The Green Vehicle Routing Problem: A Systematic Literature Review

Abstract

Recent decades have seen increasing utilization of optimization packages, based on Operations Research and Mathematical Programming techniques, for effective management of the provision of goods and services in distribution systems. Large numbers of real-world applications, both in North America and Europe, have widely shown that the use of computerized procedures for distribution process planning produces substantial savings (generally from 5% to 20%) in global transportation costs. It is easy to see that the impact of these savings on the global economic system is significant. The transportation process involves all stages of production and distribution systems and represents a relevant component (generally from 10% to 20%) of the final cost of goods. The green vehicle routing problem (GVRP) is an emerging research field that attracts many researchers. This survey paper aims to classify and review the literature on GVRPs from various perspectives. This paper covers publications between 2006 and 2019 including 309 papers. To this end, a systematic literature review has been implemented in order to respond to corresponding questions related to this area and proposed an extensive structure compromising various aspects including variants of GVRPs, objective functions, uncertainty, and solutions approach to analyze GVRPs studies in different perspectives. Some new research areas have been drawn based on problem classification, uncertainties, solution methodologies, and finally, the objective function approaches for future research directions and the results of this study show that researches on GVRPs are relatively fresh and there is still a room for large improvements in several areas.

Keywords*: Green vehicle routing problem, vehicle routing problem, operations research, literature review*

1. Introduction

To date, substantial consideration has been invested in the global transport environment due to the dangerous effects from the negative externalities throughout the transportation network. These externalities include pollution resulting from fleet activities which have been scrutinized by many scholars and environmentalists. Despite improvements in implementing 'green technology' to decrease greenhouse gas (GHG) emissions, statistics show that the amount of pollutants—mainly the carbon dioxide equivalent (CO_2e) —has increased, and human health and welfare problems arising from environmental pollutants have been dramatically heightened. Therefore, the increasing amount of GHG in the atmosphere shows that global warming and climate disruptions have become critical in our modern world, and a significant portion of freight transportation connects by means of different types of vehicles that emit vast volumes of pollutants (Erdoğan and Miller-Hooks, 2012).

Of the many aspects of transportation systems, the vehicle routing problem (VRP) has conceivably been considered one of the most important problems encountered at the operational decision level, and is in fact regarded as a specific class of combinatorial optimization problem in the scope of operations research. Traditionally, VRP addressed a type of problem in which customers must be served via several fleets at a minimum cost of operational objectives, subject to side constraints. Therefore, a fleet starts from a point, namely a depot, delivers goods to the customers in the predefined urban network and returns to the origin depot. Since this problem was initiated by Dantzig and Ramser (1959), the literature has proposed several variants. The vast number of scientific papers on reducing CO_2e emissions from road transportation has significantly increased since 2010, indicating the importance of GHG emissions.

The contribution of this study is multifold, as follows. This paper first exhibits a thorough and up-to-date review of the comprehensive studies on GVRPs. Thus, absence of existing studies on the reviewing of GVRP, objectives functions and methodology have been emphasized. Second, several variants of GVRP has been presented that are not considered or discussed in scientific papers. Third, a number of cross analyses from various aspects of GVRP has been presented that may broaden research avenues in the future.

This study applies the same process as Demir et al. (2015), who reviewed the entire body of literature by considering the environmental impact of freight transportation within a specific period. Therefore, it has been extensively evaluated the published papers in this area to predict future research fields, and primary objectives must be regarded. This paper also introduces a conceptual framework for the green context, which can be extensively performed in this area.

The paper is organized as follows. Section 2 describes the review methodology, followed by different analyses of reviewed papers in section 3. Section 4 presents opportunities within the diverse views plus several future research possibilities. Conclusions are drawn in section 5.

2. Review Methodology

This study conducts a systematic literature review (Lagorio, 2016), based on a wide range of relevant searches, by stating the main review questions and specific search words. To determine a new theme in the green freight transportation context, approaches and methods have been used in this study to achieve consistent findings. Transportation is generally a principal section of the most businesses, where it constitutes a significant proportion of the total product cost. Therefore, transportation is rapidly becoming a key issue in current business practice, centered on understanding developing economies. Nonetheless, recent developments in transportation have heightened the need to expand knowledge in this area. Increasing routes and volume of goods has achieved economic and environmental sustainability in transport, and, theoretically, environmental routes could become a feasible option to traditional transporting routes, supporting both economic and environmental sustainability in distributing goods. All else being equal, the reasonable benefit of environmental routes derives from the fact that a shorter distance leads to many benefits, as well as lowering the operating costs, a better quality of service and lower fuel consumption. The following research questions were formulated to address the objective of this study:

RQ1. What are the main variants of GVRP that are considered by different papers to associate environmental goals with the VRP area?

RQ2. What are the methodological approaches to cope with environmental issues?

RQ3. How are different objectives related to the GVRP variants?

RQ4. What are the emerging concerns that must be considered?

In recent years, research on green freight transportation has attracted much research attention. To illustrate the necessity of this work, previous review papers are considered in the field of GVRP. Therefore, the main features of recent review papers are presented in Table 1.

Table 1. Features of different review papers

Publication	Problem	The focus of the research	Number of papers reviewed
(Dekker et al., 2012)	-	Presents recent contributions of Operations Research to green logistics	75
(Demir et al., 2014)	-	Provides a review of recent researches related to emission calculation	58
(Eguia et al., 2013)	EVRP	Provides a review of methods used in EVRP	78
(Lin et al., 2014)	GVRP	Presents new classification of GVRP	284
(Park and Chae, 2014)	GVRP	Provides a brief review of solution approaches used in green vehicle routing problems (G-VRP)	42
(Zhang et al., 2015a)	-	Reviews papers of both the problem and the methodology point of view.	117
(Govindan et al., 2015)	Reverse Logistics	Presents extensive review on reverse logistics	382
(Gendreau et al., 2015)	TDVRP	Presents a comprehensive review of travel time modelling	98
(Koç et al., 2016)	HVRP	Classifies and reviews the literature on heterogeneous vehicles	103
(Govindan and Soleimani, 2017)	Reverse Logistics	Presents extensive review on reverse logistics	83
(Bektaş et al., 2019)	-	Reviews recent approaches on green transportation using OR tools	153
(Soysal et al., 2019)	IRP	Reviews recent studies on IRP considering sustainable regards	41
This study	GVRP	Reviews all published papers based on different aspects	309

Regarding the general information of reviewed papers, presented in Table 1, the there lacks an extensive review study in the green concept demonstrating all aspects of GVRP, and little agreement exists on a comprehensive category—including all types of GVRPs—with limited coverage by researchers. Most studies mentioned have only focused on a specific part of the problem. Some covered only GVRP (e.g., Lin et al. (2014), whereas other researches, focused on particular variants (e.g.,(Govindan et al., 2015)), have reviewed the reverse logistics in VRP. Koç et al. (2016) reviewed all papers related to heterogeneous vehicles in which the specifics of this paper focused on green heterogeneous vehicles, and Soysal et al. (2019) introduced a particular review on the inventory routing problem (IRP), considering sustainable measures. Moreover, to illustrate the new trend in GVRP studies, it is crucial to innovate a new line of research considering the latest studies on this area. The most advantage of this study compared with the mentioned studies is to cover the most significant aspects of the GVRPs model, hence the others just focus on some aspects of environmental issues in their survey. Presenting various cross tables enriches this study and indicates that there are open windows for potential future researches in green freight transportation problems.

2.1. Search strategy

A broad continuum of topics, including minimizing CO_2e emissions, environmental sustainability and waste collection, are devoted to green freight transportation, which is considered by various disciplines. The review of this study has been limited based on the research questions in order to embrace papers considering specific topics of green freight transportation, including VRP, approaches used in a routing scope, CO_2e emissions (fuel consumption), calculation approaches, and green VRPs.

Several databases have been used for this research, including the main academic databases. First, the main keywords have been searched covering all subject areas without specifying the period; then, the studies on GVRP are surveyed, mainly confining our search to articles published from 2006 to November 2019. To reach this goal, and subsequently, all related abstracts of relevant papers are investigated and purified the keywords, in terms of the goal and review questions.

A large and growing body of literature has been investigated in order to reach a deeper understanding of the context of GVRP. A large volume of published studies has described the contribution of the transportation sector to GHG emissions. The search procedure has been conducted in well-known academic databases, such as Elsevier, Springer, Emerald, and IEEE transaction. By searching the keywords, almost 455 papers were found from different publishers. Considering the fact that this study considers the GVRP context, the searching process is confined to articles published which are considered the main variants of GVRPs and environmental issues that are widely accepted among scholars in the literature. Therefore, the searching process was employed in two dimensions including horizontal and vertical. In the horizontal dimension, Firstly, consideration was paid to the development of the most well-known VRP models that consider the environmental issue on the timeline while in the vertical dimension, different classes of GVRPs are identified in various sources. After reviewing all articles, 309 studies were found to be most relevant to the context, which is categorized based on the various journal as seen in Appendix 1. Various features of the articles were recorded in a spreadsheet for further analysis. Note that the research attempts after 2006 concentrated on the environmental aspects of VRP, which clearly supports the results of a review paper by Lin et al. (2014).

An objective analysis of these papers is crucial in order to define the structural dimensions of the review, which addresses all publications in differing aspects. Reviewing all documents reveals a suitable categorization that comprehensively covers these publications (see Table 2). This categorization is formed with respect to various perspectives of the papers considering in this area. To ensure that suitable structural dimensions were chosen, two criteria are used, as introduced in (Govindan et al., 2015). The first criterion is that each aspect must embrace at least 50% of all papers, and the second criterion considers the appropriate number of subcategories in each category. In Table 2, a group named the "solution approaches," is defined, divided into Metaheuristic, Heuristic, Software Application, Exact, and Exact Solver categories.

