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SIMULATION-BASED ANALYSIS OF IMPROVEMENTS IN VEHICLE ROUTING WITH TIME WINDOWS USING A ONE-SIDED VCG MECHANISM FOR THE REALLOCATION OF UNFAVORABLE TIME WINDOWS

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ABSTRACT

In road freight transport, booking unfavorable time windows (TWs) through time window management systems (TWMS) for loading or unloading trucks at the loading dock often leads to avoidable long tours. Therefore, this paper investigates, based on an agent-based simulation framework, the efficiency gains and improvements in vehicle routing with TW constraints that can be achieved by a reallocation of unfavorable TWs using a one-sided Vickrey-Clarke-Groves mechanism. A branch-and-cut algorithm is used to evaluate the value of a TW in the context of a pickup and delivery problem with TWs and to generate a bid for the auction. A winner determination problem is solved for conducting the auction. We show that a reallocation of unfavorable TWs leads to distance savings for the considered tours of the auction winners of 13 % on average. Further, we can show that the TWMS provider can benefit by operating the mechanism on an electronic marketplace.

1 INTRODUCTION

In recent years, so-called web-based time window management systems (TWMS) have been established to plan and control the loading of trucks at the loading dock (Elbert et al. 2016a; Berbeglia et al. 2007). In this context, a time window (TW) is understood as a fixed time interval in which the truck must either load or unload the goods at the warehouse. Large industrial and commercial enterprises, in particular, use these systems to optimize inbound and outbound processes in their warehouses (Elbert et al. 2016b, Hagenlocher et al. 2013). TWMS providers like Transporeon, Cargoclix, or Logsol, for example, describe that if a time window is booked, the warehouse operator gets information about the type, quantity, and composition of the goods to be unloaded or loaded. With this information, it becomes possible for the warehouse operator to allocate the internal resources to single TW and docks in an optimal way (Dr. Meier & Schmidt GmbH 2023; LOGSOL GmbH 2023; Transporeon 2023). If the booked TW can be reached at the given time, this also reduces waiting times for forwarders at the loading dock (Hackius and Kersten 2014; Dr. Meier & Schmidt GmbH 2020). For small and medium-sized forwarders, on the other hand, the introduction of TWMS is often associated with efficiency losses due to the rigid allocation of TW according to the First Come - First Serve (FCFS) principle (Phan et al. 2016).

When carrying out vehicle routing, favorable TWs are quickly no longer available. This often leads to restrictions, which causes awkward tours and is therefore associated with higher costs and emissions (Hackius and Kersten 2014). Internal exchanging of unfavorable TWs between different requests is also limited due to the fewer number of requests that small and medium forwarders have compared to larger forwarders. Therefore, to the best of our knowledge, a research gap exists considering a reallocation of

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unfavorable TWs within vehicle routing. We propose a solution to counter this problem and fill the research gap by implementing a one-sided Vickrey-Clarke-Groves (VCG) mechanism into vehicle routing with TWs. The VCG mechanism is used because it has an efficient allocation rule. The underlying sealed bid second price auction leads to the outcome that it is a weakly dominant strategy for the bidders (forwarders) to reveal their true value in the auction (Krishna 2009). This leads to the result that the participating forwarder, which values the TW the most and thus has the most significant savings in transport costs, gets the TW. Further, we use a one-sided VCG mechanism where the auctioneer and not the forwarder who has already booked the TW auctions off the TW. This eliminates the incentive for forwarders to book favorable TW and auction them off with a profit. With the reallocation of a single unfavorable TWs within vehicle routing, it becomes possible for forwarders to reach distance savings and save money, as well as $C0^2$ emissions due to shorter tours.

Therefore, this paper aims to investigate if implementing the one-sided VCG mechanism for the reallocation of single TWs can improve vehicle routing with time windows and prevent driving detours. Based on the research objective, the following research questions arise:

- RQ1: Which improvements can be reached by implementing a one-sided VCG mechanism for the reallocation of single time windows into a pickup and delivery problem with time windows?
- RQ2: Which actors involved can benefit from implementing a one-sided VCG mechanism into vehicle routing with time windows?

The paper is structured as follows: In section two, we first provide a short overview of the current literature that deals with the procuring of requests or time windows and with the exchange of requests with and without time windows through electronic marketplaces. The formulation of our model is presented in section three. The key simulation results are described in section four, and the conclusion is given in section five.

