TOWARDS SUSTAINABLE URBAN LOGISTICS: THE EVOLUTION OF DIGITAL MARKETPLACE

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ABSTRACT

Many existing industrial solutions for transportation services assume tightly controlled optimization scenarios where the price does not take a centre role, yet these models heavily rely on long-term business relationships between shippers and carriers. A number of solutions have been proposed for auction-based marketplaces with market-clearing property models, where supply and demand dictate the price and through innovation and improve transparency and efficiency. The overall objectives of these efforts are aimed at finding a balance that assures maximizing capital efficiency, maximizing customer satisfaction and minimizing logistical complexity, hence maximizing scalability. Some Uber-like experiences have recently emerged, introducing fresh perspectives and putting back the spotlight on the potential of digital markets in transportation industry.

In this article, we take a look at how the ideas of digital marketplaces have evolved over time and specifically consider how the lessons learned can be applied in last-mile urban logistics. We also present a prototype marketplace for urban city logistics and draw initial conclusions.

Keywords: auctions in freight, digital marketplace, last-mile urban logistics, multi-attribute auctions

1 INTRODUCTION

Even in an industry like trucking which is quite resistant to innovation and modernization, the latest era of easily available and always connected GPS-enabled smartphones is reshaping existing ideas and transport practices. By leveraging truck drivers' smartphones easier, faster and more direct iteration is enabled between the drivers and nearby companies in need of shipping services. This market liberalization assumes skipping classical brokers and uses an online service acting as a digital broker: this solution gives autonomy also to small trucking firms and independent truckers, while enabling shorter response time, more efficient routes to pick up and delivery and a better payload.

The idea of transportation marketplaces is not new, but the rise of Internet sites and the tech industry 15 years ago had brought a number of start-ups, attempting to modernize the way shippers and carriers worked together. They failed mainly due to the lack of understanding of how the market worked, empowering the shipper and discouraging the carriers with the goal simply driving down the cost for the shipper.

The difference is that this time around the new solutions are built not aside but around basic concept of transportation being a relationship-based business. Indeed, trusted relationships are crucial as they also impact customer service and satisfaction which translates to shipper's brand and reputation. It is why the vast majority of freight is still being transported by contracted carriers and does not use the spot market. This is the reason why the newest solutions [1] don't exclude having 'preferred carriers' in order to solve the inefficiency and division of the local trucking industry in urban last-mile logistics. This time around the emphasis is on having a balanced added value proposition for both shippers and carriers. As opposed to previous solutions that mainly benefited the shipper by driving the price down, the focus is on connecting shippers and carriers directly and efficiently by avoiding external brokers, and giving the carriers tools to maximize asset utilization and efficiency leading to lower costs

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for shippers. Actually, new innovative solutions merge the e-commerce ideas with traditional freight brokerage model based on relationships, and also offer new interaction technologies through continuous vehicle connectivity and advanced analytics on carrier data allowing fully dynamic scheduling.

In this article, we first look at the overall urban city logistics, then at the evolution of digital marketplaces in the transportation industry and lastly focus on how urban logistics, still driven by traditional freight brokerage model, are facing with modern requirement for sustainability and reduction in pollution. In the following section, we present a use case of the city of Milan (Italy), which was analysed in the scope of Italian national project OPTILOG (OPTImal and sustainable LOGistics in urban areas). The project's objective is to promote and test innovative solutions for planning and management of last-mile logistics, enabling efficient and sustainable last-mile transportation service. We describe the developed platform for urban logistics in large cities, prototyping a digital broker for connecting shippers (i.e. extra-urban operators) whose vehicles don't have access to historical city centres to last-mile delivery units that satisfy city regulations for lower gas emission (i.e. bicycles, electric vehicles, etc.). We present a marketplace auction model that assigns loads to last-mile operators taking into account their characteristics and relying not only on the price of the shipment.

2 CITY LOGISTICS AND DIGITAL MARKETPLACES

Munuzuri et al. [2] identify a series of commonalities for European cities that influence their mobility and commercial activities as well as impose a series of restrictions related to the flow of freight deliveries. Freight transport has been perceived as nuisance and its issues are frequently ignored by governments (too slow and polluting vehicles). However, urban delivery needs are a necessity, and lately a number of cities have been promoting city logistic measures along with sustainability issues [3, 4]. While measures around environmental performance of vehicles are based on promoting usage of less polluting, governance measures are frequently implemented through limited traffic zone (LTZ) areas with time-window access for different types of transportation vehicles or night-time delivery options.

