Matching supply and demand in crowdshipping: A theoretical framework

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ABSTRACT

The emergence of internet and smartphones had played an important role in the increase of on-demand economy. Crowdshipping (CS) is an emerging trend that is expected to reduce the externalities caused by Urban Freight Transport (UFT). However, modelling the CS services, predicting their market share and their effect in the network is not a trivial task. CS matches the demand created by freight transport companies with the available capacity offered by passengers. Currently a gap exists in the literature on models that integrate the decisions related to the supply and the choices that identify the demand and matches them in the real-time. This paper presents a theoretical methodological framework that proposes an innovative collection of preference data in order to develop choice models that identify the need willingness of commuters to crowdship. In parallel it calculates the demand and proposes the development of a real-time matching simulator for the assignment of packets to crowdshippers and then to the network.

Key words: crowdshipping, urban freight transport, supply, demand, choice experiment, real-time, theoretical framework.

1. INTRODUCTION

The widespread use of internet and smartphones has turned online ordering and e-commerce to the prevailing method of purchasing goods. The boost in globalization coupled with the increase in online shopping put a strain of the Urban Freight Transport (UFT) system of modern cities. At the same time retailers are asked to make speedy, on-time, secure and sustainable deliveries to consumers. In parallel, local authorities and regulations demand the reduction of potential social and environmental impact of UFT, with regards to emissions, noise and safety. To address the aforementioned issue innovative freight delivery services are developed. Innovative freight delivery services provide "for-hire delivery services for monetary compensation using an online application or platform (such as a website or smartphone app) to connect couriers using their personal vehicles, bicycles, or scooters with freight (e.g. packages, food)" [1] and aim to improve last-mile logistics. Two distinct categories of innovative urban logistics services can be identified. The first one applies eco-friendly flexible light vehicles such as cargo bikes. Cargo bikes are specifically designed for transporting light loads, and thus are especially suitable for courier logistics with a high amount of small short distance shipments in metropolitan centers [2]. Due to their low operational costs, the low driver fatigue that they create and their higher environmental benefits they are currently applied for the movements of food, pharmaceutical and other products, as well as a last-mile solution for parcel delivery in very congested urban centers [3] .

The second innovative solution capitalises on supply that can be offered by travellers in the form of crowd-shipping. Crowd-shipping focuses only on the delivery of goods by citizens that travel from a point A to a point B and they can take with them and deliver a package. Users can access the services via a smartphone app, insert the information and pick-up and delivery requirements of their package and then an algorithm matches shipments with transporter. Every citizen with a smartphone and a private vehicle or in some cases, a bike is able to become a transporter. CS companies operate under a variety of business models [1]. Some companies use only motorized vehicles (cars, motorbikes) while others only bikes ([4], [5]). A variety of products can be transported ranging from food ([4], [5], [6]) and groceries ([6], [7]), to library books [8]. CS operates with various ranges from long haul where companies focus on packages that can be transported in a passenger's luggage [9] to city-range last mile deliveries. Finally, some platforms permit transporters to deviate from their predefined route to deliver a shipment [10]. The majority of companies offering CS services face various issues related to startup operations such as experimental business models, under-capitalization, high failure rates and many mergers [10]. However, larger players have already started entering the market with Amazon introducing AmazonFlex in 2016. AmazonFlex is a CSservice aiming to increase the cost efficiency of last-mile deliveries [11]. DHL has introduced a similar service in Norway [12].

As CS has started to emerge as a promising solution to decrease the externalities of UFT efforts have been made to include it in the transport models. One of the biggest challenge is to match the supply and the demand for this service since the first one is created by passenger transport while the latter is generated by freight transport. The prediction of supply and demand is done on a tactical level while the matching is conducted on the operational level. The aim of this paper is to present a conceptual framework that identifies the supply and the demand for CS services, matches them and simulates them on the operational level. To the far of our knowledge there is not yet a model that integrates supply and demand and matches them in real-time.