Table 2. The structural dimensions of this paper

Variants of GVRP	Objectives	Data/Case Study Decision	Uncertainty	Solutions approaches	CO_2 calculation method
GVRP	Single	Case study	Deterministic	Metaheuristic	Factor
HVRP	Multi objectives	Case experimental	None Deterministic	Software Application	FCM
PRP	Many objectives	Theoretical	-	Exact Solver	COPERT
EMVRP	-	-	-	Exact	OFCM
TDVRP	-	-	-	Heuristic	MEET
FCVRP	-	-	-	Hybrid	NAEI
EVRP	-	-	-	-	CMEM
Other	-	-	-	-	VSP
-	-	-	-	-	CPFM
-	-	-	-	-	MOVES
-	-	-	-	-	NTM
-	-	-	-	-	SIDRA

Abbreviations: HVRP: Heterogeneous VRP; PRP: Pollution-Routing Problem; EMVRP: Energy Minimization VRP; TDVRP: Time-Dependent VRP; FCVRP: Fuel Consumption VRP; EVRP: Electric VRP; FCM: fuel consumption model; COPERT: Computer Program to Calculate Emissions from Road Transportation; OFCM: fuel consumption model; MEET: Methodology for Calculating Transportation Emissions and Energy consumption; NAEI: National Atmospheric Emissions Inventory; CMEM: a comprehensive modal emission model; VSP: Vehicle Specific Power; CPFM: Comprehensive Power-based Fuel Consumption Models; MOVES: motor vehicle emission simulator; NTM: Network for Transport and Environment; SIDRA: Signalized Intersection Design and Research Aid.

Table 2 illustrates the six dimensions examined in this paper and satisfies the two earlier criteria. The first dimension considers the variants of GVRP, which have been comprehensively investigated in an attempt to cover all variants of GVRPs. According to Lin et al. (2014), the main variants of GVRP can be categorized into GVRP, PRP and VRP with recycling and reverse logistics (VRPRL). By reviewing all publications in this context, it is discovered that Govindan et al. (2015) and Govindan and Soleimani (2017) have already widely reviewed VRPRL. Thus, in order to focus our literature review further, it has been consciously avoided VRPRL subject, which is extensively reviewed in (Govindan and Soleimani, 2017; Govindan et al., 2015). In terms of a solution approach, it has been defined six sub-categories, which encompass various technical solutions from different approaches. The word *Hybrid* indicates that the solution approach is a combination of two or more techniques used to reach a better solution in a complex search space. In the CO_{2e} calculation dimension, the most promising methods used to calculate the volume of CO_{2e} emissions was reviewed. In this area, the most comprehensive study was conducted by Demir et al. (2014) who consider wide ranges of vehicle emission models, however, they did not consider new trends in emission models. Uncertainty is another dimension of our review, as there are various ways to consider uncertainty in the model, including stochastic, fuzzy, interval, chaos, and scenario approaches. This dimension is divided into two sub-categories, as seen in Figure 1, in order to reflect the approaches used by different researchers. In the data set dimension, the reviewed papers are divided based on whether they used data from a real case study or have focused only on theoretical aspects.

After constructing the dimensions of the study, the following procedures was performed to ensure sufficiency of materials. A spreadsheet tool was used to appraise the different aspects of the study, with all collected papers cross-checked with a separate database in order to ensure enrichment of the study. In addition, an independent researcher was asked to determine whether the quality and number of materials were sufficient for the study. The following section reports the analysis of the main categories of the classifications.

2.2. The framework of the review

The structure in Figure 1 illustrates the current study in three steps. Step 1 determines the basis for the review work; refining the selected papers and organizing structural dimensions of the review paper. The central part of our review is implemented in Step 2, where reviewing the state-of-the-art of GVRP, focusing on fundamental aspects, and extracting various types of trends are shown, and the landscape of the state-of-the-art GVRP is drawn. In Step 3, the relationship of GVRP with various dimensions of the review paper is described, as well as providing opportunities for future research on GVRP.

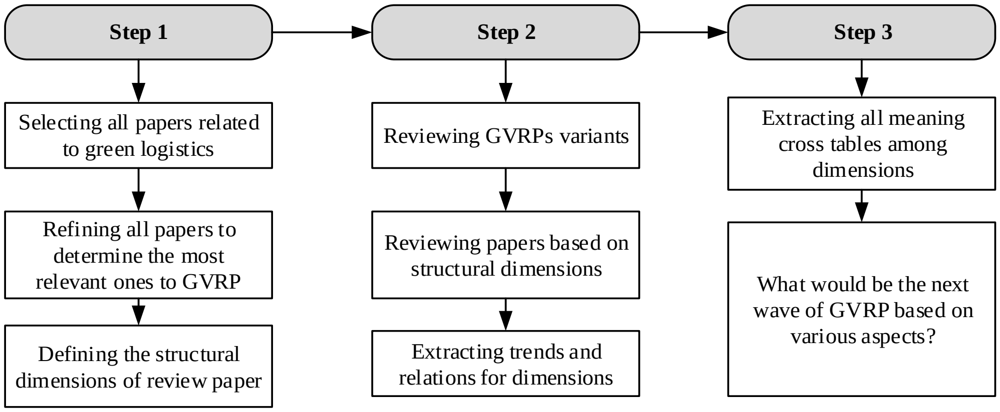

Figure 1. The framework of the review work

3. Detailed analyses of the literature

To discuss and further analyze the selected publications, a comprehensive view of green freight and transportation problem is provided to clarify the possible gaps for future research directions.

3.1. Problem classification

Based on problem classification, various subjects are presented, which is considered in the field. It is significant that most of the papers apply in two or more categories, and that the principal key in determining the category of any paper is to find the focus on a specific subject, as highlighted by other researchers. Therefore, the main categories in this area are presented as follows:

3.1.1. Network design

An interesting subject is network design and planning, and several papers examine strategic (long-term) decision variables in terms of location and supply chain network design and quantize network results throughout strategic planning. The first attempt at network design related to GVRP, as proposed by Sharma and Mathew (2011), implemented speed-dependent emission functions so as to calculate different types of pollutants, and applied non-dominated sorting genetic algorithm (NSGA-II) to grasp the reasonable solution for the network design problem. Oberscheider et al. (2013) proposed a new mathematical formulation as a multi-depot VRP with pickup and delivery and time windows to enhance relationships among supply chain network entities. Recently, the research community in freight transportation has studied refueling stations, which are widely implemented in city logistics. The best-known examples of this problem, as proposed by Erdoğan and Miller-Hooks (2012), have considered the mathematical formulation for the possible routing of vehicles to alternative fueling stations. Recent papers in this regard are extensive (see (Chen et al., 2018)))

3.1.2. GVRP with other approaches

Other papers have attempted to appraise a new scientific approach in this field, with their main issues as follows: strategic planning for electric vehicles, Green global positioning system (GPS) (Ganti et al., 2010); the characterizing of fuels and emission models (Wang et al., 2011); implementing a new device, G-Target SRV for routing optimization efficiency (Jovičić et al., 2010); considering microscopic vehicle operating conditions(Nie and Li, 2013); the application of using a neuro-fuzzy in urban transportation(Ćirović et al., 2014); multi-criteria GVRPs (Sawik et al., 2017); and home health care (Fathollahi-Fard et al., 2018).

3.1.3. Inventory management

According to Mirzapour Al-e-hashem and Rekik (2014), transportation and inventory management are vital parts of logistics, the combination of which presents an IRP. Recently, several studies have focused on the level of inventory and delivery routes simultaneously, which consider environmental criterion in the supply chain network. These studies have been named as 'inventory management'. Alkawaleet et al. (2014) are the first to examine the impact of CO_2 emissions on IRP by presenting a new mathematical formulation in which the price of CO_2 emissions is reflected in the proposed mathematical model.. Malekly (2015) published a paper in which he combined PRP and IRP, which can be implemented to draw a possible Pareto front for emissions and operational costs for green freight transportation. For interested readers, the following paper is recommended: (Alinaghian and Zamani, 2019).

3.1.4. Developing mathematical model and solution approach

These studies attempt new theoretical models that largely contribute to mathematical models or methodological approaches to find a better solution for different aspects of GVRP. Most papers outlining GVRP approaches have been discarded in this category. In terms of a mathematical model, Kara et al. (2007) presented EMVRP; Bektaş and Laporte (2011) introduced PRP; Conrad and Figliozzi (2011) presented Recharging VRP (RVRP); Kuo and Wang (2011) discussed FCVRP; and Erdoğan and Miller-Hooks (2012) suggested GVRP, which are the best-known publications in this area. In terms of a solution approach, Dabia et al. (2014) proposed an exact approach; Kramer et al. (2015a) proposed speed optimization algorithm; Rauniyar et al. (2019) designed a new evolutionary algorithm; and Li et al. (2019) presented an improved ant colony optimization model.

3.1.5. Reviews and partial reviews

Several studies present a review or partial review focusing on GVRP. In these cases, the partial review attempts to concentrate on the specific aspect of green freight transportation. Park and Chae (2014) presented a review of solution approaches used in this area; Gendreau et al. (2015) provided a comprehensive review, examining solution approaches, and modeling based travel time in the GVRP context. Zhang et al. (2015a) concentrated on swarm intelligence in green logistics. Touati and Jost (2012) focused on environmental considerations in VRPs, such as Waste Collection VRP, multi-modal VRP, dial-a-ride problem, energy routing problems, and air traffic control; all inspired by the field of sustainable transportation.

3.1.6. GVRP in other real-world settings

Various classes of quantitative and qualitative research have been discarded in this category, which covers many issues of sustainable transportation. These types of studies present a comprehensive analysis for well-known models to demonstrate their validity and application in real-word situations. For instance, Scott et al. (2010) presented a comprehensive study analyzing the impacts of gradient and payload factors in CO_2 emissions for the traveling salesman. Bandeira et al. (2012) applied GPS technology to obtain over 13,000 km of data network for different locations in the USA and Portugal in order to present a quantitative analysis of how the aforementioned factors can reduce global pollutants with respect to peak hours. Goodchild and Sandoval (2011) investigated the impact of various GHG negative environmental emissions from vehicles (such as CO_2 and nitrogen oxides (NOx)), according to circumstances, such as location changes, congestion and time window flexibility. Saberi and Verbas (2012) presented a continuous approximation model, and numerical studies and quantitative analyses were conducted to measure GHG emissions. Finally, papers by (Kopfer and Kopfer, 2013) is mentioned here as significant studies dealing with this analysis.