The introduction of multiple actors perspective is of interest to us as it allows characterization of urban freight system by multiple stakeholders with conflicting objectives. And when no centralized authority is present, as mentioned in Ref. [5], all stakeholders act autonomously, basically making urban freight transport into a distributed decision-making system where different carrier-agents negotiate through an auctioning mechanism for logistic contracts.

Over the last decade, a large emphasis on advances in transportation industry has been put on collaboration efforts of shipper–shipper [6], carrier–carrier [7, 8] and shipper–carrier [9] types. The main reason is the significant amount of empty trips leading to additional costs and higher rates for carriers, hence the constant struggle to maintain profitability. While, on the one hand, advances in Internet technologies have created new challenges and demand for meeting on-time delivery and pick-up expectations, they have also created new opportunities for increased coverage, and carrier–carrier collaboration across similar types of carriers. Peeta and Hernandez [9] have analysed a number of marketplaces for freight transportation service procurement, focusing on different operational modules used in existing marketplaces and on two types of contracts: short-term contracts (spot market) and long-term (binding) contracts. A major advantage of online marketplaces over traditional solutions is in lowering transactional costs as there is no need for extra personnel for timely transactional or contractual negotiations with each individual carrier. This leads to lowering freight bills and easier filling of carrier's excess capacity.

Electronic marketplaces can be broadly classified as clearing houses (bulletin boards), auction houses and freight exchange. In the clearing house scenario, both shippers and carriers post their requirements, and information stored in a database of loads posted by shippers and transportation capacity posted by carriers is used to initiate one-to-one negotiations. Transportation auctions assume auctioning of either long-term contracts in a large-scale combinatorial auction settings or auctioning of transportation capacity in a spot market. Finally, in an exchange, shippers and carriers exchange demands for transportation service for assurance to provide transportation capacity, where the matchmaking at competitive price is done by the online marketplace. Having said this, a number of doubts have reason over the years including the fact that 'public' marketplaces themselves do not assume responsibility for actual movement of freight (i.e. monitoring execution and performance of other businesses) but rather just focus on matching demand and offer. The marketplaces can be either public or private, where an important feature is to guarantee reliability of the marketplace by assuring all shippers and carriers have been certified based on their service records and business credentials.

In the last years, major logistic software providers, logistic provider companies, less-than-truckload (LTL) and truckload (TL) trucking services opened their own marketplaces, which due to the above-mentioned doubts (i.e. responsibility for execution of service, fear of cutting into already low margins for carriers, etc.) shut down or consolidated forming strategic alliances. A major factor in their demise was not considering that many shippers and carriers still put high value on traditional trust built through common experience and years of person-to-person negotiations. Hence, it is up to the marketplace to take the regulatory role or devise a business model based on customer feedback, to assure and provide reliable information regarding the agents that use the marketplaces in order to convince all participants and attain the necessary customer base to make the marketplace viable.

3 DIGITAL MARKETPLACES AND AUCTIONS IN FREIGHT

Online procurement auctions are frequently used to dynamically match demands and offers, enabling efficient ways to allocate resources like capacity. In classical freight transportation setting, online procurement auctions are mostly used by shippers who could not manage to place a shipment with preferred carriers due to time-window constraints, capacity issues and/or low-profitability reasons. Hence, in the initial stage, freight industry auctions became a useful mechanism for both shippers and carriers to reallocate problematic shipments to other carriers that might have resources to do it.