Therefore we propose a theoretical methodological framework that matches supply and demand. To identify the supply we will conduct an SP survey to identify the individual preferences regarding the participation to a CS delivery trip (which is essentially the supply side of the service) can determine the level of service and the total supply capacity. In addition we propose the development of a simulator that predicts the demand for parcel and express transport. Finally, supply and demand are matched real-time.

This framework is part of a modelling suite developed under the scope of an EU funded project HARMONY. HARMONY proposes an integrated approach through the development of the HARMONY Model Suite (MS) which integrates new and existing sub-models. This integrated approach is necessary to understand if, how and to what extent new policies, investments and mobility concepts can produce results that are in line with the objectives set by authorities. The HARMONY MS is envisioned as a **multi-scale, software-agnostic**, **integrated activity-based** model system, which enables end-users such as planners, decision makers, researchers and transport operators/providers to couple/link independent models and analyze a portfolio of regional and urban interventions for both passenger and freight mobility. The HARMONY MS simulates decisions both in the **Strategic Level** (Long-term), the **Tactical Level** (Mid-Term) and the **Operational Level** (Short-term).

The remaining of the paper is structured as follows. Section 2 presents the literature review. Section 3 describes the estimation of the demand for the service while Section 4 presents the estimation of the supply. In Section 5 the conceptual framework of a platform that matches the supply with the demand is being presented. Finally, Section 6 concludes the report.

2. LITTERTURE REVIEW

CS is proposed as a promising solution that entails the integration of passenger and freight mobility, aims at delivering goods using the crowd and reduces the externalities of UFT ([12].

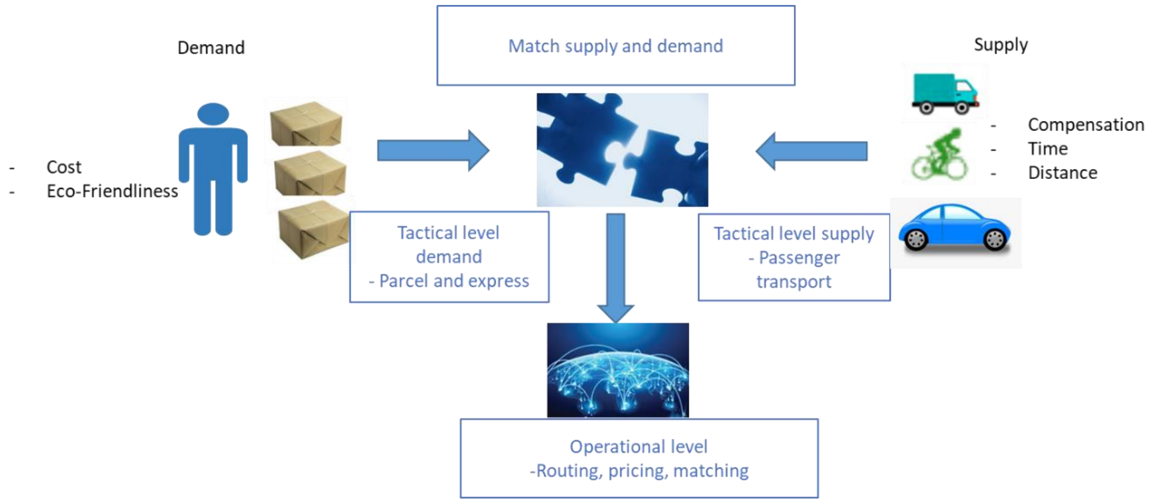

Figure 2-1 Match Supply and Demand in Crowdshipping

Demand is created by consumers or companies in the case of B2C shipments who need their parcel to be shipped to a final destination. Demand for CS is created on the tactical level and is part of the demand for parcel and express services. CS is regarded by senders as the eco-friendly solution and their choice is influenced by cost criteria. On the other hand, the supply is generated by passenger transport ([13]) . Commuters opt to become crowdshippers based on the compensation they are offered and the additional distance and time required to pick-up and deliver the shipment ([12], [14], [15]. The supply and the demand are then matched and loaded to the transport network (Figure 2-1) . At this stage the most important issues have to do with routing and matching strategies. These two issues are interdependent and higly affected by the pricing requirements [16]. Numerous studies have dealth with the demand supply and matching issues, a selection of which is presented below.

