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The Economic and Environmental Benefits of Collaborative Pick-Up in Urban Delivery Systems

Sally Justiani[1] and Budhi S. Wibowo[1*]

[1]*Universitas Gadjah Mada, Department of Mechanical and Industrial Engineering, Yogyakarta, Indonesia; E-mail: sally.justiani@mail.ugm.ac.id, budhi.sholehwibowo@ugm.ac.id*

***Corresponding Author:** Budhi S. Wibowo

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Abstract: The fierce competition between carriers in urban delivery systems has led to several negative consequences, such as inefficiency, road congestion, and harmful pollution. One way to address these issues is by encouraging horizontal collaboration, since many vehicles at this stage are less than full. This study aims to evaluate the benefits of collaborative pick-up in urban delivery systems. The problems are modeled based on the multi-depot vehicle routing problem. A case study with two carriers in Pekanbaru city, Indonesia, is presented as an illustration. The numerical results suggest that the economic benefits from the collaboration are significant when the spare capacity in the system is plenty. In contrast, the environmental benefits are typically linear with the reduction of vehicle miles traveled. The study findings provide practical insights for urban planners and logistics service providers to foster sustainable development in the city.

Keywords: City logistics, pick-up operations, horizontal collaboration, sustainability

1. Introduction

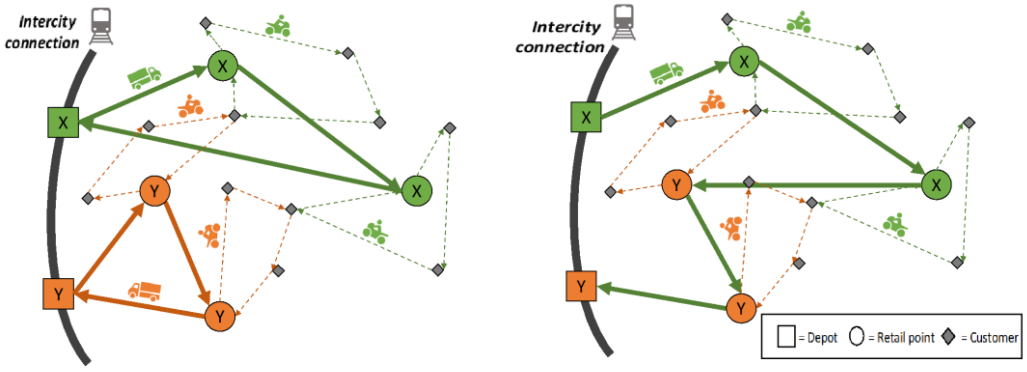
The freight transport market in an urban landscape is typically fragmented and highly competitive. An increasing number of carriers are competing to serve the ever-growing demand for transport due to the rise of e-commerce. The fierce competition between carriers leads to lower market prices, leaving the companies with thin margins. As a response, many carriers aim to gain profits from the sales volume by opening several retail points closer to the customers. By having larger networks in the city, the carriers expect to increase their presence in the market, reach more customers, and eventually gain higher revenues.

Unfortunately, this strategy also leads to some negative consequences. A large network of retailers would increase parking and loading/unloading activities in the city, interfering with the traffic flows. Moreover, retailers from different carriers are often located on the same road due to the fierce

competition [1,2]. This situation can increase traffic congestion since the same road would be traversed by numerous vehicles that provide a similar service but that belong to different companies. Besides, the increasing vehicle miles traveled would negatively impact the environment. Fossil fuel combustions from vehicles emit several dangerous pollutants and particulate matters, which can harm the health of citizens. The resulting impact can reduce the life quality of citizens and backfire on the carriers due to inefficiency.

Furthermore, the growth of e-commerce has led to smaller volumes with frequent orders, leaving plenty of spare transport capacity. The increasing market expectation for shorter transport lead times gives the companies narrow time windows to consolidate these small volumes [3]. A European statistical report confirmed that freight transport was on average less than half-full [4]. Even worse, about 15-20% of truck miles are empty, leading to inefficient logistics and expensive freight costs [4]. Without a bold initiative and a paradigm change, the existing trend in urban delivery systems would continue to hurt society, the environment, and the transport business itself.