An auction is characterized by bidding rules, market clearing rules and information relevant policies. Well-known types of open auctions include English auction and Dutch auction [10], while closed-price auctions include first-price and second-price auctions. Alternatively, combinatorial auctions deal with multiple items put out for bidding where bidders can bid on combinations of these items. These, in the transportation industry [11], are used for procurement of long-term contracts for serving packages of lanes [8, 12–17]. In case of transportation industry and an online marketplace negotiation scenario the items put out to bid are lanes or loads with specified demands. The information flow between shippers and carriers during an auction assumes that each carrier can make a bid, and shipper chooses the best bid after which the carrier can decide to make a new bid. The auction itself can be an intermediate actor, agent, or web portal. Carriers need to decide on what loads to bid on and what price to charge for a load; in order to achieve this, they need to calculate the marginal utility for the load, and this is referred to as the bidders' problem. On the other hand, the shippers consider not only the price of the transportation service proposed by a carrier but also other attributes like service characteristics and good business relationships to select winners; this is referred to as the shipper's winner determination problem (WDP). In case of electronic marketplaces, the pricing approach even though frequently automated must stay competitive and needs to simulate off-line market conditions, it must be fair and take into consideration different service packages, seasonality, volatility of demand and supply, business rules and present restrictions. An auctioning mechanism that corresponds to this type of applications is the reverse-type auction as described in Ref. [18]; the sellers (i.e. carriers) compete to obtain business from the buyer (i.e. shipper) and prices will typically decrease as the sellers underbid each other. From the above literature review, we can note that combinatorial auctions for transportation services have been researched in detail and applied in a number of commercial software tools specifically in cases of auctioning long-term transportation contracts. However, in case of sport markets that correspond to city logistics, the economic mechanisms for offering discount spot transportation prices give rise to other types of auctions that are less complex.

3.1 Multi-attribute auctions in freight transport

van Duin et al. [5] modelled the modern state of freight logistic business strained under strong pressure to respond to specific demand for delivery of goods and services, including customized product deliveries, late modification of product specification, late orders and volume changes all requiring adaptation while still requesting strict delivery times. In order to deal with this uncertainty in demand the carriers are obliged to account for potentially extra capacity and time in trip planning. This leads to overbooking which increases costs, hence carriers attempt to minimize costs and optimize their trips. The model assumes that the part of the service is assured through planned delivery tours based on contracts with numerous carriers for a fixed-based volume of freight. And another part that corresponds to additional non-contracted shipments is handled through auctions with several interested carriers in a sport market scenario, where the carrier with best cost, capacity and service quality wins the bid. The auction used is a multi-attribute, that is multi-dimensional auctions where the buyers' requested orders are described through a number of attributes that can be any combination of monetary and non-monetary units. Ma et al. [19] and Wang et al. [16, 20] modelled the WDP for TL procurement in combinatorial auctions, where important business sides constrain and considerations are included in the model.

Similarly, multi-attribute vectors can be used for describing the bidding items that have non-price attributes as required service quality and time windows of delivery. Potential factors that influence a carrier's demand price can be profit, the number of loads he/she has already won, his/her expectation for gain in the geographic area and so on. Carriers can apply specific discounts that model their behaviour in desire to obtain a fully planned schedule as soon as possible. In this scenario, carriers who have not secured income for the time period in question might be more willing to lower prices even if this leaded to for some percentage lowering their potential profit. The willingness to lower profit might also increase as rounds of the auction progress. Typically, in case of carriers in order to form a bid price several factors must be taken into consideration including costs as the distance to be driven, travel time related to the cost of a driver, estimated costs related to the use of vehicle and so on. In order to form a bid price, the carriers can use various optimization approaches to estimate their cost as versions of vehicle routing problem (VRP).

In this article, we mention VRP in the scope of transportation auctions as it is one of the tools that can be used by carriers to define/generate the price for their bids. The details of these types of approaches are out of the scope of this article; however, for the sake of completeness we note that the OPTILOG project also implements a classical VRP-TW (a VRP with time windows) with constraints [20]. The original idea behind the usage of VRP approaches is to define the optimal route by minimizing the total cost for carriers, and might work well when the carrier can impose the optimization and monitoring on its vehicles (drivers). However frequently the last-mile carriers in city logistics are associations of independent carriers under contract and imposing a specific way, limitations in the delivery itinerary in terms of delivery times or delivery sequence might present a major obstacle. The carriers are under contract and their profit depends on the number of deliveries, kilometres passed, the delivered weight and so on. Hence, they might be willing to accept recommendations but concerns have been raised that they might react negatively to strict monitoring as it is seen as an instrument of control. Therefore, in our implementation we also offer a less strict solution with distance-based clustering that can be used within our action-based marketplace.