Studies in the literature have used SP for identifying the most important factors associated with the choice of acting as a crowd-shipper (supply side) ([17], [15] [18]) the willingness to use the crowd-shipping service (demand side) ([19], [12], [20]) , or both ([14],). On the demand side, findings in ([19]) revealed that users are not predominantly motivated by saving money but tend to be driven by environmental concerns. Their findings also suggested that past experiences with innovative logistic services allow users to overcome privacy and trust issues. According to findings in [12], a possible way of stimulating people to use CS is by giving them the option to plan the delivery date and its time schedule, as users in their dataset were more prone to use crowd-shipping services when given these options.

On the supply side, studies in the literature reported sociodemographic factors to have a significant influence in the choice of acting as a crowd-shipper. Some of the most influential factors identified were age, gender, ethnicity, income, education, and number of people in the household ([16] [17], [21], [22]). Remuneration and maximum deviation time have been identified as the most important factors for both acting as a crowd-shipper and accepting a trip. In fact, ([21]) discovered that users were willing to travel longer distances, when offered higher compensations. [19]Recent studies in the literature have identified several sociodemographic and economic factors that motivate drivers for working as crowd-shippers [16]. (Le and Ukkusuri, 2019) analysed the Willingness To Work (WTW) as a crowd-shipper by building a logit model that took into consideration variables such as age, employment, salary, people in the household and ethnicity. Their finding suggested that users earning below the average national income are more likely to act as crowd-shippers. This was also the case for users who were more than 30 years old. Other variables that were found significant on this study were: gender, social media usage and mortgage. These results were concurrent with other studies in the literature ([13] [17]). With regards of the selectivity of those WTW as crowd-shippers, several studies have analysed what are the factors for accepting to deliver a package on their daily commute. (Punel, Ermagun and Stathopoulos, 2018 ([20])) developed a two-part supply model defined by both the probability of bidding for a delivery and the bid count on a CS company in the US. Their results showed that an increased in the delivery distance, decreased the chances of receiving a bid. This is not surprising as users are less likely to divert for longer times during their daily commute. An interesting finding by ([21]) suggested that respondents were willing to travel longer distances if offered a higher compensation scheme. Indeed, compensation remains one of the main drivers for acting as CS. Both studies ([21] [20]) found ethnicity, annual income and age as other statistically significant factors that increase the likelihood of travelling longer to deliver a package.

In the litterature many algoritms exist that match crowdshippers with packages. These models include different business strategies ([23]) and are sensitive to customer related factors such as penalties for late deliveries ([24]). Li et al. matched parcels with taxis and calculated the benefits for the taxi drivers ([25]) Researchers have successfully solved the matching problem by connecing ride offers with ride requests in real –time ([26], [27]).

Overall the algorithms that can be found in the litterature focus on offering empty seats to ridders in real time. For the moment none of the existing algorithms include WTP and WTW as a crowdshipper [16]. Overall a comprehensive model that integrates all the decisions that influence the supply and the demand is missing from the litterature.

3. SIMULATING THE DEMAND: TACTICAL PARCEL SIMULATOR

The parcel demand generator creates the demand for parcel and express services. Based on available statistics the average number of parcels generated by each household is developed The assumption is made that each household generates an average number of parcels daily. Therefore to calculate the total parcel demand the number of households per zone is applied as input. Additional required inputs are the network of the study area and the location of distribution centers.

