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City Vehicle Routing Problem (City VRP): A Review

Gitae Kim, Yew Soon Ong, Chen Kim Heng, Puay Siew Tan, and Nengsheng Allan Zhang

***Abstract*—Lately, the Vehicle Routing Problem (VRP) in the city, known as City VRP, has gained popularity with its importance in city logistics. Similar to city logistics, City VRP mainly differs from conventional VRP in terms of the stakeholders involved, namely the shipper, carrier, resident, and administrator. Accordingly, this paper surveys the City VRP literature categorized by stakeholders and summarizes the constraints, models, and solution methods for VRP in urban cities. City VRPs are also analyzed based on the problem of interest considered by the stakeholders and the corresponding models that have been proposed in response. Through this review, we identify the state of the art of City VRP, highlight the core challenging issues, and suggest some potential research area in this field that have remained underexplored.**

***Index Terms*—City logistics, City vehicle routing problem, stakeholders.**

I. Introduction

A variety of different types of freights such as consumer goods, materials, mails/packages, and waste products flow through the city. Notably, these flows account for one fourth of street traffic in a typical city [1]. Growth of city logistics research has been driven by the increase in city population, traffic problems, and public pressure [2]. The culmination of all the above factors calls for city Vehicle Routing Problem (VRP), which attempts to address the concerns above as a whole. This is in contrast with general studies in VRP, which typically focuses on solving the problems partially. Accordingly, VRP, particularly City VRP, which provides the core solutions in city logistics [3] has recently received renewed attention among researchers and practitioners of transportation and logistics study. Despite the trend, there has been a lack of survey on the state of art in City VRP.

In addition to the conventional vehicle routing, City VRP considers problems arising in the city, including traffic regulations, traffic congestion, road condition, parking space, air pollution, noise pollution, and emergencies. Particularly, City VRP takes into account on the economic profits and public interest involved. One of the key differences between conventional vehicle routing and City VRP is the environment of the latter which revolves around the stakeholders, but rarely considered in conventional vehicle routing. In City VRP, shippers, carriers, residents, and administrators are the four key stakeholders of interests. These four stakeholders tend to have different and sometimes conflicting objectives. For example, shippers aim to maximize service level, carriers focus on minimizing travel costs, residents want the best living conditions, while the administrators are interested in the best policy for managing the city. These goals are highly correlated with each other. For instance, there may have a conflict between shippers and carriers goals since the solution of minimum travel cost may reduce the service level. The goal of residents may be interdependent with the goal of administrators in terms of environmental conditions. As a result, if we consider only one or two stakeholder(s) in City VRP, we may arrive at a local optimal solution. In City VRP, the interests of all stakeholders are considered and should be addressed in tandem.

The objective of this review is to provide the status quo of City VRP research and examine the considerations for stakeholders and characteristics of City VRP in the literature.

The contributions of this paper are three-folds. First, this paper categorizes the literature of City VRP according to the stakeholders of interests. Second, we provide a comprehensive review of the diverse City VRPs that have been considered in the literature. Last but not least, this survey focuses on the important and commonly studied issues of City VRP in terms of the problems, constraints and solutions identified. Some underexplored research areas are then highlighted.

Due to the rising urbanization worldwide, relevant topics of City VRP have been surveyed or studied by many in the recent years. Cuda *et al.* [4] surveyed two-echelon VRPs as well as the location routing problem (LRP) in distribution systems. Demir *et al.* [5] comprehensively discussed the affecting factors and emission models of fuel consumptions in green road freight transportation. Juan *et al.* [6] introduced an interesting VRP, which is the so called VRP with multiple driving ranges where the electric vehicles have differing travel distance ranges imposed. In contrast, the present review bears two main differences to other surveys on city Logistics or VRP ([2]–[5], [7], and [8]). First, this paper focuses on City VRP,

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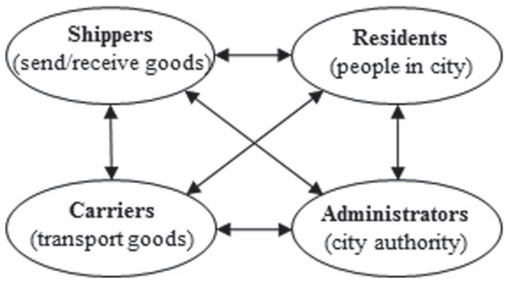

Fig. 1. Stakeholders in city logistics (see [3]).

while earlier works have placed their interest in city logistics or general VRPs. Although City VRP represents an important topic of city logistics, to the best of our knowledge, there is a lack of survey on the literature of City VRP. Furthermore, in contrast to the conventional VRP, we categorize the literature of City VRP based on the core stakeholders of city logistics. This review also investigates the characteristics of City VRP that we believe are of utmost concern to the stakeholders.

A. Motivation

Taniguchi *et al.* [3], [9] defined city logistics as "*the process of totally optimising the logistics and transport activities by private companies in urban areas while considering the traffic environment, the traffic congestion and energy consumption within the framework of a market economy*". They further established that "*the aim of City Logistics is to globally optimise logistics systems within an urban area by considering the costs and benefits of schemes to the public as well as the private sector*".

According to Taniguchi *et al.* [3], there are four key stakeholders in city logistics, namely, the shippers, freight carriers, residents and administrators, as depicted in Fig. 1. The figure shows a complete network of interactions between the four stakeholders. The bidirectional arrows portray a closely coupled relationship between all four stakeholders, where any policy implemented by a stakeholder shall affect the others either through direct influences or indirect impacts.

The independent roles and objectives of each stakeholder are summarized in Table I. Shippers aim to sell their products to customers while attempting to maximize their customer service levels. Carriers provide transportation services from shippers to customers while minimizing the transportation cost incurred. Residents wish to live in a pleasant environment free of pollution, traffic congestion, and accidents. Administrators, on the other hand, are more interested in raising the economic and environmental conditions of the city.

From our survey of the literature on City VRPs, the key objectives of the problems addressed to date revolved around the combining interests of the stakeholders involved. With the stakeholders taking center stage in City VRP and given the high interactions among them, in this survey, we review existing works according to how the interests of one or more stakeholders are taken into considerations and how the problems identified have been addressed.

TABLE I
ROLES AND OBJECTIVES OF STAKEHOLDERS [3]

Stakeholders	Roles	Objectives
Shippers	Send goods to other companies or customers (Customers of carriers)	Maximize the level of service
Carriers	Transport goods	Minimise cost of transportation
Residents	People who live, work and shop in the city	Minimise air pollution, noise pollution, traffic congestion and accidents near residential area
Administrators	Manage the city	Enhance the economic development of the city, alleviate traffic congestion, improve environment within the city

Past literatures ([2]–[5], [7], and [8]) have focused on methodologies and solutions that have been proposed to solve variants of Vehicle Routing Problem with little or no emphasis on how existing works contribute to the stakeholders of city logistics.

