A review on sustainability, Industry 4.0 and collaboration implications in vehicle allocation operations

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Abstract

Purpose – Vehicle allocation problems (VAPs), which are frequently confronted in many transportation activities, primarily including but not limited to full truckload freight transportation operations, induce a significant economic impact. Despite the increasing academic attention to the field, literature still fails to match the needs of and opportunities in the growing industrial practices. In particular, the literature can grow upon the ideas on sustainability, Industry 4.0 and collaboration, which shape future practices not only in logistics but also in many other industries. This review has the potential to enhance and accelerate the development of relevant literature that matches the challenges confronted in industrial problems. Furthermore, this review can help to explore the existing methods, algorithms and techniques employed to address this problem, reveal directions and generate inspiration for potential improvements.

Design/methodology/approach – This study provides a literature review on VAPs, focusing on quantitative models that incorporate any of the following emerging logistics trends: sustainability, Industry 4.0 and logistics collaboration.

Findings – In the literature, sustainability interactions have been limited to environmental externalities (mostly reducing operational-level emissions) and economic considerations; however, emissions generated throughout the supply chain, other environmental externalities such as waste and product deterioration, or the level of stakeholder engagement, etc., are to be monitored in order to achieve overall climate-neutral services to the society. Moreover, even though there are many types of collaboration (such as co-opetition and vertical collaboration) and Industry 4.0 opportunities (such as sharing information and comanaging distribution operations) that could improve vehicle allocation operations, these topics have not yet received sufficient attention from researchers.

Originality/value – The scientific contribution of this study is twofold: (1) This study analyses decision models of each reviewed article in terms of decision variable, constraint and assumption sets, objectives, modeling and solving approaches, the contribution of the article and the way that any of sustainability, Industry 4.0 and collaboration aspects are incorporated into the model. (2) The authors provide a discussion on the gaps in the related literature, particularly focusing on practical opportunities and serving climate-neutrality targets, carried out under four main streams: logistics collaboration possibilities, supply chain risks, smart solutions and various other potential practices. As a result, the review provides several gaps in the literature and/or potential research ideas that can improve the literature and may provide positive industrial impacts, particularly on how logistics collaboration may be further engaged, which supply chain risks are to be incorporated into decision models, and how smart solutions can be employed to cope with uncertainty and improve the effectiveness and efficiency of operations.

Keywords Vehicle allocation problem, Literature review, Logistics collaboration, Industry 4.0, Sustainability

Paper type Literature review

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1. Introduction

Transportation is essential for all businesses, economies, nations and the environment. According to the American Transportation Association [1], 10.93 billion tons of freight was transported by trucks in 2021, representing 72.2% of the total domestic tonnage shipped. Based on the 2022 Annual Report [2] prepared by the U.S. Department of Transportation, in 2021, transportation accounted for 8.4% of the U.S. GDP. Additionally, in 2020, the U.S. freight transportation system moved more than 19 billion tons of freight worth about $18.0tn. This massive economic size of the industry is expected to increase even more, as the significance of borders gradually dwindles as production, consumption and trade unremittingly spread around wider locations. The growing economy in the industry, however, creates environmental consequences. In 2020, the total goods transportation activities in the EU done by transport was 3,271 billion ton-kilometers, 54% of which was performed by road transportation (Domagala and Kadlubek, 2022). A majority of road transportation vehicles use fossil fuels, and the environmental impact of freight transportation operations is massive. This leads to the fact to achieve not only economic benefits but also climate-neutral supply chains, effective and efficient augmentation of logistics activities has become a necessity for freight distribution businesses.

The focus of this study lies on full-truckload freight distribution operations, which form a significant fraction of logistics activities. For instance, Schneider National Inc. is one of the major full-truckload companies and according to its 2020 annual report [3], it has 6,342 drivers who have driven over one million consecutive miles and approximately $4.6bn in operating revenues in 2020. Similarly, ArcBest, another full-truckload company operating in the United States had 9,178 employees (drivers, cargo handlers, officers, supervisors and administrative) and a total income of approximately $190m in 2020 [4]. The freight distribution decisions encountered by these full-truckload companies often match up with the assumptions of the so-called vehicle allocation problems (VAPs), one of the tactical problems described in the logistics literature. The VAPs, encountered by carriers specializing in transporting full loads over long distances (e.g. TL trucking, container shipping), involve the challenge of reallocating empty vehicles to pick-up points or strategically repositioning them for future demands Ghiani *et al.* (2004).

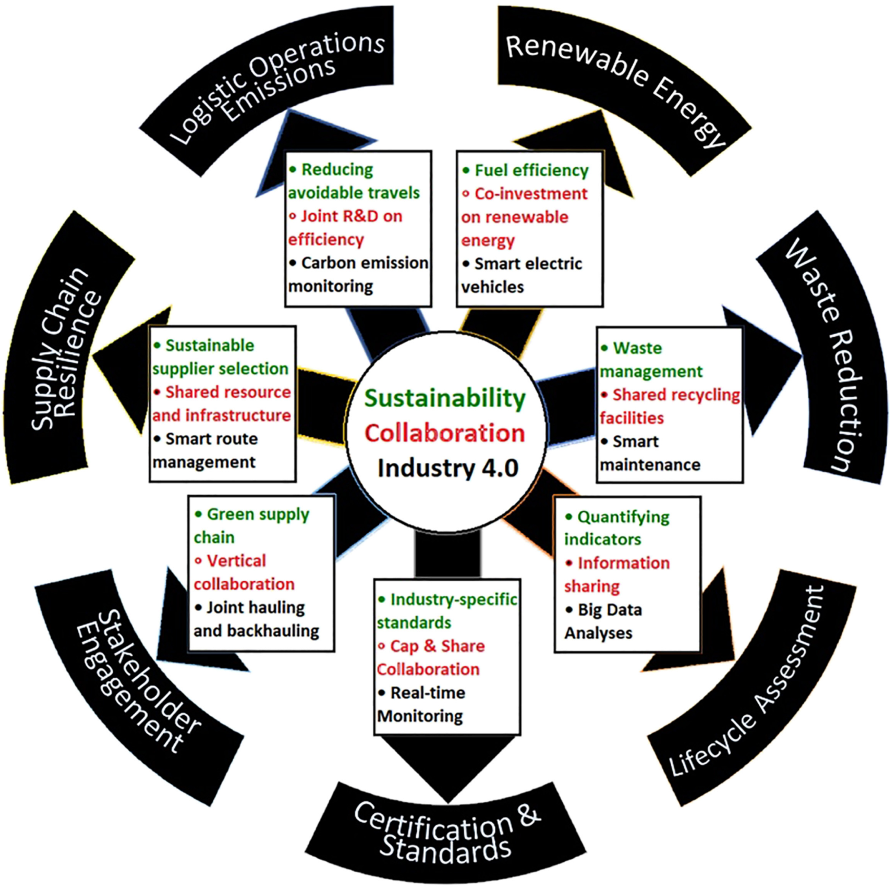
The full-truckload requests imply that demands are on arcs (amount of flow or resources required to be transported between particular nodes), rather than nodes (amount of flow or resources arriving or departing from that location) as they are in the majority of routing problems. Node-routing problems primarily deal with finding optimal paths or routes for given demands on nodes, freely selecting any arc as long as the demand node is visited. However, VAPs primarily deal with assigning vehicles to specific arcs to meet direct transportation demand requirements, which renders a decision tool for a classical model infeasible since it cannot guarantee to select the specific demand arc. Hence, the quantitative models prepared for node-routing problems are unsuitable in VAPs. Therefore, there is a clear need for decision-support models developed specifically for VAPs. Yet, the literature on VAPs is more slowly growing compared to that on the classical routing problems. This review has the potential to enhance and accelerate the development of relevant literature that matches the challenges confronted in industrial problems. Furthermore, this review can help to explore the existing methods, algorithms and techniques employed to address this problem, reveal directions and generate inspiration for potential improvements.

Several recent concepts on logistics, which emerged in line with new ideas, technological developments and environmental and social awareness, await to be incorporated into VAP models. The increasing recognition of environmental concerns, like air pollution and global warming, has prompted many stakeholders (e.g. freight transport companies, governments and nongovernmental organizations) have start to prioritize sustainability (Chu *et al.*, 2019; Kazanç *et al.*, 2021). Sustainability enables companies to generate benefits in terms of economic (e.g. profitability, costs, efficiency), environmental (e.g. fuel consumption, emission levels) and social (e.g. employee satisfaction, traffic congestion) outcomes (Soysal and Bloemhof-Ruwaard, 2017). Coordination among the three pillars (economic, environmental and social) is essential to achieve balance in sustainability (Gunasekaran and Subramanian, 2018). To ensure their long-term survival and stay ahead of competitors, companies should prioritize all three elements of sustainability (Aydın *et al.*, 2022). The increasing awareness of consumers leads them to prefer more environmentally friendly products/companies. This consumer attitude forms an economic motivation for companies to pursue greener operations while planning their activities (Mansour, 2023). Greener operations usually reduce negative externalities such as air pollution or traffic, which also contribute to social sustainability. Likewise, companies may optimize operations and reduce costs by implementing environmentally friendly logistic approaches (Huang *et al.*, 2023). Accordingly, improving sustainability performance in any of the interrelated pillars provides companies with an undeniable competitive advantage. Besides, legal restrictions (e.g. environmental protection and emission control laws) and audits are increased by legislators for sustainable processes and/or operations to become widespread. For instance, the purpose of freight transport policy has been to sustainably meet the demand that is growing for freight transport (Wiegmans and Janic, 2019). Due to all these reasons, sustainability is a frequently addressed concept in many logistics application areas.

Another example of the newly emerging concepts is Industry 4.0. The term fourth Industrial Revolution, which was introduced in 2011 at the Hannover Fair in Germany, has attracted noteworthy attention all over the world (Liao *et al.*, 2017). The emergence of Industry 4.0 has altered the business realm and revised what the management and operation manners would be like (Dhiaf *et al.*, 2022). It involves the technical integration of Cyber-Physical Systems into manufacturing and logistics, and the use of the Internet of Things in industrial processes (Ünal *et al.*, 2020). This transformation enables to implementation of sustainable mobility strategies such as smart mobility and smart logistics (Amiri *et al.*, 2022; Kagermann *et al.*, 2016). Logistics 4.0, accordingly, arose as a term that refers to logistics operations carried on by utilizing recent digital technologies. Strandhagen *et al.* (2017) emphasized five characteristics of Logistics 4.0: (1) real-time big data analytics of vehicle, product and facilities' locations; (2) on-demand manufacturing; (3) autonomous robots and decision systems; (4) real-time information exchange; and (5) smart products and cloud-supported networks. Moreover, by using of digital twins and intelligent technologies such as the Internet of Things, cloud computing, big data, simulation and Cyber-Physical Systems is revolutionizing production logistics operations in the context of Industry 4.0 (An *et al.*, 2023; Zhu *et al.*, 2023). These ideas lead to instant information flow among autonomous machines in unmanned operations. The autonomy of the machines generates the necessity to have decision models that are able to process the large dynamic data flow and to optimize decisions in many application areas, including VAPs.