To improve efficiency, carriers can initiate a horizontal collaboration, where part of their operations are planned together, rather than working in a silo and accepting the inefficiency as an inevitable by-product. Horizontal collaboration refers to a partnership between two or more companies that provide similar services/activities to benefit from economies of scale [5]. Horizontal collaboration in logistics has recently garnered substantial attention from researchers and practitioners. Such an initiative has a high potential for reducing costs, increasing efficiency, alleviating congestion, and mitigating external costs [6,7].



(a) non-collaborative pick-up (b) collaborative pick-up

Fig. 1 Illustration of pick-up operations in urban delivery systems. Source: authors

A part of urban delivery systems that has a high potential to be consolidated is pick-up operations. Pick-up operations typically consist of two echelons, where retail points become intermediaries between the customers and the depots (see Fig. 1). Our study focuses on the logistics issues in the second echelon, that is, the pick-up activities at retail points. In that echelon, carriers typically use larger vehicles, e.g., trucks or vans, to collect the payload from the retail points and carry them to the

depot. However, due to the increasing expectation of faster delivery, the vehicles in the second echelon are often less than full, making the operations inefficient and expensive. Therefore, there is a strong case for the carriers to collaborate through a joint use of resources at this echelon to improve efficiency. Our research aims to investigate the economic and environmental benefits and how to share the joint costs resulting from such a collaboration.

2. Literature Reviews

Horizontal collaboration in transport and logistics refers to the active cooperation between companies that operate at the same level of the supply chain and across supply chain networks, from occasional to long-lasting collaboration, from strategic to operational level [8]. As in supply chain management, collaboration in urban logistics requires trust and willingness to share resources and information between the actors involved [9]. The main incentives for companies to involve in a collaborative transport coalition are lower total costs, improved resource utilization, a higher degree of sustainability, and an increased service level [10]. Gansterer and Hartl [11] identified 46 research articles on collaborative transport and found that the topic is relatively young, since 50% of them have been published within the last five years.

Most of the studies in this horizontal collaboration evaluate the potential benefits of collaborative versus non-collaborative planning. For example, Ouhader and El-Kyal [7] investigated the benefits of joint planning of vehicle routing and facility locations from sustainability development perspectives. The study found that a collaborative approach can reduce transportation costs and carbon emissions and minimize traffic congestion. Quintero-Araujo et al. [12] analyzed the role of horizontal collaboration in urban freight transport by comparing them with conventional operations. The experimental results suggested that the collaboration saves 2-10% of the total cost. The study highlighted that the gains for each company could differ significantly. Therefore, a fair gain-sharing mechanism is needed to distribute the joint benefits to collaborators.

Although numerous studies have supported the potential benefits of horizontal collaboration, there are some challenges and obstacles to implementing it. Basso et al. [13] surveyed 62 scientific articles to explore practical issues in implementing horizontal collaboration. The study found that trust, coordination mechanisms, and the availability of decision support tools are critical factors in materializing collaboration. Serrano-Hernandez et al. [14] investigated the trust-related issues when forming collaborative transport and found that the benefits of collaboration could only increase linearly after a certain degree of integration is reached. Farvaresh and Shahmansouri [15] investigated a way to determine the best coalition structure for large-scale collaborative transport. The study found that cooperation and sharing mechanisms in a coalition are essential factors that motivate companies to join a collaboration.

An important aspect of horizontal collaboration is distributing the total costs or savings across the collaborators. Guajardo and Rönnqvist [16] reviewed 55 research articles and found more than 40 different cost allocation methods. The studies found that the Shapley value is the most applied method, followed by the proportional method. Further, the authors also outlined that most allocation methods were not based on practical requirements. Instead, most of the methods are based on already defined theoretical models. Niemsakul et al. [17] interviewed experts to investigate the priority of cost and benefit parameters in healthcare supply chain collaboration projects. The study found that the cost of information technology is the top concern for the collaborators. On the other hand, the process and inventory cost reduction were the most expected benefit.