In contrast to previous works, this paper attempts to identify the gaps between City VRP studies and the concerns of the stakeholders, while providing an overview of the objectives, models and solutions that have been proposed in solving the core variants of City VRP. At the end of this paper, a summary on the results of our review will be given and suggestions of areas for further research will be provided.

B. Brief History

VRP was formulated as a mathematical programming model by Dantzig and Ramser [10] (1959). In 1964, a seminal heuristic method was proposed by Clark and Wright [11]. In 1981, Lenstra and Rinnooy Kan [12] proved that VRP is NP-hard. Over the past decades, extensive studies on VRP models and their solutions have been conducted and reported. Dulac *et al.* [13] (1980) and Chapleau *et al.* [14] (1985) proposed a solution method for school bus routing in urban areas. They decomposed the problem into two stages: assignment and routing to solve the VRP. Public transit in a big city was also discussed in 1990 [15].

The work of Taniguchi *et al.* [9] (1999) on 'City Logistics' has led to renewed interest in VRP, particularly, City VRP among researchers and practitioners. For excellent reviews on city logistics, the reader is referred to [2] and [3]. Real time traffic information has been a key driver in City VRP [16], where intelligent transportation system (ITS) has been introduced to harness real time data in providing sensible routes [17]. Vehicle and access time regulations have emerged to reduce air or noise pollution and control traffic flows in urban area [18]. More recently, topics pertaining to fuel consumption and environmental issues have also received increasing attention among the researchers of City VRP.

C. VRP Background

The Vehicle Routing Problem (VRP) is an extension of the Travelling Salesman Problem (TSP). Given a depot and several

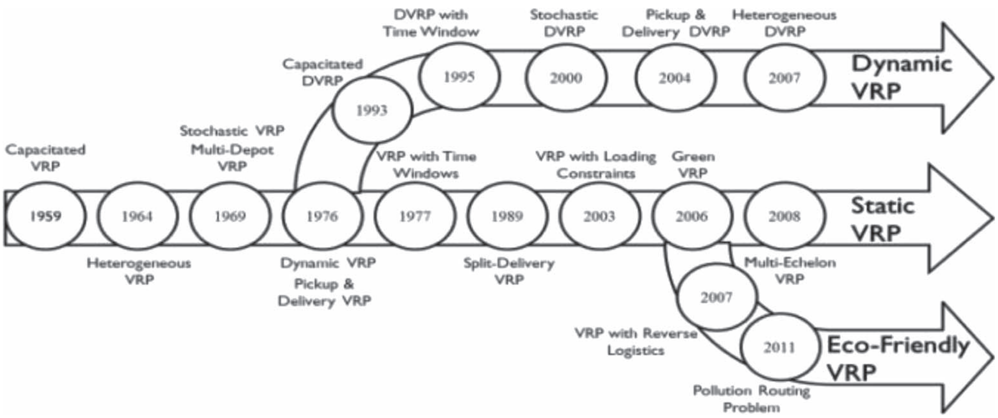

Fig. 2. Historical timeline of vehicle routing research.

vehicles and customers, the problem is formulated as an attempt to answer the question; *how do we route the vehicles to service all customers while minimizing the total travelled distance*?

In order to tackle the aforementioned question, VRP can be regarded as a fusion of two problems; the Bin Packing Problem (BPP) and the Multiple Travelling Salesman Problem (m-TSP). The former is a problem of packing several items of different volumes into a given fixed sized bin, while the latter is a generalization of the TSP involving more than one salesman. VRP was first proposed by Dantzig *et al.* [10], [19], [20], which is formally known as the Capacitated Vehicle Routing Problem (CVRP) today.

Let $G = (V, A)$ be a complete graph, where $V = \{0, 1, 2, \ldots, n\}$ is the set of vertices (0: depot, $1 \sim$ n: customer sites) and $A = \{(i, j) | i, j \in V, i \neq j\}$ is the arc set. Non-negative cost c_{ij} associated with arc $(i, j) \in A$ denotes the travel cost from i to j. Assume that there are K identical vehicles with capacity C. Let $S \subseteq V\{0\}$ be the customer set and $r(S)$ be the minimum number of vehicles required to service all customers in S. The decision variable x_{ij} is 1 if arc (i, j) belongs to the optimal route and is 0 otherwise. The basic model of VRP as given in [21] is

$$(\text{VRP}) \quad Min \sum_{i \in V} \sum_{j \in V} c_{ij} x_{ij} \tag{1}$$

$$\text{s.t.} \sum_{i \in V} x_{ij} = 1, \forall j \in V \setminus \{0\} \tag{2}$$

$$\sum_{j \in V} x_{ij} = 1, \forall i \in V \setminus \{0\} \tag{3}$$

$$\sum_{i \in V} x_{i0} = K \tag{4}$$

$$\sum_{j \in V} x_{0j} = K \tag{5}$$

$$\sum_{i \notin S} \sum_{j \in S} x_{ij} \geq r(S), \forall S \subseteq V \setminus \{0\}, S \neq \emptyset \tag{6}$$

$$x_{ij} \in \{0, 1\}, \forall I, j \in V. \tag{7}$$

The objective function (1) minimizes the total travel cost. Constraint (2) is the indegree, which denotes that exactly one arc leaves each node. Likewise, (3) denotes the outdegree which states that exactly one arc enters each node. Constraints (4) and (5) impose the requirements for the depot node. Capacity cut constraint (6) ensures the vehicle capacity requirements and the connectivity of the solution are satisfied.

Since the introduction of VRP by Dantzig *et al.* [10], many variants of VRP that model real world scenarios more closely have been investigated. Fig. 2 provides a brief overview of VRP variants (Interested readers may refer to a survey done by Lin *et al.* [8] and Pillac *et al.* [7] for more details), categorized into 3 separate tracks, namely, Static VRP, Dynamic VRP and Eco-Friendly VRP, and their period of introduction in the last five decades.

In recent years, the process of urbanization has led to the concentration of population in city areas. This not only resulted in worsening traffic congestion, it also led to the requirement for shorter reaction time to changes in customer demands and traffic conditions. Furthermore, the emergence of Internet shopping and same day delivery has pushed for shorter delivery time to transpire as top of the requirements list for logistics service providers. Moreover, the concentration of the population in city areas has also worsened pollution level in the city. In order to tackle the problems that arise from the issues above, the study of city logistics has received a surge in the last decade. Based on the analysis of Taniguchi *et al.* [9], the six main characteristics (constraints) of City VRP can be summarized as follows:

a) Each customer can have pickup and delivery orders instead of strictly pickups or deliveries.
b) Each customer is serviced within their preferred time windows.
c) Traffic regulation and laws govern the movement of vehicles in the city.
d) One of the objectives of city logistics is to improve air and noise pollution in the city.
e) Fast response to changes during execution of last mile deliveries is a necessity.
f) Intelligent Transportations Systems (ITS) is a main component of city logistics that helps to regulate traffic in the city.