The simulator first creates the number of parcels in each zone based on the number of households. It makes the assumption that parcel and express businesses distribute their parcel to distribution centres based on their proximity. Finally the parcel generator creates a set of parcels with their id, their origin and destination (Figure 3-5).

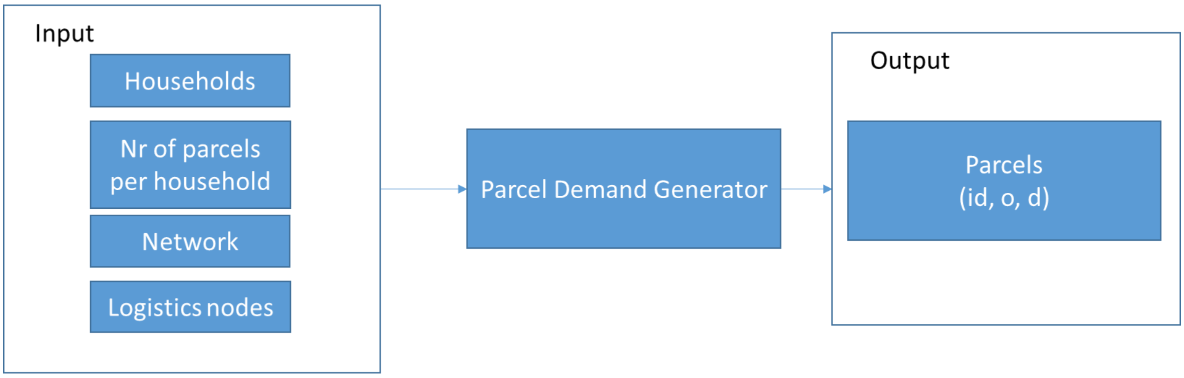

Figure 3-1 The parcel demand simulator .

The parcel demand simulator makes the assumption that parcels are delivered from business to consumer (B2C). A first version of the simulator is developed that assigns randomly parcels to CS services based on capacity availability and distance. It does not take into account does not take into account the factors that influence the WTP for services and the synthesis of parcels is based on aggregate demand statistics. Next increments will first of all segment demand into the B2C and B2B Markets. Additional data will be collected to help estimate the WTP for CS.

4. SIMULATING THE SUPPLY: FREIGHT SERVICE ORCHESTRATOR

In a traditional delivery process, logistic operators manage and optimize the supply to meet daily demands. Drivers are expected to be available when needed and their availability is given when scheduling delivery routes. On the other hand, in the CS context drivers are not expected to be available in all scenarios, hence their availability and willingness to deliver a package are important aspects to take into consideration [16]. As presented in the literature review the factors that influence the WTW of crowdshippers are low income, gender, mortage etc. Deviations from the planned route and the amount of compensation play an important role in the decision to work as a crowdshipper. In addition the majority of the studies addressing the supply of CS services apply behavioural models. Following this rationale, the CS trip generator employs behavioural models that take into consideration sociodemographic characteristics of the agent and identify those that are willing to work as crowdshippers. To collect the necessary data a Stated Preference (SP) experiment is designed where respondents choose if they are willing or not to work as crowd-shippers. SP data are then applied for the development of a choice model that is expected to calculate the binary model will be develop based on the sociodemographic characteristics of the respondents, with WTW as a CS as the dependent variable. Each agent (passenger) in the simulation environment will carry sociodemographic characteristics that will serve as inputs for the binary model, and thus those willing to be CS (supply) will be identified.

3.1 Identifying the supply

To explore and quantify the availability of supply for CS services (i.e. the willingness of a person to participate in a CS delivery and their elasticity) we employ an innovative SP experiment. SPs are commonly used in the transportation literature in order to explore behavior regarding mode choice, vehicle purchase, behavioral shift, product and service purchase, participation in transport initiatives/schemes or other transport-related choices. The case presented in this paper is a peculiar case of transport behavior, as the individual preferences regarding the participation to a CS delivery trip (which is essentially the supply side of the service) can determine the level of service and the total supply capacity.