2 LITERATURE REVIEW

One way to improve vehicle routing in road freight transport is to exchange requests between forwarders and carriers on electronic marketplaces. Practical examples of that kind of marketplace can be found on digital platforms like TIMICON or Transporeon, where requests can be exchanged through forwarders and carriers to improve the efficiency of individual vehicle routing. Also, the matching of the supply and demand of shippers and forwarders can be realized through electronic marketplaces (Transporeon 2023; TIMOCOM 2023). In theory, many papers dealing with the contracting of logistics service providers investigate improvements that can be achieved through different mechanisms (Robu et al. 2011; Xu et al. 2014; Zhang et al. 2019). For example, Xu et al. (2014) compare a one-sided VCG mechanism and a descending auction with several rounds and VCG-payments to solve the *distributed transportation procurement problem*. A scenario is proposed in which requests are auctioned online, by a shipper, or via an electronic marketplace by a third-party auctioneer to multiple carriers. Bids can be placed from the carriers for full truckload requests, where goods must be picked up and delivered, and time window restrictions must be observed.

Another paper is proposed by Karaenke et al. (2019) in which a discrete event simulation is used to compare a VCG- mechanism, a *relax-and-round framework*, and a *relax-and-round framework combined with a branch-and-cut* algorithm. The different mechanisms are used to auction off bundles of TWs from a single company that operates many warehouses intending to reduce waiting times for forwarders at the loading docks. To determine the monetary value of the bid for a bundle of TWs, the carriers have to calculate time savings based on solved Traveling Salesman Problems. To coordinate the auction, a software application is proposed, operated on behalf of the company that operates the warehouses. In Karaenke et al. (2020), it is then argued that forwarders are not willing to pay for the reservation of TW. For that reason, the use of a matching mechanism is investigated. The setting is very similar to Karaenke et al. (2019). A platform on which the mechanisms are implemented is coordinated by a central authority commissioned from a TWMS provider on behalf of a large retailer. The TWMS provider gets information about the preferences of the forwarders, in which they truthfully disclose their preferences on the bundles of TWs offered. The authors assume that if the market is big enough, a mechanism is asymptotically strategy-proof, and telling the truth about the preferences is an approximately dominant strategy of the forwarders. To maximize the social welfare of the bidding forwarders, a winner determination problem (WDP) is solved. A randomized matching mechanism with the properties of envy-freeness and approximately efficiency is applied to solve the WDP (Karaenke et al. 2020).

A further relevant line of research to this paper at hand deals with the question of what improvements can be achieved in vehicle routing by exchanging requests or truckloads of carriers. The considered trade of requests and truckloads between forwarders is thereby either realized on electronic marketplaces or horizontal collaborations that are built between multiple forwarders to agree on a mechanism for exchanging unfavorable requests (Song and Regan 2003; Wang et al. 2014; Xu et al. 2017). Berger and Bierwirth (2010), for example, investigate in their paper the benefits that can be achieved by using three different strategies for exchanging requests between small and medium-sized forwarders that do not fit into the vehicle routing in a post-market. In the first strategy, routes are optimized without exchanging. The second strategy examines two different approaches. In the first approach, the companies agree on a one-sided Vickrey auction operated by a third-party auctioneer to auction off single unprofitable requests. In the second approach, the unprofitable requests from forwarders are offered in bundles and auctioned off via a combinatorial auction. In the third strategy, a central authority optimizes the routes of all forwarders based on complete information. To evaluate the requests, a Travelling Salesman Problem with Pickup and Deliveries is solved through a branch-and-cut algorithm.

In particular, the exchange of requests or procuring requests where TW restrictions are considered between individual forwarders receives special attention in the literature. In contrast, the consideration of a reallocation of single unfavorable TWs for the improvement of individual tours with TW restrictions has not yet been considered. This paper contributes to filling this research gap by investigating a reallocation of single TWs between different forwarders through a one-sided VCG mechanism that is implemented on an electronic marketplace of a digital platform. We aim to propose a solution that leads to distance savings for forwarders and, associated with that, saves money and $C0^2$ emissions.