3.2. Variants of GVRPs

Initially, the variants of the GVRP are reviewed that have comprehensively and abundantly focused on studies to date. Note here that, although the variants are discernible, they often stand narrowly interrelated, and all related papers are not reviewed here that are outside the scope of this paper. According to the comprehensive review, all papers are categorized into eight categories in different years (see Figure 2). This is achieved by steady increasing the number of published papers for various variants. The following subsections are devoted to reviewing variants of GVRPs in detail.

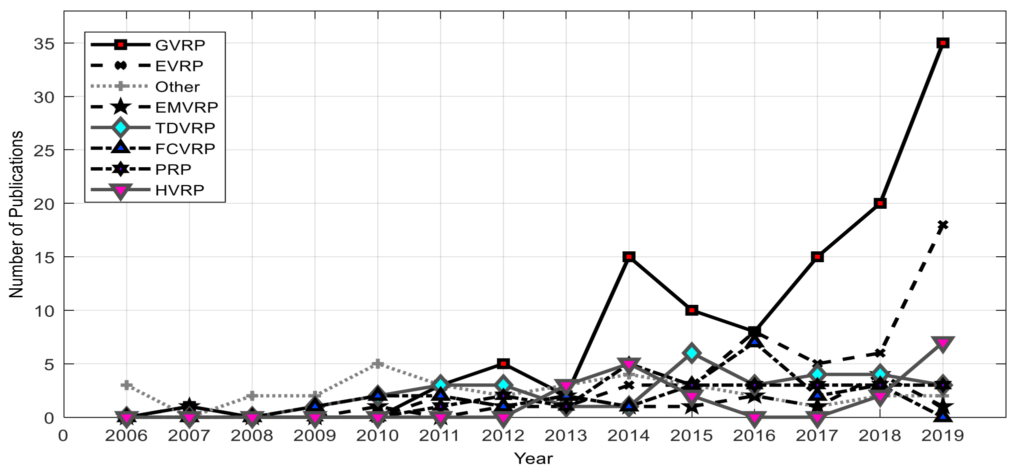

Figure 2. Trends in GVRPs

However, there are trends in our data to suggest that GVRP variants have received substantial interest in recent decades.

3.2.1. Green Vehicle Routing Problem

Most research in this category focuses on optimizing the energy consumption of transportation. (Palmer, 2007) presented the general framework, which combined transportation planning and environmental modeling with specific techniques to determine traffic volume conditions, so that the speed of each link can be determined and total CO_2 emissions estimated. The results of this study showed at least 5% of the CO_2 emissions reduction could be reached with this model. The main GVRP problems consider the location of refueling station of the vehicles. Erdoğan and Miller-Hooks (2012) presented a mathematical model regarding the location of the alternative fueling station into VRP model. They used two construction heuristics to obtain a feasible solution regarding customer and station location simultaneously, so as to minimize the possibility of running out of vehicle fuel. Latterly, Schneider et al. (2015) developed this model by presenting VRP with intermediate stops and engaged an adaptive variable neighborhood search algorithm to solve the problem. Bruglieri et al. (2016) presented a more realistic model of GVRP containing a new formulation to investigate a reduction in the alternative fuel station (AFS). For better performance in the computation process, the cost of inserting any halt between each pair of customers was pre-measured and their model included a pre-computation of AFS. Leggieri and Haouari (2017) presented non-linear formulation consumption constraints of GVRP, using a reformulation-linearization technique in which the pre-processing computation is performed to reduce the number of variables and constraints.

Montoya et al. (2016) stated the importance of AFVs in the VRP model and presented a quite simple procedure including two-phase heuristic, which manages the GVRP model, in which the first stage was conducted to create a number of routes via the classical heuristic method based on route-first cluster-second, while the 2 stage incorporated a set partitioning formulation method in order to reach the best solution in the pool. Ashtineh and Pishvaee (2019) attempted to assess different aspects of performing alternative fuels in VRP by measuring the effects of different pollutants (i.e., NOx, HC and CO) on human health and the ecosystem through various mathematical models based on Well-to-Wheel and Tank-to-Wheel analyses. The results showed that involving the whole chain of fuel leads to a 37% reduction in GHG emissions. Poonthalir et al. (2015) presented a bi-objective VRP model, which is solved via a Particle Swarm Optimization with a Greedy Mutation Operator, with restrictions on the number of refueling stops. In a similar study, Poonthalir and Nadarajan (2018) also discussed a bi-objective model of fuzzy GVRP (F-GVRP) examining the varying speed of vehicles. They used a variation of particle swarm optimization (PSO) to analyze the proposed model under varying speeds. Results of this study indicated that the total cost of the model could reduce with the assumption of varying speed compared with constant speed.

Yu et al. (2019b) present an improved branch-and-price algorithm to solve the fleet green vehicle routing problem with time windows (GVRPTW) and they have used an integer branch method to obtain a tighter upper bound. Wang and Lu (2019) propose a memetic algorithm with competition (MAC) to solve the capacitated green vehicle routing problem (CGVRP). The k-nearest neighbour (kNN) also was used to initiate the information on the location of customers.

The most common variants of the transportation model are Capacitated VRP. There have been many variants of VRPs that embedded into the GVRP model. Most GVRPs models tried to develop a capacitated VRP (CVRP) basic model to address the environmental investigation in the objective function. Elbouzekri et al. (2013) presented a technique integrated into the CVRP model to estimate CO_2 emissions by using a hybrid ant colony system in an attempt to minimize CO_2 emissions. Adiba et al. (2014) presented a new genetic algorithm to embed CO_2 emissions into the CVRP model using a well-known set of benchmarks to demonstrate the effectiveness of the model. Niu et al. (2018b) meticulously examined the fuel consumption formula in a quite different aspect, especially considering the third party, which implemented such environmental factors in open VRP (OVRP). They employed several neighbourhood search procedures in a hybrid Tabu search (TS) to solve this problem. The results of this study revealed that opened routes could reduce the aggregated total cost compared with closed routes.

Messaoud et al. (2018) present a new model in which combines dynamic VRP (DVRP) into GVRP by using ant colony optimization (ACO) to minimize environmental issues immediate consequence of the depletion of the ozone layer and time duration. Soysal et al. (2018) presented a new decision support model, in which profits of horizontal collaborations in IRP were examined. They measured many factors to show the validity of the presented model regarding given the uncertain demands of customers. The results of this study identified that horizontal collaborations among suppliers decreased the total cost and overall emissions.

3.2.2. The pollution-routing problem

Bektaş and Laporte (2011) presented PRP—the new variant of GVRP—with a distinctive objective function, comprising the fuel consumption cost and driver cost. The results of the paper elucidated the analysis of various essential factors and revealed that PRP has considerable potential in achieving a better solution in total costs. Correspondingly, Demir et al. (2012) extended a well-known metaheuristic in the routing problem named an adaptive large neighbourhood search (ALNS), whereby they considered lower speeds in the proposed model, but without the traffic condition. Franceschetti et al. (2013) extended PRP by incorporating traffic congestion in this model—named the time-dependent PRP (TDPRP)—by optimizing vehicle speeds in each link with discrete values. Franceschetti et al. (2013) focused on traffic congestion, while Dabia et al. (2014) proposed an exact method for solving PRP. From this, Dabia et al. (2014) first defined a master problem based on a set-partitioning problem and next, speed and start time variables were conducted through the pricing problem. Another significant paper published by Kramer et al. (2015a) considers a hybrid method including a metaheuristic, set covering formulation and speed optimization algorithm. To show the validity of the proposed method, a different class of models was analyzed, which obtained improved solutions compared with the state-of-the-art methods. Similarly, Kramer et al. (2015b) extended a new method based on speed and departure time optimization combination with a metaheuristic, where unbeneficial routes are considered, as some routes that were evaluated now appear as a set of attainable candidates.

Yu et al. (2019a) propose heterogeneous fleet PRP (HFPRP) which minimizes the total costs including greenhouse gas (GHG) emissions, and vehicle variable cost, and the proposed model was solved via SA. Rauniyar et al. (2019) proposed a new variant of PRP that consider two objectives, minimization of fuel consumption (CO_2 emissions), and minimization of total distance, and used a novel variant of NSGA-II regarding the multi-factorial approach to obtain optimal solutions.

The various variants of PRP, which are combined with other types of VRPs recently proposed by many scholars. Recently, Raeesi and Zografos (2019) presented a new realistic variant, termed the Steiner PRP, which examined urban freight conditions. Many variants of VRP, including fleet size and mix, time and load-dependent, with time windows, flexible departure times, and multi-trips, were embedded into the PRP through a multi-objective optimization formulation.

Eshtehadi et al. (2018) propose an adaptive large neighbourhood search for the robust PRP (RPRP) under demand uncertainty for hard worst-case robust optimization PRP in different test instances sizes. The results of this study show the positive relationship between environmental impacts the level of uncertainty.

3.2.3. The green heterogeneous vehicle routing problem

Since Taillard (1999) initiated HVRP, a large and growing body of literature has developed, which was extensively reviewed by Baldacci et al. (2008). Hence, green HVRP has been focused as the specific variant relating to the green approach in the transportation context. Subsequently, Kwon et al. (2013) projected the a specific version of the HF conducting to minimize environmental drawbacks. They focused on developing a new model for heterogeneous fixed fleets and used TS to analyze the cost-benefit of carbon emission rights. Juan et al. (2014) introduced the heterogeneous fleet regarding maximum route lengths and presented a new mathematical formulation initiating a new heuristic, named a multi-round heuristic. The results of this study showed that using a different type of vehicles leads to obtaining competitive solutions. Kopfer and Kopfer (2013) proposed a new model of different vehicle classes. They considered two criteria, load and vehicle, in the proposed model, which intended to reduce fuel consumption. As an extension of this work, Kopfer et al. (2014) developed the objective function, which considered environmental issue consisting fuel consumption and emissions.

Koç et al. (2014) presented a model that investigates the heterogeneous fleet into PRP with a specific objective function combination of different costs. The authors developed operators into hybrid evolutionary metaheuristic to reach the best trade-off between various indicators. A notable result of this study was that the objective function of heterogeneous fleets received superior performance in comparison to homogeneous fleets. Molina et al. (2014) offered a tri-objective model for VRP with a heterogeneous fleet. The objective functions included internal costs, CO_2 emissions and NOx. They extended the algorithm based on the classical Clarke and Wright savings heuristic (Clarke and Wright, 1964). Zhang et al. (2014b) performed a similar series of experiments, focusing on the various characteristics of energy consumption of multiple vehicles. They used a numerical simulation example regarding fleet size and mixed vehicle routing, which considered CO_2 emissions by using a genetic algorithm.

