A Strategic Approach for Promoting Sustainable Crowdshipping in Last-Mile Deliveries

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Abstract: Extending last-mile delivery services to individuals—crowdshippers who pick up or deliver a shipment as part of their daily activities—has sustainable benefits, but also risks (damaged parcels, late deliveries, increased emissions) for various stakeholders. So far, developed crowdshipping models have only addressed one or two risks at a time. No model promotes environmental goals separately or together with other goals. This study proposes a crowdshipping model that consists of three stakeholders (the owner of a crowdshipping platform, crowdshippers and parcel providers) and with various incentives aims to maximise the profitability of the platform and the compensation of crowdshippers, the quality of delivery, and to minimise environmental externalities. A two-level leader–follower game and the concept of Shapley value, from cooperative flow games at the follower level, are used to define the optimal strategy that provides sustainable delivery with a good balance between costs and profits. The game behaviour was explained on a crowdshipping platform provider (leader) and two coalitions: individual crowdshippers and parcel logistics providers. The aim of the example is to explain the strategy of promoting environmentally friendly parcel delivery. The results show satisfactory economic, social and environmental performance.

Keywords: last-mile delivery; crowdshipping; delivery models; sustainability; game theory; flow games; Shapley value; Analytic Hierarchy Process; AHP

1. Introduction

Crowdshipping (or crowdsourcing) is one of the last solutions for last-mile delivery. It describes the crowdshipping of the parcel delivery to a network of private persons who travel to a certain area and deliver parcels while using space in their luggage, car, van, truck or bicycle [1–3].

Crowdshipping integrates three key groups of stakeholders: (1) crowdshippers (individuals or last-mile delivery couriers), (2) customers (parcel shippers or receivers) and (3) crowdshipping platform providers. Crowdshippers and customers are connected and coordinated by a crowdshipping platform provider, a service firm which frequently originates as a start–up outside the traditional logistics industry. A platform connects and negotiates a service to benefit the involved stakeholders [4,5] and is also responsible for pricing algorithms [5]. There are several ways to manage stakeholder cooperation depending on the passivity/activity of the platform: (1) the platform can automatically match a customer with suitable deliverers/couriers, and a customer chooses the most suitable one, (2) the parcel can be delivered or picked up without the customer having a choice of deliverer, (3) the customer browses through deliverers’ postings and chooses the most suitable and (4) the customer posts the delivery request and waits until contacted by a deliverer [1]. The platform can leave the decision on the price of transport to the customer/deliverer or actively influence the price determination [1].

Crowdshipping is taking different forms of benefits for various stakeholders. The most frequently mentioned benefits for customers are lower prices, reduced delivery time and environmental emissions, personalised delivery, flexibility to send or receive a parcel on the...
weekend or after working hours, ability to chat with the deliverer and to see their reviews and rating, and accessibility to products not available in their country or area [1,4,6,7]. Businesses also benefit from the ability to compete with large online companies by offering flexible home delivery, improved relationships with their customers through increased collaboration, easy integration of application programming interface and the possibility to manage and monitor numerous deliverers through a central system [1,6,8,9]. From the perspective of parcel delivery providers, crowdshipping improves efficiency, helps meet the growing demand for faster and cheaper home deliveries and reduces operating costs [10]. Crowdshippers have found last-mile delivery beneficial due to the flexibility of their working schedule, meeting new people, lower emissions, earning some extra money, discovering the city, and helping small businesses to develop, etc. [1]. Crowdshipping also offers potential benefits to society, such as in the reduction of congestion, pollution and noise [1,11].

Despite many benefits, some risks inhibit crowdshipping. First, the risks are associated with the quality and reliability of crowdshippers. Second, some authors confirmed that private vehicle based crowdshipping often increases and does not reduce environmental pollution [12–14]. Using private vehicles instead of public transport, a bike, or walking and not efficiently consolidating and coordinating existing trips (minimising detours) provides new dedicated trips, which increases congestion and emissions [10]. The third environmental weakness is improper parking [10] and, consequently, worse quality of life for citizens. Such applications of crowdshipping are not in line with the visions of the UN’s sustainable development goal 11.6 which emphasises the decrease of greenhouse gas emissions, improvement of air quality and the limitation of any other environmental impacts [15]. This fact prompted us to research the role of a sustainable component in existing crowdshipping models. We found that in some current models, the platform actively manages deliverer selection and price determination [3,16–18]. In others, the platform is only an intermediary, which only matches deliverers and customers but does not affect the selection of the appropriate deliverer or the determination of the price of transport [19–23]. Existing models most frequently aim to minimise the price and/or maximise a profit for several stakeholders [3,16,17,19–24]. As far as we know, no crowdshipping model aims to minimise negative environmental externalities individually or in combination with others aims. Ghaderi et al. [15] are the only ones who compare the emissions generated by the delivery tasks with and without crowdshippers. However, the environmental component was not integrated into the model they propose. Some authors consider detour distance to ensure delivery accuracy but not reduce delivery distance and emissions [16,17,20,23].

To summarize, there is currently no model/tool that would allow inclusion and control of UN’s sustainable development goals(11.6)—social, economic and environmental (the costs, the quality of the delivery for the end customer and the environment). The lack of control over individual deliverers who make deliveries with their own vehicles, as a result, causes greater negative impacts on the environment and worse quality for the end customer than delivery by a parcel distributor. The purpose of new shapes of delivery, including crowdshipping, should be sustainable advantages, with focus on environmental protection. The rise in research in this area, project applications that process this topic, and program solutions in the last two years indicate the relevance of this innovation and perhaps a greater degree of implementation in the real environment. With the uncontrolled delivery of physical crowdshippers, this could even lead to a deterioration in environmental impact.

To cover the mentioned problem/gap in the literature and take advantage of the last–mile crowdshipping, which is a promising solution, this study aims to propose a crowdshipping delivery model which selects the highest quality and most environmentally friendly deliverer while balancing a trade-off between the platform provider, customer and deliverer requirements. A model guided by a platform provider guarantees higher prices to deliverers who achieve a better quality of delivery (accuracy of place and time of delivery, undamaged parcels) and lower negative impact on the environment (delivery by public transport, on foot, by bike or green vehicle). Better delivery quality and lower prices could
motivate customers to reuse the platform which consequently enables competitiveness and a profitable business to a platform provider.

A multi-criterial two-level leader-follower game approach and the concept of Shapley value from cooperative flow games at the follower level are used to find an equilibrium strategy. The players in the game are crowdshipping platform providers and deliverers. The crowdshipping platform providers are the leaders of the game while deliverers are the followers. Furthermore, deliverers are defined in two coalitions: individuals and parcel logistics providers. Coalitions work separately and compete with each other, while there is a cooperation between the members of each coalition to improve sustainability.

The contributions of this paper are twofold: (1) A set of incentives or subsidies to promote more sustainable delivery, focusing on measures the platform provider can take. (2) A tool which enables a platform provider to encourage more environmentally friendly and quality delivery through higher ratings for deliverers and consequently better possibility to win a bid.