It is critical to note that the characteristics above address the aforementioned problems in City VRP. In the next few sections, we summarize the progress made in city logistics, specifically

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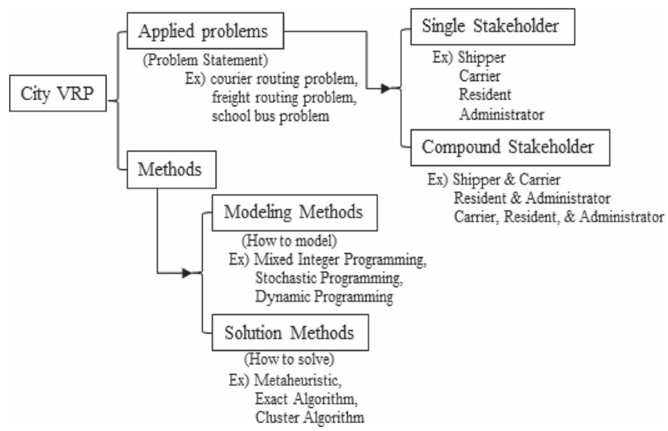

Fig. 3. Categorization of City VRP literature.

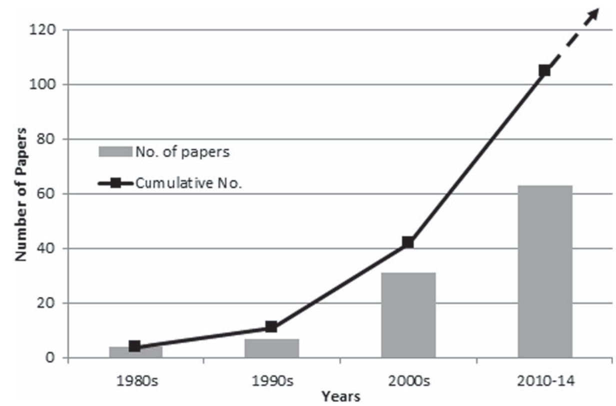

Fig. 4. The growth in City VRP publications.

focusing on the issues involving vehicle routing. Here, the City VRPs are categorized according to the stakeholders involved. The constraints, models and solution methods of VRP in urban cities are also discussed.

D. Search Process and Categorization

The databases utilized in our literature review include ScienceDirect, Compendex and Inspec. We used the search terms '*urban vrp*' and '*city vrp*' in Compendex and Inspec while '*green logistics*' in ScienceDirect to identify the relevant publications of City VRP.

According to the objectives of the stakeholders outlined in Table I, the publication articles are categorized to fall under one or more stakeholders. To be precise, the objective functions and contributions of each article are mapped to those of the stakeholders and subsequently categorized under the stakeholder(s) if a close match is asserted.

Fig. 3 presents the categorization of City VRP research works used in this review paper. First, we categorize the articles into '*Applied problems*' and '*Methods*'. 'Applied problems' denotes the type of problems that have been studied in the literature. 'Methods' denotes how a problem is modeled and solved. Then, we further sub-categorize 'Methods' into '*Modeling Methods*' and '*Solution Methods*'. Under the category of 'Applied problems', the focus is placed on the interests of each stakeholder or the interests of compound stakeholders (more than two stakeholders). Last but not least, in the summary section, the core characteristics (constraints) of City VRP considered in the interests of stakeholders are identified and analyzed.

For the sake of brevity, Fig. 3 depicts the taxonomy of City VRP literature according to how it has been described, modeled and solved. Particularly, the present review identifies how stakeholder(s) have been taken into considerations in City VRP research.

E. Growth of City VRP Research

Fig. 4 tabulates the quantity of City VRP articles that have been published in the recent decades. From the figure, an exponential increase in the number of published papers on City VRP over the years can be observed. Extrapolating from this rising trend, the number of studies for City VRP is expected to increase in the near future as depicted by the dotted line.

II. City VRP

In this section, we categorize the City VRPs into 'Applied problems' and 'Methods (Modeling and Solution methods)' as described in Fig. 3. In particular, the 'Applied problems' is further categorized in terms of the stakeholders involved.

A. Applied Problems

Vehicle routing is an important problem of city logistics. Here, studies on City VRP are categorized according to the shippers, carriers, residents, and/or administrators stakeholders(s) involved. Each sub-section then details the six main characteristics [(a)–(f)] of City VRP described in Section I.

1) Carriers: Carriers provide transportation services to shippers and/or residents. This subsection reviews City VRP that considered carriers as the sole stakeholder.

An important feature in the city environment may be the frequent stop-and-go vehicle behaviors. Vehicle specifications thus play important roles on overall fuel consumptions. In addition to vehicle capacity which is considered in heterogeneous VRP, other specifications involve the type of duty, alternative vehicle (electric vehicle), size of vehicle to fit the city area and others. Nevertheless, there is a lack of reviews on vehicle specifications relating to City VRP in the literature. Ceder [19] studied the vehicle scheduling problem by taking into account the relationships between the nature of each trip and vehicle types.

In the city area, traffic regulations are often imposed so as to control or restrict the flow of each vehicle type, number of vehicles, etc. One of the research contributions in City VRP considered the use of regulations to accommodate special cases such as emergencies [22]. In their study, traffic signal preemption was used to enable emergency vehicles to take priority at intersections or bridges. Research has also been done on fast response decision making and vehicle routing during disasters such as earthquakes in the city area [23]. Furthermore, intelligent transportation systems (ITS) have been proposed to achieve dynamic vehicle routing (DVR) in urban areas [16].

Recently it has become clear to many practitioners and researchers that distance based vehicle routing may not be the most appropriate option for addressing city logistics problems due to the heavy traffic congestions, short road spans, numerous junctions/intersections/traffic lights, poor road conditions and city regulations. In response to the above considerations, time dependent vehicle routing has been introduced to focus on the actual duration spent between two locations, instead of distance based measures [24], [25]. For example, Hu *et al.* [26] solved a wholesaler's delivery problem for a grocery company in Beijing using a time dependent VRP model. In the interest of solving more realistic problems, cases where the travel period between two locations changes dynamically with time has also been considered [27], [28].