In another major study, Masmoudi et al. (2018) presented new variants of VRP—called heterogeneous fleet VRP with synchronized visits—in which some synchronization may occur between visits to reach an identical goal. They considered light-duty vehicles organized for different fuels by using three metaheuristic algorithms in order to analyze trade-offs between vital elements.

Ghannadpour and Zarrabi (2019) consider the customers' priority, as one of the most important sustainable factors, into their proposed model which was the aim to minimize the number of fleets and maximize customer satisfaction. Baniamerian et al. (2019) proposed a mixed-integer linear programming model, considering total profit instead of the total cost for vehicles. They demonstrated that the proposed hybrid algorithm finds superior solutions in terms of computational time when compared with its competitors.

Inventory routing problem (IRP) is one of the most important logistics problems which gain much attention among scholars. Alinaghian and Zamani (2019) propose a new bi-objective model for green inventory routing problems with the heterogeneous fleet where two different objectives including The emissions the fleet size are considered simultaneously in the proposed mathematical model. Another important variant of the VRPs model that has been employed in HVRP is VRPTW. Rabbani et al. (2018) present a new multi-objective of the HVRP model with time windows under stochastic uncertainty. In another version of VRPs, the multi depot version of HVRP was also proposed by Li et al. (2019), where maximizing revenue and minimizing costs, time and emission are considered as the objectives function of the proposed model using improved ant colony optimization (IACO) and L-P metrics approach.

3.2.4. Energy-Minimizing Vehicle Routing Problem

The original formulation of EMVRP, based on a new load-based cost objective, was presented by Kara et al. (2007), where the objective function—which is a function of the weight of vehicles and distances in both delivery and collection cases—must be minimized. Figliozzi (2010) demonstrated a new formulation for EMVRP in which the objective functions relate to emissions and fuel consumption. Rao and Jin (2012) proposed a new EMVRP based on multi-objective optimization, which relates to classical capacitated VRP (CVRP) examining urban freight transportation network. In the same vein, Psychas et al. (2015) presented the multi-objective of EMVRP by considering three different objective functions, including travel time, distance and fuel consumption. They performed a new version of the NSGA-II to obtain the best trade-off among objective functions and implemented a variable neighbourhood search (VNS) algorithm to enhance the quality of solutions. Pradenas et al. (2013) investigated VRP with backhauls by using a novel metaheuristic named scatter search. They analyzed the trade-off between distance travelled and GHG emissions, indicating the inverse relationship of transportation and energy consumption.

Ghannadpour (2019) proposes a new model of EMVRP with time windows (EVRPTW) considering customer satisfaction. Therefore, this paper attempts to maximize the customers' satisfaction using their preference and considers the customers' priority for servicing and solve the proposed model with NSGA II and CPLEX Solver.

There has been some extension of this model with combined with other well-known variants of VRPs. Peiying et al. (2013) proposed a mathematical model in which Vehicle Routing and Scheduling Problem (VRSP) in picking up and delivering customers to airport service were embedded into EMVRP to considering environmental concerns of delivering and picking up the parcels to the customers. Psychas et al. (2018) conducted several investigations into proposing multi-objective energy reduction open VRP, which was solved via new variants of the Influenza Virus Algorithm (IVA). The parallel multi-start process embedded into IVA to obtain a better solution in terms of higher exploitation and exploration considered the most significant factor of any population-based algorithms.

3.2.5. Time-Dependent Vehicle Routing Problem

While the traversal times of arcs may differ over the planning horizon, a fresh area of research in freight transportation—named, TDVRP—examines how to manage the difficulties that arise from the various factors of travel speed variability. Gendreau et al. (2015) provided an extensive review of TDVRP which considered travel time modelling and solution methods. This problem was introduced by Pradenas et al. (2013), who overlooked FIFO property in their proposed model. Next, Ichoua et al. (2003) concentrated on the corresponding methodological approach. In the context of green transportation, the first attempt, carried out by Kuo et al. (2009), stated that travel speed might vary and used a TS to solve the VRPs, satisfying the objective function related to fuel consumption. In the same way, Kuo (2010) presented an optimization model of TDVRP examining fuel consumption by using simulated annealing (SA).

Lewczuk et al. (2013) published a paper in which they described a variant of TDVRP affected by traffic conditions. They also focused on measuring CO_2 emissions in congestion conditions. A mathematical optimization model that considered various aspects of real conditions was solved via a modified version of a genetic algorithm combined with a start algorithm. Norouzi et al. (2017) measured optimal speed in their model. Here, congested routes in an urban network were discarded to reduce carbon emissions and to minimize both objectives via a PSO algorithm so as to attain the highest quality of Pareto optimal solutions. Hooshmand and MirHassani (2019) propose a new extension of TDVRP considering alternative green-fuel powered vehicles to minimize CO2 emissions. Then, a hybrid heuristic algorithm is used to solve the mixed integer mathematical model to solve large instances.

VRP with time windows (VRPTW), as an important extension of the routing problem, has been widely employed in the GVRP context. Figliozzi (2012) presented a variant of TDVRP examining both hard and soft time windows. The author considered two different objectives, involving the number of routes and total time or distance, that were minimized by using a metaheuristic algorithm and termed iterative route construction and improvement. The results of this study showed that the proposed algorithm for this kind of problem has important consequences.

3.2.6. Fuel consumption in VRPs

The term *fuel consumption* has been used recently in many scientific contexts related to green freight transportation, and a new variant of GVRP—named FCVRP—has emerged, indicating the importance of minimizing fuel consumption. Significantly, although environmental aspects have been considered in most GVRPs, extensive new studies in this area focus on the consumption of fuels to express the importance of reducing negative environmental impacts in the transportation context. As far as known for all, the first work on FCVRP was a model presented by Suzuki (2011), examining CO_2 emissions as a priority. This involved the three main elements affecting fuel consumption, including distance, speed and load. To optimize the proposed model, a TS was implemented to obtain further experimental analysis.

Xiao et al. (2012) indicated that fuel consumption has a significant impact on transportation costs. They considered the fuel consumption rate in the proposed model, the extension of classical CVRP, and employed SA to solve both FCVRP and CVRP to analyze the validity of the proposed model in terms of fuel consumption. Gaur et al. (2013) presented a new model of FCVRP, combined with Cumulative VRPs. They used an intelligence heuristic partitioning for four variants of this problem. MirHassani and Mohammadyari (2014) presented an FCVRP model, in which air pollution and fuel consumption are considered to be minimized via the gravitational search algorithm in order to obtain optimal solutions in a reasonable computational time. A recent study by Psychas et al. (2016) involved a bi-objective version of FCVRP, in which the first objective examines travel time, and the second, corresponds to fuel consumption. Two types of modeling, including asymmetric and symmetric problems, were presented for multi-objective optimization, and a new version of NSGA-II, initiated with multiple initial populations, was used to solve those models. Zhang et al. (2015b) embedded three-dimensional loadings into FCVRP and developed a meta-heuristic algorithm—named the evolutionary local search (LS)—to cope with this problem. Rao et al. (2016) studied environmental sustainability by presenting mathematical modeling of FCVRP, where road gradient was considered when evaluating the objective function. To solve this model, they proposed a bi-objective hybrid LS, inspired by a hybrid LS. Niu et al. (2018a) implemented the concept of outsourcing logistics in FCVRP, leading to more complexity than its original model. The authors, therefore, suggested fuel consumption OVRP to satisfy outsourcing logistics constraints by using a novel hybrid TS algorithm, after which various experiments for types of route (closed and open) and types of vehicle were performed. Niu et al. (2018a) propose an integration of FCVRP and traditional OVRP to obtain optimal routes in the urban networks considering fuel consumption objective function. They use a hybrid method base on TS to deal with this problem. The results of this show that open routes can save the total cost by almost 19%.

3.2.7. Electric Vehicle Routing Problem

Electric vehicles (EVs), which use sustainable energy, are regarded as the cleanest fleet for producing zero emissions, and have recently received considerable attention from commercial developers and scholars. There has been a valuable study (Eguia et al., 2013), which presents a comprehensive survey on the mot leading solution approach connected with EVRP. The greatest challenge for this type of fleet arises from the duration and price of the battery, the driving distance and the replacement of conventional vehicles. The earliest studies related to this variant of GVRP were conducted by Gonçalves et al. (2011). Gonçalves et al. (2011) included both EVs and conventional vehicles in their proposed model, without examining the location of recharging stations. Conrad and Figliozzi (2011) included fast recharging features of EVs in a new mathematical model, named the RVRP. The results of this study, in which recharging time was assumed to be constant, showed a high correlation between travel distance and the derived solution bounds.

Yu et al. (2017) concentrated on plug-in hybrid EVs by introducing a new variant of the GVRP model, named the Hybrid VRP, using both electric charging and conventional fuel stations. This model was solved via a hybrid SA through developing two differences in the method. Schneider et al. (2014) stated the significance of the properties of EVs to reduce emissions and presented a mathematical model by considering two realistic constraints including recharging stations and time windows. They also presented a hybrid TS and variable neighborhood search (TS-VNS) to solve the model. Bruglieri et al. (2015) discussed how flexible routes could reduce total cost by assigning recharging battery level as a decision variable. Thus, they proposed a VNS branching to reach the optimal solution. Zhen et al. (2019) propose mixed-integer linear programming of the EVRP model, which is solved with an improved particle swarm optimization algorithm (IPSO). The experiments of this study show that the proposed approach has high efficacy for solving various test instance sizes. Zhao and Lu (2019) present a non-polluting and sustainable model of EVRP, which encourages logistics companies to use electric vehicles. They propose the ALNS method to solve twenty instances randomly generated from real-world data considering many real constraints including multi-trip, charging stations, and heterogeneous fleet. The results of this study indicate that using the proposed approach algorithm can reduce 7.52% of the total cost.