The tool is primarily intended for platform owners (beginners or existing ones) who want to take control of the implementation of crowdshipping activities with the goal of long-term success. Incentives are also helpful for platform providers who already actively manage the crowdshippers’ activities but wish to increase their efficiency with additional incentives. These research findings could encourage and guide policymakers in increasing the efficiency of various existing incentives or implementing new environmental incentives for (1) platform owners who actively manage activities, (2) existing crowdshippers who use or intend to use green delivery options and (3) potential individuals who are thinking of becoming crowdshippers.

We upgraded the delivery crowdshipping models of Atasoy et al. [3], Ghaderi et al. [15] and Tho V Le et al. [16] by proposing a model which considers the interests of three, not two, crucial groups of stakeholders, and offers solutions that are not only economic and/or social but also environmental.

This paper is organised as follows. Section 1 introduces the background of crowdshipping, its benefits and weaknesses, followed by our motivations, the literature gap, the aim and contribution of this paper. Section 2 describes the literature review results on environmental incentives and current crowdshipping models. Section 3 presents the crowdshipping game formulation, which is explained in the Section 4. The article concludes with a discussion and conclusion, including limitations, presented in the Sections 5 and 6.

2. Literature Review

The literature review addresses two areas. The first is existing crowdshipping delivery models to determine the extent to which they are already striving to reduce the negative environmental effects. The second is incentives a platform provider can implement to encourage crowdshippers to provide more environmentally friendly deliveries.

2.1. Crowdshipping Delivery Models

Three models were found wherein a platform provider is supposed to have an active role in motivating crowdshippers or customers to collaborate. In these three cases, the platform was a separate legal entity and not owned by a parcel logistics provider. Atasoy et al. [3] introduced a model that balances platform and deliverer interests by determining dynamic prices paid by a platform to a deliverer. Testing a model using real-world data indicated that their model increases the deliverer’s profit while still maintaining the profitable operations of a platform. Ghaderi et al. [15] developed a model which balances three and not only two stakeholders’ interests. The model aims to minimise costs for the customer and maximise profit for the platform provider and a crowdshipper. Evaluation of the model indicates that individual pricing results in a higher matching number than dynamic compensations and charging higher prices to customers and paying higher compensations to deliverers delivers much higher total profits and surplus for all three groups of stakeholders. The optimisation model of Ghaderi et al. [15] also focuses on the economic aspect of
sustainability and enables satisfactory payment to the crowdshipper and maximum profit for the platform provider. The customer is not considered in this model. However, this is the only one of the three articles aiming to minimise negative environmental externalities.

Two models were found wherein a platform plays an active role but is not owned by a platform provider but by a logistics service provider [19,23]. Lan et al. [22] present a model that considers logistics parcel provider costs, customer satisfaction and crowdshippers’ remuneration. Analysis of the relations between multiple objectives highlighted that considering only company costs may reduce customer satisfaction, while improving customer satisfaction will reduce the number of crowdshippers willing to cooperate. The Kafle et al. [18] model differs slightly from the model presented by Lan et al. [22]. The logistics service provider trucks still perform part of the delivery by themselves. To minimise costs, the model thus needs to simultaneously select a crowdsourcer and determine the logistics provider’s truck route to minimise costs. Results indicated reductions in cost and travelled miles. More than half of the customers were served by crowdshippers. In addition, the model was found to be sensitive to factors such as a penalty for late delivery, truck unit operating costs and time value of crowdshippers.

In the following models, a platform is only an intermediary (has a more passive role) that does not influence the choice of crowdshipper or the price of the service provided. Therefore, models focus on finding the maximum crowdshippers’ and customers’ matching with minimal costs [22]. Zhang et al. [23] consider costs and two additional connectivity aspects, profit and risk, and formulated them as the profit problem. The authors propose a route optimisation model to model the balance between kinds of control policies. Lifetime in message lifetime management and the hop concept were introduced into the proposed crowdshipping delivery system to lower costs and risks and increase service quality. Al-lahviranloo and Baghestani [20] primarily aimed to address the impact of a crowdshipping platform on the travel behaviour of participants, but they also considered matching patterns. The model they presented maximises utility for each deliverer regardless of the system status. The model’s aim is not maximising the number of matches.

One paper was found to consider taxi drivers as crowdshippers [20]. A presented model handles people and parcels in an integrated way by the same taxi network. The numerical results confirm a trade-off between the profit of a taxi company and the acceptance rate of parcels, benefits for a taxi company and the potential to alleviate urban congestion and environmental pollution. The acceptance rate was more sensitive to parcel fare and cost per kilometre than the discount per extra minute and initial fare.

2.2. Incentives or Subsidies for Promoting Environmentally Friendly Deliveries

It is challenging to convince crowdshippers to behave in environmentally friendly manners without supporting policies [10]. Therefore, this part of the literature review focuses on potential incentives that crowdshipping platform providers can use to promote environmentally friendly crowdshipping deliveries. This article does not consider incentives that other stakeholders, such as governmental bodies or municipalities, can use to encourage shifting to more greenways parcel delivery.

Crowdshipping platform providers can regulate environmentally friendly delivery by making payment conditional on delivery [5]. They can increase the compensation for crowdshippers that deliver parcels by foot/bicycle or use public transport. To attract crowdshippers using cars or vans, they also can, for instance, target mainly or only electric or hybrid vehicle owners [1]. In these cases, payments are performed via credit card at confirmed driver pick-up or delivery [5]. Ciobotaru and Chankov [1] and Ta et al. [24] admit that disclosing drivers’ identities and rating schemes of a crowdshipper to customers also encourages crowdshippers to act more environmentally friendly. Some crowdshipping providers implement a rating system that assigns each driver’s rating which is later applied in selecting the proper and best-rated driver for a specific delivery [25]. A platform
prefers better-rated drivers. A bad rating is given to a driver who does not complete a request satisfactorily (delayed delivery, not using a green vehicle for delivery, etc.). “These preferences could also be coupled to certain dynamic conditions, i.e., when many parcels are waiting for delivery and in case of a relatively low amount of available drivers” [22] (p. 6). Uber, for example, applies a ‘busy fee’ (i.e., surge price) in this situation. Only the best-ranked drivers are entitled to this bonus [17]. However, such options require formulating a more comprehensive matching algorithm [26].

Limiting the deviation of crowdshippers’ delivery trips from their original trips is another mechanism to decrease negative environmental externalities [10]. Crowdshipping platform providers can specify the maximum time or distance a driver can make to receive the full payment. If a crowdshipper exceeds a specific time or distance, he is penalised with a lower fee [16,21,27,28].

A platform provider can also promote sustainable delivery by computing carbon footprint savings for each driver, who is granted green credits, which can be traded for lower public transport, parking or infrastructure prices [17].

In summary, environmental externalities reductions are neglected in the existing delivery models. We therefore intend to upgrade models where a platform provider has an active role with incentives which will encourage environmentally friendly and quality deliveries and will bring financial benefits to all involved stakeholders. The model will enable a platform provider to select the most sustainable deliverer among two groups of deliverers (parcel providers and individual crowdshippers).