Due to the lack of available data regarding traveller's preferences to participate to a CS initiative or conduct a CS trip, in-depth exploration of such preferences would require us to employ a stated-preference experiment, as part of an integrated survey to register user preferences and willingness-to-participate to CS.

The SP experiment exploring CS is a part of a larger survey designed and implemented in the context of HARMONY project (as described in the introduction). Data collection includes activity diaries and trip chains, other SP experiments (regarding mode choice and future vehicle purchase), as well as, experiments focusing on dynamic adaptation of travel behavior given new information or disruptions in daily travel. The CSSP experiment essentially explores the willingness of a survey respondent to participate in such an initiative given specific circumstances and varying levels of attributes such as reimbursement, deviation from original route, content and weight of delivery package and other relevant attributes.

The survey respondent will be asked a set of introductory questions before the experiment. These questions will register the general tendencies and attitudes of the respondent towards the CS service, their willingness-to-participate to such an initiative independently of specific routes or reimbursement and experience with such as service. Then, the survey will proceed with the actual SP experiments. The respondent chooses between participating in a CS delivery for a specific OD and trip purpose given a set of varying attributes. Table X 3.1 presents an initial set of attributes and levels that are considered important for a CSSP.

Table 4-1. Attributes in stated preference experiments

Attribute	Levels
Content of Package	• Regular (non-specified) parcel • Paperwork or mail • Food • High value parcel • Pharmaceutical or other

Weight of package	• <1 kg • 1-5 kg • 5-10 kg • 10-20 kg • More than 20 kg
Deviation from original OD (in time)	• Less than 5 minutes • 5-15 minutes • 15-30 minutes • 30-60 minutes • More than an hour
Reimbursement	• 1 € • 2 € • 3 € • 4 € • 5 €
Insurance in case of loss	• Covered by the CScompany • Covered by sender • Split

Figure 3-1 presents a draft screen of the actual experiment. The trip purpose and travel time are variables (shown boxes), varying intra and inter-respondent. The number of different options may also be more than 2, remains to be decided at a later point.

Please imagine that you are ready to begin your daily trip to Work which usually takes 25 minutes.
Would you consider participating in a crowdshipping delivery under the following circumstances?

Attributes	Option A	Option B	Option C
Content of Package	Paperwork or mail	High value parcel	I would not consider delivering a package, given options A and B
Weight of package	2 kg	<1 kg	
Deviation from original OD (in time)	5 minutes	15-30 minutes	
Reimbursement	1€	5€	
Insurance in case of loss	Covered by company	Covered by sender	
Choice	○	○	○

Figure 4-1 SP experiment for CS supply

3.2 Supply generator

This section presents a conceptual integrated urban logistics modelling and simulation framework that emulates the decision making of logistic operators and the behaviour of passengers willing to serve as crowd-shippers. The proposed framework will allow the evaluation of different scenarios where freight supply configurations vary based on city logistics paradigms. The framework will interact with a realistic traffic simulation environment based on the representation of the transport network (lanes, speed limits, traffic signals), agents (passengers, freight) and their daily activities and travel behavior on the operational level. This framework proposes the dynamic simulation of the transport network by using real time data calibrated for obtaining a realistic setting of its actual state. Dynamic simulation allows to receive dynamic travel times, vehicle trajectories of passengers and freight, as well as real-time information on congestions and incidents in the network. This information, along with detailed on the available fleet and the results of the aforementioned models are used for the development of the CS trip generator. :

- **CS trip generator**: A sub-component that has as inputs the freight demand (from depot to customer/micro consolidation centres), the activity schedules of passengers, CS behavioural models, and aims to identify the CS supply.
- **CS route optimiser:** A sub-component that has as input the travel times of each link and generate routes to implement crowdshipping.
- **Single-actor micro-freight (parcel, food deliveries, etc) optimiser**: A sub-component that will aim to optimise the operations of a single operator (i.e. E-cargo bikes, delivery bots, electric vans).
- **Multi-actor micro-freight optimizer:** A sub-component that will aim to optimise the delivery of micro-freight by integrating the operations of multiple service providers.
- **Freight services orchestrator:** A component that will orchestrate all the above services based on the total freight demand.