3 MODEL DESCRIPTION

3.1 Simulation Framework

To investigate possible improvements of a reallocation of single unfavorable TWs through a one-sided VCG mechanism, we model the mechanism and the *pickup and delivery problem with time windows* (PDPTW) in a simulation framework. As simulation software, we use the AnyLogic University Version 8.8.1. Before describing the basic algorithm of the agent-based simulation framework, the main actors involved in a model must first be described in more detail. One of the main actors is the forwarder, whose task is to perform vehicle routing with the given restrictions. The second main actor is the platform operator, who offers the reallocation of TWs on the platform as an application. The other actors represented in the model are the shippers and their customers, who, as already described, use TWs to optimize their internal processes. The basic flow of the simulation model is shown in Figure 1.

The model consists of four individual forwarders $f \in F$ and one platform operator represented by individual agents. Four different agent populations represent the shippers and their customers. At the start of the model, networks are generated based on downsized PDPTW instances proposed by Li and Lim (2001) for each of the four forwarders f. The data of the instances used to generate the network is read from an Excel file. An algorithm first proposed by Leyton-Brown et al. (2000), further developed by Elbert et al. (2019), and now adjusted to our problem is used to generate the four networks based on PDPTW instances.

The generation of the networks for the individual forwarders starts with reading the location data of the customers, the shippers, and the depot from the Excel file. In addition, different graphical elements are also assigned to the agent population's individual agents depending on which actor it is. Once the location data and the graphical elements are assigned to the individual agents, they are published on the main agent. Next, a distance matrix is generated for all four networks using the location data for each instance assigned to the different forwarders. These distance matrices are then used as input parameters for the Branch-and-Cut (B&C) algorithm and vehicle routing.