3. Methodology

Last-mile based crowdshipping can be defined as an interactive decision-making process between more stakeholders. Each decision-maker (stakeholder) has their own wishes and requirements, and the wishes of one decision-maker may conflict with the wishes of another. Game theory can be used effectively to find an equilibrium strategy to achieve a win-win for stakeholders included in the game while minimising the negative impact on the environment [29,30].

Game theory is a “formal method for analysing the interaction between a group of rational players who behave strategically. Each player seeks to maximise their own utility in a situation where outcome depends not only on its own but also on other players’ choices. Their choices, in turn, are influenced by the choice they believe the other player will make because they also seek to maximise a function over which they do not have complete control” [31] (p. 3). Games are classified as coalitional or competitive, where the Nash equilibrium generally defines the optimal strategy, but can also be hierarchical, with some players taking a privileged role [32].

3.1. Crowdshipping Game Formulation

The players/decision-makers in this game are crowdshipping platform providers and two groups of deliverers: individuals and parcel logistics providers. A crowd of individuals are preferred due to the greater flexibility in delivery schedules, pick-up and delivery conditions, better prices and, consequently, revenue, better responsiveness and reduction of traffic, energy and emissions [1,5,7,21,23]. Traditional van or truck delivery is not as efficient as that by an individual due to restrictions on delivery by the municipality or geographical conditions such as limited truck access [19] and higher operative costs. However, they are required in a crowdshipping delivery at least in the initial phases.

Each player has their request and expects the best possible outcome:

1. The crowdshipping platform provider aims to offer quality and affordable service to gain as many customers as possible. Therefore, he needs to attract sufficient quality and reliable individuals to achieve optimal outcomes for himself, individual deliverers and customers. Satisfied individuals will be ready to provide delivery services and will attract additional deliverers. Satisfied customers will, consequently, support crowdshipping, and the platform will operate at a profit.
2. Individuals are willing to participate in crowdshipping if they get a reasonable payment [7]. According to Le and Ukkusuri [11], they hesitate to make significant trip detours from their original travel routes for a longer time. However, they agree to drive a longer way for additional payment if they deliver a parcel to someone they know.

3. The parcel delivery provider will support crowdshipping activity (1) if the courier has enough space in the vehicle, (2) if the collection or delivery of the consignment is close to the route he is carrying out, (3) if delivery is planned within working hours and (4) if the payment corresponds to his wishes [7].

A crowdshipper platform provider is a leader in this game. At the follower level, two coalitions, individuals and parcel logistics providers, react to the leader’s moves (Table 1). All players in each coalition have comparable characteristics and are subject to similar legal roles [33].

Table 1. Crowdshipping game and objectives of the players.

| Optimisation Problem and Objectives of the Players |
|---------------------------------------------------|
| **1st level/Leaders**                             |
| Crowdshipping platform provider                   |
| Maximise the total commission fee.               |
| Achieve suitable delivery (on-time delivery, undamaged delivery, delivery at the agreed location, and especially environmentally friendly delivery) by penalising those not providing sustainable services. |
| **2nd level/Followers—Coalitions**                |
| Individual crowdshippers                          |
| Maximise their rating and profit.                |
| Parcel logistics providers                        |
| Delivery commissions are not fixed but depend on sustainability rating. |

In the presented model the following variables and notations will be used:

- $V$—is a set of nodes (source or sink) of the directed graph $G = G(V, E)$; $|V| = m$ is the total number of nodes in the system and $E$ are the edges (arcs) defined as ordered pairs of vertices. Source nodes are elements of set $P \subseteq V$, and sink nodes are elements of set $D \subseteq V$. Those sets can be disjointed or not.

- $N$—is the finite and non–empty set of players at the follower level. $|N| = n$ is the total number of players.

- $P$—is a set of available crowdshipping platform providers $P_h \in P$.

- $C$—is a set of coalitions $S_k \in C$.

- $x_{ij}$—are the flow units’ non negative integer variable moving from node $i$ to node $j$ as a component of a flow $X = (x_{ij})$.

- $x_{ijk}$—are the flow units’ non negative integer variable moving from node $i$ to node $j$ as a component of a flow by coalition $S_k$ and $x_{ijk} \leq x_{ij}$.

- $c_0$—is the maximal possible capacity of arc $c_{ij} \in E, i, j \in V$ and $i \neq j$. This is the part of the commission that remains with the platform provider after payment of all potential penalties (late delivery, damaged parcel), sustainable taxes to governmental bodies, etc.

- $c_{ijk,h}$—is the part of capacity $c_{ij}$ assigned to coalition $S_k \in C$, by platform provider $P_h \in P$, according to the sustainable environmental delivery mode adopted by coalition members. The value is zero if the coalition does not use the arc and $c_{ijk,h} \leq c_{ij}$.

- $v(S_k)$—is the maximum flow value for coalition $S_k$ through the network of its members.

- $\delta_{i,j,m_h}$—is a binary value 0 or 1. The value is one if the coalition member uses the arc and is zero in the other cases.

- $x_{ijk,m_h}$—is the coalition’s member $m_h \in S_k$ sustainability rating variable with values between 0 and 1 according to sustainable requirements presented in Table 2.

- $c_{ij,m_h}$—is the part of capacity $c_{ij}$ moving from node $i$ to node $j$ by the coalition’s member $m_h \in S_k$ and $x_{ijk,m_h} \leq x_{ij}$.
\( p_{r,ijk,mh} \) —is the final coalition’s member \( mh \in S_k \) evaluation with a defined scale (Figure 1) according to sustainable requirement \( r \), on arc \( e_{ij} \in E \). The value \( p_{r,ijk,mh} \in [0, 1) \) is 0 if the arc \( e_{ij} \in E \) is not used by \( mh \in S_k \).

3.1.1. Leader Level—Crowdshipping Platform

The platform provider aims to minimise negative environmental impact by encouraging more environmentally friendly delivery modes, minimising the detour and delivery distance, delivery time and deliveries to the wrong location. Accordingly, it assigns commissions to the coalition that pays more attention to the environment and provides the highest total sustainable rating. A platform also considers the economic dimension of sustainability by offering cost-efficient delivery and the social dimension by providing a quality delivery (punishing late and damaged parcel delivery and disrespectful behaviour).

Before each round of the game, the platform provider, in collaboration with a customer, evaluates coalitions and their members using a criteria set \( (C_1, \ldots, C_n) \), found in past literature (Section 2.2.) and some suggested by the authors, presented in Table 2. The criteria used addressed several aspects of sustainability. For the simplicity, flexibility and ability to consider quantitative and qualitative criteria in the same decision process, the Analytic Hierarchy Process (AHP) can also be efficiently used to define related weights \( (w_1, \ldots, w_n) \) and final evaluation of coalitions. The platform provider, an active player in this decision process, uses technical data, gathered by a platform, about the sustainability of each delivery and related feedback information from customers to evaluate the criteria. Criteria are related to the same aspect of sustainability. Thus, independence is maintained in each round of the game. In case such assumptions cannot be fulfilled (e.g., passive role of the platform provider) the hierarchy structure of the AHP method can be replaced by the network structure of the Analytic Network Process (ANP).