The last but not the least, another example of the newly emerging concepts that will be addressed in this study is the idea of collaborative logistics operations among businesses. With the help of developing technologies in VAPs, collaboration strategies allow trucks to be repositioned to efficiently meet future demands in order to minimize problems arising from the imbalance between supply and demand in different locations (Zolfagharinia and Haughton, 2014). Some organizational and managerial solutions in logistics collaboration areas have been determined for improving functional and interorganizational coordination (Caputo and Mininno, 1996). These solutions can provide competitive advantages, allow to enter new markets and help to use resources more efficiently. Both vertical (among companies at different levels of a distribution channel) and horizontal (among companies at the same level of a distribution channel) collaboration in vehicle allocation operations have the potential to contribute to increasing the total added value generated by the channel and/or reduce the related costs (Soysal *et al.*, 2018). However, collaborative operations yield a wider range of decisions (e.g. capacity allocation, drivers truck assignment, demand) sharing to be optimized under a larger number of constraints (e.g. fair distribution of demand, aggregate vehicle capacity, delivery priorities), significantly increasing the problem complexity and giving rise to the need to reflect such alterations in decision support models.

Vehicle allocation operations are important for climate-neutral supply chain targets. The review explores the implications of sustainability, Industry 4.0 and collaboration in the context of vehicle allocation, which can be regarded as critical factors for achieving climate neutrality in supply chains. First, by exploring sustainable practices, such as route optimization, load consolidation and alternative fuel usage, our review sheds light on how vehicle allocation operations can be managed in moving towards a climate-neutral supply chain. Second, Industry 4.0 technologies, including real-time tracking, electric vehicles and automation, enable more efficient resource utilization, improved operational planning and better decision-making. Lastly, by exploring collaborative approaches, information-sharing mechanisms and coordination strategies, the review paper emphasizes how aggregated resources and planning may improve efficiency and reduce waste, in line with the development of climate-neutral supply chains. Figure 1 exemplifies how climate-neutral



Source(s): Author's own work

Figure 1.
Exemplar relations of climate neutral supply chain key performance indicators with sustainability (green bullets), Industry 4.0 (red bullets) and collaboration (black bullets) dimensions

supply chain key performance indicators are interconnected with sustainability, Industry 4.0 and collaboration.

The main objective of this study is to identify the gaps, interests, and patterns in the literature on the emerging logistical trends (sustainability, Industry 4.0, and collaboration) that contribute directly to reaching the climate-neutral supply chain in VAPs. For this purpose, the Web of Science (WOS) Core Collection database has been searched by using the keyword "vehicle allocation" in the "topic" field. The resultant studies have been narrowed down to those that propose quantitative models incorporating assumptions on/properties of one or more of the aforementioned emerging logistics trends. The scientific contribution of this study is twofold: (1) This study analyses decision models of each reviewed article in terms of decision variables, constraint and assumption sets, objectives, modeling and solving approaches, the contribution of the article, and the way that any of sustainability, Industry 4.0 and collaboration aspects are incorporated into the model. (2) We provide a discussion on the gaps in the related literature, particularly focusing on practical opportunities and serving climate-neutrality targets, carried out under four main streams: logistics collaboration possibilities, supply chain risks, smart solutions and various other potential practices. As a result, the review provides several gaps in the literature and/or potential research ideas that can improve the literature and may provide positive industrial impacts, particularly on how logistics collaboration may be further engaged, which supply chain risks are to be incorporated to decision models, and how smart solutions can be employed to cope with uncertainty and improve the effectiveness and efficiency of operations. As far as we know, this is the first review of the VAP literature.

The rest of this study is organized as follows. Section 2 presents a description and an overview of VAPs. Section 3 provides analyses of the VAP literature. We present academic and managerial insights and discussions based on these analyses in Section 4. Finally, a conclusion of our study is provided in Section 5.

2. The vehicle allocation problem

Freight transportation processes can be classified as short-haul and long-haul based on the distances between the origins and destinations of the shipments. In short-haul freight transportation, goods are carried between the pickup and delivery points located in the same city/region (Ghiani *et al.*, 2004). This kind of transportation typically serves smaller amounts of goods to retailers/end-users, such as shelf inventory operations between supermarkets and regional depots, or online food orders of customers. Long-haul freight transportation includes intercity deliveries and is usually completed in one or more days (Kantawong, 2020). A wider range of objectives, including all B2B (e.g. raw material shipments), B2C (e.g. online shopping deliveries) and C2C variations (e.g. online second-hand shopping deliveries) with different sizes/amounts of loads are common in long-haul freight transportation operations.

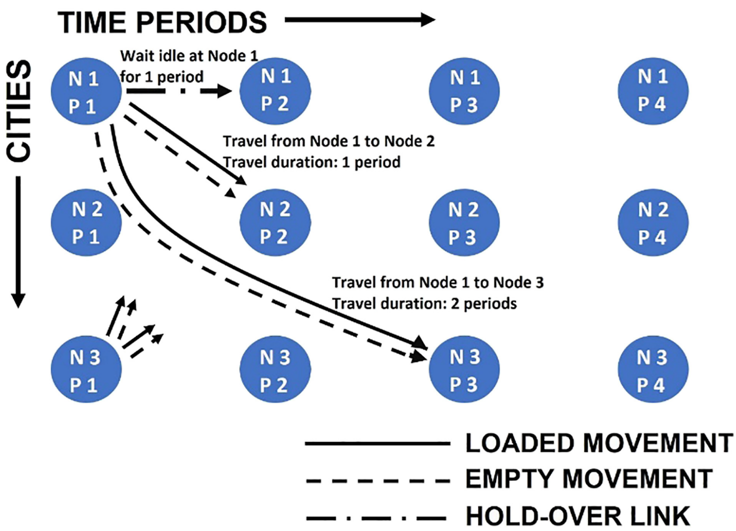
Road freight transportation, defined as "a set of activities that are responsible for a movement of goods carried by a fleet of motor vehicles between origins and destinations within a transportation network" (Zak *et al.*, 2011), is probably the most frequent transportation mode for both short-haul and long-haul transportation operations. Due to the fact that short-haul transportation is performed mostly in urban areas, small and medium-sized road vehicles (e.g. cars and trucks) are preferred as they are the best-matching means of transportation with the characteristics of urban travel (variable destination points, smaller-sized/amount of freights, narrow streets, traffic congestion, multiple stops, etc.). Ease of integration to short-haul systems, ready-to-use infrastructure (e.g. roads, depots) for almost all locations, and ability to construct different fleets that can serve different logistics operations are exemplary reasons for road freight transportation being one of the most frequently used long-haul transportation modes in many logistics systems among other alternatives.

The ability to utilize the vehicles as either partially loaded trucks (less-than-truckload, LTL) or fully loaded trucks (full-truckload, FTL) is another reason for the decision makers to prefer road freight transportation in logistics operations. In LTL transportation, a single delivery does not occupy the full capacity of a truck; therefore, a truck can carry the loads collected from multiple locations at the same time, such as in-vehicle routing problems, which increases vehicle utilization (Cruz *et al.*, 2020). This aggregation allows to consolidate smaller loads and utilize larger energy-efficient trucks, potentially resulting in faster and cheaper transportation. This setting has given rise to several well-established problems in the operations research literature, including vehicle routing problems, pick-up and delivery problems, inventory routing problems and ride-sharing problems. Vehicle routing problems, which have always been a hot research topic in operations research, primarily focus on finding efficient routes for a fleet of vehicles to deliver goods to a set of customers (Braekers *et al.*, 2016; Ni and Tang, 2023). Pickup and delivery problems deal with finding optimal routes for a fleet of vehicles to pick up goods from specified locations and deliver them to other locations (Zang *et al.*, 2022). Inventory routing problems integrate vehicle routing with inventory management, where vehicles must replenish inventory at customer locations during their deliveries (Shaabani, 2022; Soysal *et al.*, 2019). Ride-sharing problems deal with real-time matching of passengers and drivers to share rides, aiming at efficient resource allocation in dynamic settings (Agatz *et al.*, 2012; Guo *et al.*, 2023).

In FTL transportation, a single delivery occupies the full capacity of a truck; therefore, a truck can carry a single order at a time (Skobelev and Lada, 2016). In this case, dedicated vehicles to a single demand/customer allow to calibrate the services specifically to each customer, increases flexibility for customers and creates a higher value. Both LTL and FTL options may increase customer satisfaction under specific circumstances.

The VAPs are often encountered in FTL transportation operations, particularly (but not limited to) long-haul deliveries (Ghiani *et al.*, 2004). These type of problems refers to managing the loaded (in order to fulfill demands—FTL shipment requests) or empty (in order to relocate the vehicles for future demands) movements of a fleet of vehicles across a given planning horizon (Frantzeskakis and Powell, 1990). In a classic VAP, one of the three decisions should be given for each vehicle located in each node at every decision period: a loaded movement, an empty movement or a hold-over (waiting in the current location). These decisions have significant contributions to the performance levels of the logistics operations in terms of economic (e.g. transportation cost, profitability of operations), environmental (e.g. carbon emissions and fuel usage during transportation operations) and social sustainability (e.g. driver well-being, driver working hour, customer satisfaction) aspects. Loaded movements directly contribute to the economic performance of the company but generate environmental and social externalities and the vehicle may end up in an unpromising location (i.e. a node which is unlikely to be an origin point of a future demand, which may cause an empty reallocation trip). Empty movements cause environmental and social externalities, do not contribute immediately to the company's revenue, but relocate vehicles to generate future profits (Vasco and Morabito, 2016). Hold-overs do not generate any immediate environmental or economic outputs, holding the vehicles' position for future movements. Studies on VAPs typically aim to maximize profits, minimize costs or emissions or reach these goals simultaneously through optimizing the aforementioned decisions. Note that various decisions other than the aforementioned ones can also be considered, such as demand acceptance/rejection, vehicle type selection, sell/buy, maintenance decisions, etc.

Figure 2 shows a schematic presentation of the decision options for a classic VAP. The logistic network illustrated in this figure consists of 3 cities (each represented by a row) and 4 time periods (each represented by a column). Three types of flow are illustrated in the figure. The



Source(s): Powell (1986)

Figure 2. Schematic presentation of decision options in VAPs for a logistic network

hold-over flow refers to the vehicle staying idle in its current position for potential future demands. Empty flow refers to the vehicle being reallocated to another node for potential future demands, without carrying any loads. Finally, loaded flow refers to meeting a customer demand.

VAPs are confronted in various areas in practice. These areas include but are not limited to fresh produce logistics, heavy machinery logistics, food logistics, etc. Moreover, despite VAPs typically arise in FTL road transportation (e.g. Ikeda *et al.*, 2015; Li *et al.*, 2019; Powell *et al.*, 2000), several operations employing other transportation modes may reflect the assumptions of VAPs, such as maritime (e.g. Crainic *et al.*, 1993; Lam *et al.*, 2007) and railway transportation (e.g. Boile and Peric, 2013; Upadhyay and Bolia, 2014).