Our study contributes to the literature in the following areas. First, we focus on the collaborative effort of pick-up operations in the second echelon that is rarely discussed in the literature. Second, we offered a preliminary decision support tool for companies to design optimal networks and estimate the benefits of collaboration. Lastly, unlike most previous studies that are solely based on theoretical models, our study directly involves the stakeholders to determine the most practical sharing mechanism.

3. Methods

3.1 Mathematical Models

In collaborative pick-up, companies cooperate by sharing depots and vehicles to visit the retail points. The scenario assumes centralized planning where a set of depots from different companies are willing to share and exchange required data to plan collaborative pick-up. We model the case as a multi-depot vehicle routing problem (MDVRP) that seeks to define the optimal routes that minimize the total costs, where each vehicle should start and end at the same depot with regard to duration and capacity limit.

The MDVRP can be represented using a graph $G(N, E)$, where N is the vertex set, and E is the edge set. The vertex N is subdivided into two subsets, i.e., the set of retail points $N_c = \{1, 2, \dots, n\}$, and the set of depots $N_p = \{n+1, n+2, \dots, n+p\}$. Each retail point i has a demand q_i and a service time s_i. The depot also has a time window $[0, T]$, meaning all vehicles should return to the depot before T. The system has a set of vehicles $K = \{1,2,..k\}$ where K_i refers to the subset of vehicles belonging to depot i. Each vehicle has a capacity Q which restricts the number of vehicles it can visit along the route. The edge (i, j) has associated variable cost c_{ij} and travel time t_{ij}.

For this problem, we define three decision variables: a binary variable x_{ijk} that has a value of 1 if vehicle k travels from node i to j; a continuous variable y_{jk} representing the cumulated demand of vehicle k when departing from retail point j; a continuous variable z_{jk} representing the cumulated

time for vehicle k when departing from retail point j. We adopt a three-index formulation of MDVRP as proposed in [18]. The detail of MDVRP formulation is as follow:

Objective Function:

$$\min \sum_{k=0}^{m} r_k + \sum_{i=0}^{n+p} \sum_{j=0}^{n+p} \sum_{k=0}^{m} c_{ij} x_{ijk} \tag{1}$$

Subject to:

$$\sum_{i=1}^{n+p} \sum_{k=1}^{m} x_{ijk} = 1, \quad \forall j \in N_c \tag{2}$$

$$\sum_{j=1}^{n+p} \sum_{k=1}^{m} x_{ijk} = 1, \quad \forall i \in N_c \tag{3}$$

$$\sum_{\mathrm{i}=1}^{n+p} x_{ihk} - \sum_{j=1}^{n+\mathrm{p}} x_{hjk} = 0, \quad \forall h \in N; \forall k \in K \tag{4}$$

$$\sum_{\mathrm{i}=1}^{n} \sum_{j=1}^{n+p} q_i x_{ijk} \leq Q, \quad \forall k \in K \tag{5}$$

$$y_{ik} - y_{jk} + Q \times x_{ijk} \leq \mathrm{Q} - d_j \quad 1 \leq i \neq j \leq n; \forall k \in K \tag{6}$$

$$\sum_{\mathrm{i}=1}^{n+p} \sum_{j=1}^{n+p} s_i x_{ijk} + \sum_{\mathrm{i}=1}^{n+p} \sum_{j=1}^{n+p} t_{ij} x_{ijk} \leq \mathrm{T}, \quad \forall k \in K \tag{7}$$

$$z_{jk} \geq z_{ik} + s_i + t_{ij} - M(1 - x_{ijk}) \quad 1 \leq i \neq j \leq n; \forall k \in K; M \geq T \tag{8}$$

$$\sum_{j=1}^{n} x_{ijk} \leq 1, \quad \forall k \in K_i; \forall i \in N_d \tag{9}$$

$$\sum_{i=1}^{n} x_{ijk} \leq 1, \quad \forall k \in K_i; \forall j \in N_d \tag{10}$$