Desaulniers et al. (2016) presented four variants EVR with time windows considering the number of recharges (single and multiple) and a full or partial recharge, solved via an exact branch-price-and-cut algorithm to obtain optimal solutions. Hiermann et al. (2016) incorporated a heterogeneous fleet into EVRP to cope with such complications adopted from battery capacity in order to determine the time of recharging and the location of stations. They used an exact approach and a combination of two metaheuristics, ALNS and embedded local search (ELS), to handle the considering model.

3.2.8. Other related problems

All variants of the GVRPs above are associated with the environmental aspects of VRP. However, these are only focused on the operational-level routing decision and have overlooked other aspects related to the supply chain, such as design of the network, road tolls, reliability index, and health care concerns. Conversely, some optimization problems concerning green freight transportation cannot be categorized by these variants. In effect, it has been deliberately transferred this type of problem into a new category, termed ‘other related problems’. In this section, such studies have been reviewed, which are indirectly connected to VRP that involve ecological considerations. Paksoy and Özceylan (2014) examined a comprehensive mathematical model for supply chain network design comprising environmental concerns in a proposed objective function. In this model, many factors—such as road roughness, fuel consumption and travel time—were analyzed, and some managerial intuitions suggested were used to create an effective decision model for authorities.

Ramos et al. (2014) concentrated on presenting a proper stricter of reverse logistics systems, in which tactical and operational planning are considered simultaneously, focusing on social elements—which have been widely neglected in the literature—together with environmental aspects. They proposed a mathematical model with three objective functions. Danloup et al. (2015) studied the capabilities supply networks in terms of a sustainable perspective for food industrials, which has considerable potential in minimizing CO_2 emissions due to the large volume of work conducted by transport fleets in this area. The proposed new mathematical programming, concerning the collaboration among food industrials, will lead to reducing GHG emissions. They performed a simulation approach to determine the capability of the model and showed that a collaboration among partners can reduce emissions in the transportation sector. Sharma and Mathew (2011) examined environmental considerations in the road-network capacity by proposing a bi-objective mathematical program accounting for health-damage costs as well as travel time. A modified NSGA-II was given in order to reach the best trade-off for both objectives. Fathollahi-Fard et al. (2018) proposed a mathematical model, including environmental considerations in terms of home health care, in which such health care services are provided through a group or nurse at the patient's home. They used four heuristics based on SA to solve this problem, with two objectives consisting of traveling distance and CO_2 emissions.

3.3. Uncertainty in GVRP

Regarding various analyses, some parameters may be considered deterministic as currently known, and others considered non-deterministic or uncertain. The uncertain parameter may have a significant influence on solution quality. Optimizing a mathematical model, including uncertain parameters, is thus too sophisticated, however, the methods for optimization under uncertainty may be too complex, requiring the use of a specific method. To cope with uncertain parameters, there have been various approaches used in optimization modeling, including the fuzzy approach, chaos theory, stochastic approaches, dynamic programming, and the time-dependent approach. Hence, in order to encounter uncertain parameters effectively, it is necessary to determine the degree of uncertainty. Thus, the main parameters, considered uncertain in the green transportation context, can include travel time, speed, waiting time, demand, traffic conditions, and so on.

Encouraged by the above explanation, and now, the various parameters are emphasized to understand the main inclination of this paradigm in the literature. The diagram of different uncertain parameters is expressed in Figure 3.

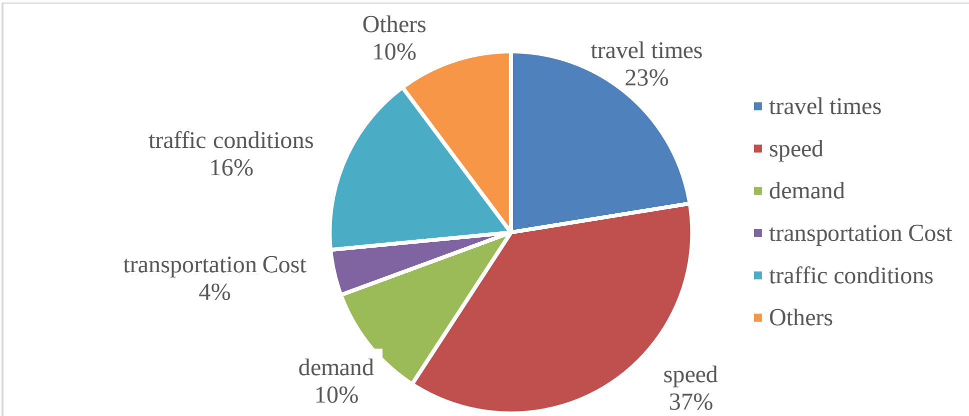

Figure 3. The distribution of uncertain parameters

As shown in Figure 3, speed of the vehicle (36.73%) is the most substantial uncertain parameter, with travel times (22.45%) in second position. Both of these parameters mainly derive from the time-dependent approach and have been widely studied, with many authors addressing two or more parameters in their studies. Some parameters, rarely used in the literature, are grouped in the *others* category, including waiting time (Mohammadi et al., 2013), capacity (Sun et al., 2018), logistics operating costs (Ćirović et al., 2014), noise (Eguia et al., 2013), and local environmental status (Jovanović et al., 2014).

3.4. Solution methodologies

In this section, different approaches are analyzed based on a mythological viewpoint. Although there may be many other solution methodologies reported in the literature, Figure 4 illustrates the main categories of solution methodologies, including metaheuristic, heuristic, exact, exact solver, hybrid, and software applications.

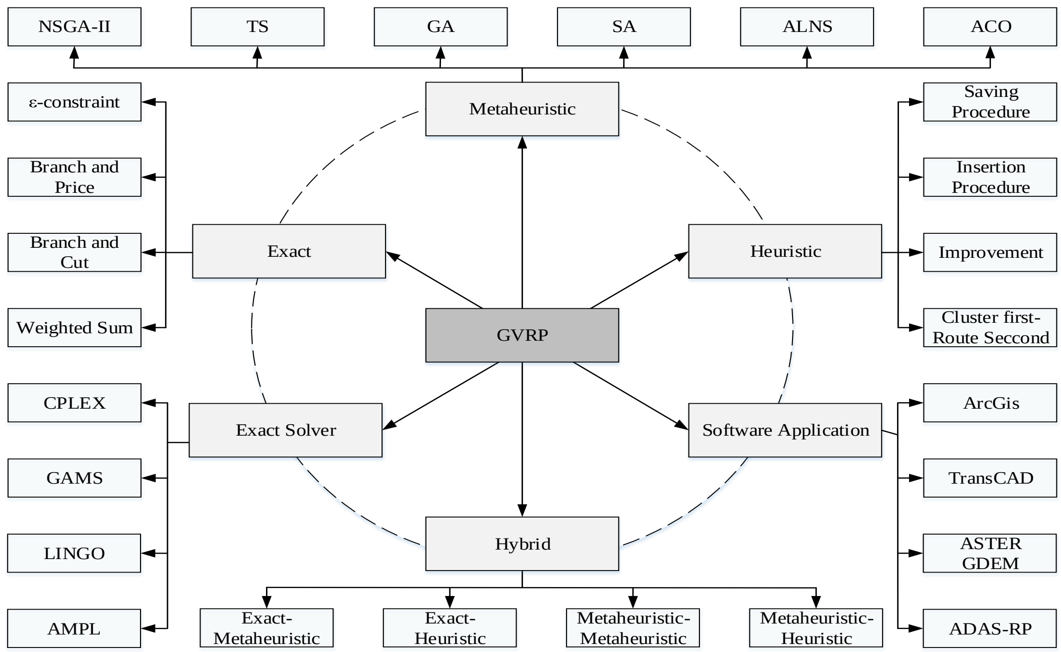

Figure 4. The general framework of solution methodologies

The first category concerns metaheuristic algorithms. The most significant methods employed in solving GVRP here are: genetic algorithm (GA) (Xiong, 2010), SA (Omidvar and Tavakkoli-Moghaddam, 2012), TS(Ehmke et al., 2016), NSGA-II (Alinaghian and Zamani, 2019), ant colony optimization (Li et al., 2019), ALNS (Demir et al., 2012), artificial bee colony (Zhang et al., 2014a), PSO (Norouzi et al., 2017), greedy randomized adaptive search procedure (García-Álvarez et al., 2018), and the influenza virus algorithm (IVA) (Psychas et al., 2018). Using software applications is an extremely powerful solution approach to apply to real-world situations. Among others, TransCAD (Christie et al., 2006), ArcGIS (Ericsson et al., 2006), the vehicle routing solution package (Palmer, 2007), ASTER GDEM (Corréïa et al., 2010), and ADAS-RP (Minett et al., 2011) are the main software used in various studies.

Another category in this dimension highlights the use of exact methods, which are extremely inadequate to solve a large-scale optimization problem. Flagship algorithms, including the ε-constraint method (Soysal et al., 2014), branch and cut (Cheng et al., 2017), branch and price (Hiermann et al., 2016), and weighted sum (Zeng et al., 2016), are the most eminent methods in this category. Some researchers have attempted to solve these problems with general exact solvers, such as CPLEX (Taha et al., 2014), Lingo (Paksoy and Özceylan, 2014) and GAMS (Alkawaleet et al., 2014). The heuristic methods have been tailored for specifics problems. This category can include the saving procedure (Aranda Uson et al., 2012), insertion procedure (Rao and Jin, 2012), improvement procedure (Oberscheider et al., 2013), and the cluster-first route-second procedure (Erdoğan and Miller-Hooks, 2012).

Sometimes, using a specific approach leads to difficulties, such as a low-quality solution, trapping in local optima in search space, or high computation time; therefore, scholars intelligently hybridize two or more algorithms to simultaneously employ strengths. Hybrid methods include exact-metaheuristic (Qian and Eglese, 2016), metaheuristic-metaheuristic (Jabir et al.) and metaheuristic-heuristic (Maden et al., 2010) algorithms in order to obtain better results.