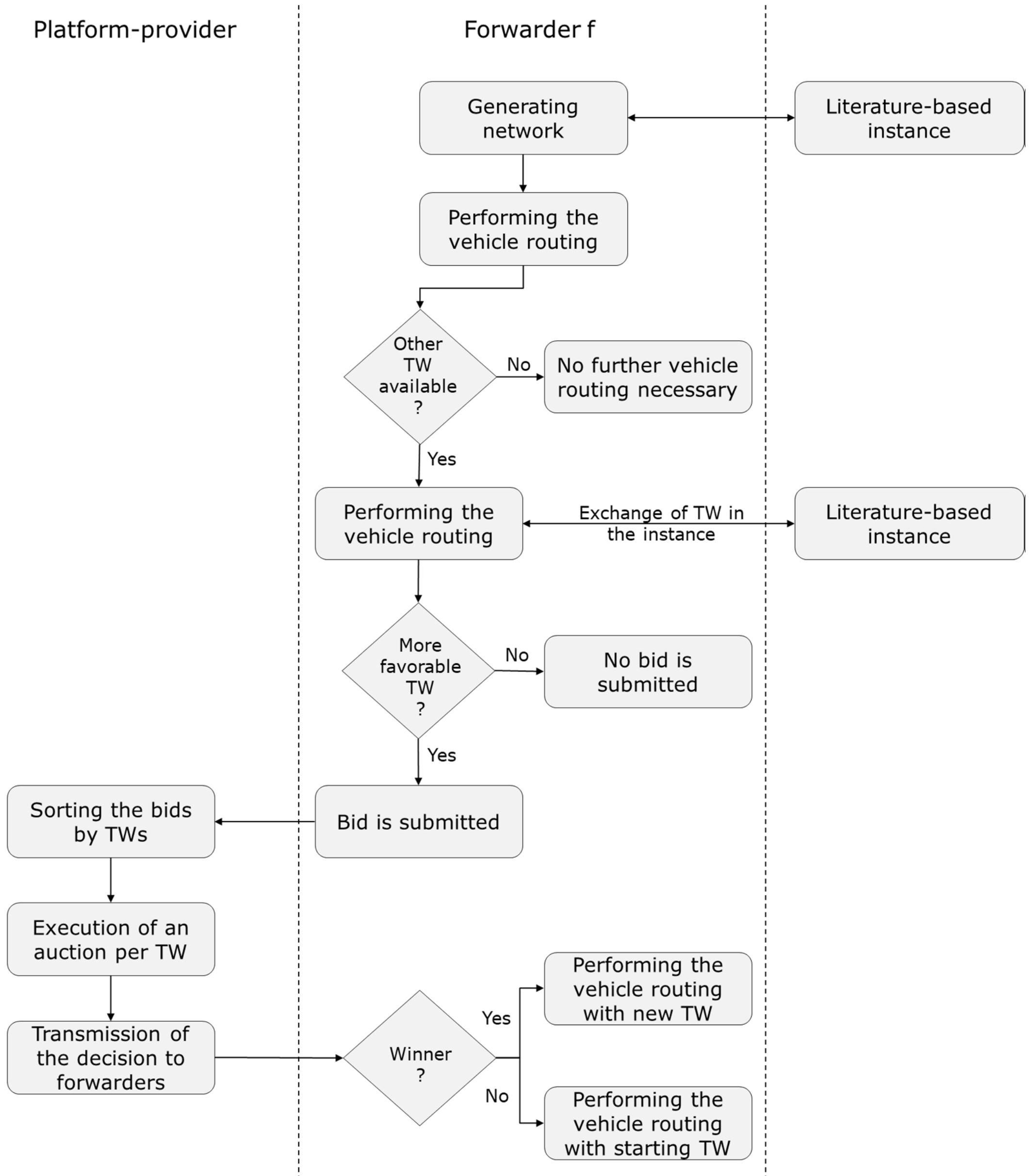

Figure 1: Flowchart of the simulation model.

To get the true valuations for TWs of the bidders, the problems are solved exactly by using a B&C-algorithm presented by Ropke et al. (2007). In the Java-based environment of AnyLogic, we integrate an IBM®ILOG CPLEX 12.6.2 (IBM ILOG CPLEX Optimization Studio 22.1.0) API to model the B&C-algorithm and solve the PDPTW. As a result of solving the problem exactly, we get minimal transport costs for the given instances. In the next step, it is then checked if a TW offered by the other forwarders can be integrated into their own tour. If that is the case, the TW of the PDPTW instance is changed, and the problem is solved again. With the second result, it is now possible to evaluate the offered TW. Suppose the transport costs are lower than before a bid is submitted. Then the platform operator gets the bids from the different forwarders and sorts the bids depending on the requested TW. Afterward, the auction is conducted, and the single TWs are reallocated. Ultimately, the improvements achieved in vehicle routing depend on the auction outcome and are calculated at the end based on the new TW.

3.2 Optimization Model and Bid Generation

To formulate the model, a set of forwarders $F = \{0 \dots . |F|\}$ is introduced first. Each forwarder has to solve individual PDPTWs with different TWs to determine the value of a bid v_f where $f \in F$ and the value of a bid is equal to the value of a single TW within their tour.

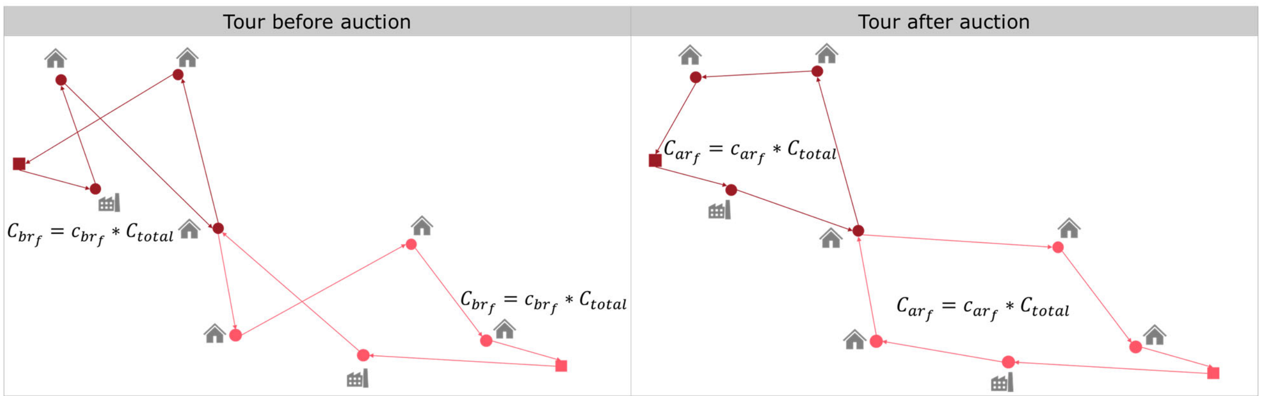

Figure 2: Cost before and after the reallocation of a time window.