Unexpected situations such as traffic jams or accidents compound on the difficulty of dynamic vehicle routing in the city. An efficient way to resolve this problem is through the application of multi-layer or multi-echelon vehicle routing [29]–[31]. The most commonly used multi-echelon VRP is the two-echelon VRP, which consists of two levels of vehicle routing. In the first level, vehicles travel from a single depot to multiple satellite facilities. The second level then encompasses routing the vehicles from the satellite facilities to the customers. The goal of this problem is defined as to minimize the total transportation costs at both levels. With such a structure, the risk of delay can be reduced.

The use of spatial data has been shown to be useful on a number of vehicle routing problems such as the trash collection problem of which demands are located along the arcs and at nodes in the city [32], [33]. Geographical information system (GIS) has also been put into use in City VRP [34]. By including greater details in the available spatial information, a multi-hierarchical urban map was introduced by Galindo *et al.* [35]. In their study, drivers may choose routes with specific factors taken into consideration such as crime rate, popularity of the area, and preference of neighborhoods, despite an increase in the resultant transportation cost.

Many forms of uncertainties can be found in City VRPs including traffic condition uncertainties, vehicle condition uncertainties, customer demand uncertainties, etc. To model the presence of uncertainties, travel time and(or) customer demand are(is) assumed to be stochastic process(es) [36], [37]. Kim *et al.* [38] assumed the travel time is stochastic and nonstationary (time-varying distribution). To reduce the uncertainty of travel time in dynamic vehicle routing, Kong *et al.* [39] used both historical traffic data and real time information to find the optimal routing.

Some studies have also discussed vehicle-related conditions including vehicle type, fuel consumption, and vehicle breakdown in City VRP research. Depending on the condition of the road, parking area or city regulations, the size or capacity of vehicles need to be considered during vehicle route planning [19], [40]. Vehicle breakdown has also been an issue in city area, which leads to delays or re-routes [41], [42]. On fuel consumption of vehicle, alternative fuel vehicle routing has been studied with limited refueling infrastructure [43]. Gaur *et al.* [44] studied a cumulative VRP with the objective of minimizing the total fuel consumption, instead of minimizing total distance.

Besides the six main characteristics (constraints) of City VRP, various types of problems have been considered in the literature. These include multi-depot vehicle routing, street routing, postal mailing vehicle routing, and public transit. Multi-depot constraint was considered in City VRP by Dulac *et al.* [13] and Yang *et al.* [40]. Matis [45], [46] introduced a street routing problem, which has a large number of customers in the urban area and solved it using a GIS based decision system. Hollis *et al.* [47] examined a vehicle routing and crew scheduling problem for the Australia post. Waste collection as an arc routing problem is also among of the commonly tackled problems in City VRP [20]. For real time response in urban distribution, a knowledge based model was proposed in [48] in order to respond to disruptions rapidly using the knowledge of past experiences. Vigo [49] suggested an asymmetric CVRP for urban area, while Schupbach and Zenklusen [50] proposed a personal rapid transit (PRT) system as a mode of public transportation.

2) Carriers and Shippers: From our survey, shippers and carriers are found to be mostly concerned with the economic issues of implemented policies. This view is amplified by the characteristics of city logistics considered by articles that involves the aforementioned stakeholders.

To the best of our knowledge, only a few studies involving only the aforementioned stakeholders have considered environmental or public issues. For example, work has been done on assessing the potential of carbon reduction through collaboration between carriers in carbon credit trading [51]. As a public issue, there have also been studies on the optimization of school bus routes [14], [52].

Response to changes in traffic or customer demands, which represents an integral part of City VRP, has been studied in various ways from solving the dynamic vehicle routing problems with fuzzy travel times and fuzzy time windows [53] to vehicle routing problems with time windows where it is possible to increase the number of servicemen for each route so as to decrease service time [54]. Another study entailed solving a dynamic vehicle routing problem with the use of online traffic information [16].

Pickup and delivery activities are among the main logistics requirements in a city. It is no wonder that vehicle routing problem with pickup and delivery has received continual attention in this field. Pickup and delivery problems include routing problem using both vehicle and people [55], dial-a-ride problem [56], and problem with time-dependent fuzzy velocity [57].

Customer's time window is also an important characteristic of City VRP. Studies have been done to assess the impact of time windows on cost of logistics [58] and minimization of transportation costs with time window constraints [59], [60]. More realistic conditions such as time dependent travel times [61], [62] and incorporation of satellite facilities [63] have been considered in vehicle routing problem with time windows (VRPTW) as well. There are some variations of VRPTW. For instance, the possibilities of increasing the number of servicemen are considered to improve customers' service times [54] and the model combined with pickup and delivery constraints allows the vehicles to carry resources such as on foot personnel [55]. Research has also been done on dynamic scheduling for

VRPTW [53] and decision support system based on real time information [64]. Furthermore, works on enhancing real time vehicle routing with capacity and time window constraints have been proposed, including knowledge representation methods in a variety of algorithms [65].

3) Residents and Administrators: In the framework of city logistics, residents and administrators care about the social, environmental and energy issues of implemented policies. This view is further reinforced by the characteristics of City VRP considered by papers that involves the aforementioned stakeholders.

Some studies have dealt with traffic flow or road conditions in the city area. For example, works have been proposed on modelling the flow of freight vehicles [66] and traffic [67]. Some authors have also considered the modelling of emissions in traffic [67]. Optimisation of traffic flow [68], [69] has also been researched upon in the recent years. Perrier *et al.* [70] proposed a method for vehicle routing in snow plowing operations involving city area. There have been other related studies such as the effects of spatial variability of road vehicle density on traffic conditions [71] and the potential of a combination of GPS and GLONASS sensors in fleet tracking [72].

In the various efforts to reduce air pollution in the city, research concerning air pollution ranges from analysis on the effects of traffic factors on emissions [73], [74] to optimal driving strategies that reduce the environmental impacts caused by transportation [75]. In particular, Felstead *et al.* [73] considered the effects of extreme driving behaviour on vehicle emission, while Figliozzi [74] studied the effects of congestion on emission levels for urban freight transportation. Lai *et al.* [76] concentrated on the driving cycles of public transportation by taking into consideration the available information on traffic congestion and vehicle emissions. Javor and Szucs [77] delved into traffic modelling to reduce fuel consumption.

Past research involving both administrators and residents is not confined to air pollution alone. As mentioned above, the potential of Intelligent Transportation System (ITS) on City VRPs have been explored as reported in the literature. Works in this field include estimation of traffic data such as travel time [17], vehicle velocity [78], regulation of urban traffic through economics based models [79], and usage of grid and cloud computing in the implementation of ITS [80]. In particular, Lee *et al.* [17] employed data mining to predict current travel time using real time and historical data in the city area, while Liu *et al.* [78] considered floating car data to estimate routing velocity. The data considered above were collected from ITS.