3.2 Marketplace for city last-mile logistics

In an urban city scenario with daily outsourcing of delivery orders (DOs) to carrier companies for transporting [20–23], a multi-actor auctioning system can be used for allocation of orders through bidding in a group of companies accredited with the auctioning system of the logistic company. In fact, it is not unusual that the company that accepts the transportation order doesn't own transportation capacity (i.e. the considered case of city of Milan), actually often large companies prefer to outsource the delivery to logistic companies that further negotiate the distribution of orders with smaller companies with transportation capacity. This generic setting of the OPTILOG project platform corresponds to the modern logistic tendencies where the focus is on city logistics, that is the second part of the market interaction once large TL carriers have brought the merchandise to the city and last-mile logistics step in. As an example, the model described in Ref. [16] is a two-tier solution with two layers of terminals (i.e. ULD (Unit Load Device)). One on city borderlines where national trucks arrive and merchandise is consolidated/deconsolidated onto smaller trucks and further delivered to second later terminal where it can be consolidated/deconsolidated onto sustainable vehicles (e.g. electric vehicles, cargo bikes, etc.) and delivered to destination (i.e. destination itself or parking bays where last metres of delivery are made on foot) in city centre that has specific regulations (e.g. ZTL (Limited Traffic Zone) zone, Area C). Schwind et al. [15] modelled the exchange of cargo capacity in a city through an online logistic marketplace, a combinatorial auction and inner-city terminals that all belong to the same company (i.e. intra-enterprise setting). Their overall scope is on reducing the total cost of transportation of the logistics company, owning all the terminals and carrier vehicles, through reduction of direct delivery costs. In an extension, Gujo [23] considers a multi-attribute inter-enterprise solution, hence a multi-actor perspective, where the main objective is not only reduction of delivery costs but also meeting customer preferences, thus maintaining customer loyalty and holding market position.

Similarly, in OPTILOG's city logistics setting we consider several UDCs that have individual set of customers already assigned to them based on the destination post codes. This corresponds to the realistic situation where national TL carriers are directed towards specific extra-urban hubs the night before and the information about the merchandise that arrives in the morning is well known to each hub. The merchandise is further directed to particular parts of the city based on postal codes of DOs. The introduction of UDC units enables last-mile delivery through usage of cargo bikes and sustainable vehicles that reduce pollution in congested city centres.

3.3 Current setting for our use case (city of Milan)

Overall in today's city logistics, including the city of Milan, a large portion of freight carrier services in the city is provided by LTL carriers having fixed long-term negotiated contracts with either shippers or logistic provider companies delivering merchandise with their TL fleet to large terminals outside of city lines (e.g. GLS express couriers for the case of Milan). Smaller vehicles of LTL type and specifically sustainable solutions as electric, compressed natural gas, liquefied petroleum gas, hybrid propulsion or cargo bikes are encouraged with a number of sustainable city logistic initiatives, including limited mobility for vehicles not satisfying low pollution standards in the city centres (i.e. LTZ, Area C in Milan). As new regulations and limitations for limiting pollution and traffic congestion are introduced across Europe and Italy the freight industry needs to adapt, hence, even in case of express couriers, a two-tier approach is considered where in addition to large terminals on city borderlines used for received consolidation/deconsolidation of merchandise from large TL carriers, a second level of smaller 'warehouses' (i.e. UDCs) is introduced for consolidation/deconsolidation of merchandise of medium size trucks and sustainable vehicles that are allowed access to LTZ. Additionally, loading/unloading bays close to final destinations are present to deal with parking issues.

In case of Milan and for the two-solicited major express couriers we have similar situation being implemented or in implementation. In case of the first express carrier, we have several out of city warehouses and a number of corresponding UDCs, where the last-mile fleet is around 100 vehicles of small dimensions for the transport of small to medium packages (less than 100 kg) with daily management of delivery in two rounds. In case of the second major express carrier we have again out of city warehouses and UDCs in the city serviced with low polluting vehicles as a dozen electrical vehicles, cargo bikes, several small boxed trucks and so on. Hence, for our development settings three different types of packages were considered for delivery (envelopes, boxes, and fridge-size packages) with several types of vehicles available for delivery within the urban city centre: cargo bikes, vans and small trucks. Different vehicles differ not only by dimension but also by the type of merchandise that can transport, specifically cargo bikes can only transport envelopes, small tracks only fridge-size packages, while vans can transport all three types of merchandise. The carriers have set up their systems this way to improve efficiency.