In Figure 2, it can easily be seen that the value of the TW that is essential for conducting the auction can be calculated by subtracting the costs after a possible reallocation of TWs C_{ar_f} from the costs before the reallocation C_{br_f} of the single TWs occurs.

$$v_f = C_{br_f} - C_{ar_f} \qquad \forall f \in F \qquad (1)$$

To solve small instances of a PDPTW for each forwarding agent and to determine the cost before and after the exchange, a version of the B&C-algorithm proposed by Ropke et al. (2007) is used. Therefore, the PDPTW is based on a directed graph $G = (N, A)$ where N represents the set of nodes $\{0 \dots .2n + 1\}$, A the set of arcs, and n the number of requests. The origin and destination depots of one forwarder are given by the nodes 0 and $2n + 1$. $P = \{1 \dots . n\}$ represents the set of pickup nodes and $D = \{n + 1 \dots .2n\}$ the set of delivery nodes and $P, D \subset N$. At every node $i \in N$, the truck has to load $q_i \geq 0$ for $i \in P$ or unload $- q_i$ for $i \in D$ in a given service duration $d_i \geq 0$.

To fulfill the requests i, the forwarder has an unlimited number of trucks. The fleet of trucks is identical and has a capacity of Q. The routing cost (distance) for every arc $(i, j) \in A$ is c_{ij} and the travel time t_{ij}. Whereby the travel time in this model is equated with the routing costs $c_{ij} = t_{ij}$. At each node $i \in P \cup D$ a time window $[e_i, l_i]$ must be considered, where e_i represents the earliest possible arrival time and l_i the latest possible arrival time. For the nodes of the depots, the time windows $[e_0, l_0]$ and $[e_{2n+1}, l_{2n+1}]$ represents the beginning and end of the working time of the truck drivers.

In addition, for these nodes is also valid that $q_0 = q_{2n+1} = 0$ and $d_0 = d_{2n+1} = 0$. For x_{ij} as a binary variable, it is valid that if a truck travels along an arc $(i, j) \in A$ the variable $x_{ij} = 1$ and otherwise 0. With the variable Q_i the current truck capacity is associated when the truck leaves the loading dock of node i. The variable B_i indicates the time when the truck's handling starts at the loading dock of node i. For both variables B_i and Q_i it is valid that $i \in P \cup D$.

$$min \sum_{i \in N} \sum_{j \in N} c_{ij} x_{ij} \tag{2}$$

subject to

$$\sum_{i \in N} x_{ij} = 1 \qquad \forall j \in P \cup D \tag{3}$$

$$\sum_{j \in N} x_{ij} = 1 \qquad \forall i \in P \cup D \tag{4}$$

$$e_i \leq B_i \leq l_i \qquad \forall i \in N \tag{5}$$

$$B_j \geq B_i + d_i + t_{ij} - M_{ij}(1 - x_{ij}) + (M_{ij} - d_i - t_{ij} - \max\{d_i + t_{ij}, e_i - l_i\})x_{ij} \qquad \forall i, j \in N \tag{6}$$

$$\max\{0, q_i\} \leq Q_i \leq \min\{Q, Q + q_i\} \qquad \forall i, j \in N \tag{7}$$

$$Q_j \geq Q_i + q_j - W_{ij}(1 - x_{ij}) + (W_{ij} - q_i - q_j)x_{ji} \qquad \forall i, j \in N \tag{8}$$

$$B_i \geq e_i + \sum_{j \in P \cup D \setminus \{i\}} \max\{0, e_j - e_i + d_i + t_{ij}\} x_{ji} \qquad \forall\ i \in P \cup D \tag{9}$$

$$B_i \leq l_i - \sum_{j \in P \cup D \setminus \{i\}} \max\{0, l_i - l_j + d_i + t_{ij}\} x_{ij} \qquad \forall\ i \in P \cup D \tag{10}$$

$$Q_i \geq \max\{0, q_i\} + \sum_{j \in N \setminus \{i\}} \max\{0, q_j\} x_{ji} \qquad \forall i \in N \tag{11}$$

