this concept, the capacity of each station is limited [36]. Thus, this could be a constraint for the model. The other development of GVRP is called HFGVRPTW or heterogeneous fleet green vehicle routing problem with time windows [43].

Some of the research only has one or single objective. One of the objectives that usually being considered in GVRP is to minimize total travel distance [8, 21, 36, 37, 38, 39, 40, 41, 42]. Some of the research claimed that by minimizing total travel distance could give an indirect effect to reduce the operating cost. Other than minimizing total travel distance, another concern of the researches is about minimizing total carbon emission that produces [33, 35, 43, 44, 45, 46, 47, 48, 49, 50] and energy consumed from the routing process [51, 52]. This issue is important to be examined in order to consider the environmental issues. The other important objective by implementing GVRP is also minimizing fuel consumption of the vehicle [53, 54, 55, 56, 57].

From the literatures that have a single objective, then the classification based on the solution technique used in each literature also has been generated. The literature is classified into four classes which are exact method, heuristic, metaheuristic, and hybrid method. In exact method, there are some researchers who develop mixed integer linear programming (MILP) [39, 51, 59], MILP combine with branch-and-cut [37, 58], branch-and-price [43], and develop mathematical model for problem being analyzed [5, 23, 38]. For heuristic methods, existing research used some techniques such as reduction procedure [37] and local search procedure [8, 44, 45, 23, 24, 60].

In metaheuristic method, previous researchers tried to implement some technique such as neighborhood search [33], genetic algorithm (GA) [24, 44, 50, 61], tabu search [47, 48], simulated annealing (SA) [42], and ant colony optimization (ACO) [21, 45, 52]. Other than that, there are also some hybrid method used such as exact-metaheuristic by combining set covering model with iterated local search (ILS) [5], heuristic-heuristic by combining column (CG) generation and adaptive large neighborhood search (ALNS) [26], heuristic-metaheuristic by combining large neighborhood search (LNS) with ACO [45], and metaheuristic-metaheuristic by combining GA and SA [62].

4.2. GVRP with multi-objective

One concept for GVRP with multi-objective is emission-based heterogeneous fixed-fleet vehicle routing problem (EHFFVRP) [34, 64]. It is a new variant of the heterogeneous fixed fleet vehicle routing problem (HFFVRP), in which a fleet consists of a fixed number of vehicles with different capacities, fixed costs and variable costs [64].

Other than single-objective, researchers that try to develop GVRP concepts also use multi-objective. The example of this multi-objective are minimizing fuel consumption and optimizing customer satisfaction [63], minimizing fuel consumption and carbon emission [64, 65, 66], minimizing total cost and carbon emission [67, 68, 69, 70,71], minimizing total travel distance and carbon emission [72, 74, 78, 80] or fuel consumption

[73, 79, 81], minimizing total travel distance and energy consumed [75, 76, 82], minimizing cost and air pollution [87], and improving energy efficiency and customer satisfaction [77].

For GVRP with multi-objective, the literature also classified into four classes which are exact method, heuristic, metaheuristic, and hybrid method. There are some researchers who develop GVRP with multi-objective using exact methods. The examples of this method are ε-Constraint [9, 86], mathematical model and try to solve model by using CPLEX software [83], mix integer programming [84], and MILP [85]. For heuristic method, existing researches used Clarke and Wright Savings Heuristic Algorithm (CWSHA) and Sweep Algoritm (SwA) [28], multi-objective evolutionary algorithm (MOEA) [88], planning algorithm and using MOBILE5 software to help in calculating emission [14].

Moreover, for metaheuristic method, previous research used split-based adaptive tabu search (SATS) [64], time varying (TVa) and particle swarm optimization with greedy mutation operator (PSOGMO) [89], non-dominated sorting genetic algorithm II (NSGA II) [32, 93], Ant colony optimization (ACO) [90], variable neighborhood search [94], variable neighborhood tabu search algorithm [91], and GA [92]. Besides, in multi-objective GVRP there are some hybrid methods that have been implemented such as exact-exact, exact-metaheuristic, and heuristic-metaheuristic.