4 SYSTEM ARCHITECTURE

Before we proceed to describing our system architecture it is important to note that with this work our goal was to demonstrate the feasibility of applying an auctioning system in a day-to-day city logistic activities, and not to prove that any particular bidding strategy or scheduling method is better than others. Rather than that our objective is to model and improve current business practices in last-mile city logistics with automated strategies. As in any auction, the final price will be determined by the bidding in the open market. The overall ideas of this approach are not directly to optimize the planning but on automating the market interactions in a multi-actor logistics negotiation.

In Fig. 1, the overall process of delivery is simulated. Once a client makes a DO consisting of one or more packages to be delivered to a certain address, the order is received by the system and stored in its database. Once majority of DOs for the day are received and stored (i.e. there is a cut-off time usually; major express carriers, having a role of a shipper in our settings, iterate twice per day), a VRP algorithm is run or alternatively a distance-based clustering approach for the scenario of third-party carriers. This leads to a creation of a delivery schedule (DS) that is again stored in the database. For each available DS in the database, the 'reserve' price is calculated by the digital marketplace based on estimates of fair market value. In our setting, the 'reserve' price depends on the fair market value and hence it is not hidden. This step is meant to help out both the shipper and the end carriers participating in the auction. Once the DS is put on auction, several iterations are taken by the system to make a decision. By clearing the auction, the DS is allocated to the winning carrier.

Regarding the system architecture our platform is a client–server system, where the server component OPTI-server manages in obtaining DOs, creation of clusters of DOs to obtain DS and all auction-related activities. The client applications include (i) generator of DOs, a component that simulates clients who need to ship merchandise thereby creating DOs or allows loading on historical data, and (ii) OPTI-client carrier, a component that simulates the behaviour of bidders in an auction. In our case, the carriers are last-mile logistic companies that can participate in an auction, make bids and win it. The OPTI-server component has four modules that manage, receive DOs, cluster DOs into DSs, calculate 'reserve' price for every DS and run the auction. The communication between various client-server software components is through TCP/IP sockets. We present the various components trying to follow the order of execution in a real environment.

The generator of DOs has a task to generate DOs made out of one or more packages and to send them to the marketplace, that is OPTI-server so that they can be processed by the auction system, that is OPTI-engine. Overall our component is designed to be used in both simulation and pilot running settings. That is, the generator of DOs analyses historical data

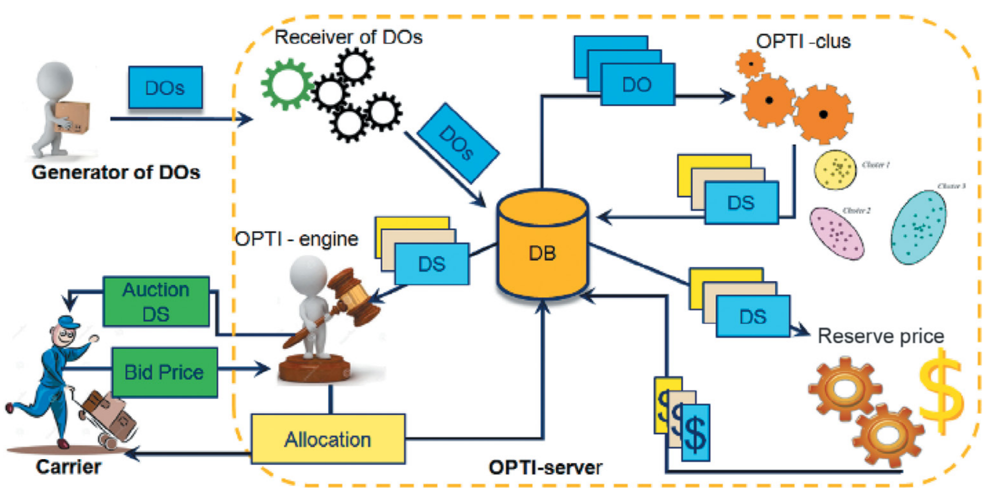

Figure 1: Work flow and system architecture.

to obtain distribution of relevant attributes as: the number of packages, the type of packages (i.e. envelope, box or fridge-size package), relative dimensions (i.e. length, width, depth and weight), coordinates of the order (i.e. latitude and longitude) and anticipated time and day for the delivery. The mentioned distributions are later on used to produce larger amounts of data for simulation purposes. On the other hand, the component can also load historical data from shippers (e.g. express carriers) and runs simulation using real data.