From our literature review, it has been found that interests in traffic regulation or traffic control are significant in studies that involve the aforementioned stakeholders. To date, various aspects of freight delivery optimization have taken traffic conditions into considerations. For example, Dezani *et al.* [81] used Petri Net analysis as the fitness function and genetic algorithm as an optimization method to provide vehicles with travel time optimised routes at real time. This analysis was used to control the stream of traffic into the city. Studies have also been conducted at a more generic scale such as analysis of circumstances where blended headways would result in savings in the number of vehicles/routes [15] and traffic optimization to reduce air pollution [77]. Besides research on optimization, works relating to traffic management system [80] and on the road freight vehicles estimation so as to analyze traffic flows [82] have also been studied.

4) Carriers, Residents, and Administrators: Environmental or public issues are among the key concerns of residents and administrators. The consideration of carriers with residents and administrators brings about a new degree of concern on transportation costs. A large number of articles that deal with environmental issues such as air pollution have been found in the literature. VRP takes into account the emissions of gases such as Greenhouse gases [83] and carbon emissions [84]–[87], while minimizing transportation costs. In particular, fuel consumption has been used as a measure of air pollution [88]–[92]. There were studies that considered both gas emissions and fuel consumption in tandem [93], [94]. Faulin *et al.* [95] considered the total environmental costs such as gas emission, noise, and congestion in their work.

Intelligent transportation system (ITS) has the capability to provide drivers with updated optimal routes in real time DVRP. Route guidance applications such as ITS can be used to update drivers with real time traffic information [96] or to find optimal routes with lowest emission or fuel consumption ([88], [94]). In the city, administrators use traffic regulations to reduce traffic congestion and logistics costs. For example, Beijing government prohibits trucks from entering the downtown area during certain times of the day [97]. Cova and Johnson [98] investigated an evacuation vehicle routing scenario using a lane based routing strategy to achieve faster response time in the event if an evacuation. The administrators are in charge of emergency services in the event of power outages occurring in metropolitan areas. Weintraub *et al.* [99] proposed an emergency vehicle dispatching system for the electrical breakdown in Chile. Jimenez *et al.* [100] analysed driving cycles of public buses in Madrid to improve urban routing. Green logistics have also received increasing attention in industry practices recently due to the pressures from environmental regulations, customers and companies [101].

5) Shippers, Residents, and Administrators: From our literature review, it is known that shippers are mostly interested with the economic impacts of the implemented policies, while residents and administrators are more concerned on the social, environmental and energy aspects of the policies.

Environmental issues are one of the main concerns addressed in research contributions that involve the aforementioned stakeholders. A number of studies have been conducted on assessing the environmental impacts of the implemented policies, retailer's financial performance [18] and optimization of environmental factors in logistics given the policies. For example, Li [102] aimed to minimize fuel consumption in solving the vehicle routing problem with time windows and considered the waiting times at the client sites.

Time window, as one of the main characteristics of City VRPs, is another concern addressed in the literature. Studies are not limited to the time window constraints alone as there have been works on satisfying time window constraints and other constraints such as parking constraints, loading/unloading capacities and balancing cost & number of deliveries in city areas [103]. There has also been research on the environmental aspects of logistics issues while considering time windows given implemented policies such as time access regulations [18] and routing solutions that satisfy time window constraints while minimizing fuel consumption [102].

A number of aspects of traffic regulations have been studied upon in the field. Alonso *et al.* [104] looked into bus lines assignment to divided-stops and proposed a solution that increases average bus speeds and lowers social costs, while Quak & Koster [18] assessed the environmental and financial performance of retailers given government implemented policies such as time access regulations to city areas [18].

6) All Stakeholders: Our literature review also revealed that all stakeholders are collectively concerned with the economic, social, environmental and energy impacts of the implemented policies.

Particularly, studies on routing optimization have been performed extensively. For example, continuous space models have been used to aid in deciding between short slow and long fast routes to minimise travel time [105]. Another example entails entropy models being utilised to model traffic flow and optimise bus routing [106].

A variety of vehicle routing problem with time windows have also been investigated. These include the VRPTW with real time traffic data [107], VRPTW with multi-depot and pickup and delivery [108] and VRPTW with backhauls [109]. The varieties are not limited to the aforementioned variations. For example, Demir *et al.* [110] solved the pollution routing problem (PRP), which is an extension of VRPTW with the objective of minimising fuel consumption among other factors. Other variants that included environmental factor(s) optimization are the bi-objective Pollution Routing Problem (PRP) [111], time-dependent PRP [112], VRPTW with minimisation of emission and fuel consumption as the objective [113] and Traveling Salesman Problem with time windows (TSPTW) with minimization of emission and fuel consumption as the objective [114].

Recently, a new variant of TSP relating to the usage of electric and hybrid vehicle has been studied. Tadei *et al.* [115] introduced the multi-path TSP with stochastic travel costs and showed how to find the probability distribution of the minimum random travel cost between two nodes in the operational level. Maggioni *et al.* [116] applied this method on real data taken from a sensor network.

Research on optimization of environmental factors is abundant in variety too. Some of the contributions in this area are as stated before. Other contributions include joint optimization of cost, service and environmental factors for a dial-a-ride problem [117] and an estimation of the trade-offs between emissions, cost and service quality in logistics services [118].

B. Methods

In the previous section, we have reviewed the applied problems of City VRP. This section investigates how those applied problems have been formulated and solved in the literature. Modeling and solution methods are discussed in detail.

1) Modeling and Solution Methods: Table II presents how the City VRP have been formulated and solved in the literature.