$$\sum_{i=1}^{n} x_{ijk} = 0, \quad \forall j \in N_d; \forall k \notin K_j \tag{11}$$

$$\sum_{j=1}^{n} x_{ijk} = 0, \quad \forall i \in N_d; \forall k \notin K_i \tag{12}$$

$$x_{ijk} \in \{0, 1\} \quad i \in N;\ j \in N; k \in K \tag{13}$$

Equation (1) is the objective function that minimizes the total resource and travel costs. Constraints (2) and (3) guarantee that each retail point is visited exactly once. Constraint (4) ensures that any vehicle that arrives at a node also departs from that specific node. Constraints (5) and (6) guarantee that the vehicle capacity is not exceeded. Similarly, constraints (7) and (8) ensure that the route duration does not exceed the maximum time allowed. Note that the variable M in constraint (8) refers to a big number. Constraints (9) and (10) ensure that each vehicle starts and returns to its depot. Constraints (11) and (12) ensure that each vehicle cannot start from and return to other than their depot. Lastly, constraint (13) defines the variable domains.

3.2 Performance Measures

3.2.1 Economic Aspect

We examined the economic benefit of the proposed solutions based on the cost difference between the non-collaborative and collaborative scenarios. The costs comprise two components: fixed cost r_k and variable cost c_{ij}. The fixed cost r_k refers to the cost for dispatching a vehicle k, including the driver costs and the vehicle depreciation. The variable cost c_{ij} refers to the travel cost resulting from fuel usage from node i to j. We assume a steady vehicle speed when traversing the routes; therefore, the fuel consumption is constant.

3.2.2 Environmental Aspect

We estimated the environmental impact of both scenarios based on their contribution to traffic congestion and carbon emission. Carbon emissions were estimated based on the Bilan Carbone® method, also known as the ADEME model, which takes account of all greenhouse gases for all physical flows (see, e.g., [20,21]). The ADEME model approximates carbon emissions based on the distance traveled (d_{ij}^k) and the cumulated load (y_{ij}^k) of vehicle k when traveling from location i to j. Let us define E_{full}^k as the emission of vehicle k when its capacity is total, E_{empty}^k as the emission of vehicle k when the load is empty, and Q_k as the maximum capacity of vehicle k. Thus, the emission ε resulting from all the vehicle flows can be estimated as follows:

$$\varepsilon = \sum_{i=0}^{n+p} \sum_{j=0}^{n+p} \sum_{k=0}^{m} d_{ij}^k \left(\left[E_{full}^k - E_{empty}^k \right] \frac{y_{ij}^k}{Q_k} + E_{empty}^k \right) \tag{14}$$

3.3 Cost Allocation Models

According to the game theory concepts, fair cooperation should at least satisfy the "efficiency" and "rationality" conditions [16]. A game considers a set of participants $W = \{1, \dots, w\}$ who participated in the cooperation. Let us denote $C(W)$ as the total cost from the grand coalition. The cost allocation method then distributes the $C(W)$ by assigning a cost allocation vector $\phi = \{\phi_1, \dots, \phi_p\}$, called imputations, to each player in W. Cooperation is considered efficient when the total cost resulting from coalition W is shared amongst its members according to the allocation ϕ such that $\sum_{j \epsilon p} \phi_j = C(W)$. Further, rational cooperation is considered when no subset of participants would receive a total cost less than the total cost allocated according to the allocation ϕ.

In this study, we considered four cost allocation methods used in collaborative transportation, namely: (1) proportional to the number of pick-ups (PP), (2) proportional to payloads (PL), (3) proportional to costs (PC), and (4) Shapley's method or proportional to marginal contribution (PM) (see Table 1 for details).