$$Q_i \leq \min\{Q, Q + q_i\} - (Q - max_{j \in N \setminus \{i\}}\{q_j\} - q_i)x_{0i} \sum_{j \in N \setminus \{i\}} \max\{0, q_j\} x_{ij} \qquad \forall i \in N \tag{12}$$

$$x_{ij} \in \{0,1\} \tag{13}$$

With objective function (2), the transport costs are minimized. Constraints (3) and (4) are introduced to guarantee that each node is visited only once. Equations (5) and (6) ensure that the TW restrictions are observed and that no subtours are formed. Constraints (7) and (8) ensure that a truck's capacity is not exceeded during transport. To guarantee the validity of (6) and (8) M_{ij} has to be set to $M_{ij} \geq \max\{0, l_i + d_i + t_{ij} - e_j\}$ and W_{ij} to $W_{ij} \geq \max\{Q, Q + q_i\}$. The Constraints (9) and (10) strengthen the condition that forwarders adhere to the given time windows at the nodes during the vehicle routing. Furthermore, Constraints (11) and (12) strengthen the condition that the capacity limit of the truck is exceeded during the tour.

After introducing the optimization model for the PDPTW, it is now possible to determine the value of a bid v_f for a single TW of one forwarder by subtracting the routing costs after the reallocation c_{ar_f} from the routing costs before the reallocation c_{br_f} and the multiplication with the total cost per kilometer C_{total}.

Equation (14) shows the determination of the value.

$$v_f = C_{br_f} - C_{ar_f} = (c_{br_f} - c_{ar_f}) * C_{total} = ((min \sum_{i \in N} \sum_{j \in N} c_{ij} x_{ij})_{br_f} - (min \sum_{i \in N} \sum_{j \in N} c_{ij} x_{ij})_{ar_f}) * C_{total} \quad \forall f \in F \tag{14}$$

The transport costs used in Equation (14) consist of fuel and lubricant costs C_{fl}, driver costs C_{dr}, imputed depreciation costs C_{dept}, tire costs C_{tire} and toll costs C_{toll}.

$$C_{total} = C_{fl} + C_{dr} + C_{dept} + C_{tire} + C_{toll} \tag{15}$$

3.3 Winner Determination Problem and VCG Mechanism

The basic idea of this paper is that transport costs and emissions can be saved by the reallocation of unfavorable TWs through a mechanism. To test these assumptions, as described above, a one-sided VCG mechanism is implemented for the reallocation of single unfavorable TWs within a PDPTW. The setting of the mechanism is as follows. The VCG mechanism we propose in our paper is an efficient, incentive-compatible, (ex-post) individual rational and (ex-post) weak budget balanced mechanism. A mechanism is efficient if it has an efficient allocation rule. Therefore, the forwarder (bidder), which values the TW the most, wins the auction. The basis of the VCG mechanism is a sealed-bid second-price auction, also called the Vickrey auction (Ausubel and Milgrom 2006). This auction format is very useful because it is a weakly dominant strategy for the forwarders to bid their true value of the TW. That implies that the VCG mechanism is incentive compatible and, thus, truthfully bidding maximizes the payoff of the forwarder. The decision of a forwarder to participate in the mechanism is essential. Therefore, individual rationality is another important property the mechanism should have. It is the case if the participating bidder has an equilibrium payoff of zero. To ensure further that the platform operator as auctioneer receives a profit from the mechanism, it should be weak budget balanced. Thus, at the end of the auction, the sum of all payments is bigger than zero, and a surplus is expected (Krishna 2009). Suppose the reallocation of single TWs occurs after the TWs have already been booked and customers have not yet frozen the TWs to optimize their internal processes. In that case, it becomes possible to reallocate the TWs with the help of a one-sided VCG mechanism. In our model, only one specific TW of one dock is auctioned off per auction. The allocation problem can thus be formulated as a WDP for single TWs. To sell the single TWs to the bidding forwarders, the auctioneer has a set of time windows, $s \in S = \{1 \dots . |S|\}$ which leads to unfavorable tours for the offering forwarders. If an offered TW leads to improvements for the planned tour of other forwarders, then a bid is submitted to the auctioneer. The auctioneer then gets a set of bids $\mathrm{B} = \{\mathrm{B}_1, \mathrm{B}_2 \dots . \mathrm{B}_f\}$ from different forwarders $f \in F$ for one TW. In this context, a bid consists of a tuple $\mathrm{B}_f = \langle O_f, v_f \rangle$ where $v_f \geq 0$ represents the value of the TW and $O_f \subseteq S$.