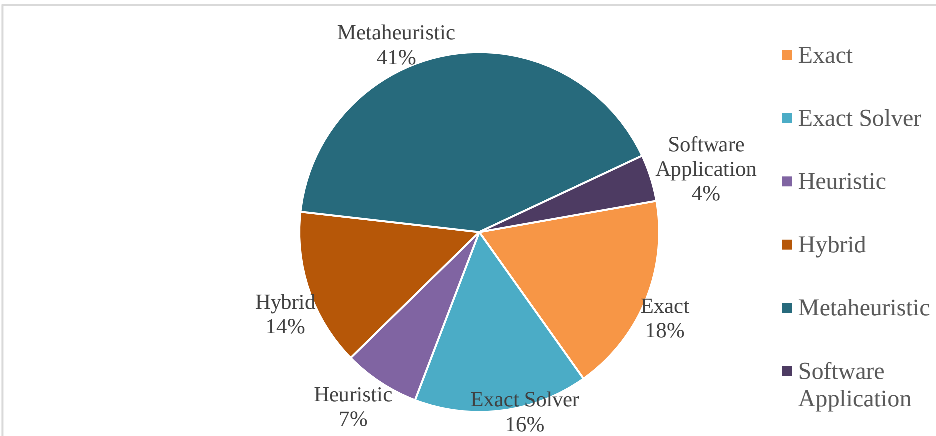

Figure 5. The percentage of using different solution methodologies in the literature

To better understand the contribution of different solution methodologies, Figure 5 illustrates the percentage of applying different solution approaches in the literature. From the condensed review above, it can conclude that metaheuristic algorithms are increasingly recognized as significant, the most applicable approach and are currently receiving considerable attention from scholars and practitioners. This result highlights the fact that little has been published on the use of software applications to date. Additionally, the small contribution of the heuristic approach (about 7%) indicates that most studies attempt to combine them into other approaches due to local optima deficiency, which commonly relates to this type of methodology by focusing on solving a particular problem. The complementary point of this section derives from Figure 6, which illustrates the trend in implementing different solution approaches in the literature. This figure demonstrates the increasing trend in using metaheuristic algorithms and confirms the significance of this approach. Overall, the exact approach and metaheuristic algorithms are the approaches most preferred by researchers.

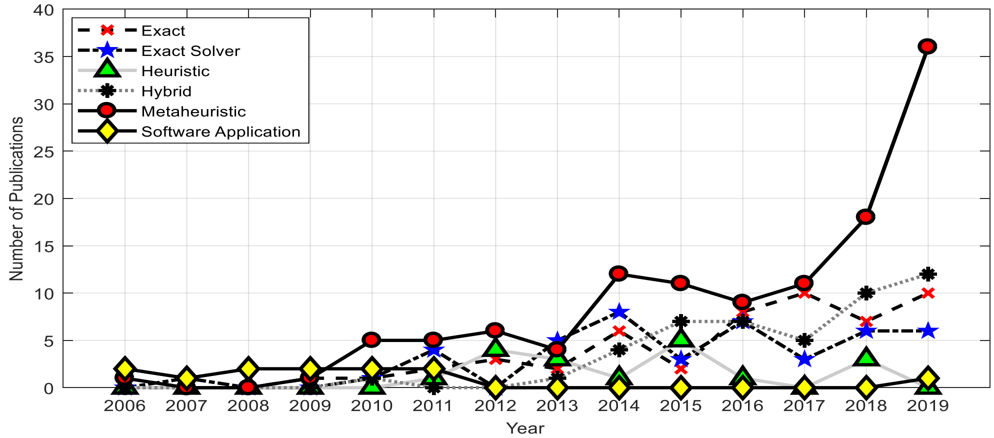

Figure 6. The distribution of different methodologies approaches published in recent years

To perceive the reasonable relationship between solution methodology and other dimensions, some valuable information is provided in Appendix 4 and Appendix 5, in which the number of publications in each cross-classification cell is reported, and some interesting implications are available. Appendix 4 provides the rational interrelations between GVRP variants and applicable solution techniques and shows that the main methods in solving many GVRP variants are metaheuristic algorithms, which have gained importance over recent years. It should be mentioned here that the solution techniques are deliberately divided into three main groups, comprising exact (consisting exact and exact solver), approximation (entailing metaheuristic, heuristic and hybrid algorithms) and others (consisting of software application), to bring a comprehensive picture of the published papers.

Reviewing the results of Appendix 5 reveals some motivating facts about these important relationships. For example, almost all problems examining the different objectives are associated with approximation approaches. It is worth noting that 29.45% (119 out of 309 papers) of the papers studied are considered metaheuristic in single objectives models, and only 7.1% used this approach in bi-objective optimization problems, which only generated appropriate instances. Therefore, it is strongly believed among scholars that metaheuristic algorithms can be declared the dominating approach for solving GVRPs.

3.5. Objective function

Approaches regarding different objectives can be investigated in several ways. Figure 7 illustrates trends in utilizing different objectives functions. Based on this figure, the popularity of different types of objectives functions in each year can be seen. While multi-objective approaches (bi-objectives and multi objectives) have received considerable attention recently, a lack of these approaches in recent publications is clearly observed (42 papers for bi-objectives and 15 papers for multi-objective papers). However, it can conclude a steady trend in using multi-objective approaches. In the following subsections, it is addressed each approach in detail.

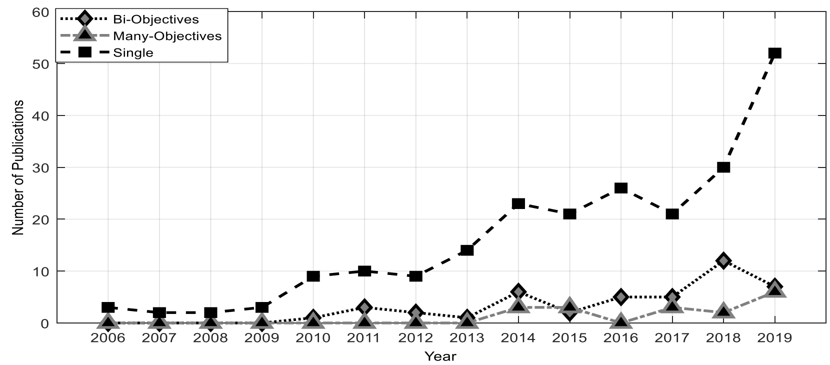

Figure 7. The distribution of different objectives approaches published in recent years

3.5.1. Single objective approach

Figure 8 illustrates that single objective optimization is the most widely used approach in green transportation context, and 231 out of 309 papers (almost 74.7%) published in this area indicate the importance of the single objective approach for researchers. Reviewing the main components of the objective functions reveals important implications for using this approach in the literature.

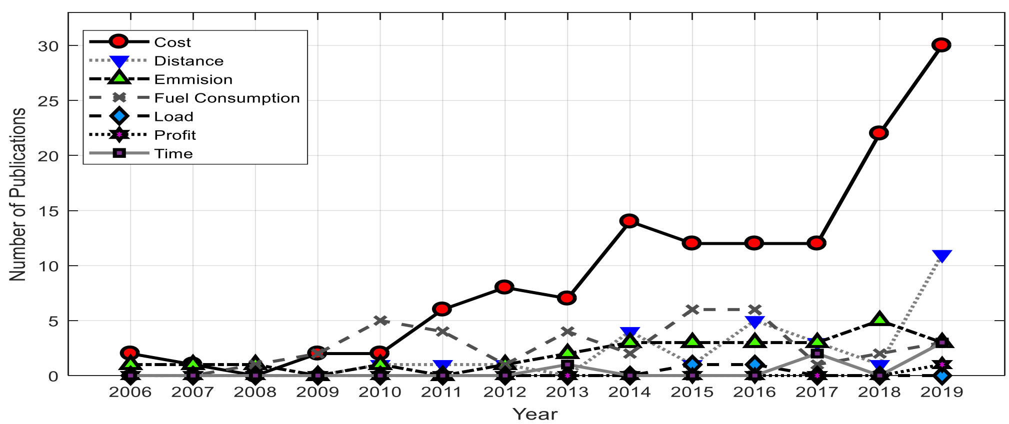

Figure 8. The distribution of different single objective function published in recent years

Cost is generally known as the most important component of the objective function in the single objective approach; hence, the components of cost used have been concentrated in the literature. Figure 9 shows the popularity of different components used as a cost in the single objective models published in recent years. Summarizing the results, it is concluded that operational cost and emission factors are the most significant components used in single objective models.

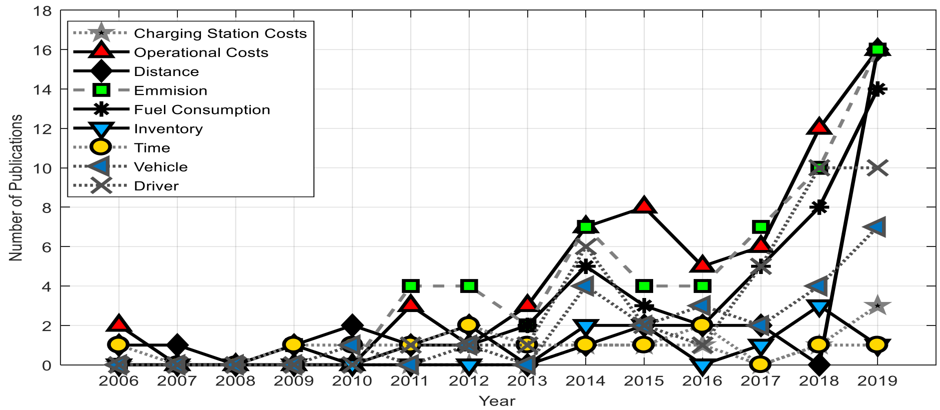

Figure 9. The distribution of different components used as cost in single objective models published in recent years

3.5.2. Bi-objective approach

To present models that are more practical in most real-world problems, researchers have attempted to develop a bi-objective optimization model. Bi-objective optimization models have been considered here in a general category, entitled multi-objective optimization (MOO). Figure 7 demonstrates a wide gap between single objective and bi-objective problems regarding the amount of published papers. The trend for using the bi-objective approach indicates a steady growth of papers that have used the multiple objectives approach in recent years. The first attempt to present a bi-objective optimization model in GVRP was conducted by Urquhart et al. (2010), who proposed two different models of a bi-objective optimization model for GVRP problem. In the first model, the distance and number of vehicles were considered, while in the second, CO_2 emission was used instead of the distance. Conrad and Figliozzi (2011) presented a bi-objective model on the RVRP in which the first objective was related to several routes or vehicles and the second objective considered total costs.