While the classical objective in VAPs is either profit maximization or cost minimization, VAPs have been practiced to achieve various goals. In the field of emergency vehicle management, different focal points can be observed, such as minimizing the number of ambulances (van Buuren *et al.*, 2018), maximizing coverage area (Andrade and Cunha, 2015; Liu *et al.*, 2016), minimizing distance (Wu, 2016) or minimizing traveling time (Ibri *et al.*, 2012). Huang *et al.* (2012) and Schmaler *et al.* (2016) concentrated on maximum efficiency, whereas Lin *et al.* (2013) concentrated on minimum waiting time for the automated material handling systems. Miller *et al.* (2005) and Roorda *et al.* (2006, 2009) focused on household vehicles utility maximization.

Despite the growing academic interest in VAPs since the initial attempt to address the problems (Hughes and Powell, 1988; Powell, 1986, 1987), there are not any published literature reviews to the best of our knowledge. Accordingly, in this paper, our aim is to present a state-of-the-art assessment of the VAP literature, particularly focusing on the relation of the literature with several emerging logistics trends, and to discuss possible future directions from this perspective.

3. Analysis of the VAP literature

This section provides a state-of-art assessment of the VAP literature. For corresponding analyses, we have made a topic-based search [5] for "articles" using the keyword "vehicle allocation" in the "Web of Science (WOS) Core Collection" database. Among the resulting 132 articles, 64 studies that address a VAP were included into the analysis. It is observed that each of the 64 studies provides a decision model or framework to cope with the VAP variant they address. What follows are the findings of these analyses. We will first provide several descriptive information on the literature, which is followed by a detailed exploration of the content of the papers.

3.1 Descriptive analysis of the VAP literature

This subsection provides a descriptive analysis of the VAP literature in terms of publication years, keywords and tendencies. Our aim here is to provide researchers a quick understanding of the state of and tendencies in the field as well as to show the increasing academic interest, which alludes to the necessity for and importance of a literature review in the field.

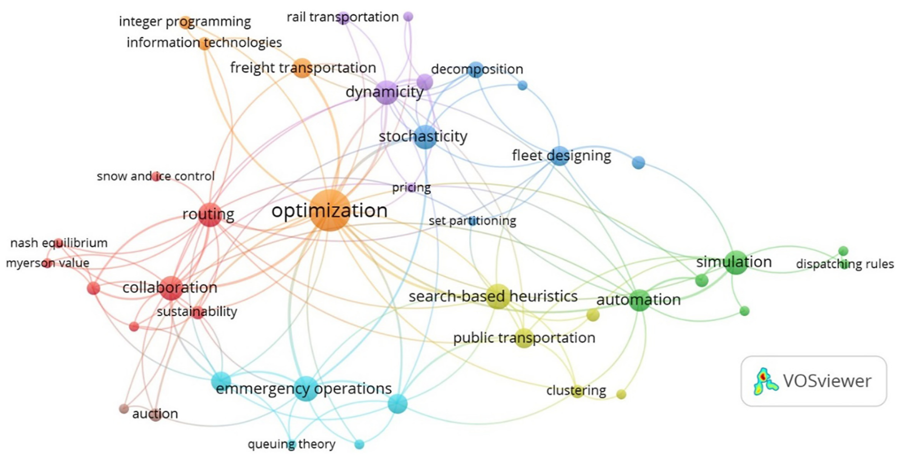
Table A1 in Appendix shows a detailed list of articles published each year. It can be observed from the table that, although only a few studies have been conducted until 2000s, there has been a significantly increasing interest in the area since then. Additionally, Table A2 in Appendix presents the distribution of the articles in terms of indicating the number of relevant articles published in each journal. Through these tables, a comprehensive overview of the progress and distribution of literature in the field is provided.

Figures 3 and 4 illustrate the co-occurrences of the keywords, which allude to the research topics that are simultaneously studied by the researchers. To facilitate a more concise

	Optimization	Collaboration	Dynamicity	Routing	Emergency Operations	Stochasticity	Automation	Reliability	Search-based heuristics	Machine Learning	Simulation	Location	Fleet designing	Public transportation	Freight transportation	Decomposition	Sustainability	Clustering	Auction	Information Technologies	Semiconductor manufacturing	Household	Variability	Content Caching	Integer Programming	Rail transportation
Optimization	-	3	3	1	4	5	2	2	4	2	1	1	1	1	3	1	1	1	2	2	1				1	1
Collaboration	3	-	1	2			1			1		2					1		1							
Dynamicity	3	1	-			1	1	1		3				1	1	1										1
Routing	1	2		-					1			1	1	1	1		1			1						
Emergency Operations	4				-	2		2	1			2					1		1							
Stochasticity	5		1		2	-				1			1		1	2	1									
Automation	2	1	1				-			1	2							1			2			1		
Reliability	2		1		2			-	1			1		2				1								
Search-based heuristics	4			1	1			1	-				1	1				1					1			
Machine Learning	2	1	3			1	1			-						1										
Simulation	1						2				-		1	1							1	1	1			
Location	1	2		1	2			1				-					1									
Fleet designing	1			1		1			1		1		-			1						2				
Public transportation	1		1	1				2	1		1			-				1					1			
Freight transportation	3		1	1		1									-	1				1						
Decomposition	1		1			2				1			1		1	-										
Sustainability	1	1		1	1	1						1					-									
Clustering	1						1	1	1					1				-						1		
Auction	2	1			1														-							
Information Technologies	2			1											1					-					1	
Semiconductor manufacturing	1						2				1										-					
Household											1		2									-				
Variability									1		1			1									-			
Content Caching							1											1						-		
Integer Programming	1																			1					-	
Rail transportation	1		1																							-

Source(s): Author's own work

Figure 3.
The co-occurrence frequency of the keywords of the articles addressing VAPs



Source(s): Author's own work

Figure 4. The co-occurrence map of the keywords of the articles addressing VAPs

representation, we employed the practice of aggregating similar keywords when constructing the figures. For instance, keywords such as "variable neighborhood search" and "genetic algorithm" were combined under the category of "search-based heuristics." Similarly, "evacuation management" and "ambulance allocation" were aggregated into the broader term "emergency operations." This aggregation approach streamlines the visualization process while retaining the essence of the keywords' underlying concepts. Figure 3 presents keywords that are addressed by more than one study, arranged based on the total number of co-occurrences. The cells indicate the number of times these relevant keywords intersect, representing the number of articles where they appear together. For example, the figure highlights common themes found in the literature, such as "routing," "collaboration" and "sustainability" or the relationship between "automation" and "simulation." Moreover, the keywords in the figure are ordered with respect to the total number of appearances, revealing the topics that gain a higher interest from the literature. This descriptive output enhances understanding of the existing literature and provides guidance for future research endeavors.

The map in Figure 4 further illustrates the state-of-art, which has been generated by VOSviewer based on the co-citation counts, clustering keywords together. From this map, it can be observed that the keywords used in the relevant literature are divided into 8 clusters (each represented by a different color). Although "optimization" stands out as the most prominent keyword, various keywords have been cited together in the studies, such as "public transportation and clustering," "integer programming and information technologies" and "collaboration and sustainability." This summary highlights the significance of the map generated through VOSviewer in revealing the relationships between themes in the research field.

The keyword summary of the literature also reveals the application areas of the VAPs. Among others, emergency operation practices (e.g. Ibri *et al.*, 2012; Liu *et al.*, 2016; van Buuren *et al.*, 2018; Wu, 2016) stand out with the frequency of the related keywords. Despite that VAPs are typically confronted in long-haul freight transportation, emergency operations also reflect the related assumptions: demands occur between specific nodes (in other words, on arcs), vehicles can be used to meet a single demand at one time and loaded (typically carrying patients) emergency vehicle movements satisfy the demands whereas empty vehicles are moved/repositioned in order to meet future demands. Another finding that is worth mentioning is the frequency of dynamicity assumptions in the studied problems, such as dynamic pricing (e.g. Andrade and Cunha, 2015) or dynamic vehicle allocation (e.g. Lam *et al.*, 2007; Shi *et al.*, 2014; Upadhyay and Bolia, 2014; Vasco and Morabito, 2016), which alludes to the need for decision aid tools that can cope with the dynamic environments in real-life problems.

3.2 The VAP literature from the perspective of emerging logistics trends

This section provides a detailed analysis of the 24 articles from the VAP literature, which involve an assumption related to any of the addressed logistics trends (sustainability, Industry 4.0 and logistics collaboration) in their quantitative models. Table 1 provides

Table 1. Decision variables, constraints and assumptions addressed in the reviewed VAP studies

	Decision variables				Constraints/assumptions											
Articles	1	2	3	4	1	2	3	4	5	6	7	8	9	10	11	12
Beaujon and Turnquist (1991)	√										√		√			
Kamarthi *et al.* (2003)		√				√				√					√	
de Oliveira Simonetto and Borenstein (2007)	√					√		√								
Fan *et al.* (2008)	√								√			√	√		√	
Beltran *et al.* (2009)				√											√	√
Chen *et al.* (2009)	√											√	√			
Wu *et al.* (2010)	√					√					√	√	√			
Tan *et al.* (2011)	√										√		√			
Huang *et al.* (2012)	√			√			√						√			
Ibri *et al.* (2012)	√		√											√	√	
Fan (2013)	√							√			√		√			
Zolfagharinia and Haughton (2014)		√					√			√	√				√	
Turner *et al.* (2015)	√	√	√			√				√						
Yang *et al.* (2015)	√	√			√	√			√	√						
Kaewpuang *et al.* (2016)	√	√			√	√	√		√	√					√	√
Schmaler *et al.* (2016)	√								√	√		√				√
Zolfagharinia and Haughton (2016)		√		√	√		√							√		√
Kim and Lee (2017)	√							√	√		√	√				
Irannezhad *et al.* (2018)	√				√	√	√			√		√		√	√	√
Rui *et al.* (2019)				√	√		√			√		√				
Kang *et al.* (2020)				√	√											
Lei *et al.* (2020)	√			√				√		√			√	√	√	√
Shima *et al.* (2021)	√								√		√					√
Shen *et al.* (2022)	√		√						√			√	√			

#	Decision variables	#	Constraints and assumptions
1	Related to the vehicles	5	Vehicle Inventory
2	Related to the load operations	6	Dynamics and Diversities (Characteristics) of Vehicles
3	Related to emergency and evacuation	7	Cost Structures and Revenue Dynamics
4	Others	8	Traffic Patterns and Time Management
#	Constraints and Assumptions	9	Uncertainties in Transportation/Logistics Operations
1	Time Limitations	10	Data Accessibility in Transport Operations
2	Vehicle Capacity	11	Network-Specific Rules
3	Visiting Sequence	12	Others
4	Vehicle Movement		

Source(s): Author's own work

information on the most frequently employed decision variable, constraint and assumption sets in these quantitative models. We would like to point out that the decision variables defined in the reviewed articles are categorized into four sets and constraints/assumptions are categorized into twelve sets based on the most often encountered features and themes. This analysis could help practitioners and researchers to better understand the field and design their future work.