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$$max \sum_{f \in F} v_f \, x_f \tag{16}$$

subject to

$$\sum_{f | i \in O_f} x_f \leq 1 \quad \forall i \in S \tag{17}$$

$$x_f \in \{0,1\} \tag{18}$$

With the objective function (16), the valuation of the submitted bids is maximized. The Constraint (17) ensures that only one forwarder gets the TW.

To introduce the VCG mechanism, we first look at the allocation rule with the set of possible allocations A. Therefore, we admit that the true valuations $v \in \mathrm{V}$ of the forwarders lie on an interval $v_f = [\rho_f, \gamma_f] \subset \mathbb{R}$ and that negative values $\rho_f < 0$ are possible. With an efficient allocation rule $q^*: V \to A$ the social welfare is then maximized.

$$q^*(v) \in \arg\max_{q \in A} \sum_{f \in F} q_f x_f \tag{19}$$

Equation (20) now shows the rule with which the social welfare is maximized when forwarder i with $i \in F$ participates in the auction and in Equation (21), the maximized social welfare of the other forwarders is shown if forwarder i don't participate in the auction.

$$w(v) \equiv \sum_{f \in F} q_f^*(v) x_f \tag{20}$$

$$w_{-i}(v) \equiv \sum_{f \neq i} q_f^*(v) x_f \tag{21}$$

Definition The VCG mechanism $M^{VCG} = (q^*, m^{VCG})$ with the payment rule $m^{VCG}: V \to \mathbb{R}$ is an efficient mechanism.

$$m^{VCG} = w(\rho_i, v_{-i}) - w_{-i}(v) \tag{22}$$

The VCG mechanism is also an incentive-compatible, (ex-post) individual rational and (ex-post) weak budget-balanced mechanism in our proposed context. Because the auction of the TWs s takes place after the official allocation (with the FCFS principle), shortly before the TWs are frozen by the customers and only unfavorable TWs are auctioned, there is a Pareto improvement for the involved actors. It is further assumed that no negative externalities arise for the participating actors. Assuming that the mechanism does not generate additional costs $\rho_f = 0$ for the actors involved and $v_i \geq max_{f \neq i} v_f$ we get the following payment rule:

$$m_i^{VCG} = w_{-i}(0, v_{-i}) - w_{-i}(v) \tag{23}$$

Now with this assumption, the payment of the winning forwarder m_i^{VCG} is equal to the second highest bid, and telling the truth is like in the second-price auction, a weakly dominant strategy (Krishna 2009). If the mechanism has the additional property that it is possible for the auctioneer to make a profit, we have an (ex-post) weak budget balanced mechanism. In the special case that only one forwarder participates in the auction, the auctioneer's profit is equated with the second highest bid. So, the auction winner has to pay only the auctioneer's profit.

4 RESULTS

To investigate the improvements of the reallocation of individual TWs using a VCG mechanism, we compare the transport costs of the four forwarders before and after the auction is conducted. We can show that with our proposed solution, a Pareto improvement for all actors involved can be reached. Figures 3 and 4 show the results. The depot of Forwarder 1 can be seen on the right, Forwarder 2 opposite on the left, Forwarder 3 above, and Forwarder 4 below. Figure 3 shows the result before the auction is conducted. Each forwarder calculates the optimal tour with the given TW restrictions. It can be seen that after calculating the optimal tours with the B&C-algorithm, avoidable detours have to be made, especially by Forwarders 1, 2, and 4, due to the given TW restrictions. For Forwarder 3, the best solution seems to have already been found. Furthermore, it can be seen that all forwarders have booked a TW at the same loading dock at Customer 4 on the same day. Thus, a reallocation of TWs among the four forwarders becomes possible by using the VCG mechanism.

Figure 4 shows the result after the reallocation. Forwarders one and two can shorten the approaching routes. The approaching routes for Forwarders three and four remain identical.