A rating of deliverers in this model does not consider those who just joined a platform, which means that rating scores of these deliverers are unavailable. To allow and encourage new crowdshippers’ entry, the platform assigns them the coalition average evaluation, which encourages sustainable behaviour of new members and does not penalise the coalition.

### Table 2. The criteria set and data source.

| Criteria—\( C_n \) | Definition | Data Source |
|---------------------|------------|-------------|
| Detour distance \[16,17,23\]. | A distance from a crowdshipper’s origin to the pick-up point and from a drop off point to a crowdshipper’s destination. | Technical data |
| Optimal route \[19,22\]. | Optimal travel distance between the pick-up and delivery node. | Technical data |
| Use of a green vehicle/public transport modes/bicycle or make a delivery by foot. | A crowdshipper uses public transport, environmentally-friendly vehicles, a bicycle or delivers a parcel by foot. | Technical data |
| Space in crowdshipper’s luggage, car, van, truck, bicycle etc. \[3,17,19,23\]. | The number of parcels delivered by a crowdshipper. | Technical data |
| Early/Late delivery \[3,17,19,21–23\]. | A crowdshipper delivered a parcel later as agreed./A crowdshipper delivers a parcel earlier than agreed. | Technical data |
| Delivery at the wrong location. | A parcel is delivered at a non-agreed location. | Technical data |
| Damaged parcel. | A parcel or a product was damaged upon acceptance. | Technical data |
| Crowdshipper behaviour. | A crowdshipper’s behaviour was disrespectful upon acceptance of a parcel. | Feedback data |
| Crowdshipper experience. | Number of sustainable deliveries. | Feedback data/Technical data |

The pairwise comparison matrix \( A \) is defined based on a pairwise comparison using the Saaty evaluation scale from one to nine \[34\].
The criteria assessment should be done by an expert panel composed of platform providers involved in the game, in cooperation with clients and relevant governmental organisations. This criteria assessment is not univocally applicable, even if the criteria used are. The differences in the assessment are mainly related to the level of development of these platforms in the area concerned and the applicable regulations. For these reasons, the article only provides guidelines for the definition of the expert panel.

The comparisons matrix \( A \) is reciprocal and has only one eigenvalue \( \lambda_{\text{max}} \) different from zero. Let \( w \) be the associated right eigenvector. The components of \( w \) are the criteria weights. Using Saaty’s method, based on the arithmetic mean, a proper approximation of the components of the principal eigenvector can be computed as \( [35] \):

\[
w_j = \frac{1}{l} \sum_{i=1}^{l} \frac{a_{ij}}{A_i} \quad \text{for } i = 1, \ldots, l;
\]

where \( A_i = \sum_{j=1}^{l} a_{ij} \) for \( j = 1, \ldots, l \).

The consistency of the method has to be checked by using the maximum eigenvalue method \([36]\). The Consistency Index (CI) is defined as \([36]\):

\[
CI = \frac{\lambda_{\text{max}} - l}{l - 1},
\]

where the approximation of the maximum eigenvalue is computed as \( \lambda_{\text{max}} = \sum_{i=1}^{l} A_i w_i \).

The Consistency Ratio (CR) is computed as the quotient between the Consistency Index and the Random Index (RI) \([36]\). In the case of consistency, the Consistency Ratio must be less than or equal to 0.1.

Obtained weights are used to evaluate coalitions and coalition members. A modified nine-stage Saaty scale (Figure 1) is defined and used to assess each coalition member separately:

\[
\alpha_{ijk,m_h} = \sum_{r=1}^{l} w_{r} P_{r,ijk,m_h} \quad i, j \in V, m_h \in S_k.
\]

Figure 1. Nine–stage scale used to assess coalition members.

In this case, the crowdshipping platform solves the optimisation problem:

\[
\max_{S_k \in C} \sum_{ij \in V} c_{ijk,m_h} x_{ij}
\]

where the approximation of the maximum eigenvalue is computed as \( \lambda_{\text{max}} = \sum_{i=1}^{l} A_i w_i \).
subject to:

\[ c_{ijk} = \alpha_k c_{ij}, \quad i, j \in V, \quad S_k \in C, \quad P_h \in P, \]  
\[ 0 \leq \alpha_{ijk,m_h} \leq 1, \quad i, j \in V, \quad m_h \in S_k, \]  
\[ \beta_k = \min_{m_h \in S_k} \alpha_{ijk,m_h}, \quad i, j \in V, \quad S_k \in C, \]  
\[ a_k = \frac{\beta_k}{\sum_{S_k \in C} \beta_k}, \quad S_k \in C, \]  
\[ \sum_{S_k \in C} a_k = 1. \]  

The aim of this phase of the game—Equation (4)—is to maximize the crowdshipping platform’s total part of commissions \( c_{ijk} \) with respect to the other platforms through an environmentally sustainable policy of delivery. This means that sustainable behaviour saves the platform provider from having to pay potential penalties or green taxes. Flow units variables \( x_{ij} \) are used to determine the most sustainable platform and coalition but are not constrained in the game’s second stage.

The part of capacity \( c_{ijk} \) assigned to coalition \( S_k \in C \) is computed in Equation (5) according to the sustainable environmental delivery mode adopted by coalition members. In Equations (6)–(8) is computed \( a_k \), the overall coalition evaluation as the normed evaluation of the worst member. Equation (9) defines competition between coalitions \( S_k \in C \) and encourages them to improve and go green.

3.1.2. Followers Level—Coalitions

In the second stage of the game, coalitions \( S_k \in C \) work separately, and there is cooperation between the members of the coalition to improve the sustainable coalition rating \( a_k \). Crowdshippers and parcel providers aim to maximise compensation by using more environmentally friendly modes of transport, not exceeding the maximum time of delivery and delivering undamaged parcels to get a high rating from the customer.

The concept of the Shapley value from the cooperative game is used at the follower level. It involves equally distributing gains and costs among players working in a coalition or different coalitions. The Shapley value is generally used when each player’s contributions are unequal, but each player cooperates to achieve the gain [37].

Delivering parcels using space in their luggage, car, van, truck or cargo bike can in this game be defined as a flow in a network, and parcels travelling through the network are called flow units. The network is defined as a directed graph \( G = (V, E) \). Source nodes are supply nodes where units enter the network. Sink nodes generally have a demand, which is defined as the number of units that need to be directed to them [38].

The game can be defined as a function \( v \) from the set of coalitions to the set of real numbers. Let \( S_k \in C \), be a coalition, then the characteristic function of the game at the follower level \( v(S_k) \) is the maximum flow value for coalition \( S_k \) through the network of its members.

To ensure the stability of the game, so that no coalition has an incentive to split, for all \( x_i \in X \) it is necessary to require that \( \sum_{S_k \in C} x_i \geq v(S_k), \quad S_k \subseteq C \) and \( \sum_{x_i \in X} x_i = v(N) \).