In Table 1, the group of decision variables related to vehicles (1) covers a wide range of decisions from the number of vehicles to be involved in the system to vehicle selection for a particular move. The group of decision variables related to freight operations (2) is related to the processes ranging from the quantity of transport packages to the order of distribution, such as which load a truck will carry first or how much load will be transported. The group of decision variables related to emergency situation and evacuation (3) determines emergency response and evacuation actions.

Time limitations (1) refer to the assignment of a specific time window to the operations of vehicles and drivers (e.g. the time period within which a vehicle must reach the customer or the time of driver's return). Vehicle capacity restrictions (2) specify the load carrying limitations of vehicles at a particular weight or size (e.g. the maximum amount of load a truck can carry). Visiting sequence restrictions (3) emphasize the requirement for drivers to visit multiple customers in a specific order (e.g. a courier who must collect packages in a specific order). Vehicle movement restrictions (4) limit the movement of vehicles in certain operations (e.g. the maximum number of vehicles a car park can hold). Vehicle inventory restrictions (5) limit the number of vehicles that can be found in a given area (e.g. the number of ambulances a hospital can have or the number of buses allocated for a bus route). Vehicle dynamics and diversities (6) define the specific characteristics of vehicles and their particular operating conditions (e.g. a homogeneous or heterogeneous fleet of vehicles, working in day or night shifts). The cost structures and revenue dynamics (7) handle the costs to be incurred and the gains to be made during transportation operations. The assumptions on traffic patterns and time management (8) explain traffic conditions and time constraints affecting transport processes with specific characteristics (e.g. travel speeds, road conditions, traffic congestion). The set of assumptions on uncertainties (9) reveals the variability and stochasticity faced by transport processes (e.g. uncertain energy consumption, cost uncertainty, travel time variability). Data accessibility in operations (10) emphasize the information and technology dimension of transportation (e.g. access to real-time vehicle information). Finally, network-specific rules (11) define critical regulations and rules on transportation processes. Note that any decision variables and constraints/assumptions that do not fit into any of these categories are aggregated in "others" title.

Table 2 presents an overview of these articles, and columns summarize the relevant papers in terms of the logistics trends considered in their models, the mathematical modeling approaches utilized, the objective of the corresponding mathematical model, the solution algorithm applied and the type of data used to address the problem. The table indicates that integer programming-based approaches are the prevailing modeling techniques used in the reviewed studies. While cost/time minimization and profit maximization remain to be traditional objectives, a number of studies also include several other goals like lowering emissions or reducing production loss. Another point worth emphasizing is that over half of the studies demonstrate practical applications of their VAP models, which highlights the applicability of the topic in the real world.

A more detailed review of the articles can be found in Table 3. This table presents the main contributions of the related attempts along with application areas. Methodological adjustments/interferences to address corresponding logistics trends are explicitly mentioned. Moreover, the table particularly elaborates on the empirical studies that employ real-life data.

No	Paper	S	I	LC	Model	Objective	Solution	DT
1	Beaujon and Turnquist (1991)			H	NLIM	Maximize revenue	Frank-Wolfe algorithm	HD
2	Kamarthi *et al.* (2003)	RI			Simulation	Minimize turnover time and percentage of late orders	Simulation	HD
3	de Oliveira Simonetto and Borenstein (2007)	W			LIM	Minimize total cost	Renaud and Boctor's algorithm	RD
4	Fan *et al.* (2008)	E/ TCS		H	LIM	Maximize profit	Monte Carlo sampling-based method	HD
5	Beltran *et al.* (2009)	E			Analytical	Minimize total cost	Heuristic route generation and genetic algorithms	RD
6	Chen *et al.* (2009)	EP			ILP	Minimize evacuation time	Two-step Solution Method	HD
7	Wu *et al.* (2010)	E/ EP			LIM	Minimize environmental emissions, system costs, and evacuation time	Multiobjective optimization method	HD
8	Tan *et al.* (2011)	E/ EP			LIM	Minimize total evacuation time	The grey fuzzy linear programming method	RD
9	Huang *et al.* (2012)		AO		Simulation	Maximize the expected throughput	Convergent optimization via the most promising area stochastic search algorithm	RD
10	Ibri *et al.* (2012)	EO	IOT		MIPM	Minimize the sum of traveling time, number of unsatisfied calls and number of uncovered zones	Genetic Algorithm	RD
11	Fan (2013)	E/ TCS		H	SLPM	Maximize profit		RD
12	Zolfagharinia and Haughton (2014)	ES		V	MIPM	Maximize profit	Computer software	HD/ RD
13	Turner *et al.* (2015)	EO	AV		Analytical	Minimize waiting time	Task swap allocation (TSA) algorithm	HD
14	Yang *et al.* (2015)	E		H	IPM	Minimize total vehicle allocation costs	Lagrangian heuristic algorithm	HD
15	Kaewpuang *et al.* (2016)	E		H	LIM/SM	Minimize the total delivery costs	Game Theory	RD

(*continued*)

Table 2.
Detailed analysis of articles on VAPs incorporating assumptions on sustainability, Industry 4.0 and logistics collaboration in quantitative models

No	Paper	S	I	LC	Model	Objective	Solution	DT
16	Schmaler *et al.* (2016)		AO		Simulation	Minimize loss for production	Flloyd–Warshall algorithm	RD
17	Zolfagharinia and Haughton (2016)	ES		V	MIPM	Maximize profit	Computer software	HD
18	Kim and Lee (2017)	E		H	LIM	Maximize profit	Computer software	HD/RD
19	Irannezhad *et al.* (2018)	E		H	LIM	Minimize total transport costs	Simulation algorithm	RD
20	Rui *et al.* (2019)		IOT		LIM	Maximize platform utility	Heuristic - Optimal collection path schedule algorithm	HD
21	Kang *et al.* (2020)		AV		LIM	Minimize the content accessing latency	K-means Clustering Algorithm	HD
22	Lei *et al.* (2020)	E			GTM	Maximize expected total revenue and minimize user's total ridesharing cost	Non-myopic algorithm	RD
23	Shima *et al.* (2021)	PS			TPOM	Minimize total dwell time	K-means and Genetic algorithms	RD
24	Shen *et al.* (2022)	RV			ORPF	Minimize rescue vehicle travel time	K-shortest path algorithm	HD

S: Sustainability	RD: Real-life data	H: Horizontal	MIPM: Mixed-integer programming model
I: Industry 4.0	RV: Rescue vehicle	V: Vertical	IPM: Integer programming model
LC: Logistics collaboration	EP: Evacuation planning	NLIM: Non-linear integer model	SM: Stochastic model
DT: Data type	EO: Emergency operations	PS: Passenger Satisfaction	GTM: Game theoretic model
RI: Returnable items	ES: Employee satisfaction	ORPF: Optimal reliable path finding	HD: Hypothetical data
E: Emissions	AO: Automated operations	SLPM: Stochastic linear programming mode	TPOM: Three-phase optimization model
W: Waste	IOT: Internet of things	LIM: Linear integer model	
TCS: Traffic congestion/safety	AV: Automated vehicles	ILP: Interval-parameter linear programming	

Note(s): * Based on the online search made on 16.08.2023
Source(s): Author's own work

Table 2.

Table 3 demonstrates that a widely recognized aspect of the Industry 4.0 concept within the VAP literature is the adoption of automated vehicles, particularly unmanned aerial vehicles, as a means of operational automation. As an alternative, Huang *et al.* (2012) and Schmaler *et al.* (2016) developed VAPs to optimize vehicle allocation decisions throughout an automated material handling system, offering a distinct perspective on how to approach Industry 4.0 ideas in VAPs. One of the most often mentioned elements of Industry 4.0, the Internet of Things, offers another perspective on how Industry 4.0 might be included into a

Table 3.
The research papers classified in emerging trends categories

Category	Research papers	Main contribution	Methodological interference of emerging trends	Application
Industry 4.0	Huang *et al.* (2012)	Proposed a conceptual framework to handle the vehicle allocation for an Automated Materials Handling System in the semiconductor industry	Developed a simulation model in the Automated Materials Handling System in practical settings to acquire better estimates of the performance measure of interest	The empirical study is based on real data obtained from a 300 mm wafer fab in a leading semiconductor company in Taiwan, China. The Automated Materials Handling System in the fab consist of 10 intrabay and one interbay systems; and initially, five vehicles are allocated to each system. The data is collected after a transient period (up to 250 h)
	Schmaler *et al.* (2016)	Presented a new system (called Vehicle Area Controller System) to overcome system failures	Focused on minimizing failure impact on the Automated Materials Handling System	The empirical study is based on real data procured from a fab, located in Dresden, Germany, belonging to the American semiconductor manufacturer Global Foundries. The Automated Materials Handling System in the fab has 825 tools, 425 vehicles, 20.000 storage locations and more than 13 km of track. The study is supported by the European Union and the Free State of Saxony
	Rui *et al.* (2019)	Investigated the sensing data collection and processing problem in a vehicular network and proposed the data fusion and Location-Dependent Sensing Task Assignment Mechanism algorithm to schedule the collection path for a single vehicle and sort the order for multiple vehicles to obtain maximum platform utility	Proposed a multi-source data fusion model that can help reduce the amount of collected data under the condition of different data changing rates, which is proven to offer a better data-processing effect	A hypothetical case
	Kang *et al.* (2020)	Proposed an Unmanned Aerial Vehicles allocation algorithm based on the K-Means clustering method, and a Long-Short Term Memory based content's popularity prediction scheme to support the intelligent caching at the Unmanned Aerial Vehicles to minimize the content accessing latency	Allocating Unmanned Aerial Vehicles which are temporary small-cell base stations in the overloaded areas	A hypothetical case
Industry 4.0 and sustainability	Ibri *et al.* (2012)	Developed a decentralized distributed solution approach based on a Multi-agent system to manage the emergency vehicles	Interacting intelligence software units that are linked to physical or functional entities (e.g. vehicles, calls) for real-time emergency vehicle allocation problems	The empirical study is based on real data (emergency calls, stations, and zones) corresponding to real addresses that are geolocalized on the Switzerland map. The experiments are conducted on two datasets in which the time between two successive emergency calls are 15 and 30 min, respectively, and the travel times are calculated using the MapPoint tool
	Turner *et al.* (2015)	Presented a Task Swap Allocation algorithm that increases vehicle allocation to the state-of-the-art consensus-based bundle algorithm and one of its extensions while meeting time constraints	Considered a search and rescue scenario with heterogeneous autonomous vehicles and survivors. The goal is to maximize the number of survivors while minimizing the average waiting time before their rescue	A hypothetical case