While the receiver of DOs has a task of saving in the database every DO with information about every accompanying package that was sent by generator of DOs through TCP/IP, it also maps geographical coordinates from DOs to a bi-dimensional spatial grid (i.e. for the city of Milan the cells have dimensions of 100 m × 100 m). This information is further used by OPTI-clus module for clustering DOs based on the following constraints: spatial, temporal and type of merchandise. With spatial constraints the goal is to merge several DOs that are 'close' in space. For instance, the system offers an interface with optional parameters to define the number of adjacent cells on horizontal and vertical axes, in this way generating the division of the city area into non-overlapping regions and with it merging of appropriate DOs. Regarding temporal constraints and how they influence the clustering stage of DOs, it has been assumed, based on current practices, that the delivery periods can be selected (i.e. start day and hour, end day and hour), for example: start period 1 November 2016 08:00:00 and end period 1 November 2016 18:00:00. Also these periods can be further divided into non-overlapping time windows for more specific customer delivery (e.g. 2 h, 4 h, etc.). And regarding the last constraint, in the OPTILOG project we consider three types of merchandise (i.e. envelopes, box and fridge-size packages) and three types of transportation vehicles (i.e. cargo bikes, vans and small trucks) which based on their characteristics are suitable for some of the types of merchandise. As mentioned, while vans can transport all types of merchandise, bicycles can transport only envelopes and small trucks only fridge-size packages. For this reason, our simulation results include an additional condition that the merchandise needs to be of the same type when clustering DOs into DSs. Hence given all the DOs of the day present in the database, our distance-based clustering is applied and bundles of DOs and DSs are put together based on some maximum distance of delivery locations and keeping in mind the delivery times and vehicle-type-package-type constraints. It is important to mention that the platform allows skipping of all these steps and loading DSs obtained through VRP-TW implemented in OPTILOG planner for the case when optimized routes can be imposed on the drivers of the carriers.

A separate module calculates the 'reserve' price for every generated DSs present in the OPTI-server database. This is a price representing the base (i.e. maximum, market value) price of a DS that a shipper is willing to pay. Here we use current practices and calculate this value for every DS based on various fix costs for each type of the package. For example, the prices used in our prototype version are envelope – 5€, box – 15€ and fridge-size package – 30€.

4.1 The auction managing module

The auctions are managed by a software module named OPTI-engine inside our marketplace server (i.e. OPTI-server). The main functions of the OPTI-engine range from publication of items in an auction, receiving and valuating bid offers to identification and assignment of DSs to carriers who win auctions. Several traditional methods for auctioning are included as closed-bid auction and Dutch auction, both with first and second prices. For first-price closed-bid auctions carriers place their bids simultaneously, where the bids correspond to monetary value for which they are willing to fulfil the DS that was put up for auctioning. In this case, the DS is assigned to the carrier that has proposed the most convenient offer (e.g. lowest offer). In second-price sealed-bid auctions as opposed to the previous case, the DS is assigned to the bidder that has offered the most convenient price but paying price is equal to the second-best bid. In the second approach, the Dutch auction or open descending-bid auctions, there is an auctioneer (i.e. administration or automated OPTI-engine) that performs the auction and iteratively receives offers as lower and lower bids from carriers, until no carrier is prepared to make a lower offer. Also for this auction type, first and second price methods are implemented. These are classical approaches where both auction types with different final price definition methods, in order to valuate different offers, take into consideration only the bid price without considering all the quality of the offered service.

In order to resolve this issue and take into consideration multi-attribute aspects of bids, we apply bid weighting, where carrier-relevant attributes are considered as price, punctuality, security, operating time and so on. The weight of each one of these attributes is either default for each carrier (i.e. parameters provided by express carriers) or defined based on historical information. The overall weighted combination of these factors is used further on for putting emphases on either shipper preferences or delivery cost minimization during auctioning through influencing the bid price (i.e. delivery cost for each bid). The final weighted factor is defined for each carrier within an auction, with values from 0 to 1, in order to appropriately weight the received bids from the carriers based on its characteristics and shippers' preferences.

4.2 The bidding agents module

An important software client component that is meant to help out the bidders (i.e. carriers) is OPTI-client carrier simulating the last-mile logistics company. Actually, each carrier in our system has a profile with his fleet of vehicles and specific characteristics for each one of them, as maximum volume and weight they can carry, their current position, current state of volume/weight saturation or the percentage of discount they can make based on current daily scheduling. A carrier with these characteristics can participate in an auction for assignment of DSs, which once won are further used for daily planning of his fleet's deliveries.