Table 1 Allocation methods. Source: authors

Allocation rule	Formulation	
Proportional to the number of pick-ups (PP)	$\phi_j^P = P_j - \frac{P_j}{\sum_j P_j}\left(\sum_j C_j - C(W)\right) \quad \forall j \in W$	(15)
Proportional to payloads (PL)	$\phi_j^V = V_j - \frac{V_j}{\sum_j V}\left(\sum_j C_j - C(W)\right) \quad \forall j \in W$	(16)
Proportional to costs (PC)	$\phi_j^C = C_j - \frac{C_j}{\sum_j C_j}\left(\sum_j C_j - C(W)\right) \quad \forall j \in W$	(17)
Proportional to marginal contribution (PM)	$\phi_j^M = \sum_{S \subset W; j \epsilon S}\left[\frac{(\lvert W\rvert - \lvert S\rvert)!\,(\lvert S\rvert - 1)!}{\lvert W\rvert!}\right] \times [C(S \cup j) - C(S)] \quad \forall j \in W$	(18)

4. Case Study: Pekanbaru City

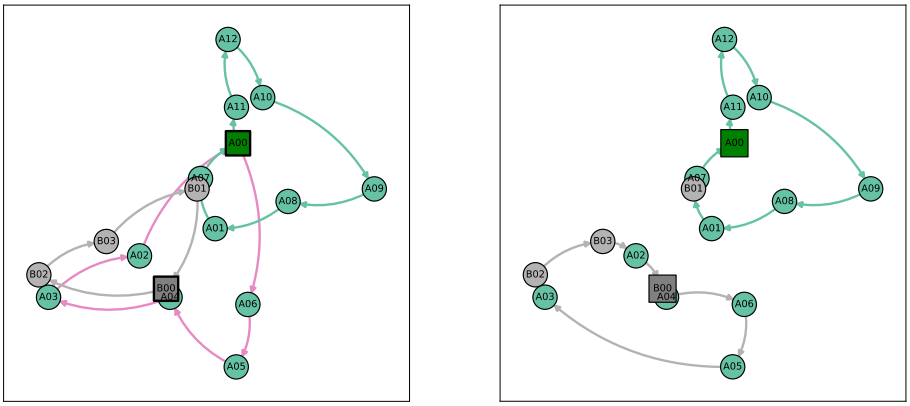
To illustrate the benefits of collaborative pick-up, we implemented the proposed models in one of Indonesia's most populated metropolitan cities, i.e., Pekanbaru. Such a study requires several companies to share their data regarding their pick-up activities. Therefore, we called several private companies in the city to join the study. We received positive responses from two parcel delivery companies who were willing to share their data to see the potential benefits of collaborative pick-up.

Let us denote the first company as A and the second company as B. Both companies have several retail points spread out across the city. Company A has twelve retail points, and company B has three. Both companies dispatch several vehicles to pick up packages from their respective retail points every day. Company A dispatches two vehicles, and company B dispatches one vehicle. Currently, there are no fixed routes scheduled for the vehicles. In other words, the companies let the drivers decide how to pick up the collected packages from the retail points. One of the constraints is that pick-up operations should be done within two hours to align with the intercity transport schedule. Besides, the vehicle can only carry 200 kg of payload.

4.1 Optimal Networks

We implemented collaborative and non-collaborative models of pick-up operations using Python programming language and solved the problems using the Gurobi optimization solver. The optimal networks for both scenarios are shown in Fig. 2. In non-collaborative pick-up, each company uses its vehicle to pick up packages at retail points. Company A deployed two vehicles with two unique routes. We observe that the routes for company A's vehicles have a different number of retail points to visit and different total distances to travel. However, the total time to serve the routes and the total loads are relatively balanced. Conversely, Company B only deployed one vehicle to serve three retail points. Despite using the same type of vehicles, the loads for Company B's vehicles were significantly lower than Company A's. It indicates that the vehicle capacity from Company B was underutilized, which could motivate collaboration.

In collaborative pick-up, both companies jointly pick up all the packages from both respective retail points. Our model suggests that it only requires two vehicles to pick up the packages. Therefore, there is one vehicle less in the system. To optimize the total cost, the first vehicle should be dispatched from depot A while the second is dispatched from depot B. The first vehicle is scheduled to visit eight retail points, and the second vehicle needs to visit seven retail points. As a result of the collaboration, both schedules contain mixed-retail points from both companies.