(*continued*)

Category	Research papers	Main contribution	Methodological interference of emerging trends	Application
Sustainability	Kamarthi *et al.* (2003)	Investigated the vehicle dispatching strategy links two aspects dispatching rules and vehicle allocation schemes. Dispatching rules assign the highest priority to a packaging order waiting in the queue for transportation service. The vehicle allocation scheme designates where the vehicle should be positioned after the package is delivered to its destination	Addressed a vehicle dispatching strategy problem to make use of returnable packaging many times	A hypothetical case
	de Oliveira Simonetto and Borenstein (2007)	Presented an operational management tool that considers the solid waste processing capacity of sorting units using simulation and heuristics techniques for vehicle routing and allocation problems	Proposed a simulation model that concerns the allocation of waste collection vehicles, determination of the daily amount of solid waste and to avoid waste of labor force and reduce the amount of waste sent to the landfills have been used	The empirical study is based on real data from the solid waste collection process in Porto Alegre, Brazil, which consists of collecting more than 60 tons of solid waste per day from 150 neighborhoods and distributing them to 8 recycling facilities. The experiments are performed for 15 distinct dates considering a collection team (one driver and two garbage collectors), 24 trucks, and 10 sorting units
	Chen *et al.* (2009)	Developed an inexact optimization method, which is for vehicle allocations and route plans, to manage evacuation systems under uncertainty and conduct uncertain analysis of complex relationships existing among various system components	Proposed a model to achieve optimal planning of vehicle allocation with a minimized system time under the condition of inexact information	A hypothetical case
	Beltran *et al.* (2009)	Presented a procedure for solving the transit network design problem to minimize the operator's costs, users' costs, and external costs, taking into account the modal elasticity of the demand and availability of a green vehicles fleet	Used a heuristic method to allocate green vehicles that were introduced to start renewing transit fleets by the European Community to comply with the Kyoto Protocol	The empirical study is implemented on the real road network of the Esposizione Universale di Roma neighborhood of Rome, Italy, which hosts the headquarters of many companies and public institutions. The road network of the study area, which is subdivided into 21 traffic zones, consists of 49 nodes, 90 unidirectional links, 32 bus lines, and one subway rail line. The experiments are performed on three network designs (10, 20, and 30 transit lines)
	Wu *et al.* (2010)	Optimized the resource allocation and route planning decisions in evacuation systems and analyzed complex relationships among evacuation time, cost, and environmental emissions	Developed an interval-parameter multi-objective optimization method to minimize evacuation time, economic cost, and environmental emissions	A hypothetical case
	Tan *et al.* (2011)	Reflected the relationships among vehicle allocation pattern, evacuation time, system satisfaction level, and system reliability level with the provided scientific tool to support evacuation management	Proposed an environmental-oriented evacuation management model that has an objective function to minimize evacuation time	The empirical study is based on real data obtained from Chinese cities (e.g. the city of Wuhan), wherein the evacuees are to be evacuated from one evacuation origin to three destinations. The experiments are performed on an approximately 68.4 km traffic network, where an average of 1,000 persons are transported to each destination by three types of public transit

(*continued*)

Table 3.

Table 3.

Category	Research papers	Main contribution	Methodological interference of emerging trends	Application
	Lei *et al.* (2020)	The proposed integrated model assumes that there are both uncertainty and elasticity of ridesharing demand, multiple modes and path options of travelers, dynamic pricing strategy, and controlling the deployment of vehicles to generate profit	Saving fuel consumption by reducing wastes of fuel and amounts of emission through ride-sharing	A hypothetical and an empirical case. The empirical study is based on real data obtained from Chicago taxi trips between 7:00 a.m.–9:00 a.m. on May 1, 2015. The experiments are performed on a subarea of Chicago, which has 16 identical zones grouped into one central business district and three residential areas, served by approximately 400 vehicles
	Shima *et al.* (2021)	Proposed a framework for optimizing timetables using a public bus operation dataset, K-means clustering, and a Genetic Algorithm and aimed to optimize the allocation of vehicles per time zone throughout the operational hours during the day	Developed an optimization model to focus on the reliability of the bus transport service from the point of passenger (related to headway, travel time, and waiting time) and bus operator (related to operational aspects)	The empirical study is based on real-world bus operating data. The experimental design includes GPS coordinates, time stamps, and location coordinates of buses, and the number of stops of each. Each stop's duration was calculated to represent its "dwell time"'
	Shen *et al.* (2022)	Proposed an optimization model that takes into account the rescue vehicle allocation problem as well as uncertainties in travel time, link correlations, and disturbance items based on rescue vehicle speed. To determine the optimal route and corresponding shortest travel time, the study examines the allocation of rescue vehicles to hospitals and their ambulances	Developed a heuristic algorithm to address the modified integer programming model to minimize the total time for all vehicles to be assigned to each rescue area	A hypothetical case
Sustainability and logistics collaboration	Fan *et al.* (2008)	Addressed the stochastic dynamic vehicle allocation problem in a carsharing context, using uncertain demand	Optimized carsharing programs by using stochastic linear integer programming to provide lower fuel consumption, reduce vehicle emissions, and increase traffic safety	A hypothetical case
	Fan (2013)	Developed a stochastic optimization framework to address the dynamic vehicle allocation problem for carsharing systems, in which the service operator needs to manage and determine the optimal vehicle allocation	Used stochastic linear programming to optimize carsharing programs that provide lower fuel consumption, reduce vehicle emissions, and increase traffic safety	A hypothetical case
	Zolfagharinia and Haughton (2014)	Considered "home base stays" for trucks while designing dispatching rules as drivers need to return to their homes/families. Conducted a comprehensive simulation study that gauged the benefit of advanced load information	Added constraint to ensure the maximum number of hours a driver can be away from home is not exceeded and repositioning empty, idle, or loaded trucks. Used collaborative transportation to ensure that trucks (containers) are re-positioned in a way that efficiently fulfills future demand	The empirical study is based on real data from a company operating in the truckload industry, with a base (depot) in Toronto, Canada. The experiments are performed in the service area where operations occur with 6 tractors between pick-up and drop-off locations in the province of Ontario
	Yang *et al.* (2015)	Planned an urban freight distribution network with Urban Freight Consolidation Centers where the freight demands fluctuate dynamically in time, and short-term and long-term leased vehicles are hired together	Increased vehicle utilization and reduced delivery frequency cause lower emission levels that occur during logistics operations. Consolidated with other products from different origins is used to transport incoming shipments	A hypothetical case

(*continued*)

Category	Research papers	Main contribution	Methodological interference of emerging trends	Application
	Kaewpuang *et al.* (2016)	Addressed the joint consideration of vehicle allocation, routing, cost sharing, and coalition formation among shippers from the integrated optimization and game theoretic perspectives	Sharing vehicles (vehicle pool) has been a significant impact on the environment by less fuel consumption. Creating a vehicle pool has enabled multiple shippers to collaborate	The empirical study is based on real data obtained from three small shippers using the Solomon and Singapore maps. The Solomon dataset has 25 customers, approximately 21 demands of each, and 25 heterogeneous vehicles. The Singapore dataset has 14 supermarkets as customers, homogeneous vehicles with a capacity of 30 packs, and time window length of approximately 63 min
	Zolfagharinia and Haughton (2016)	Proposed a flexible dispatching model that incorporates operational details of trucking companies (e.g. the current location of trucks, number of hours that a truck is away from home, previous commitments), and designed simple and intuitive policy to make profitable decisions in dynamic environments	Adding constraints introduces an upper bound for an allowable time for drivers to return to the depot that is the home base of drivers. Obtain advanced load information that improves the performance of the carrier to provide collaborative transportation between a carrier and its clients	A hypothetical case
	Kim and Lee (2017)	Illustrated the correlation among vehicle inventory, vehicle allocation, vehicle relocation, and efficiency of relocation through two optimization models in a quantitative manner	Implemented the carsharing concept to reduce vehicle driving and air pollution in crowded cities	The empirical study is based on real data obtained from traffic information in Seoul, Korea. The experimental design comprised the location of 25 district offices (virtual vehicle rental stations with an average distance of 20.72 km between two offices) and a total of 162,221 customer demands
	Irannezhad *et al.* (2018)	Evaluated the transport costs and the pollutant emissions when solving the problem of repositioning inland empty containers for reuse while integrating vehicle allocation and routing and considering dynamic network travel times, heterogeneous vehicle types, network restrictions per vehicle type, and multi-dimensional capacity of vehicles and container demands	Assessing the pollutant emissions that depend on fuel consumption calculated based on the truck type and the average speed in the optimum route. Analyze the environmental and economic benefits of horizontal cooperation among shipping lines in inland freight transportation (Shipping Cooperation)	The empirical study is based on real data obtained from shipping lines in inland freight transportation via the Port of Brisbane, Australia. The experimental design involves import and export container movements that lasted for weeks and collaboration scenarios
Logistics collaboration	Beaujon and Turnquist (1991)	Extended the previous work in the area of fleet sizing and empty vehicle management by providing a more explicit treatment of the dynamic and uncertain behavior of transportation systems	Designed a model to determine where should vehicle pools be located and how large should these pools be at any given time and at any given time and location, and how should available vehicles be allocated to loaded and empty movements and vehicle pools	A hypothetical case

Source(s): Author's own work

Table 3.

VAP. In two articles (Ibri *et al.*, 2012; Rui *et al.*, 2019), the Internet of Things has been integrated within VAPs in terms of real-time data collection from vehicles and interacting intelligent software units.

Among the three selected trends in logistics, sustainability, specifically the environmental pillar, is the predominant focus. In numerous VAP-related studies, emissions from logistics operations have been recognized as an external environmental issue. These studies employ several methods for reducing emissions by either using cutting-edge technology or improving decisions in the already-existing technological frameworks. Examples involve the usage of green vehicles or selecting environmentally efficient allocation decisions, such as lower fuel consumption. Notably, the study of de Oliveira Simonetto and Borenstein (2007) stands out for its attention to environmental concerns, as they designed a decision support model for operations planning of solid waste collection. As shown by both Tables 2 and 3, the majority of the VAP papers on sustainability issues concentrate only on the economic and environmental pillars, disregarding social concerns in their studies. The social dimension of sustainability is emphasized in a small fraction of papers in the VAP literature, including those by Fan *et al.* (2008), Chen *et al.* (2009), Wu *et al.* (2010), Tan *et al.* (2011), Fan (2013) and Zolfagharinia and Haughton (2014). These studies consider factors such as employee satisfaction, evacuation planning and traffic congestion/safety. In terms of addressing different social sustainability issues, such as driver satisfaction, traffic congestion or safety, there is still opportunity for development.

Another concept that is included in VAPs is logistics collaboration. In particular, horizontal logistics collaboration appears in the related literature in the form of, for example, car sharing and vehicle pooling. Nevertheless, it should be mentioned that in our examination of the literature we were unable to find any other papers that address the idea of vertical collaboration in VAPs except the works of Zolfagharinia and Haughton (2014, 2016).