Then the Shapley value of the game, \( SH(N, v) \), can be defined as an \( n \)—dimensional vector, with components defined as follows [37]:

\[ SH_i(N, v) = \sum_{S \subseteq N} \frac{(|S|-1)!(n-|S|)!}{n!} [v(S) - v(S - \{i\})]. \]  

The arc capacities are parts of commissions, paid by the customers to the platform provider, after payment of all potential penalties. As the leader, the crowdshipping platform provider tries to attract as many customers as possible and provides quality service while keeping costs low. This approach impacts the followers in the game (Table 1).
Moreover, the followers also formulate their multi-objective optimisation model by computing the Shapley value—Equation (10)—for each player in the coalition through the network of members:

$$\max_{m_h \in S_k - \{m_k\}} \text{SH}_{m_h}(N, v)$$  \hspace{1cm} (11)

subject to:

$$m_k = \left\{ m_h \in S_k : \min_{m_h \in S_k} \sum_{i,j \in V} a_{ijk,m_h} \right\}$$,  \hspace{1cm} (12)

$$c_{ij,m_h} = \delta_{ij,m_h} a_{ijk,m}, i, j \in V, m_h \in S_k - \{m_k\}$$,  \hspace{1cm} (13)

$$\sum_{m_h \in S_k} x_{ijk,m_h} = x_{ijk}, i, j \in V, m_h \in S_k - \{m_k\}$$,  \hspace{1cm} (14)

$$\sum_{S_k \in C} x_{ijk} = x_{ij}, i, j \in V$$.  \hspace{1cm} (15)

This model presents full collaboration in each coalition: individual crowdshippers, parcel service providers. To enhance sustainability, a partnership between the members of each coalition is permitted. Orders, therefore, can be switched between deliverers/couriers of each group, except the member with the lowest rating.

The Shapley value makes it possible to define the best shipping plan based on the capacities of the arcs that are strongly connected with the sustainability on the arcs. The flow units to be transported are not considered variables as in Vehicle Routing Problem (VRP).

4. Explanatory Example

The game behaviour was tested on a crowdshipping platform provider (leader), which has managed to obtain the most significant profit among the platform providers that are operating in last-mile crowdshipping, and two coalitions: $S_1$—individual crowdshippers and $S_2$—parcel logistics providers. A crowdshipping platform can be managed by its provider (a designer of a platform) or by a parcel provider (e.g., Post of Slovenia, GLS, DHL, UPS, etc.) who buy or rent a crowdshipping solution by any reason. One coalition is represented by individual crowdshippers, such as students, employees, pensioners, unemployed, etc. A second coalition includes parcel providers who already deliver parcels to their contract customers (e.g., DHL, Post of Slovenia, DPD, etc.). However, they might want to make better use of cargo space, earn more, be more sustainable, etc., so they decide to become a platform user. Each coalition consists of three members, which allows differences in the members’ efficiency to be considered and sustainability requirements dictated by the crowdshipping platform provider to be met. The first coalition for example includes individual crowdshippers (one student, one pensioner and one employee). The second coalition includes parcel providers (one deliverer of GLS, one of DPD and one of DHL).

Before each round of the game, the platform providers make an evaluation of each coalition using the criteria defined in Table 2, and Equations (3), (7) and (8), and then solve the optimisation problem at the first/leading level. In this way, the best (most environmentally sustainable) platform provider and coalition is selected, and the contract is awarded to this coalition. As it is assumed that each coalition member can fulfil the task, no quantity constraints—Equations (13) and (14)—are considered. The crowdshipping platform thus plays an active role in the game.

In the game’s second phase, the chosen coalition redefines the set of members and temporarily excludes the member (or members) with the worst score. They can use this break to improve their performance and be active again in the next round. Then, based on the Shapley value, the player with the highest score is selected, but if it is necessary, other high scoring members of the coalition may also be considered.

Without loss of generality, it is possible to assume that the coalition $S_1 = \{m_1, m_2, m_3\}$ (e.g., individual crowdshippers) has been selected and receives the contract. As mentioned earlier, this game is not about optimising routes and quantities but determining the most
sustainable deliverer. It is therefore assumed that all coalition members can make the delivery.

Figure 2 shows a simple logistics network with a source node (P) and a sink node (D), and three transit nodes (A, B, C). The edges are coloured according to their affiliation to the members of the selected coalition.

The first member $m_1$ of the coalition (e.g., an employee) has the top edges marked in red in Figure 2, the second member $m_2$ (e.g., a student) has the middle edges marked in green, and the third member $m_3$ (e.g., a pensioner) has the bottom edges marked in blue. The capacities on the arcs for each member are also shown in a table under the graph.

| Coalition $S_t$ - $\alpha_{(1,m_h)}$ values on arcs |
|---|---|---|
| $m_1$ | $m_2$ | $m_3$ |
| P–A | 0.2 |  | 
| P–B | 0.2 |  | 
| P–C | 0.1 | 0.1 | 
| A–B | 0.1 |  | 
| C–B | 0.1 |  | 
| A–D | 0.2 |  | 
| B–D | 0.1 | 0.1 | 
| C–D | 0.1 |  | 

Figure 2. The logistic network characteristics.

In the second phase of the game, using Equation (3), each coalition member is assigned a common score that integrates the coalition member’s sustainable attitude on the arcs of the graph. In a real evaluation, scores are obtained using the AHP method. However, since in Slovenia this service is not used yet, there are no available data about platform providers, customers and competent government organisations involved in the game. Thus, the values used are defined by the authors to explain the course of the game.

The scores are computed in Figure 2. The third member $m_3$ has the lowest score and thus is not considered in this phase of the game—Equation (12).

Without loss of generality, it is assumed that capacities $c_{ij}$ on all arcs are equal to one, so for each coalition member they are proportional to the scores. Using Equation (13), capacities $c_{ij,m_1}$, $c_{ij,m_2}$ on the arcs $i, j \in V$ are computed. They are used to define the Shapley value—Equation (10)—and solve the optimisation problem at the follower level of the game—Equation (11).

The flow values function associated with the capacities of the first member $m_1$ and the second member $m_2$ of the coalition (and sub-coalitions) are:

\[
v(m_1) = 0.2; \quad v(m_1, m_2) = 0.3; \\
v(m_2) = 0.1; \quad v(m_1, m_2) = 0.3; \\
v(\emptyset) = 0.
\]

The associated Shapley values for each member are:

\[
SH_{m_1}(N, v) = \frac{1}{2} [v(m_1) - v(\emptyset)] + \frac{1}{2} [v(m_1, m_2) - v(m_2)] = 0.2; \\
SH_{m_2}(N, v) = \frac{1}{2} [v(m_2) - v(\emptyset)] + \frac{1}{2} [v(m_1, m_2) - v(m_1)] = 0.1.
\]

The solution of the optimisation problem at the follower level is $max \{SH_{m_1}, SH_{m_2}\} = SH_{m_1}$ so the first coalition member is the most sustainable choice.
In this numerical example, quantity constraints and restrictions regarding the vehicles’ capacities are not considered, but in the case of restrictions, Equations (13) and (14) ensure that the cargo will be distributed among the coalition members.