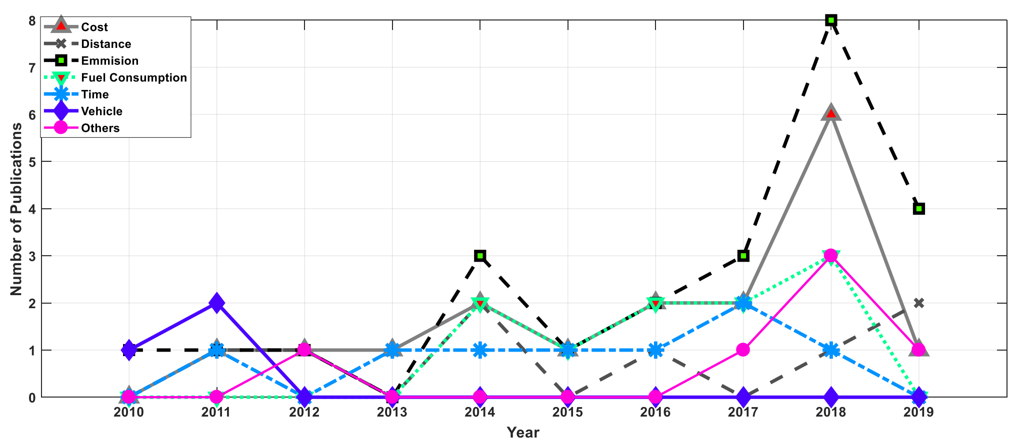

Figure 10. The distribution of different bi-objective function published in the literature

Following on from Figure 10, there has been increasing interest in using emission as the most influential factor in recent published papers. Contradicting the results of single-objective modes, cost is placed in second position in terms of the number of published papers.

3.5.3. Multi-objective approach

Real-world problems regularly involve the satisfactory conclusion of conflicting objectives, which should be solved simultaneously. In order to cope with these problems that involve more than two objectives, researchers have encountered some difficulties in obtaining an acceptable and high-quality solution for a given optimization problem. The first difficulty indicates an increase in the number of objectives leading to poor solutions for those problems categorized as multi-objective optimization problems. The second difficulty, known as the main one, is connected to an exponential growth in the number of non-dominated solutions that are required for estimating the Pareto front. There are some approaches, such as ranking methods (Garza-Fabre et al., 2009), reference point, decomposition-based methods (Han et al., 2019), niching techniques (Tanabe and Ishibuchi, 2019), region search (Liu et al., 2019), and diversity ranking methods (Chen and Li, 2019), in multi-objective optimization that can cope with those difficulties. As follows from Figure 7, multi-objective optimization models had not received any attention before 2014 when the first study in this area was conducted by Ramos et al. (2014). They considered the three pillars of sustainability in their proposed model, which included environmental, economic and social factors. Other prominent studies were implemented by Molina et al. (2014), considering internal costs, CO_2 emissions and NOx emissions. Moutaoukil et al. (2014) also addressed the three pillars of sustainability. Considering all papers in this category, it can be seen various objective functions used in the literature, as shown in Figure 11. From this figure, calculating the level of emissions is the most promising factor in the multi-objective approaches, and cost would then be another significant factor used in objective functions. The term *others* is used to show the percentage of those factors that observed in less than 4% of the literature.

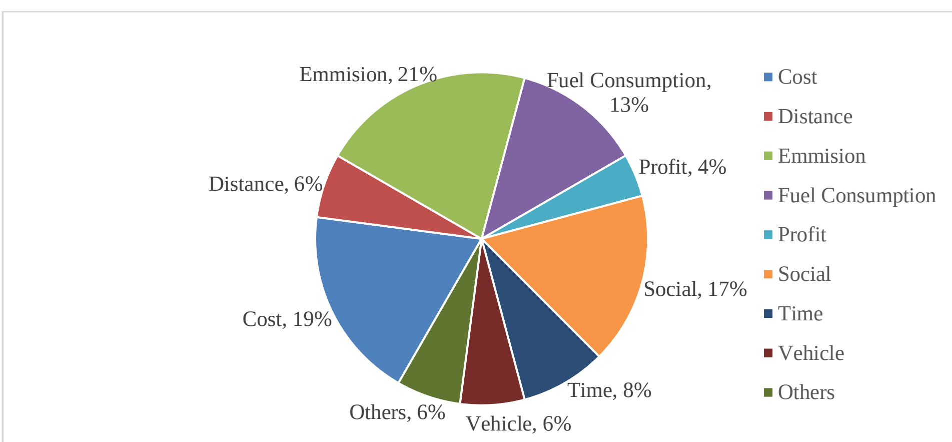

Figure 11. The percentage of using different cost function in multi-objectives models

As seen in Figure 11, the top three factors, including emission (21%), cost (19%) and social factor (17%), are the most common factors in this approach, and that over 57% of all factors are the three pillars of sustainability, which indicates the significance of sustainability in defining the objective functions.

On the social dimension, social concerns in the domain of GVRPs can be included such various range of factors that consider both customers and staff, and some concepts such as flexible working, diversity, and satisfaction are taken into consideration for both groups. In the following subsection, sustainability issues in GVRP have been considered more in-depth.

3.6. Sustainability in GVRP

The most of GVRPs model just consider the environmental and economical aspect of routing problem, and social factors are mostly overlooked in the literature. These challenges result in the development of a new concept called sustainable in routing problem in which targets to balance three pillars of sustainability, i.e. economic, environmental, and social dimensions. Researchers have not treated social sustainability in much detail, and there is no consensus on the definition of this concept in this area. By reviewing the most relevant papers in this field, it can be seen that the social sustainability concept has emerged with some issues such as human resources, safety concerns, and customer satisfaction. (Ramos and Oliveira, 2011) tended to minimize balancing the workload as an important social concern among stops by using a heuristic model. (Labuschagne et al., 2005) placed social concerns into the human resources category considering equity and safety issues into four main areas, being equity and safety within the internal human resources category.

Once the role of the human in the routing problem highlighted, the important issue comes into mind addressing safety issues. Surprisingly, there has been little attention to possible accidents and environmental concerns. The only work, in this case, was presented by (Faulin et al., 2011) interoperating both safety and environmental concerns in a road transportation problem. They proposed a heuristic minimizing the total cost of the problem. The most relevant study in this term has been implemented by (Li et al., 2019) who developed a multi-depot GVRP considering four objectives including revenue, costs, time, and emission by using improved, ant colony optimization. (Moutaoukil et al., 2014) stated that such social indicators (e.g., accident risk, noise, and congestion) are hard to measure, and they regarded the number of vehicles and total traveled distance to grasp an idea for those indicators.

4. Future Research Directions of GVRPs

To fully understand the existing gaps in the literature regarding different aspects of GVRP, the comprehensive insights obtained from this study are offered. Based on the implications of this paper, future investigations are necessary in order to validate the kinds of conclusions that can be drawn from this study. Therefore, the results of this paper are classified into the following subsections.

4.1. Opportunities for problem classifications

There have been emerged varied of studies in GVRP. Interesting research questions for future research could derive from the relationship between problem classifications and the variants of GVRPs. Therefore, the interrelationship between problem classifications and GVRP variants has been presented , as shown in Appendix 3. The main opportunities for problem classifications are as follows:

1- It is apparent that no extant research in the literature focuses on PRP, EMVRP, FCVRP, and EVRP. As far as known, only a few studies have investigated the GVRP variants (Lin et al., 2014); in particular, no study—to our knowledge—has comprehensively considered all GVRP variants,. Certainly, there have been specific papers consisting of surveys, reviews and case studies in exploring all variants of GVRPs (Lin et al., 2014). Consequently, this study discloses that review studies are essential and, in this regard, a gap exists in the literature.

2- Most studies examining different problem approaches to GVRPs focus on specific aspects. For example, city logistics problems have mainly considered TDVRP; on the other hand, no studies consider HVRP and city logistics problems.

3- Lastly, this innovative modeling method may interest researchers. Many classical VRP variants do not occur in any GVRPs variants. Several valuable studies integrate VRP variants into green transportation context, such as open VRP (Niu et al., 2018a), VRP with pick-up and delivery (Tajik et al., 2014), multi-trip VRP (Tirkolaee et al., 2018), multi-depot VRP (Ma et al., 2018), and multi-echelon VRP (Soysal et al., 2015). Nevertheless, consideration of other operational constraints driven from other VRP variants (for example, site-dependent VRP, periodic VRP, and multi-compartment VRP), remain open to investigation.

4.2. Opportunities for considering uncertainties

The findings of this study, as illustrated in Figure 3, provide a general view to determine the opportunities for employing uncertain parameters. Accordingly, many scholars consider that speed is the most dominant parameter. Figure 3 reveals some interesting facts; for example, in such studies where travel time is considered to be as the uncertain parameter, it can be concluded that TDVRP is observed to define the general model. This fact is also apparent in the speed parameter, dominantly presented in TDVRP models. Moreover, some studies have focused on other parameters, such as logistics operating costs (Ćirović et al., 2014), local environmental status (Jovanović et al., 2014), noise(Eguia et al., 2013), and capacity (Sun et al., 2018), which could all indicate future research directions. Therefore, the main opportunities for considering uncertainties are as follows:

1- Formerly, most studies considered time-dependent concepts to manage uncertainties. Nevertheless, in recent decades, some new methodological approaches have appeared in the literature; namely, chaos theory, quantum computation, and the fuzzy logic approach, which have previously been largely neglected in the literature. From the fuzzy theory perspective, researchers impede fuzzy logic to enhance the non-linear programming model, which considers some parameters in order to optimize possible variations. Most studies in this area consider the fuzzy chance-constrained mixed integer non-linear programming model (Sun et al., 2018; Wang et al., 2019). In terms of stochastic optimization, however, only a few studies have shown an application of this approach in the green freight transportation context. These studies feature the most prominent research in stochastic optimization, largely focusing on speed and travel time parameters (Rahimi et al., 2017). Therefore, another future direction in this area could be to extend this approach to other parameters. In addition, no study to date has considered two-stage stochastic approaches instead of regular stochastic programming, which may be an interesting potential future direction. In terms of robust optimization application, numerous studies have investigated this approach in this context. Tajik et al. (2014) attempted to present a new PRP model, in which time window and pickup-delivery constraints are implemented with uncertain travel time. Another important study in this area was conducted by (Eshtehadi et al., 2017). They consider two parameters, namely demand and travel time, as uncertain inputs in the mathematical model. All studies mentioned here have only considered demand and travel time parameters, without considering other significant parameters.