Besides freight distribution, our review reveals that the three selected trends in logistics interact with many types of operations that face with a version of VAP, such as unmanned aerial vehicles, automated material handling systems, solid waste collection operations, search and rescue plans, emergency evacuation activities, bus transport services and carsharing or vehicle pooling systems. Half of these studies present real or real-based case studies, which also alludes to wide practical implications of the addressed problems. Yet, it is worth to mention that there is no study in the field that covers logistical problems related to the three dimensions (Industry 4.0, sustainability and collaboration) simultaneously.

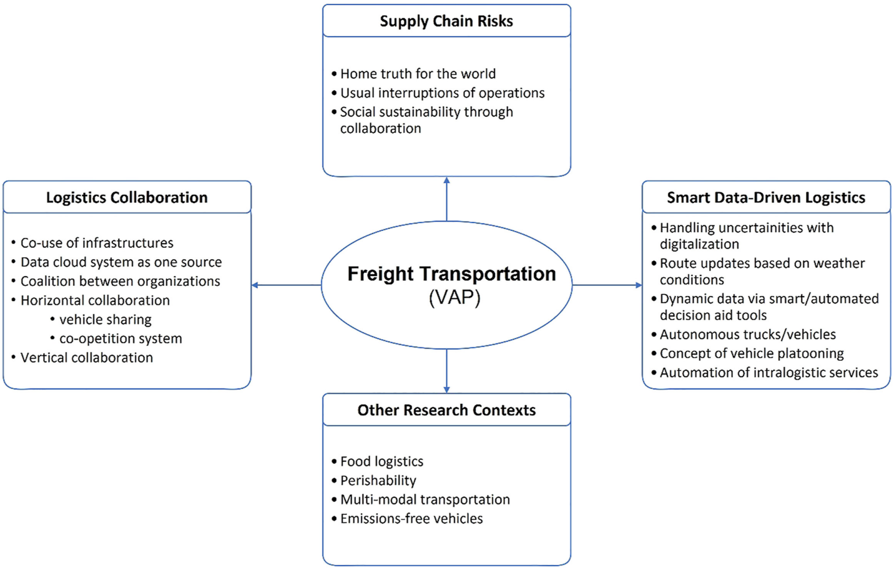
4. Discussions

This section provides academic and managerial insights on VAPs from the sustainability, Industry 4.0 and logistics collaboration points of view, building on the findings discussed in the previous sections. The discussions are summarized as categories and sub-categories in Figure 5.

4.1 More of logistics collaboration

As acknowledged above, logistics collaboration has potential to improve logistics systems in terms of various performance indicators. In what follows, we will provide several collaboration ideas/discussions which can inspire both industrial decision-makers and researchers.

Couse of infrastructures such as facilities (e.g. warehouses or x-docks), trucks, containers, material handling equipment or information systems can provide logistics service providers significant savings in logistics metrics (e.g. less supply lead time, dissemination of operating costs). For instance, a mining company, Black & Veatch [6], shares its resources and



Source(s): Author’s own work

Figure 5.
The summary of the discussions and proposed future research directions

infrastructures with local communities and multiple mines to better utilize scarce resources (e.g. water, power) and to reduce environmental impact. Freight Traffic Control 2050 (FTC2050) project [7] demonstrates the potential gains that can be obtained by means of closer operational collaboration between freight carriers to reduce urban traffic and energy demand without disrupting customer service levels. Collaborative working through shared use of resources (e.g. third-party micro-consolidation points to serve as handover locations between drivers and porters/cargo cyclists) has been analyzed in the project. Such practices can allow increased flexibility for supply chain members while managing logistics activities and can improve capacity utilization rates for the corresponding coutilized infrastructure. These flexibilities, which generate pooled/consolidated problem variants, can be respected by the proposed models on the topic.

Collaborative use implementations can be practiced beyond the co-use of infrastructures, such as having a data cloud system that enables the integration of information from several enterprises as one source. For instance, the FTC2050 project suggests designing a software “Hub” platform for integrating different carrier data sets and employing a third-party “Freight Traffic Controller” to ensure equitable distribution of demand across the network. Such a platform could allow us to better utilize available logistics resources, and therefore, contribute to the progress of economic welfare and the reduction of environmental and social externalities from logistics-related activities. Managing such platforms requires solving dynamic (e.g. online information related to the demand, weather conditions, breakdowns, etc.) VAP variants that can be addressed by researchers in the field. Such research attempts would be also useful to quantify the potential gains from this kind of collaboration.

The concept of collaboration in logistics has been often discussed in terms of creating a coalition where a number of similar-sized organizations share their vehicles/facilities. We could not observe any studies on the collaboration of asymmetric-sized actors, e.g. a company and freelancer truck owners that operate in the same long-haul FTL road transportation system. Collaboration takes place when self-employed shippers undertake a particular part of transportation activities under conditional contracts. In this context, platforms that facilitate collaboration among shipper companies and freelancers while respecting the differences in the working conditions of each party can provide several advantages. Convoy [8], Cargopedia [9], LKW-Walter [10] and Eulogis [11] are examples of such platforms. Through digital auctioning, these platforms offer: (1) decreasing total costs for shippers, (2) increasing the degree of flexibility, (3) increasing earnings for carriers by improving their capacity utilization rates and (4) reducing carbon footprint. Optimization of VAP decisions for shippers can also be integrated into such platforms to further improve the efficiency of the processes.

Cooperating with larger organizations can be beneficial for freelancers, yet, cooperating among themselves can also be a viable option. Job finding/selecting for freelancers is typically a bidding problem with uncertainty, where demands on various arcs/routes appear with time and price constraints, and freelancers place bids to beat their competitors. In the aforementioned digital auctioning platforms, bids are made individually in a noisy and uncertain environment for the bidder. Integrating a decision tool to such platforms that can aid the allocation of vehicles of the freelancers among the demands could not only improve the profitability of the truck owners but also could improve the service levels and customer satisfaction.

Horizontal collaboration and vehicle sharing are the solution alternatives that may help to obtain effective use of capacities and minimization of idle vehicles for reducing carbon emissions, congestion and increasing traffic safety. Goldsby *et al.* (2014) refer to horizontal collaboration as one of the most effective approaches that can be used to increase the efficiency of freight transportation for the three pillars of sustainability. Voruganti *et al.* (2011) study a single carrier tariff setting problem and show that partial collaboration between two non-competing carriers may be as beneficial as full collaboration. Still, concepts and systems, particularly for FTL transportation, are yet to be investigated and developed for companies to fairly share their facilities, information, vehicles, and demands.

Horizontal collaboration may be established among organizations competing with each other, without disrupting the competitive environment dynamics. Instead of a "full collaboration", in a so-called "co-opetition" system, the players open up new markets by cooperating among themselves and at the same time compete to increase their own market shares. For example, The Hershey Company [12] has announced that it has entered into an alliance with The Ferrero Group [13] through a joint warehousing, transportation, and distribution initiative. The two companies also work together to maximize corporate social responsibility efforts with the expectation of reducing CO_2 emissions and energy consumption in warehousing and freight, with fewer vehicle journeys needed to move products to customers. This collaborative innovation is closely intertwined with the agile functioning of the supply chain, as facilitated by supply chain collaboration (Al-Omoush *et al.*, 2023). In the study by Neamatian Monemi *et al.* (2017), a co-opetition model for a Hub Location Problem between two logistics service provider companies has been presented. The main gain of this co-opetition is an increased share of the generated additional market for two subcompanies belonging to the same mother company. Padmanabhan *et al.* (2022) presents a co-opetition system proposal for pick-up and delivery problems, where excess demands are shared among companies by a central authority. Application of similar ideas in VAPs to construct a cooperative system between competing actors has potential to contribute to aggregate and individual gains from both supplier and customer perspectives.

Another concept that is yet to be enhanced in the VAP literature is vertical collaboration. As well as horizontal collaboration, vertical collaboration can contribute to reducing costs, improving sustainability, and increasing service levels. For instance, Nutella [14] agreed to collaborate with Loop (a leading reuse platform) and Carrefour (a leading retailer) for a reuse pilot scheme in Paris, France. Through the plan, shoppers will be able to purchase a specially designed reusable Nutella jar by paying a deposit to Carrefour and Carrefour will then collect the empty jars and send them back to Nutella for washing and reuse. Such vertical collaboration arrangements can be established in VAPs by particularly sharing data/information between different levels of the supply chain, potentially improving the operation in terms of response speed, flexibility and costs/profits. Sharing the instantaneous travel time information, for instance, could help to reduce the system nervousness, or sharing potential empty travels and/or idle vehicles (with some incentives such as price discounts) may encourage the customers to adjust their decisions for mutual economic benefits. Decision support models that respect such operations have potential to improve the current literature and may be subject to practical use.

Supply chain collaboration offers numerous advantages that enhance efficiency, reduce costs and increase competitiveness (Duong and Chong, 2020). Through improved coordination and communication, partners can streamline processes, achieve cost reductions and optimize inventory management, resulting in enhanced operational efficiency (Ma *et al.*, 2019). The sharing of real-time data and information among collaborators enhances supply chain visibility, leading to better demand forecasting and inventory planning (Baah *et al.*, 2022). However, these collaborations have various limitations and barriers including a lack of communication, security and privacy concerns, behavioral and cultural issues (Kakhki *et al.*, 2018). The presence of weak relationships among organizations can give rise to various obstacles to collaboration, including territoriality, strategic misalignment, a lack of leadership, gaps in collaborative skills, low levels of trust and poor system connectivity (Fawcett *et al.*, 2015; Mahmud *et al.*, 2021). To create a successful collaborative network that overcomes these limitations, blockchain technology, known for its decentralization, tamper-resistance and transparency, presents an opportunity to alter supply chain collaboration by enabling smooth information flow and secure communication among partners Xia *et al.* (2023). Critical factors for success include selecting the right partners with consolidation potential and mutual trust on the strategic level for cooperative planning (Dahl and Derigs, 2011). From an operational perspective, it is critical to establish solid connections for the flow of information and implement efficient coordination processes within the coalition. In order to enable seamless information flow across collaboration partners, secure and trustworthy communication methods must be made available. Companies can also develop and utilize decision support systems to address collaboration obstacles. Such approaches are helpful in facilitating effective decision-making, enhancing communication and streamlining partner collaboration procedures (Basso *et al.*, 2019; Xu *et al.*, 2013).

4.2 Modeling supply chain risks

Long-haul freight distribution operations are carried on in a wide geography that may possibly involve different cities or even countries, varying road conditions and divergent factors. The distances between the hubs and the traveling vehicles may also retard any responses to unexpected situations or events. Supply chain risks, in such a setting, have more significant effects on the performances of operations, and therefore, are to be incorporated into mathematical models constructed for VAPs. There is a vast literature on supply chain risk management. Recent review studies on the topic (e.g. Baryannis *et al.*, 2019; Ganesh and Kalpana, 2022; Pournader *et al.*, 2020) may help readers to obtain a broader view on what kinds of risk aspects can be integrated into the VAPs and how they can be modeled or incorporated into VAP models. Among many opportunities, here we would like to mention a number of prominent risk sources that could provide practical returns if they are respected in quantitative decision models for VAPs.