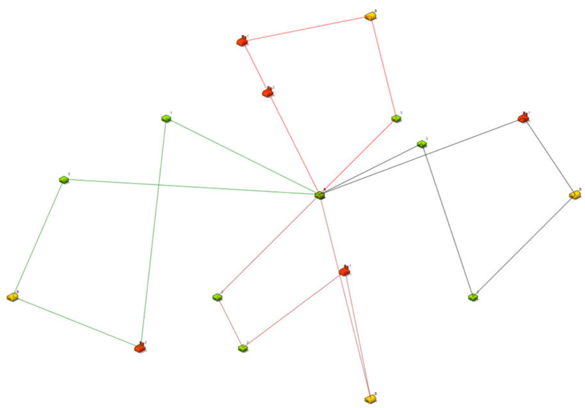

Figure 3: Tour before reallocation.

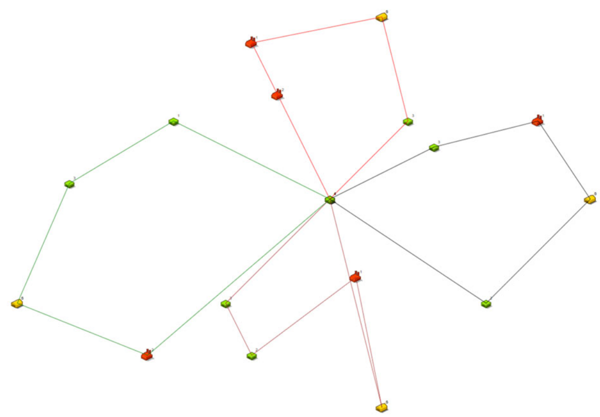

Figure 4: Tour after reallocation.

In Table 1, the results of the model are summarized quantitatively. It also becomes clear that Forwarders 1 and 2 win the auction. Like all other forwarders, the Forwarder 3 checks whether a bid should be placed. Due to the expected loss, however, no bid has been submitted.

Table 1: Results of the reallocation.

Forwarder	Routing cost before reallocation [km]	Routing cost after reallocation [km]	Bid Value [€]	Submit bid / Winner	Cost savings [€]	Profit auctioneer [€]
1	143,02	125,34	27,74	Yes/Yes	22,74	5
2	180,91	154,97	40,73	Yes/Yes	26,43	14,30
3	100,86	119,78	-29,70	No/No	0	0
4	131,19	122,08	14,30	Yes/No	0	0

Forwarders 1 and 4 bid on the same TW. Forwarder 1 submits the higher bid. Thus, a price for the TW equal to the second highest bid must be paid. Therefore, exactly the value that Forwarder 4 has bid. Forwarder one also wins the auction. Here, the second highest bid is equal to the auctioneer's minimum price. No actor involved in the auction is worse off. Forwarders 1 and 2 are better off by shortening their routes and, thus, decreasing transport costs. So, with the reallocation of unfavorable TWs, distance savings of the considered tours can be realized from the auction winners of 13 % on average. The auctioneer makes a profit of € 19.30 on the auction of the two TWs. Further, the delivery time to the customer is shortened, which leads to an improved delivery service. Thus, it can be summarized that by implementing the one-sided VCG mechanism, a Pareto improvement can be achieved for the actors directly and indirectly involved in the reallocation.

5 CONCLUSION

In this paper, we show for the first time which improvements can be achieved by reallocating unfavorable TWs using a one-sided VCG mechanism. To investigate the improvements, we developed an agent-based simulation framework, where individual agents (the forwarders) calculate the exact value for a bid for a single TW based on a B&C-algorithm, and the submitted bids are reallocated by the platform operator using a WDP. We could show that distance savings, transport cost savings, and savings of CO^2 emissions can be realized through reallocation. Furthermore, it could be shown that all actors involved benefit by participating in the proposed mechanism. The platform operator makes a profit by providing the mechanism on an electronic marketplace. The forwarders can shorten the approaching route within a tour and thus reduce the delivery time, which might benefit the customers.

A limitation in the presented paper and the proposed model is that only four forwarders could be considered so far to reallocate TWs at one loading dock via the one-sided VCG mechanism. Thus, research is needed to reallocate unfavorable TWs across multiple loading docks. Furthermore, different mechanisms for exchanging individual TWs should be compared with each other, and additional forwarders should be included to consider a scenario that is as realistic as possible.

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