5. Discussion

There are only a few platforms in Slovenia. Some are just developing services, do not yet have a specific management model and no input data, as their solution has not yet been tested. Others have certain management models but do not provide the services required by our model (e.g., they do not allow delivery to individual crowdshippers) or do not yet have users—individual crowdshippers. Therefore, we could not test the behaviour of the model in an actual situation. We could have tested the model using hypothetical data, but they might not represent real-world conditions and yet could influence the model performance and results. Even applying a mixture of data—some hypothetical and some actual—is not an option, due to lack of input data. Although aware that this is a significant shortcoming in this article, we hope the study will encourage researchers to test the model in a real environment.

The current game can be tested through a platform where a platform provider or owner—not a customer—selects a proper, sustainable as possible deliverer and decides on the price. A customer would help to evaluate deliverers—Equation (3)—which would affect the selection of a deliverer. However, the deliverer would not only be selected based on the customer’s ratings but also on other ratings that the customer would not determine (Table 2). We also believe that a platform provider or a platform owner must set the sustainable rules of the game (penalties, incentives) and take control of compliance to obtain sustainable results.

Past models individually consider economic \([3,16,17]\) and social goals \([3,16,17,23]\). This paper, in contrast, proposes an approach where the owner of a platform regulates the game to simultaneously optimise costs, customer and crowdshipper satisfaction, and to reduce negative environmental impacts. By controlling costs, a platform offers competitive prices and therefore, can maximise the number of shipments—Equation (4)—which in turn would strengthen its position on the market and enhance the likelihood of its long-term success. The model ensures higher prices for deliverers who provide quality work but also care about the environment—Equation (14). Individually, not simultaneously, as in this article, both problems were already solved by Lan et al. \([22]\) and Ghaderi et al. \([15]\).

A criterion to evaluate a coalition and its deliverers used by Ghaderi et al. \([15]\) and three additional criteria (optimal route, use of green vehicle, delivery in a wrong place) are applied in this paper to promote environmental delivery. The algorithm also enables the transfer of parcels between each coalition member, excepting the member with the lowest rating. It might happen that one deliverer cannot deliver a package to a final destination due to access restrictions or time constraints. Thus, a package can be passed to the next highest scoring deliverer. This possibility enables the maintenance of quality delivery and in some cases can also decrease negative externalities.

The model also promotes positive competition between coalitions—Equation (9)—which encourages them to deliver sustainably and consequently obtain the commission.

The current criteria set to assess coalitions and deliverers consider the requirements of only two stakeholders (platform providers and customers) but ignores the requirements/needs of deliverers. Crowdshippers are willing to join a platform if they get sufficient compensation, a user-friendly platform, and good working conditions \([11,39]\). For example, deliverers must be protected from potential customers who might deliver harmful or illegal freight \([19,40]\). The existing model can, therefore, be upgraded in the future so that a deliverer can rate a customer. In addition, policymakers are also encouraged to propose additional criteria according to sustainable requirements of the European Union. In order to achieve uniformity in the assessment, policymakers should also be involved in determining the upper and lower limits of each assessment value on the assessment scale.
This should be done for each criterion. Despite the shortcomings, the added value of this set of criteria is that it satisfies the three key dimensions of sustainability.

In the proposed game there are only two coalitions defined according to the similarities of members. If necessary, the platform provider can add more coalitions such as food deliverers, taxi drivers or others. In addition, a traditional package provider can be excluded from a game in the case of a sufficient number of crowdshippers and other coalition members. However, package providers are recommended to ensure customer service quality in the initial phase of the introduction of crowdshipping [20].

Platform providers, after each round of the game, evaluate crowdshippers using criteria from Table 2. Weights for criteria presented in Table 2 are defined jointly by all platform providers $P_h \in P$ to ensure equity in Equation (4). It is thus very important that the Multi Criteria Decision–Making (MCDM) method used is simple, flexible and able to consider quantitative and qualitative criteria in the same decision process. In addition, it is very important that relations among criteria are clearly presented to evaluators since the evaluation must be consistent and objective. The AHP method used a clear nine-stage scale and arranged criteria in a hierarchy structure that is generally well accepted by evaluators and allows them to obtain a consistent evaluation in a relatively short time. This is very important for achieving sustainable and quality delivery.

6. Conclusions

A delivery model which incorporates the objectives of platform providers, customers and shippers, and ensures long-term success and reduces negative environmental externalities does not exist. However, it is needed for two reasons. First, crowdshipping is expected to contribute to the reduction of the negative externalities of last-mile distribution, which increased drastically during the COVID-19 years. Second, transferring the share of shipments to individuals would improve services for end customers, which deteriorated during the COVID-19 pandemic due to lack of employees.

Badly managed crowdshipping operational approaches could increase pollution and costs, decrease customer service quality and limit benefits to some stakeholders. A multi-criteria two-level leader-followers game approach and the concept of Shapley value from cooperative flow games at the follower level are used in this paper to find an equilibrium strategy that provides a win–win for three groups of stakeholders while minimising the negative impact on the environment. The main result of this paper is a model where a platform provider or platform owner regulates a game to attract and retain (1) customers, by offering competitive delivery prices and quality delivery and (2) crowdshippers in the system by setting up optimal remuneration based on delivery quality and environmentally friendly solutions. A long-term financial efficiency of a platform provider could be guaranteed as well.

A presented model enables the platform provider to evaluate all coalition members based on nine criteria. Currently, a game includes two coalitions, but a platform provider can increase or reduce its number. The same applies for criteria. The current list of criteria is extensive and includes several measures for each of three crucial dimensions of sustainability.

Dynamic remunerations are paid by the platform to a deliverer. The remuneration varies depending on the rating the delivery person receives. The assessment takes into account several economic, social and ecological criteria to balance the interest of different groups of stakeholders and ensure long-term success.

In recent years and in the future, a growing number of unqualified people have and will continue to become involved in last-mile crowdshipping work. Thus, a crowd evaluation is crucial to retaining quality crowdshippers, offering quality services, and maximising platform profit. Our delivery model brings managerial benefits to platform providers who want to actively control individual crowdshippers. First, the algorithm helps them select the most appropriate crowdshipper from one of the coalitions that achieved the best score during the evaluation process. The best rating is given to the
crowdshipper who does quality work and thereby contributes to the loyalty of package recipients/senders and also to lower negative impacts on the environment. This is one of the essential benefits and innovations of this model compared to previous models that only considered delivery accuracy criterion and/or distance of detour criterion \[16,17,20,23\]. The quality of delivery is determined by five criteria in the proposed model; the same goes for environmental protection. Only two environmental protection criteria have already been used, individually, in previous models \[16,17,20,23\]. The criteria can be determined by the platform’s manager and also potentially by government bodies and/or city authorities according to their own choice or global trends or needs.