TABLE II
CITY VRP MODELING (WITH OBJECTIVES) & SOLUTION METHODS

Objectives	Modeling Methods	Solution Methods
Environmental cost (27) [44, 51, 57, 75, 83-91, 93, 94, 95, 101, 102, 108 110-114, 117-119]	**Integer & Mixed Integer Programming (42)** [20, 26, 29, 31, 36, 40-43, 47, 48, 51, 52, 54, 55, 57, 59-61, 70, 74, 75, 83, 84, 86, 87, 91-93, 96, 101-103, 107-114, 119]	**Metaheuristics (32)** [20, 24, 25, 28, 30, 33, 40, 42, 51-54, 56-59, 61-63, 81, 86, 90, 91, 96, 102, 104, 109-111, 114, 120, 122]
Travel cost (19) [26, 30, 31, 34, 37, 38, 40, 47, 48, 55, 63, 68, 74, 84, 85, 98, 107, 109, 120]	**Statistics (4)** [15, 73, 76, 78]	**New Heuristics (14)** [29, 31-33, 35, 37, 44, 45, 64, 84, 92, 99, 101, 112]
Distance (18) [35, 38, 43, 45, 46, 49, 53, 54, 58, 65, 74, 83, 86, 92, 95, 99, 101, 109]	**Network Model (3)** [34, 69, 98]	**Exact Algorithm (9)** [26, 34, 38, 47, 64, 74, 103, 107, 114]
Travel time (16) [24, 25, 27, 28, 39, 53, 59, 61-63, 70, 105, 108, 111, 119, 121]	**Stochastic Model (2)** [37, 51]	**Savings Algorithm (5)** [24, 27, 43, 49, 95]
Fleet Size (9) [14, 52-54, 58, 61-63, 74]	**Time Space Model (2)** [36, 50]	**Two Stage Heuristics (5)** [14, 24, 26, 55, 70]
Driver Cost (5) [47, 57, 93, 110, 112]	**Knowledge Based Model (2)** [17, 48]	**Remove-Insert Heuristic (5)** [13, 27, 55, 61, 117]
Fixed Cost (4) [19, 30, 55, 91]	**Dynamic Programming (1)** [38]	**Cluster Algorithm (4)** [43, 46, 60, 97]
Service time (2) [70, 99]	**Simulation (1)** [77]	**Decomposition (3)** [70, 85, 107]
Time windows (2) [50, 65]	**Others (12)** [15, 53, 57, 66-68, 71, 79, 81, 82, 105, 106]	**Search Algorithm (3)** [60, 65, 103]
Others (19) [14, 20, 22, 31, 36, 41, 42, 53, 56, 57, 59, 60, 66, 69, 79, 103, 104, 117, 118]		**Greedy Heuristics (2)** [103, 113]
		Others (22) [18, 19, 23, 28, 36, 37, 41, 55, 66, 68, 74, 82, 83, 87, 88, 93, 98, 107, 113, 118, 119]

In Table II, *objective* denotes the target or goal of the problem formulation, which focuses on the objective function. *Modeling method*, on the other hand, focuses on the model type, including mathematical models, simulation, and others. The most well studied objectives of City VRP are Environmental Cost (with 27 articles), followed by Travel Cost (with 19 articles), Distance (with 18 articles) and Travel Time (with 16 articles identified). Environmental cost relates to the emission of CO_2 or greenhouse gas, fuel consumption, and environmental performance. Travel cost involves not only the traveling cost but also route duration or congestion cost. Travel time denotes the traveling time between two locations or the waiting time. Fixed cost denotes the vehicle purchasing cost, depot opening cost, and vehicle setup cost. Other objectives include the number of bus stops, insurance cost, service cost, operation cost, entropy, unbalanced workload, and depreciation cost.

Most of the problems studied are modelled using either Integer Programming (IP) or Mixed Integer Programming (MIP), with a total 42 articles identified. Statistics, stochastic and network model have also been used. Statistics denote statistical analytic models while stochastic is in the form of stochastic process or programming model. Network model includes graph theory model and network flow model. Other models include fuzzy-based, auction-based, fluid dynamics, entropy, empirical, continuous space, and Petri Net models.

Most papers utilized metaheuristics to solve the problems (with a total of 32 articles identified). Metaheuristic methods in this literature include ant colony, genetic algorithm, neighborhood search, scatter search, simulated annealing, compressed

TABLE III
OBJECTIVE OF STAKEHOLDERS VERSUS OBJECTIVES IN LITERATURE

Stakeholders	Objectives of Stakeholders	Objectives in Literature
Shippers	Maximize the level of service	Service time(2), Time windows(2)
Carriers	Minimise cost of transportation	Travel cost(19), Distance(18), Travel time(16), Fleet size(9), Driver cost(5), Fixed cost(4)
Residents	Minimise air pollution, noise pollution, traffic congestion and accidents near residential area	Environmental cost(27)
Administrators	Enhance the economic development of the city, alleviate traffic congestion, improve environment within the city	-

TABLE IV
OBJECTIVES & MODELING METHODS

Objectives	Modeling Methods
Environmental cost	Integer Programming, Mixed Integer Programming, Stochastic Model, Others
Travel cost	Knowledge Based Model, Network Model, Integer Programming, Mixed Integer Programming, Stochastic Model, Dynamic Programming, Others
Distance	Mixed Integer Programming, Dynamic Programming, Others
Travel time	Integer Programming, Mixed Integer Programming, Others
Driver Cost	Integer Programming, Mixed Integer Programming, Others
Fixed Cost	Mixed Integer Programming
Fleet Size	Integer Programming, Mixed Integer Programming, Others
Service time	Mixed Integer Programming
Time windows	Time Space Model
Others	Network Model, Integer Programming, Mixed Integer Programming, Time Space Model, Others

TABLE V
MODELING & SOLUTION METHODS

Modeling Methods	Solution Methods
MIP	Cluster Algorithm, Decomposition, Exact Algorithm, Greedy Heuristics, Metaheuristics, New Heuristics, Remove-Insert Heuristic, Savings Algorithm, Two Stage Heuristics, Others
IP	Cluster Algorithm, Exact Algorithm, Greedy Heuristics, Metaheuristics, New Heuristics, Search Algorithm, Two Stage Heuristics, Others
Dynamic Programming	Exact Algorithm
Time Space Model	Others
Stochastic Model	Metaheuristics, New Heuristics, Others
Network Model	Exact Algorithm, Others
Others	Metaheuristics, Others

annealing, tabu search and others. A substantial number of articles proposed efficient and novel algorithms or procedures to solve the respective studied problems. We denote those methods as 'new heuristics' (newly proposed heuristic method in their articles). Remove-insert heuristic includes 2-OPT, multi-exchange shortest path, insertion heuristics based on minimum delay metric and the parallel insertion algorithm. Exact algorithm includes enumeration, branch and bound, branch and price, column generation, Markov decision process and Dijkstra algorithm. Decomposition method denotes Dantiz-Wolfe decomposition and geographical decomposition. Search algorithm includes the depth-first search and other local search algorithm. Except exact algorithm, most methods are heuristics in nature. In other attempts for solution, there are agent-based approaches, labeling algorithm, mini-max regret and the sweep algorithm [18], [19], [23], [28], [36], [37], [41], [55], [66], [68], [74], [82], [83], [87], [88], [93], [98], [107], [113], [118]–[120].

We map the results of Table II to the objectives of the stakeholders in Table I. The comparison is illustrated in Table III. Most studies in the literature focus on the objectives of carriers. The objectives of residents have also been addressed in many studies. On the other hand, the objectives of shippers have been shown in only a few studies. Moreover, the objectives of the administrators have yet to be well explored.