(a) Non-collaborative scenario (existing) (b) Collaborative scenario (alternative)

Fig. 2 The optimal networks in the collaborative and non-collaborative scenarios. Source: authors

Table 2 Performance of collaborative vs. non-collaborative scenarios. Source: authors

Aspect	Measures	Non-collaborative pick-up			Collaborative Pick-up	Saving	
		A	B	Total		Total	(%)
Economic	Fixed costs	150.00	75.00	225.00	150.00	75.00	33%
	Variable costs	64.54	21.14	85.68	56.93	28.75	34%
	Total cost	214.54	96.14	310.68	206.93	103.75	33%
	Avg. cost/pick up	17.88	32.05	20.71	13.80	6.91	33%
	Avg. cost/kg	1.16	10.68	1.56	1.045	0.515	33%
Environ-mental	# Vehicles	2	1	3	2	1	33%
	CO_2 (kg)	4.03	1.11	5.13	3.61	1.53	29%
	Avg. CO_2/pick-up	0.34	0.37	0.34	0.24	0.10	29%
	Avg. CO_2/ kg	0.02	0.12	0.03	0.02	0.01	33%

4.2 Performance Comparison

The benefits of joint operations are apparent in Table 2. The model suggests that if both companies decide to collaborate, there is a potential cost saving of 33%, or 103.75 less than the total cost of two independent pick-up operations. Interestingly, although Company A already has a more extensive network and larger payload, the pick-up cost from a joint operation (13.80) is still lower than Company A's average cost (17.88). This result can give a rationale for Company A to collaborate with Company B. Moreover, collaborative pick-up can cut emissions by 29% and reduce vehicles on roads, which positively contributes to the life quality of the population nearby. Therefore, collaborative pick-up provides not only economic benefits for both parties but also creates

environmental benefits for society. The remaining question is how to fairly distribute the cost amongst the players in the collaboration, which will be discussed in the following sub-section.

4.3 Cost Allocations

Table 3 shows the imputations from various cost allocation methods. In general, the proposed imputations from all methods satisfy the rational property since they are lower than the individual cost. Besides, the total imputations from all methods equal the total joint costs, indicating that all methods are efficient. Based on this result, we observe that all methods satisfy the basic properties of fair allocations: "efficiency" and "rationality". Therefore, choosing which method is more practical is a matter of preference.

Table 3 Imputations based on different cost allocation methods. Source: authors

Cost allocation method	Imputations			Avg. cost per pick-up		Individual Savings	
	A	B	Total	A	B	A	B
PC	142.90	64.03	206.93	11.91	21.34	33%	33%
PP	159.21	47.72	206.93	13.27	15.91	26%	50%
PL	162.14	44.79	206.93	13.51	14.93	24%	53%
PM	162.66	44.27	206.93	13.56	14.76	24%	54%

4.4 Scenario Analysis

Despite the clear benefits, we should note that the previous results were subject to the model parameters. The payloads in each pick-up location can vary from day to day, and the number of retail points from both companies can grow in the future. If these parameters change, the expected benefits from the collaboration will also fluctuate. Therefore, we investigated how the model parameters affect the proposed imputations.

To address the issue, we conducted a scenario analysis. We assume that the logistics configuration of Company A has hit maturity. Therefore, it will be less likely to change in the future. In contrast, we assume that Company B's business is still in its growing phase, so the network and the demand parameter will still be likely to change. In the analysis, we consider three growth scenarios, as follows:

- **Scenario 1** represents the market penetration strategy where Company B exploits its current market to increase the average payloads per retail point.
- **Scenario 2** denotes the market expansion strategy where Company B explores new customers by expanding its logistics network in other areas.
- **Scenario 3** represents the situation where the growth of Company B hits the maturity phase.

The scenario parameters are shown in Table 4, and the simulation results are presented in Table 5. The result suggests that the cost savings were dependent on capacity utilization. If collaboration can reduce the total number of required vehicles, cost-saving will be huge. It is rational since the total cost is affected mainly by the fixed cost, i.e., vehicle depreciation. On the other hand, emissions seem

not to be affected by vehicle numbers. It is more likely driven by the total distance traveled. Therefore, route optimization would significantly affect total emissions.