One of these risks is a home truth for the world; in a number of places/countries that long-haul freight distribution reaches, there exist wars, terrorist actions and/or lack of legal authority. Operating in such locations raises the ultimate risk, life threat for the employees that are involved in the operations. A significant social sustainability concern to be incorporated into mathematical models for VAPs could be minimizing such risks. For this purpose, arranging the timings of the travels, reducing idle times that drivers wait in risky locations and using different transportation modes are possible directions for enhancing the classical VAP models. Also, Industry 4.0 applications such as driverless transportation in these areas, automated emergency actions, or premise surveillance with drones can be respected in decision models. For example, Volvo Autonomous Solutions announced that it will partner with global logistics provider DHL Supply Chain to use its autonomous trucks in their operations [15]. The autonomous trucks have potential to decrease the encountered life threat during operations in risky geographies.

More common supply chain risks are also subjects for possible enhancements of the mathematical models in the current VAP literature. A basic example could be usual interruptions of operations, such as road closure, vehicle breakdown, traffic conditions, accidents, etc. For instance, according to the US Federal Motor Vehicle Carrier Safety Administration reports [16], a total of 79,451 large truck accidents occurred between 1st January 2022 and 30th June 2022 across the United States, each of which has potential to cause a serious road blockage. In 2004, an oil tanker ran aground in the Suez Canal, causing a Sony ship carrying their product supplies to get stranded in the canal for two weeks. Stocks were run short in several parts of Europe, forcing Sony to bring in supplies on hired Antonov cargo planes at vast expense [17]. Such interruptions are important not only for economic reasons but also for environmental and social sustainability concerns such as deterioration or drivers' workload. Modeling these risks may involve reducing the possibility to face such events, as well as codefining response preparations for them. A particular concrete example is investing in backup vehicles that may replace any vehicles in case of breakdown or accident. In this case, location–relocation of the backup vehicles is possible decisions to optimize.

It has drawn attention in several studies that logistics collaboration increases vehicle utilization, which contributes to environmental sustainability by reducing emission levels. Nevertheless, the investigated links between collaboration and environmental sustainability concerns in the VAP literature are mostly limited to emissions, whereas there is not any research exploring how collaboration can improve the social sustainability performance of systems. A potential research direction in the field would be investigating the worth of collaboration acts in terms of potential sustainability accomplishments. Social sustainability concerns in the customer end of supply chains, such as supply disruption (due to any accidents or vehicle breakdown), delivery delay, deterioration of and/or damage to the product, etc., are to be incorporated into VAP models. Customer satisfaction in this sense is a basic performance indicator. Vehicle replacement or monetary compensations are possible ways to handle such situations that could be addressed in decision models.

Provided the vast literature and high academic and industrial interest on supply chain risk assessment, many other research directions are also available for future studies. For instance, investigating the fields of sustainable and behavioral supply chain risk management is one potential direction for future studies. There can be a better understanding of how to manage sustainability risks on the supply chain and how human behaviors and decisions affect the supply chain risks (Pournader *et al.*, 2020). Another possible approach that may be considered is by conducting case studies that explore how to achieve a fit among strategy, structure and procedure in supply chains of companies with risk assessment, leading to a better understanding of the practical applications of related concepts in the field (Nakano and Lau, 2020). Furthermore, exploring the practicality of supply chain risk management modeling in real-world applications, as well as the necessity to consider the limitations (e.g. data quality, supply chain structure and performance) of relevant modeling-based solutions may be considered as another research gap that will guide future studies (Fagundes *et al.*, 2020). Lastly, requirements such as integrating both qualitative and quantitative methods for supply chain risk management, focusing on various specific risk types (e.g. sustainability-related risk, demand risk, compliance risk), and risk assessment in different layers of the supply chain are suggested as future research directions (Tran *et al.*, 2018).

4.3 Smart data-driven logistics solutions

Managers need to be ready to come up with novel solutions since innovation has become vital on a worldwide scale if they want to keep their businesses sustainable in a competitive business environment (Hamdan *et al.*, 2022). In this context, with the developing technology, especially after the emergence of Industry 4.0, digitalization can be considered as an effective tool throughout the decision-making processes of transportation operations by better-handling uncertainties. These uncertainties can be broadly divided into two main groups: supply uncertainties that affect the driving condition and arise from different disturbances on the road, and demand uncertainties, where different variations can be observed over time (Lam *et al.*, 2008). Smart data-driven solutions can aid decision-makers to cope with both types of uncertainty and improve the effectiveness and efficiency of operations.

Weather conditions, which are one of the potential uncertainties that may affect vehicle movements, routes and lead times, change over time and cannot be controlled. Weather conditions can be an even more determinant factor in long-distance transportation where the operation time and distance are higher. For this reason, route updates according to weather conditions can be used in VAP that are especially encountered in long-haul freight transportation. Successful forecasts of these conditions are important for the effective management of transportation operations. Although weather conditions cannot be controlled, real-time data and updated (and potentially more accurate) forecasts may be obtained from several profit/nonprofit organizations, as well as from the company's own smart vehicles/facilities in order to minimize possible disruptions, meet demands on time and achieve a proactive delivery plan. Developing dynamic decision aid models that respect such real-time data and related constraints is a potential improvement opportunity for the literature.

Dynamically updating problem data during the execution of operations is not beneficial only in terms of weather conditions but also for many other problem parameters, such as demands, costs or traffic conditions. Demand is possibly the most prominent one among these, critically shaping all vehicle allocation operations. Given that the level of uncertainty grows as the planning horizon extends, handling demand variations becomes a major challenge for such problems. Frantzeskakis and Powell (1990), for instance, developed a heuristic algorithm to overcome such challenges. Alternatively, instead of relying on long-run plans, dynamically updated data and recalculated optimal solutions via an automated/smart decision aid tool may provide improved responsiveness and corresponding customer satisfaction for companies. In this context, new models on dynamic VAPs can be developed that can be incorporated into such smart decision-aid tools.

In addition to the use of real-time data for better decisions, autonomous trucks are another concept that Industry 4.0 brought to light, which also has potential to revolutionize the transportation industry (Nasri *et al.*, 2018). There are some leading companies that present digital, electric and autonomous shipping technologies to the world such as Embark [18], Volvo [19], Daimler [20] and Einride [21]. These vehicles that eliminate the human factor allow for an increase in operation times per day, reduce lead time and decrease the number of utilized vehicles. Also, autonomous vehicles are generally powered by electricity. This can lead to logistics operations with less fuel consumption and lower emission levels. Future research on the efficiency and requirements of autonomous vehicles and decision models that respect the specific characteristics (e.g. energy consumption estimates, travel time evaluations, charging time/places, operation ranges, etc.) of such vehicles may help practitioners to benefit from the advantages of the technological improvements and smart solutions.

The number of self-driving freight vehicles employing the features of vehicle platooning might increase in the near future. The concept of vehicle platooning refers to a group of vehicles that can communicate with each other through wireless systems, GPS, radar-sensing systems, etc., and travel closely at high speeds. A lead vehicle controls the speed and direction of the whole platoon. The following vehicles have precisely matched braking and acceleration rates that allow safe travel. For instance, Volvo Trucks North America, together with FedEx and the North Carolina Turnpike Authority, used advanced driver assistance system technology to conduct on-highway truck platooning as part of an ongoing research collaboration [22]. Another example of vehicle platooning from the industry is shown by Continental and Knorr-Bremse [23] who formed a partnership with the goal of developing highly automated commercial vehicle driving. The use of vehicle platooning can contribute to the idea of reducing fuel consumption, emissions, and traffic accidents. Driverless vehicles can join to the available platoons which could ensure a more steady-state traffic flow as well. The study of Mahrle *et al.* (2019) conducts a simulation to estimate the heavy truck platoon's fuel economy compared to a reference vehicle traveling alone. Similar analyses employing optimization and simulation techniques could be conducted to reveal how such developments may affect vehicle allocation decisions and what the potential benefits and/or challenges are.

Features brought by digitalization and automation also change traditional facilities. For instance, automated warehouses utilizing digital technologies (such as sensors, robots, automated guided vehicles, automated material handling systems, etc.) enable (1) lower labor costs, (2) faster and efficient customer order processing, (3) a boost in storage space and capacity (4) better overall workplace health and safety, etc. Savings in operational costs through the above factors allow us to observe productivity increase in intralogistics activities. The project ILIAD [24] aims to enable the transition to automation of intralogistics services with key stakeholders. The project proposes robotic solutions (e.g. self-deploying fleets of heterogeneous robots that can operate along with humans) that can integrate with current warehouse facilities. Integrated VAPs that involve the steps taken to move and store a product from a supplier to a customer can consider altered assumptions related to the automated warehouses, such as dynamic information sent through machines on product deterioration, demand changes, machine failure (demand postponement), etc.

4.4 Other possible future research directions

In addition to the aforementioned significant fields in each of which a number of contributions to the VAP literature can be made, there are several other research topics that researchers can enhance the VAP literature in terms of sustainable, collaborative and Industry 4.0-related applications. In what follows, we will provide additional academic examples of such topics and managerial insights about VAP.

Despite the importance of food logistics and its wide coverage in many other research fields, it appears that food logistics has never been covered in the VAP literature. Due to the specific requirements of food logistics such as high level of hygiene, definite temperature, delivery time, legal regulations, etc., food logistics decisions form more complex decision problems where traditional models cannot be used (Soysal, 2015). There is a need for decision models that address the food logistics problems in the VAP literature.

An important characteristic of many food products is perishability, but perishable products are not limited to food. Perishability applies to various materials and/or products in many other industries. Moreover, perishability is not only an economic factor but also an environmental indicator regarding waste minimization. Decision support models that can handle perishability have potential to enhance the VAP literature and improve the performance of practical decisions in terms of both economic and environmental aspects.

Another potential contribution to be made to the VAP literature is incorporating multimodal transportation into decision models. Multimodal transportation can help to optimize deadlines, reduce inventory and transportation costs, improve service quality and decrease damage risk. Moreover, since enabling companies to lower both distribution costs while also cutting carbon emissions, it seems to be one of the most effective techniques for reducing the carbon footprint of products (Laurent *et al.*, 2020). The combination of these advantages can also provide higher environmental sustainability. As a cost of these advantages, more complicated decision models are needed in order to cope with an increased number of decisions and constraints.