In summary, we observe that current literature mainly focuses on minimizing environmental costs in addition to the classical objectives such as distance travelled and travel time, uses mathematical models such as mixed integer programming model and integer programming model and employs methods in metaheuristics as the preferred choice of solution methods.

2) Relationship Among Objectives, Modeling, and Solution Methods: In Table II, the models, objectives, and solution methods used in City VRP research studies have been identified. In this section, we investigate how these objectives, models, and solution methods are linked in the City VRP literature. Two forms of coexistence are examined: objectives & modeling methods and modeling & solution methods. In particular, we aim to answer the following questions: What objectives have been used in City VRP models? What solution methods have been used to solve the models?

Table IV summarizes the objectives used in City VRP models. For example, the minimization of distance was used in the mixed integer program and dynamic programming models. A variety of different objectives have been used in integer or mixed integer programming model. Environmental and travel costs have been used in various models. Time windows can be observed in the time space model.

Table V presents the solution methods that have been used to solve City VRP models. For example, dynamic programming model used an exact algorithm as the solution method. Mathematical models for VRP such as MIP or IP require a large number of variables (dimension). The number of nodes in the network is particularly large in cities (size of problem). Thus, researchers preferred the use of heuristic methods in solving large scale and complex VRPs. From the solution methods perspective, both metaheuristics and exact algorithm have been widely used.

III. DISCUSSION

In this section, we present the summary of our review and discuss the potential research directions for City VRPs in terms of two perspectives: core characteristics and stakeholders. Through the analysis provided below, the consideration of stakeholders and characteristics of City VRP in the literature will be examined.

A. Core Characteristics

Fig. 5 shows the number of publications for solution methods and core characteristics (constraints) of City VRP from 1980s

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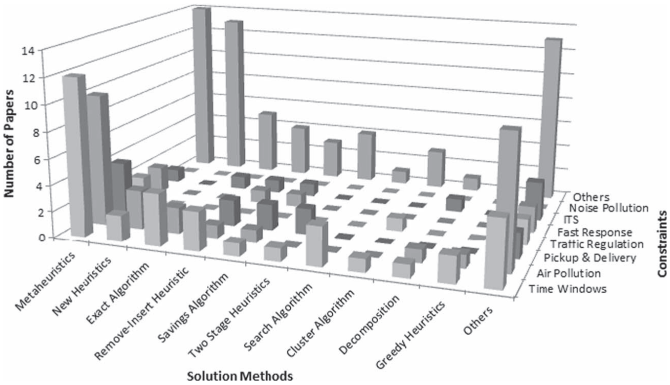


Fig. 5. Solution methods and constraints.

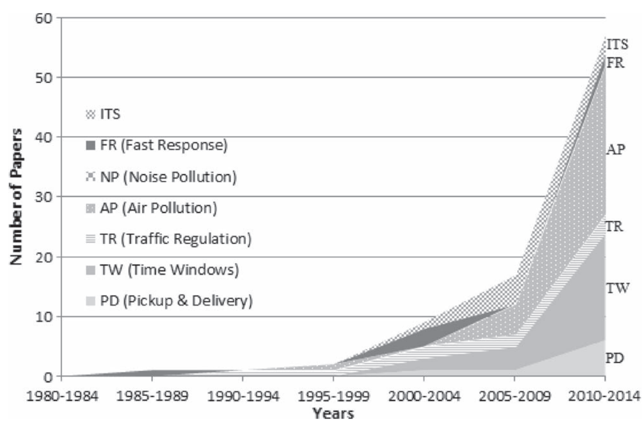
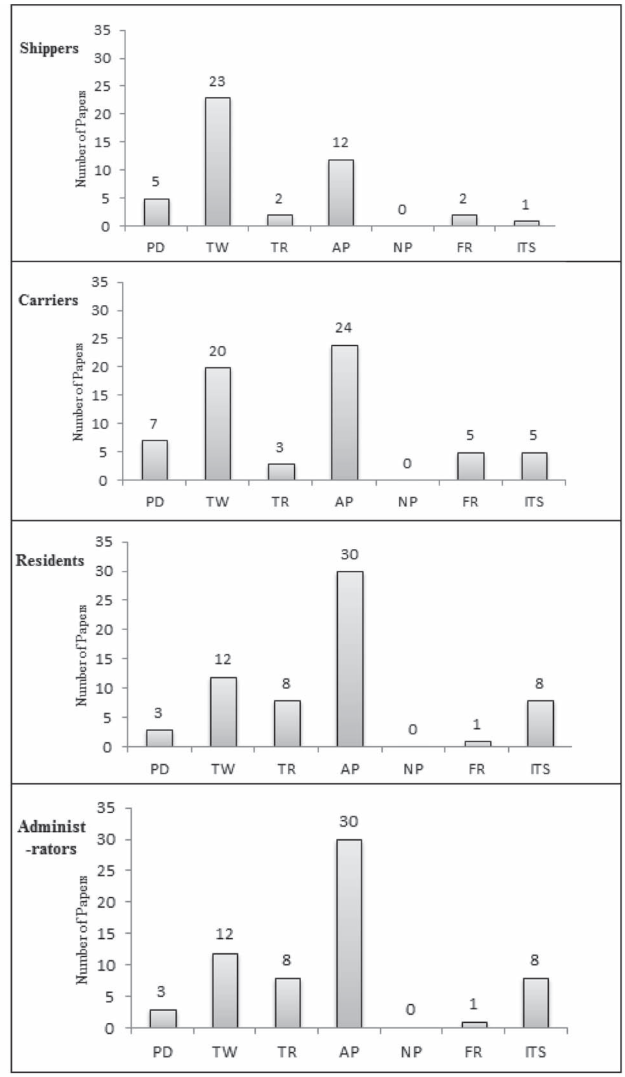


Fig. 6. Trend of City VRP constraints.

to 2014. The solution methods are described in Table II and core characteristics are in Section I. Others in ‘constraints’ axis include travel time, fuel consumption, and vehicle or road conditions. From the chart, time windows and air pollution constraints using metaheuristics have garnered the most interest in the literature, followed by pickup & delivery constraint. Time windows constrained problems have been solved by various solution methods (most methods in ‘solution methods’ axis), while the problems with air pollution constraints are more popularly paired up with metaheuristics, new heuristics and exact algorithm as the preferred solution methods. Pickup & delivery constrained problems have been solved by metaheuristics, remove-insert heuristic, saving algorithm and two stage heuristics. For ITS, various methods including metaheuristics, exact algorithm, remove-insert heuristics, saving algorithm and decomposition method have been used. Among the solution methods, metaheuristics is the most preferred solution method of all, regardless of the VRP characteristics.