5. TRENDS AND FUTURE DIRECTIONS OF HGVRP

Table 2 shows the VRP variant researches from 2009 until 2020. It is depicted that there are some researches that used homogeneous fleet. Besides, the number of researches that consider heterogeneous fleet is still growing. However, the research is still limited and developed, thus some further research can try to adopt heterogeneous fleet in their research because this concept helps in increasing the flexibility of vehicles. Moreover, heterogeneous fleets should be applied because it is more realistic than other homogeneous vehicle routing problem variants.

In addition, from the review process, it can be seen that some research focuses on electric vehicle as the alternative fuel vehicle. On the other hand, there are some other AFVs that can be used. Thus, further work can explore other type of AFVs to get more comparison within the type of AFVs. Further researches may explore the implementation of heterogeneous fleet in different type of AFVs. The further research also may explore the trade-off between the use of different type of fleet or solution approach with a single or multi-objective of the research.

Table 2. Summary of Literatures Reviewed

		Research
Type of Fleet	Homogeneous fleet	73, 65, 19, 80, 38, 44, 74, 75, 66, 92, 71, 58, 18, 20, 37, 90, 62, 78, 81, 15, 70, 86, 16, 100, 89, 45, 88, 14, 24, 21, 85, 52, 57, 87, 50, 9, 63, 28, 36, 96, 46, 47, 61, 77, 68, 79, 82, 39, 51, 40, 97, 99, 41, 42, 29, 30, 25, 60, 17, 93, 94, 49
	Heterogeneous fleet	53, 31, 33, 54, 84, 55, 95, 35, 98, 5, 64, 59, 27, 67, 8, 43, 32, 76, 69, 91, 22, 23, 26, 56, 48, 72, 83, 34
Solution Approach	Exact method	73, 65, 19, 53, 38, 66, 92, 31, 33, 58, 37, 84, 90, 35, 78, 81, 86, 98, 5, 64, 59, 27, 85, 9, 67, 63, 36, 43, 76, 79, 82, 91, 39, 22, 51, 23, 40, 26, 48, 99, 41, 72, 83, 34, 25, 60
	Heuristics	38, 44, 75, 18, 20, 37, 90, 55, 70, 100, 89, 45, 88, 14, 24, 8, 28, 46, 91, 23, 56, 60
	Metaheuristics	19, 80, 44, 74, 66, 92, 71, 33, 18, 90, 62, 78, 81, 89, 64, 45, 27, 24, 21, 52, 50, 67, 63, 28, 32, 96, 47, 61, 77, 68, 69, 91, 22, 48, 99, 41, 42, 34, 30, 60, 93, 94, 49
	Hybrid	33, 54, 18, 62, 98, 5, 45, 21, 57, 9, 67, 63, 28, 48, 29, 30, 25

6. CONCLUSION

This study conducted a literature review of current research about green vehicle routing problems. The literatures were collected from scientific journals, proceedings, and academic articles that focus on GVRP. There are more than 133 literatures that discussed about GVRP and its development. However, in this study there are only 90 literatures included to be analyzed. These literatures have been reviewed and classified in order to determine the further research that can be discussed.

Based on the literature review, some of current research on GVRP used homogeneous fleets as the transportation of their supply chain. However, some of the researchers are trying to develop research about the use of heterogeneous fleets. Even though there have been several researches that used multi-objective in their research, most of the studies are used single objective. Thus, further research should consider the research objective that should be used, especially when the certain objective has been used and analysed in the previous research. Besides, there are some solution approaches used in the research on GVRP including exact method, heuristics, metaheuristics, and hybrid.

In short, this study could give a better understanding about the state-of-the-art of research on HAFVGVRP. Thus, based on the literature review, the further research should try to combine and develop the use of heterogeneous fleet particularly alternative fuel vehicles with the solution approaches provided. Besides, this study has limitations including the limited size of survey. This study only covers a limited number of

literatures while there are some other publications that might discuss the development of GVRP. There also might be some publications about GVRP that is published in databases or sources used in this study. Therefore, in order to strengthen this study, further research might extend the scale of the review and conduct a more detail classification.

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