The framework envisages modelling the adoption of micro-freight and CS services for last mile delivery. This is based in the introduction of dedicated urban distribution centres as pick up points. In the case of micro-freight distribution, delivery tours are derived by solving a travelling salesman problem (TSP) and fed into the simulation environment. For crowdshipping, behavioural models will be used for identifying those agents willing to work (WTW) as crowd-shippers and an optimisation algorithm will match the supply with the demand.

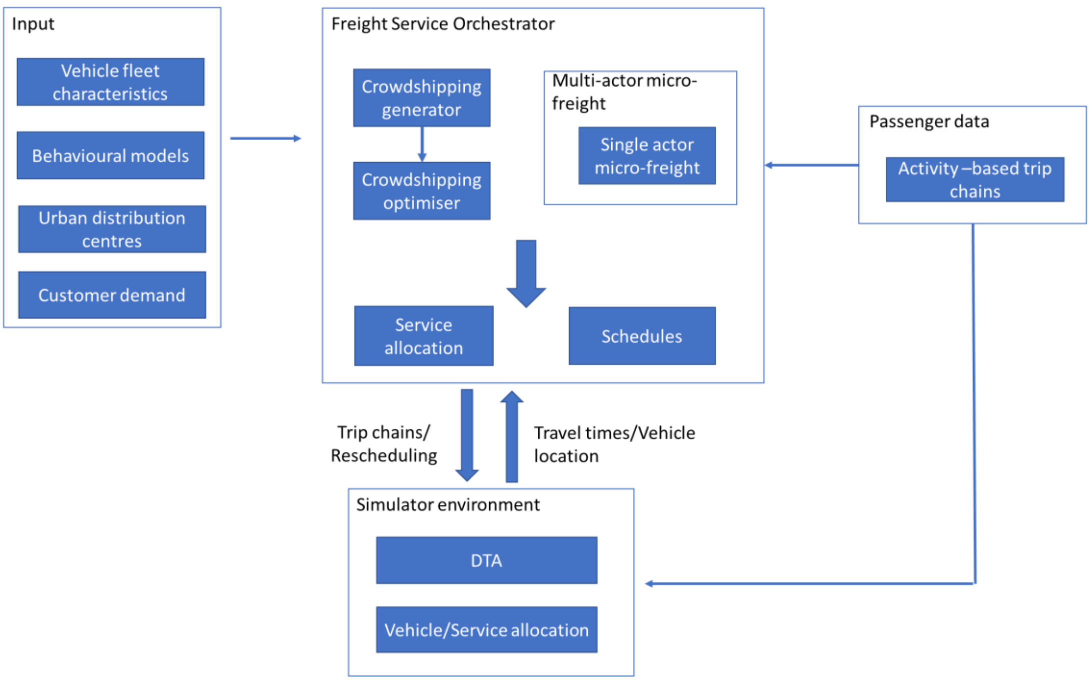

Figure 4-2. Integrated urban logistics modelling and simulation for supply

5. ROUTE OPTIMISER: MATCHING SUPPLY AND DEMAND

The CS route optimiser aims to link the crowdshippers (supply) with the crowd shipping customers (demand). It takes into consideration some of the factors that motivate the passengers to deliver a package in their daily commute: remuneration, package size and travel time tolerance (TTT). In order to match the supply to the demand, an optimisation algorithm will be used to match the CS agents to CS customers with the lowest deviation time from their activity chains. The simulation environment will use Dynamic Traffic Assignment (DTA) to find the fastest route (travel times) between origin and destinations in the simulated network. The algorithm will initialize by querying the simulation network for travel times for the supply (CS agents) and demand (CS customers). With this information, the algorithm will link the CS agents with those trips that minimize their deviation time. Based on results from the SP experiments, a binary logit model will be developed for emulating agents accepting CS trips. This model will be based in variables related to package size, time of day, remuneration and TTT.