If during the planning stage the carrier receives notification of publication of an auction from the OPTI-engine the carrier needs to verify that inside of his fleet has one or more vehicles that can transport the load present in the DS that is being auctioned. A vehicle is capable of transporting a load if there is remaining space (i.e. volume) on the vehicle and weight of the overall charge doesn't exceed the limits of the vehicle. If yes, the carrier selects its vehicles and formulates bid prices for each one of the vehicles. This implies having specific discounts which model their behaviour in desire to obtain a fully planned vehicle schedule as soon as possible. In case he/she wins the DS put on auctioning, the carrier can incorporate it in his/her daily planning and modify the available discounts per vehicle.

In order to determine the bid value, the carrier needs to obtain the following information about candidate vehicles: the maximum percentage K_i of discount that he/she is willing to make for delivering with vehicle i based on already secured schedule; the remaining volume V_i and weight W_i that a particular vehicle i can carry; the average distance of the locations in the DS D_{ds} relative to the current position of the vehicle; volume of the load V_{ds} and weight of the load W_{ds} relative to the DS that is on auction.

The bid value BidValue_i for a particular vehicle i is calculated through the use of the 'reserve' price ReservePrice_{ds} for the DS on auction, as follows:

$$\text{BidValue}_i = \text{ReservePrice}_{\text{ds}} \times (1 - \text{Discount}_i) \tag{1}$$

$$\text{Discount}_i = \frac{K_i}{3} \times \left(\frac{V_{\text{ds}}}{V_i} + \frac{W_{\text{ds}}}{W_i} + \frac{1}{D_{\text{ds}}} \right) \leq K_i \tag{2}$$

From eqns (1) and (2) it can be noticed that the larger the volume and weight saturation are, the larger will be the applied discount.

5 SIMULATION SETTINGS AND RESULTS

The generic simulation was performed with 11,000 DOs covering the whole area of Milan for a duration of 10 days (~1,100 DOs per day). The cluster bundles were formed with OPTI-clus and on average cover areas of 600 m × 600 m with deliveries within 4 h temporal windows. This led to around 6,400 DSs that have been put on auction through the use of OPTI-engine. The number of carrier companies that registered with the marketplace has been set to 4, and each one of them has their own vehicle fleet (i.e. first carrier has six bicycles, second has four vans, third has two bicycles and two vans, and fourth has six small trucks). We focused on measures as the average occupancy varies for types of vehicles and the financial savings obtained by the auctioning mechanism. However, it is crucial to understand we are not only aiming to prove that auctioning mechanism works in city logistics but that the main stakeholders are incentivized to use it. The considered vehicle fleets are made out of three types of vehicles: bicycle (weight 35 kg, volume 0.05 m^3, envelopes); van (weight 770 kg, volume 4.2 m^3, envelopes, box, fridge-size packages); small trucks (weight 2,000 kg, volume 10 m^3, fridge-size packages). During the simulation, every carrier is fulfilling its own daily schedule for every vehicle; their overall aim is to obtain as many as possible DSs compatible with the characteristics of owned vehicles and have a fully booked daily schedule across the fleet with no empty hauls. As mentioned, the auction module was introduced not only to obtain more favourable prices and reductions for shippers but also to incentivized sustainability issues in urban logistics across carriers and allow them competitive advantage (Figs 2 and 3).

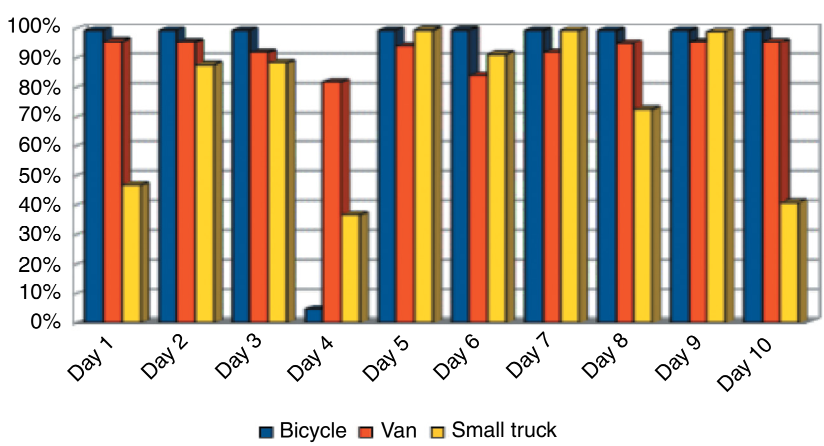

Figure 2: Average daily volume occupancy for different types of vehicles using the auction-based scenario.