Fig. 6 shows the trend of studies for characteristics of City VRP over the years. It is worth noting that the number of models with time windows and air pollution have increased sharply from 2009 as the research studies on City VRP ramps up. Pickup and delivery constraint has also increased along this trend. Other characteristics (constraints) of City VRP including ITS, fast response, and traffic regulation have also been steadily studied over the years.



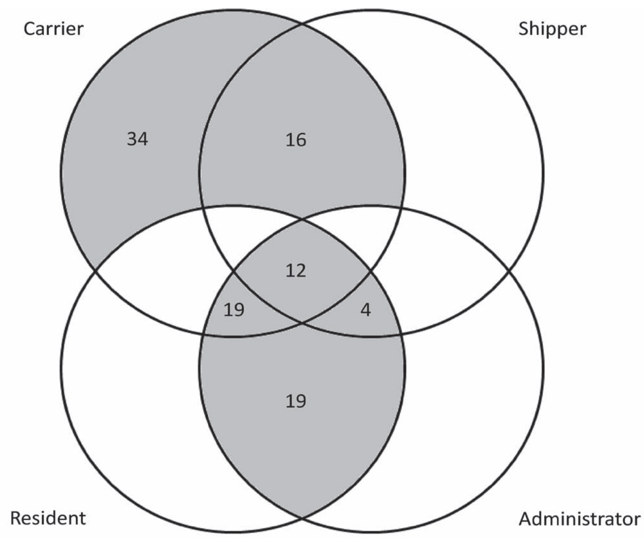
* Note: PD (Pickup and Delivery), TW (Time Windows), TR (Traffic Regulation), AP (Air Pollution), NP (Noise Pollution), FR (Fast Response), ITS (Integrated Transport System)

Fig. 7. Constraints in each stakeholder.

B. Stakeholders

From Fig. 5, we identify that time windows and air pollution have been mostly considered in the City VRP literature, while other constraints have on the other hand received little attention. We investigate this observation further by making a categorization based on stakeholders.

Fig. 7 presents the characteristics of City VRP that have been considered with respect to each stakeholder. Traffic congestion and environmental problems are categorized as the key concerns of both the residents and administrators stakeholder. This explains the equivalent number of articles published on issues relating to residents and administrators stakeholders. Problems that are of interests to residents and administrators stakeholders mostly relate to air pollution followed by time windows constraints. They have also dealt with the traffic regulation and ITS. On the other hand, shippers mainly focus on problems involving time windows to maximize the level of service. Carriers have emphasized on problems involving both time windows and air pollution. Besides, they have considered a variety of



Stakeholders	References
Carrier	[13, 19, 20, 22-35, 36-50, 99, 120]
Carrier & Shipper	[14, 51-65]
All	[105-114, 117,118]
Carrier, Resident & Administrator	[83-88, 90-95, 97, 98, 100, 101, 119, 121, 122]
Shipper, Resident & Administrator	[18, 102-104]
Resident & Administrator	[15, 17, 66-82]

Fig. 8. Venn diagram of stakeholder representation.

constraint types including pickup & delivery, fast response, and ITS. Comparing with residents and administrators, shippers and carriers have relatively lower interests on traffic regulation and ITS. Instead, they are more focused on time windows or pickup & delivery constraints.

The gray areas in Fig. 8 represent the combinations of four stakeholders that are represented by one or more articles, while the white regions represent the coexistence of stakeholders that have no published articles in the literature. For example, if an article considered the issues of both the carriers and shippers (two stakeholders), then this article belongs to the coexistence of carriers and shippers, which has a total of 16 articles found as depicted in the diagram. As observed from the Venn diagram, most City VRP articles have concentrated on benefiting the carriers followed by the residents and carriers. This coincides with our conclusion from Fig. 5 where most articles have considered air pollution and/or time windows as their preferred characteristics to work upon in City VRP. A substantial number of 19 articles have contributed to the interests of carriers, residents and administrators. The coexistence of residents and administrators accounts for 19 articles. 4 articles were found to aid the coexistence of residents, administrators and shippers. Finally, as expected only 12 papers that considered all the stakeholders have been found.

C. Potential Research Direction

As provided in Section I, we have identified six core characteristics of City VRP and the four stakeholders involved. Through our present review, we have observed how the related studies for characteristics and stakeholders have been conducted since 1980s. Based on this observation, several potential research directions of City VRP have been identified, which is presented in what follows.

a) Greater study on the four core characteristics of City VRP including traffic regulation, noise pollution, fast response, and ITS. These four constraints have received little attention in the literature. As mentioned in the introduction, these characteristics are of particular importance to City VRP. Therefore, there is a need for greater research in these areas. In particular, no prior research has been found to relate to noise pollution.
b) Greater Study on the development of efficient solution methods. Most studies of solution methods have relied on metaheuristics. It would be noteworthy to consider other computational paradigm including agent based, online optimization, and simulation approaches.
c) Greater study that involve the coexistence of all four stakeholders. To date, there exist only 12 published articles that have considered all stakeholders. In City VRP, all four stakeholders take on major roles. Otherwise, the search my may lead to some local optimum.
d) Generation of benchmark data set or problems. There is a lack of benchmark data set for City VRPs. Like other VRP variants, benchmark problem is thus a necessity for fostering greater research on City VRP.

IV. Concluding remarks

This paper reviews the City VRP focusing on how existing works contribute to the four stakeholders (shippers, carriers, residents, and administrators) in city logistics. In particular, we examine the consideration of stakeholders and characteristics of City VRP in the literature. Due to the correlations among the four stakeholder goals, City VRPs has to consider all interests of the stakeholders in their modeling and problem solving. This paper attempts to bring insights to this issue, while providing an overview of the model and the objectives and solution methods that have been proposed for addressing City VRPs. City VRP research works reported in the literature are categorized into four stakeholders and analyzed according to the notion of applied problems and modeling/solution methods.

Taniguchi *et al.* in [9] identified six main characteristics (constraints) of City VRPs. From our literature review, among the six main characteristics of City VRP, most studies have focused on time windows and air pollution. It has been noted that there has been a lack of sufficient study on other characteristics including ITS, noise pollution, pickup & delivery problems, traffic regulation, and fast response.

In City VRP, all four stakeholders are noted to be highly correlated. Nevertheless, most studies have considered only single or part of them independently. As highlighted in the introduction, City VRP is the culmination of the decisions of all four stakeholders. Hence, there is much potential and need for greater studies that would benefit all stakeholders, thus leading to more significant contributions in City VRP research. From this review, we have identified the challenging issues in City

VRP, which include the need to place greater emphasize and study on the four core characteristics (traffic regulation, noise pollution, fast response, and ITS) of City VRP, the development of efficient solution methods, more research that focus on the interests of all four stakeholders as a whole, and the need for new City VRP benchmark data sets or problems.

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