The current list of criteria covers three key aspects of sustainability and the needs/desires of three key stakeholders. This is another of the manager’s advantages, since the platform manager can choose from a number of initiatives in one place. This is not offered in such a comprehensive form by any of the previous research. Platform managers can also add new initiatives. So far, developed algorithms only consider requirements of limited number (only customers or and platform or crowdshipper or and platform) but not all included stakeholders. The proposed algorithm enables the selection of a crowdshipper by considering needs/requirements of three crucial groups of stakeholders, which is a managerial benefit not offered by any past studies. The tool is designed to take into account the needs of the platform, while the suppliers and customers should bring more competitiveness to the platform in the market: to deliverers a satisfactory payment, and the customers higher quality service.

The model also proposes a method for evaluating crowdshippers. The proposed method is generally well accepted by evaluators and allows them to obtain a consistent evaluation in a relative short time. However, other methods that are able to evaluate different types of conflicting criteria can be used.

Finally, the algorithm with variable prices encourages crowdshippers to deliver better quality and rewards them accordingly. Crowdshippers get higher remuneration, which could be a reason for them to stick with this and not any other platform. These motivational elements should be investigated in a future study in order to confirm the assumption, which, if true, would contribute to a sufficient number of crowdshippers, which is one of the reasons why some platforms did not remain on the market or are not operating.

They can adopt, adapt or extend the algorithm according to their needs (add incentives, exclude package distributors, etc.), business models and processes, or can upgrade their current delivery model with incentives presented in this study.

It is difficult to expect logistics platform owners to apply models similar to those presented in this article without encouragement or coercion from policymakers or competent government organizations. This study can, therefore, encourage and guide policymakers in implementing a range of incentives intended to alter urban freight operations and delivery models used by platform providers and increase the use of public transport and electric or hybrid cars. For example, a policymaker can enable the use of urban infrastructure (e.g., parking spot, bike sharing system, etc.) to deliverers which were granted tradable credits due to carbon footprint savings, by a platform provider.

Besides managerial and policymaker implications, this study also provides an important theoretical contribution. The presented model calls for testing accuracy and performance and for confirmation regarding whether the varying commission strategy outperforms fixed prices in terms of acceptance of delivery, delivery costs and platform profit. The proposed algorithm can be used as a basis for further development.

This study upgrades and complements past models where the owner of a platform regulates the game \[16,17,20,23\], with the owner being the platform developer as well as the package supplier. The innovations of this article compared to previous articles are as follows: (1) Past authors only individually consider economic \[3,16,17\] and social goals \[3,16,17,23\]. Environmental goals have been completely neglected in past research. The proposed model simultaneously improves economic, social and environmental goals. (2) Our model, in contrast to past models \[3,16,17,23\], considers requirements of three,
rather than just two stakeholders, making it easier to achieve long-term efficiency. A model proposed by Ghaderi et al. [3,16,17,23] is the only model that balances three stakeholders’ needs, though it considers only economic aspects of sustainability. (3) A few past studies included limited evaluation criteria. Lan et al. [3,16,17,23], for example, considered customer satisfaction, late delivery and route optimisation. Zhang et al. [3,16,17,23] applied two evaluation criteria (service quality and route optimisation). We added seven criteria that cover three key dimensions. Each dimension can be measured by not only one but several criteria.

Our study has some limitations and offers some possibilities for future research. A model has to be tested in a real environment to determine its usefulness, weaknesses, and to propose upgrades and changes based on the findings. An expert panel can be defined with the help of the proposed guidelines and the criteria from Table 2 can also be related to the real world, checking the consistency of the weights obtained with the AHP method and thus the opinions of the different experts.

The model assumes that all parcels are the same and can be delivered by all crowdshippers, regardless of the mode of transport they are using. In reality, it may happen that the delivery person travels by bicycle and cannot take a heavy package, or travels by train and cannot take such a large package. It is therefore recommended to incorporate parcel characteristics (dimensions, weight, type of good) into a model.

In addition, in reality, a crowdshipper is expected to get lower prices than a parcel provider, which has a higher operative cost. However, the presented model does not differentiate prices between members of different coalitions. It is therefore necessary to incorporate different prices into a model and analyse the effect on a platform’s profit and crowdshippers’ acceptance rate.

In one of the future studies, it would make sense to incorporate incentives for new crowdshippers into the model. We suggest that the platform assign them the coalition average evaluation to encourage new entries. Safran and Che [41] used similarity scores, which reflect the crowdshipper’s expertise, skills and personal preferences.

The use of game theory to achieve sustainable crowdshipping in last-mile deliveries allows the rationalization of these processes by estimating and indicating decision paths that ensure increased sustainability through an active role of the platform provider in each step. This approach is based on a multi-criteria evaluation of deliverers using the AHP method. The AHP method is easy to use and has a good understanding, but its weakness is the rank reversal only when a non-optimal alternative is replaced by a worse one. To reduce this potential problem can be used the Logarithm Methodology of Additive Weights (LMAW) presented in [42].

In order to be able to confirm some of the assumptions we made in the discussion, it would be reasonable in a future study to examine the impact of the amount of payment and environmental protection incentives on the crowdshipper, the impact of the quality of delivery on customer loyalty, etc., using qualitative, quantitative or a combination of both methods.

Moreover, the proposed game can be upgraded considering flow units to be transported, such as variables in Vehicle Routing Problem (VRP).

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References

1. Ciobotaru, G.; Chankov, S. Towards a taxonomy of crowdsourced delivery business models. *Int. J. Phys. Distrib. Logist. Manag.* 2021, 51, 460–485. [CrossRef]

2. Frehe, V.; Mehmann, J.; Teuteberg, F. Understanding and assessing crowd logistics business models—using everyday people for last mile delivery. *J. Bus. Ind. Mark.* 2017, 32, 75–97. [CrossRef]

3. Atasoy, B.; Schulte, F.; Steenkamp, A. Platform-Based Collaborative Routing using Dynamic Prices as Incentives. *Transp. Res. Rec.* 2020, 2674, 670–679. [CrossRef]

4. Carbone, V.; Rouquet, A.; Roussat, C. The rise of crowd logistics: A new way to co-create logistics value. *J. Bus. Logist.* 2017, 38, 238–252. [CrossRef]

5. Punel, A.; Stathopoulos, A. Modeling the acceptability of crowdsourced goods deliveries: Role of context and experience effects. *Transp. Res. Part E Logist. Transp. Rev.* 2017, 105, 18–38. [CrossRef]

6. Pan, S.; Zhang, L.; Thompson, R.G.; Ghaderi, H. A parcel network flow approach for joint delivery networks using parcel lockers. *Int. J. Prod. Res.* 2021, 59, 2090–2115. [CrossRef]

7. Dai, Q.; Jia, H.; Liu, Y. Private vehicle-based crowdshipping for intercity express transportation: Feasibility assessment. *Int. J. Distrib. Sens. Netw.* 2020, 16, 1500147720908203. [CrossRef]

8. Mladenow, A.; Bauer, C.; Strauss, C. Crowdsourcing in logistics: Concepts and applications using the social crowd. In Proceedings of the International Conference on Information Integration and Web-based Applications & Services, Brussels, Belgium, 11–13 December 2015; pp. 1–8.