Table 4 The model parameters across the. Source: authors

Alternative Scenario	Parameter				Non-Collaborative			Collaborative	
	# A's points	# B's point	Demand A	Demand B	Cost A	Cost B	# Vehicles	Joint Cost	# Vehicles
Base	12	3	189	9	214.54	96.14	3	206.93	2
Scenario 1	12	3	189	48	214.54	96.14	3	284.21	3
Scenario 2	12	9	189	33	214.54	204.89	4	300.17	3
Scenario 3	12	9	189	140	214.54	213.32	4	383.32	4

Table 5 Estimated benefits across the scenarios. Source: authors

Alternative Scenario	Total cost		CO2 emissions		Vehicle reduction	Increase in utilization
	Saving	(%)	Reduction	%		
Base	103.75	33%	1.53 kg	29%	1	33%
Scenario 1	26.47	9%	1.41 kg	27%	0	0%
Scenario 2	119.25	28%	2.35 kg	37%	1	19%
Scenario 3	44.53	10%	3.05 kg	35%	0	0%

5. Discussion

From the case study, we observe that collaborative pick-up is particularly useful in a system with abundant spare capacity. Collaboration can help achieve economies of scale and reduce the number of required vehicles on the road. However, in a system where most vehicle capacity is nearly full, collaborative pick-up may not be economically attractive for the companies. This is because the cost saving from re-routing is typically less significant. This result is consistent with previous studies [5, 10], implying that the main economic benefit of horizontal collaboration is gained from higher resource utilization.

From an environmental perspective, our result also suggests that vehicle-generated pollution is linear with the vehicle miles traveled. Therefore, optimizing the transport network has a significant contribution to mitigating emissions, as has been suggested in [19,20]. Moreover, with collaborative transport, there will be fewer vehicles on the road, improving traffic mobility in the city. However, the effect of consolidated freight on road congestion may not be significant compared to a collaboration of logistics facilities. In this collaborative scheme, the companies agree to join and share their logistics facility, reducing the numbers of stops required for vehicles [7].

We also evaluated four common allocation methods and found they were rational and efficient. However, among the cost allocation methods, our collaborators were more attracted to distributing the cost proportional to the number of pick-ups. The collaborators' preference differs from what most literature suggests as the most popular method, which is Shapley's value [13,15]. While the concept of marginal contribution is intriguing, they found it difficult to understand, which may jeopardize the collaboration. The PP method was considered a stable proxy to estimate the fair imputations across the collaborators since it is easy and relatively rare to change. Besides, the proposed imputations were

not significantly different from the more complex Shapley's method, making them a good enough solution for the problem.

6. Conclusions

In this study, we evaluated the benefits of collaborative pick-up in the second echelon of urban delivery systems, where plenty of spare capacity is available. We presented a case from two real companies in Pekanbaru city, Indonesia, and developed an analytical model based on MDVRP to evaluate the benefits. Our results suggested that collaborative pick-up could effectively reduce operational costs, decrease vehicle emissions, and indirectly minimize traffic congestions that align with sustainable development goals. Cost saving is mainly driven by economies of scale, while emission reduction is driven by network efficiency. Further, our study adds insights into the perception of companies on the gain-sharing mechanisms. They seem to prefer a method that is simpler, practical, and "easy to control" to distribute the benefit to collaborators.

Nonetheless, our study has some limitations. First, it only evaluates the potential economic and environmental benefits of a transport collaboration. Some organizational issues that may arise in practice, such as operational complexity, information system, trust, and competition-related concerns, have not been addressed. Second, although the study was based on empirical data, it only included two companies as collaborators. Therefore, it may be interesting to extend the research by including more companies in the future to evaluate whether the findings are consistent. It is also interesting to complement the research with a qualitative assessment, especially on the behavior of logistics companies toward the collaborative effort.

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