The last but not the least, the emergence of emissions-free vehicles, which include battery electric vehicles and hydrogen fuel cell trucks, can be regarded among prominent developments, which can revolutionize the future of freight transportation. Significant amounts of CO_2 emissions are caused by freight which has a detrimental impact on air pollution, noise and ecosystems and also is almost entirely reliant on fossil fuels as an energy (Vanek, 2019). Global efforts to use more emissions-free vehicles in freight transportation contribute to the objective of the full decarbonization of the road freight sector. Several ongoing projects related to clean freight transportation perform feasibility analyses on regional delivery and long-haul truck applications. The objective of "Hydrogen Solutions for Heavy-duty transport Aimed at Reduction of Emissions in North-West Europe" project [25] is to develop markets for low-carbon heavy-duty hydrogen-fueled vehicles for logistics applications and gain practical experience in different regions. Pilot studies performed by Hovi *et al.* (2020) in Norway with battery electric vehicles show that operators are positive about working conditions, energy savings and lower operating and maintenance costs. However, they have to perform considerable tailoring of route/location choices due to the restrictions aroused by the use of electric vehicles. Downtime costs, energy consumption estimations and restrictions on charging times, charging locations or payload limits need to be respected while making vehicle allocation decisions in long-haul freight transportation.

5. Conclusion

This review undertakes the goal of exploring the quantitative models in the VAP literature, particularly which incorporate assumptions on/properties of any of sustainability, Industry 4.0 and logistics collaboration concepts that can contribute to climate-neutral supply chain targets. Descriptive analyses of the field are followed by detailed discussions on the gaps and potential future research directions on the aforementioned concepts. To the best of our knowledge, this is the first attempt that aims to provide a literature review on VAPs.

The descriptive statistics suggest that the interest in VAPs has been growing over the years. Yet, the number of papers that address the aforementioned emerging trends in VAPs is still limited. This review analyzes the VAP literature providing information on the decision variable, constraint and assumption sets; objectives, modeling and solving approaches; and detailed explanations on how each reviewed study contributes to the logistics literature and how they handle one or more of the addressed logistics trends. The detailed discussions on the revealed gaps and potential studies in the field are carried out under four main streams: logistics collaboration possibilities, supply chain risks, smart solutions and various other potential practices.

According to our discussions, it is worth to mention that in line with the developments in digital technologies, collaboration among supply chain actors is getting easier than before. Several projects funded by respected organizations aim to motivate supply chain actors to collaborate with each other and provide guidelines on how to set up and sustain such collaborations. However, the research on VAPs does not currently address various potential forms of collaboration such as co-use of infrastructures, co-opetition or vertical collaboration.

Smart freight transportation systems and advanced information and communication technologies enable many opportunities such as sharing information on different features related to the transportation process, comanaging distribution operations and consolidating demands and resources among the supply chain actors at the same or different levels. Each of these opportunities can be elaborated on by researchers while developing decision-support models for VAPs.

Businesses operating in freight distribution should give priority to effective and efficient logistics activities given the immense economic importance of the transportation and logistics industry in order to deal with the growing distances between supply chain actors. Being a predominant sustainability aspect in the current literature, developing environmentally friendly operations may be a natural next-in-line sustainability target, provided the wide academic literature to benefit from. However, our discussions reveal that beyond economic concerns, climate–neutrality interactions of the literature are mostly limited to reducing operational emissions. It is a fact that emissions are one of the prominent indicators used to assess the environmental performance of freight distribution operations. Reducing emissions, with the goal of climate-neutral supply chains, may still be costly but seems to be inevitable with developing governmental targets and increasing number of regulations, in addition to the customer awareness which may correspond also to a monetary return for the cost. Yet, emissions generated throughout supply chain, further environmental externalities such as waste and product deterioration, or the level of stakeholder engagement etc., are to be monitored in order to achieve overall climate-neutral services to the society. From a broader sustainability viewpoint, growing attention on social concerns such as traffic congestion, employee welfare, working conditions, etc., are to be incorporated into decision models.

There is evidence in the literature that logistics collaboration and Industry 4.0 based technologies can be useful tools to exploit in order to gain economic benefits while improving towards climate-neutrality targets, particularly reducing emissions. Embracing collaboration on both horizontal and vertical levels can be a game changer, with regard to both economical end environmental achievements. Horizontal collaboration encourages innovation and market expansion by allowing corporations to work with rivals to enter new markets while still competing for market dominance, while reducing unnecessary travels to reduce emissions. Pooling and sharing ideas allow couse of resources and infrastructure, jointly handling customer demands, or making joint research and development activities for higher-impact results. Vertical collaboration has potential to involve customers into decision processes, allowing mutually profitable operation plans. Both horizontal and vertical collaboration practices can be sustained only if a mutually beneficial plan, in which one side of the collaboration does not exploit the other side(s), but both sides equivalently earn from the plan and make mutual compromises when needed. Even in a co-opetition case, sustainable collaboration depends on the ability of the parties to treat their competitors as collaborators while handling the subjects of cooperation. Other factors, such as transparency between collaborators, smooth information flow or shared motivation towards maximizing overall supply chain surplus also contribute to long-lasting collaboration agreements.

Investing in digital/smart technologies is becoming almost a prerequisite for research and development in majority of industries. Logistics actors can, for instance, explore digital marketing platforms that support conditional agreements, accept the differences between parties and provide advantages like cost savings, increased flexibility and lower carbon footprint through digital auctioning. Additionally, utilizing digital technologies can streamline cooperation, making it simpler for stakeholders to work together and efficiently communicate information. Flexibility and adaptability provided by smart technologies are also essential since collaborative efforts may need to be adjusted in order to respond to shifting conditions and market dynamics.

In summary, exploring diverse forms of collaboration and harnessing the potential of smart solutions and advanced technologies can significantly enhance the performance and sustainability of vehicle allocation operations, contributing to the broader goal of achieving climate-neutral supply chains. This review has potential to guide future research efforts in the field, advancing the understanding and optimization of VAPs within the context of modern and environmentally responsible supply chains.

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Appendix

Year	Articles
1986	Powell (1986)
1987	Powell (1987)
1988	Hughes and Powell (1988)
1990	Frantzeskakis and Powell (1990)
1991	Beaujon and Turnquist (1991)
1993	Crainic *et al.* (1993)
2000	Powell *et al.* (2000)
2003	Kamarthi *et al.* (2003), List *et al.* (2003), Sung and Song (2003)
2005	Miller *et al.* (2005)
2006	Roorda *et al.* (2006)
2007	de Oliveira Simonetto and Borenstein (2007), Lam *et al.* (2007)
2008	Fan *et al.* (2008), Lee *et al.* (2008)
2009	Beltran *et al.* (2009), Chen *et al.* (2009), Na and Shoubin (2009), Roorda *et al.* (2009)
2010	Wu *et al.* (2010)
2011	Tan *et al.* (2011)
2012	Huang *et al.* (2012), Ibri *et al.* (2012)
2013	Boile and Peric (2013), Fan (2013), Lin *et al.* (2013)
2014	Shi *et al.* (2014), Upadhyay and Bolia (2014), Zolfagharinia and Haughton (2014)
2015	Andrade and Cunha (2015), Atasoy *et al.* (2015), Hanczar and Peternek (2015), Ikeda *et al.* (2015), Li and Tian (2015), Turner *et al.* (2015), Yang *et al.* (2015)
2016	Angelopoulos *et al.* (2016), Kaewpuang *et al.* (2016), Liu *et al.* (2016), Sanchez-Martinez *et al.* (2016), Schmaler *et al.* (2016), Tari and Hashemi (2016), Vasco and Morabito (2016), Wu (2016), Zolfagharinia and Haughton (2016)
2017	Kim and Lee (2017), Mesa-Arango and Ukkusuri (2017)
2018	Irannezhad *et al.* (2018), van Buuren *et al.* (2018)
2019	Gkiotsalitis *et al.* (2019), Jixian *et al.* (2019), Li *et al.* (2019), Rui *et al.* (2019), Sullivan *et al.* (2019)
2020	Chavhan *et al.* (2020), Cruz *et al.* (2020), Jian *et al.* (2020), Kang *et al.* (2020), Lei *et al.* (2020), Pitakaso *et al.* (2020)
2021	Shima *et. al.* (2021)
2022	Shen *et al.* (2022)

Source(s): Author's own work

Table A1. Annual distribution of articles on general VAP

Journal	#	2019 impact factor	Authors
Transportation Research Part C: Emerging Technologies	5	6.077	Atasoy *et al.* (2015), Beltran *et al.* (2009), Gkiotsalitis *et al.* (2019), Lam *et al.* (2007), Liu *et al.* (2016)
Transportation Science	4	3.384	Beaujon and Turnquist (1991), Frantzeskakis and Powell (1990), Powell (1986), Powell *et al.* (2000)
Transportation Research Part B: Methodological	3	4.796	Lei *et al.* (2020), Powell (1987), Roorda *et al.* (2009)
Transportation Research Record	2	1.029	Fan (2013), Fan *et al.* (2008)
Transportation Research Part E: Logistics and Transportation Review	2	4.69	List *et al.* (2003), Zolfagharinia and Haughton (2014)

(*continued*)

Table A2. The journals which most frequently accommodate articles addressing VAP

Journal	#	2019 impact factor	Authors
Computers and Industrial Engineering	3	4.135	Cruz *et al.* (2020), Tari and Hashemi (2016), Upadhyay and Bolia (2014)
Computers and Operations Research	2	3.424	Lin *et al.* (2013), Vasco and Morabito (2016)
Journal of The Operational Research Society	2	2.175	Lee *et al.* (2008), Sung and Song (2003)
Journal of Advanced Transportation	2	1.67	Li *et al.* (2019), Tan *et al.* (2011)
Mathematical Problems in Engineering	2	1.009	Yang *et al.* (2015)
Waste Management	1	5.448	de Oliveira Simonetto and Borenstein (2007)
IEEE Transactions on Vehicular Technology	1	5.379	Kaewpuang *et al.* (2016)
International Journal of Production Economics	1	5.134	Shi *et al.* (2014)
Transportation Research Part D: Transport and Environment	1	4.577	Irannezhad *et al.* (2018)
International Journal of Production Research	1	4.577	Huang *et al.* (2012)
European Journal of Operational Research	1	4.213	Zolfagharinia and Haughton (2016)
Engineering Applications of Artificial Intelligence	1	4.201	Ibri *et al.* (2012)
Transportation Research Part A: Policy and Practice	1	3.992	Sullivan *et al.* (2019)
Management Science	1	3.931	Hughes and Powell (1988)
International Transactions in Operational Research	1	2.987	Andrade and Cunha (2015)
Operations Research for Health Care	1	2.627	van Buuren *et al.* (2018)
Operations Research	1	2.43	Crainic *et al.* (1993)
Transportmetrica A-Transport Science	1	2.424	Mesa-Arango and Ukkusuri (2017)
Engineering Optimization	1	2.165	Pitakaso *et al.* (2020)
International Journal of Systems Science	1	2.149	Wu *et al.* (2010)
Kybernetes	1	1.754	Chen *et al.* (2009)
Transactions on Emerging Telecommunications Technologies	1	1.594	Rui *et al.* (2019)

Table A2.

Source(s): Author's own work

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