9. Pournajaf, L.; Xiong, L.; Sunderam, V.; Goryczka, S. Spatial task assignment for crowd sensing with cloaked locations. In *Proceedings of the 15th International Conference on Information Integration and Web-based Applications & Services, Brussels, Belgium, 11–13 December 2015*; pp. 73–82.

10. Simoni, M.D.; Marcucci, E.; Gatta, V.; Claudel, C.G. Potential last-mile impacts of crowdshipping services: A simulation-based evaluation. *Transportation* 2020, 47, 1933–1954. [CrossRef]

11. Le, T.V.; Ukkusuri, S.V. Modeling the willingness to work as crowd-shippers and travel time tolerance in emerging logistics services. *Travel Behav. Soc.* 2019, 15, 123–132. [CrossRef]

12. Sampaio, A.; Savelsbergh, M.; Velleurturf, L.; Van Woensel, T. Crowd-based city logistics. In *Sustainable Transportation and Smart Logistics, Javier Faulin, A.A.J., Scott, E., Grasman, P.H., Eds.*; Elsevier: Amsterdam, The Netherlands, 2019; pp. 381–400.

13. Qi, W.; Li, L.; Liu, S.; Shen, Z.-J.M. Shared mobility for last-mile delivery: Design, operational prescriptions, and environmental impact. *Manuf. Serv. Oper. Manag.* 2018, 20, 737–751. [CrossRef]

14. Buldeo Rai, H.; Verlinde, S.; Merckx, J.; Macharis, C. Crowd logistics: An opportunity for more sustainable urban freight transport? *Eur. Transp. Res. Rev.* 2017, 9, 1–13. [CrossRef]

15. UN. Make Cities and Human Settlements Inclusive, Safe, Resilient and Sustainable. Available online: https://sdgs.un.org/ goals/goal11 (accessed on 10 October 2022).

16. Ghaderi, H.; Tsai, P.-W.; Zhang, L.; Moayedikia, A. An integrated crowdshipping framework for green last mile delivery. *Sustain. Cities Soc.* 2022, 78, 103552. [CrossRef]

17. Le, T.V.; Ukkusuri, S.V.; Xue, J.; Van Woensel, T. Designing pricing and compensation schemes by integrating matching and routing models for crowd-shipping systems. *Transp. Res. Part E Logist. Transp. Rev.* 2021, 149, 102209. [CrossRef]

18. Malan, P.C. An Agent-Based Approach to Customer Crowd-Shipping. Master’s Thesis, Stellenbosch University, Stellenbosch, South Africa, 2022.

19. Kafle, N.; Zou, B.; Lin, J. Design and modeling of a crowdsourced system for urban parcel relay and delivery. *Transp. Res. Part B Methodol.* 2017, 99, 62–82. [CrossRef]

20. Li, B.; Krushinsky, D.; Reijers, H.A.; Van Woensel, T. The share-a-ride problem: People and parcels sharing taxis. *Eur. J. Oper. Res.* 2014, 238, 31–40. [CrossRef]

21. Allahviranloo, M.; Baghestani, A. A dynamic crowdshipping model and daily travel behavior. *Transp. Res. Part E Logist. Transp. Rev.* 2019, 128, 175–190. [CrossRef]

22. Soto Setzke, D.; Pfügliger, C.; Schreieck, M.; Fröhlich, S.; Wiesche, M.; Krcmar, H. Matching drivers and transportation requests in crowdsourced delivery systems. In *Management Digitaler Plattformen; Wiesche, D.M., Sauer, P., Krimmling, P.D.J., Krcmar, P.D.H., Eds.*; Springer Gabler: Wiesbaden, Germany, 2018; pp. 269–283.

23. Lan, Y.-L.; Liu, F.; Ng, W.W.; Gui, M.; Lai, C. Multi-Objective Two-Echelon City Dispatching Problem With Mobile Satellites and Crowd-Shipping. *IEEE Trans. Intell. Transp. Syst.* 2022, 23, 15340–15353. [CrossRef]

24. Zhang, C.; Du, Z.; Parmar, M.D.; Bai, Y. Pocket-switch-network based services optimization in crowdsourced delivery systems. *Comput. Electr. Eng.* 2017, 62, 53–63. [CrossRef]

25. Ta, H.; Esper, T.L.; Hofer, A.R. Designing crowdsourced delivery systems: The effect of driver disclosure and ethnic similarity. *J. Oper. Manag.* 2018, 60, 19–33. [CrossRef]

26. Farizky Wijanarko, F. Potential Impact of Car-Based Crowdshipping on Vehicle Mileage and Carbon Dioxide Emission: An Agent-Based Modelling Study Case. Master’s Thesis, Delft University of Technology, Delft, The Netherlands, 2022.

27. van Cooten, C. Crowdsourced Delivery—The Traditional Delivery Method Reinvented. Master’s Thesis, Eindhoven University of Technology, Eindhoven, The Netherlands, 2016.
28. Le, T.V.; Stathopoulos, A.; Van Woensel, T.; Ukkusuri, S.V. Supply, demand, operations, and management of crowd-shipping services: A review and empirical evidence. *Transp. Res. Part C Emerg. Technol.* 2019, 103, 83–103. [CrossRef]

29. Rasmusen, E. *Games and Information: An Introduction to Game Theory, Edition*; Balcwell publishing: Oxford, UK, 2007.

30. Turocy, T.; Von Stengel, B. *Game Theory. Encyclopedia of Information Systems*; Elsevier: New York, NY, USA, 2003.

31. Basaran, A. A method for strategic decision making in a watershed-game theory. In Proceedings of the 45th Congress of the ERSA, Amsterdam, The Netherlands, 23–27 August 2005; pp. 1–20.

32. Tuljak-Suban, D. Competition or cooperation in a hub and spoke-shipping network: The case of the North Adriatic container terminals. *Transport* 2018, 33, 429–436. [CrossRef]

33. Saeed, N.; Larsen, O.I. Container terminal concessions: A game theory application to the case of the ports of Pakistan. *Marit. Econ. Logist.* 2010, 12, 237–262. [CrossRef]

34. Saaty, T.L.; Vargas, L.G. The analytic network process. In *Decision Making with the Analytic Network Process, 2nd ed.*; Hillier, F.S., Ed.; Springer: Berlin/Heidelberg, Germany, 2006; Volume 282, pp. 5–9.

35. Saaty, T.L. *Fundamentals of Decision Making and Priority Theory with the Analytic Hierarchy Process*; RWS Publications: Pittsburgh, PA, USA, 1994.

36. Safran, M.; Che, D. Real-time recommendation algorithms for crowdsourcing systems. *Appl. Comput. Inform.* 2017, 13, 47–56. [CrossRef]

37. Pamučar, D.; Žižović, M.; Biswas, S.; Božanić, D. A new logarithm methodology of additive weights (lmaw) for multi-criteria decision-making: Application in logistics. *Facta Univ. Ser. Mech. Eng.* 2021, 19, 361–380. [CrossRef]