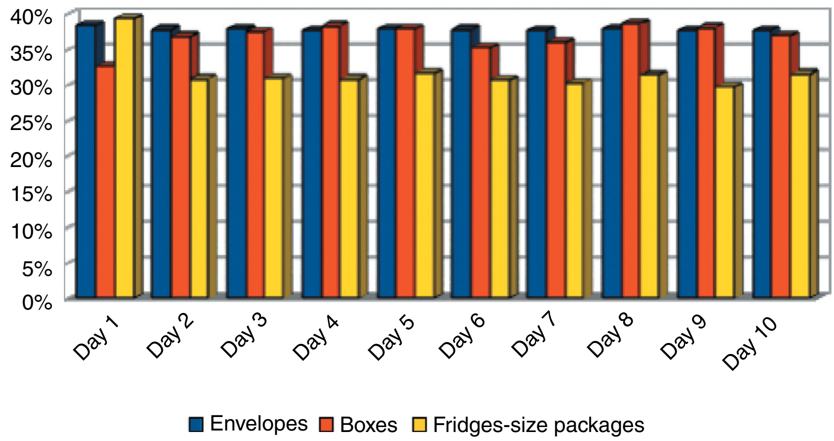

Figure 3: Daily savings for the shipper obtained using auction-based scenario (e.g. first-price Dutch auction).

After running different types of auction on our simulated data set we present main conclusions. We first calculate daily average occupation for every type of vehicle relative to their volume and weight. As expected, vans have almost always maximum occupancy of weight and at least 80% occupancy of volume as they can transport all three types of packages. While bicycles occupy almost all volume but almost never more than 5% of their maximum weight due to the type of the merchandise they can transport (i.e. only envelopes). Small trucks that can transport only fridge-size packages frequently occupy a lot of their volume and never less than 55% of their allowed weight. Clearly only vans can transport all types of merchandise they are able to optimize their loads. These results are as expected and the efficiency of running auction-wise scenario has been proved. Regarding the financial saving of shipper through auctioning DSs, we calculate average daily savings for different types of auction mechanisms and for every type of package, comparing the classical scheme of having fixed prices for each type of package.

We note that improvements can be seen by utilizing the Dutch auction type as opposed to the closed-price auction, as carriers have time to correct their strategy throughout iterations. What is interesting is that one can save up on all types of packages, for example for fridge-size packages on average we see savings of 27.87% while shipping envelopes give on average 37.6% savings compared to fixed cost scheme. Overall even though this is not the main objective of this work, using auction mechanisms will lead to possible reduction of the cost of transportation for shippers (i.e. express carriers) for all types of packages. As mentioned previously with this work our overall goal is not to drive down the fair market value and force carriers to underbid each other but to motivate carriers to be more competitive through introducing sustainable solutions for their vehicles and satisfying end customer conditions for DOs.

We aim at doing this by using a multi-attribute approach and tracing the delivery itself as well as feeding back to the system information and updates on punctuality, security, operating time, price – which on its own is influenced by gas emissions and fees needed to pay the LTZ and so on.

6 CONCLUSION

Modern digital marketplaces for urban logistics are still driven by traditional freight brokerage models while facing demanding requirements for on-time delivery and sustainability. In this article, we introduced a marketplace auction model that assigns loads to last-mile operators taking into account their characteristics and relying not only on the price of the shipment. Our contribution to a classical marketplace approach is twofold. First, we introduce a method for distance-based clustering to help out carriers valuate bids. This approach does not impose specific routes that carrier vehicles need to take but rather calculates the average distance and cost. Hence, its better suiting for last-mile carriers in city logistics represented mainly by association of independent carriers under contract where imposing a specific route or conditions on the delivery itinerary in terms of delivery sequence might present a major obstacle. Second, we present a multi-attribute approach to auctioning which besides classical advantages of competitive markets incentivize carriers to be more competitive not by directly reducing price but by using more sustainable vehicles and better customer satisfaction in the scope of city logistics.

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