2- By reviewing all papers in the context, it is concluded that the forecasting approach was rarely investigated. The only study in this subject, to our knowledge, is reported in (Ćirović et al., 2014), in which the cost of each link is estimated using the neuro-fuzzy model. Therefore, investigating the forecasting approaches (e.g., neural network and regression) of different parameters would be an interesting subject in GVRP as a future research direction.

3- Demand, speed, and travel time are the most promising parameters viewed as an uncertainty in this area. Nonetheless, other non-deterministic parameters have clearly been overlooked. Such new parameters, related to sustainability (e.g., social concerns, customer willingness, driver pattern, and operational risks) of the supply chain network can be investigated as another future research direction.

4.3. Opportunities in solution methodologies

Providing interrelationships between solution mythologies and GVRP variants, as shown in Appendix 4, can disclose some significant opportunities for future research. For example, metaheuristic algorithms are dominant methods for all variants of GVRPs, indicating the significance of this approach compared with others. Exact methods are only rarely implemented in TDVRP. As mentioned, metaheuristic is the most applicable approach in solving GVRPs, however, no consensus exists among researchers about the appropriateness of such methodology. For a better understanding, all solution methodologies are intentionally categorized into two main groups: approximation (metaheuristic, heuristic and hybrid) and exact (exact and exact solver). Appendix 4 shows approximately 60% (183 out of 309) papers used the approximation approach to solve the problem, while about 32% (97 out of 309) papers performed the exact approach to obtain optimal solutions. There have been many potential opportunities in solution methodologies, and the most significant of them can be presented as follows:

1- Most studies attempted to solve a large and complex problem in which using the approximation approach was obligatory, while in fact, the quality of solutions is the most challenging subject. In addition, it is important to note that the exact approach is hardly accepted for a real-world problem. Considering these key points, a large gap between practical and theoretical solutions is a significant topic, which is concerned as a potential issue for future research.

2- Considering the metaheuristic approach, 32, 18, 17, and 11 papers clearly used a GA, SA, ALNS, and TS approach, respectively, indicating a lack of knowledge of the new metaheuristic methods in these studies. Moreover, few studies have focused on implementing a new metaheuristic: see for example, Monkey King Evolution (Meng and Pan, 2016), IVA (Psychas et al., 2018) and the Artificial Immune System (Balamurugan et al., 2018) in GVRPs, seen as being indicative of a significant gap in the literature.

3- Conceivably, hybrid algorithms may present another suitable approach to cope with solving complex problems, whereby innovative methods, combining exact and approximation approaches should be retained to attain better solution methods. Accordingly, studies by Maden et al. (2010), try to improve solution quality by developing hybrid algorithms.

4.4. Opportunities for single and multiple-objective approaches

Objective functions are the core components of mathematical models, which are interesting for future research directions. Among various objective functions, a substantial amount of the latest literature on green transportation problem considers single objective optimization. This is because of the simplicity in performing this kind of problem compared with the multi-objective optimization problem (including bi-objectives and many-objectives). Figure 7 illustrates that cost is the most significant function in the single objective optimization approach, and emission and fuel consumption also feature. Meanwhile, revenue has received less attention compared with other functions. Considering these functions, researchers have overlooked some sustainable factors—including customer satisfaction and driver workload—which may present a potential research direction. Some objective functions are considered in multi-objective approaches, but no specific papers consider them in single objective optimization. In this regard, some objectives such as route balance (Tunga et al., 2017), reliability of the system (Rabbani et al., 2018), total capacity (Sawik, 2018), customer satisfaction (Ghannadpour and Zarrabi, 2019), and social cost (Ramos et al., 2014), could be addressed here. In terms of GVRP's variants, HVRP and EMVRP have rarely been considered in the single objective optimization approach. Also, in terms of solution methodologies, researchers have paid less attention to the heuristic approach. Following, some opportunities for single and multiple-objective approaches are explained.

1- In real-case problems, there have rarely been single objective problems, even though it is crucial to consider multi-objective functions. Only 61 (44 papers in bi-objectives and 17 in many-objectives) among 309 papers—which is almost 20%—consider multi-objective problems, which confirms the high potential of implementing multi-objective optimization problems in the green transportation context. From the methodological viewpoint, the exact solver approach is rarely used for bi-objective problems, while the heuristic approach is completely overlooked in many-objective problems in the green transportation context.

2- Several papers in the literature have considered more than three objectives in their proposed models. (see, for example, (Muñoz-Villamizar et al., 2017)), indicating the importance of this kind of approach.

Appendix 2 contains further details. The most significant difficulty in performing the multi-objective approach (for example, the Pareto-based metaheuristic algorithm), is the quality of the solution which needs to be enhanced by incorporating new approaches. For instance, the reference points approach used in the none-dominated genetic algorithm-III (Wu et al., 2018) achieves better optimal solutions. Performing such exact methods, such as weighted sum approaches (Rahimi et al., 2017; Sawik, 2018) fails to solve some problems in non-linear programming approaches. Therefore, a combination of well-known approaches to obtain more robust and appropriate methods may be an interesting topic for future research. In this regard, (Govindan et al., 2014) is suggested.

3- Some scholars regard new green, social and resilience objective functions to be the leading area for research in the freight transportation context. Reviewing the trend of sustainable objective functions indicates that researchers will pay more attention to sustainable objective functions, which can be acknowledged as a future direction for research. Interesting paper to mention in this regard is (Eguia et al., 2013).

5. Conclusions

This paper considers a systematic literature review of recent and state-of-the-art papers in different scientific journals focusing on the green freight transportation context, which are extensively addressed in the last decade. In total, 309 papers published between 2006 and November 2019 have been chosen, reviewed, classified, and evaluated in order to determine further work is foreseen, which includes an extensive study on a larger number of published papers in this area.

This paper is the most recent contribution to ongoing discussions about green freight transportation problems. To obtain a clear future direction, some interrelationships are proposed in terms of various dimensions. The innovative way of modeling, using advanced methods in analyzing uncertainties, and considering new parameters related to sustainability, are recognized as future opportunities for researchers. An additional future direction is identified, which is based on the methodological approach of applying new metaheuristic algorithms and utilizing hybrid methods. Considering multi-objective optimization models have been suggested in some variants of GVRPs, which are generally neglected, and developing objective functions to capture green, social, and resilience concepts for future research in this area. Finally, as a result of this study, it is concluded that the numbers of research studies interested in GVRP have grown rapidly and that this paper could thus trigger new research agendas in this context.

Appendix 1. The main source of literature based on different years

Row Labels	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Grand Total
Applied Soft Computing									1	1	1	1	1	1	6
Computers & Industrial Engineering				1	1					1	2	1		3	9
Computers & Operations Research							1			3	1		3	8	16
European Journal of Operational Research							2		1	4	5	2		5	19
Expert Systems with Applications								1	4				1	2	8
International Journal of Production Economics						1		1	3	4	2		2	2	15
Journal of Cleaner Production												2	6	10	18
Mathematical Problems in Engineering												1	2	2	5
Sustainability									1			1	3		5
Transportation Research Part B: Methodological						1		2	1	1	3	1	1	2	12
Transportation Research Part C: Emerging Technologies	1					1					3	2		1	8
Transportation Research Part D: Transport and Environment						1		1	1			3	3	1	10
Transportation Research Part E: Logistics and Transportation Review							2	1	1		1	4	1	1	11
Transportation Science									1		1	2		1	5
Other	2	2	2	3	9	10	11	9	21	17	14	11	21	30	162
Grand Total	3	2	2	4	10	14	16	15	35	31	33	31	44	69	309

Appendix 2. Different objective functions utilized in GVRP for many-objective models.

Number of Publication	Type of Objectives	Reference
12	Tri-Objectives	(Ghannadpour, 2019; Goeke and Schneider, 2015; Molina et al., 2014; Moutaoukil et al., 2014; Psychas et al., 2017; Raeesi and Zografos, 2019; Rahimi et al., 2017; Ramos et al., 2014; Sadeghi Rad and Nahavandi, 2018; Xiao and Konak, 2015; Yang et al., 2015; Zhu and Hu, 2019)
4	Four-Objectives	(Ghannadpour and Zarrabi, 2019; Li et al., 2019; Muñoz-Villamizar et al., 2017; Rabbani et al., 2018)

Appendix 3. The mutual interrelationship between problems and GVRP variants.

Row Labels	EMVRP	EVRP	FCVRP	GVRP	HVRP	PRP	Other	Grand Total
City Logistic	2	3	2	12		3	11	58
Conceptual	10	12	18	57	15	18	2	136
Designing and location	1	29	2	21			8	61
different analysis	1	1	1	5	3	1	3	16
Inventory management	1		1	11	1	2		16
Literature review		1		5	1		5	13
Special Studies		1		4			4	9
Grand Total	15	47	24	115	20	24	32	309

Appendix 4. The mutual interrelationship between solution methodologies and GVRP variants.

Row Labels	Exact	Exact Solver	Heuristic	Hybrid	Metaheuristic	Software Application	Not Applicable	Grand Total
EMVRP	2	2	2	3	6			15
EVRP	9	7	1	6	23		1	47
FCVRP	4	4	2	4	10			24
GVRP	22	17	5	19	43	2	7	115
HVRP	3	5	1	2	8		1	20
Other	4	5	1	2	4	10	7	33
PRP	7	3	1	4	9			24
TDVRP	2	1	5	6	16		1	31
Grand Total	53	44	18	46	119	12	17	309

Appendix 5. The mutual interrelationship between the number of objectives and solution methodologies.

Row Labels	Single	Bi-Objectives	Many Objectives	Not Applicable	Grand Total
Exact	38	9	6		53

Exact Solver	40	2	2		44
Heuristic	15	3			18
Hybrid	35	8	3		46
Metaheuristic	91	22	6		119
Not Applicable				17	17
Software Application	12				12
Grand Total	231	44	17	17	309

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