After the trips have been accepted, the CS route optimizer creates the tours of the CS trips. Because the simulation environment will use DTA for the route selection, it is not necessary to send the actual routes but the coordinates of each leg of the trip. Crowdshippers new routes are modified in the simulation network for only those agents that accepted the CS trip. The accepted trips chains will be fed to the traffic simulator, where network conditions (e.g. congestion, incidents) and driver behavioural models, (e.g. route choice, driving model) will be used to create a realistic scenario. This will help assess the impact of congestion and possible increases in travel time on the total cost of a CS trip. The relationship between the supply, demand and the different factors consider for matching potential CS with CS customers can be found in Figure 5-1.

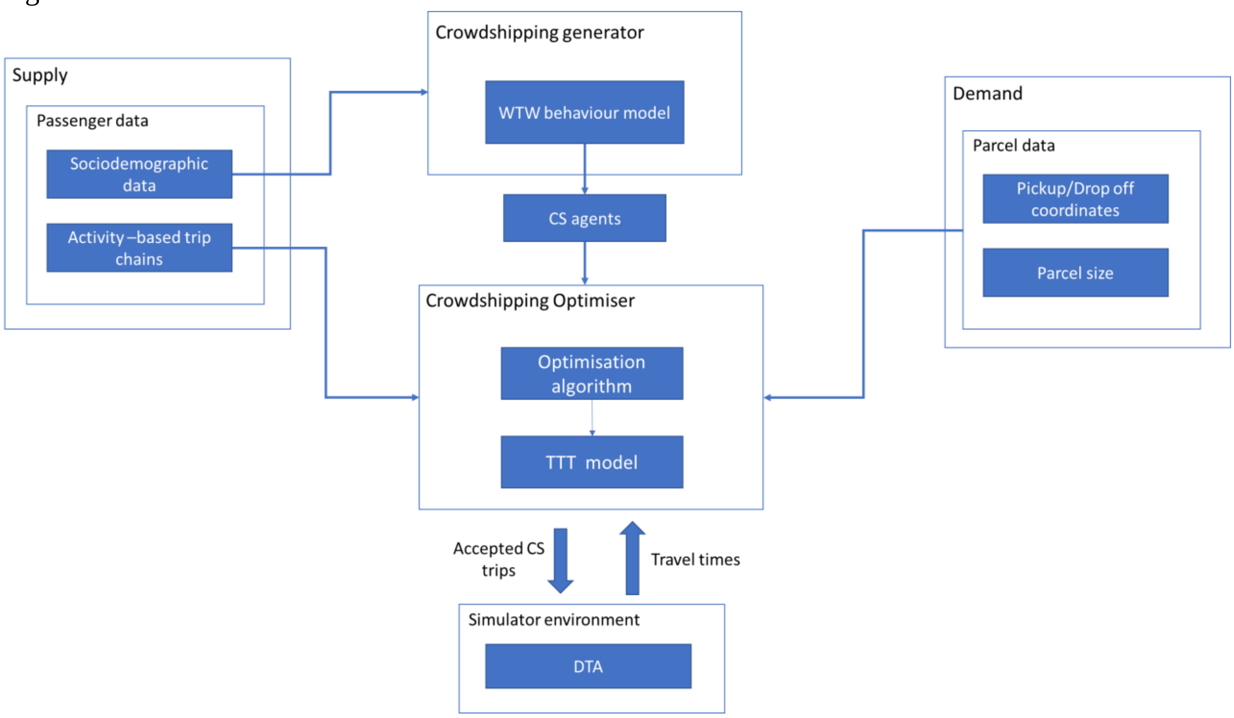

Figure 5-1. CStrip generation process

6. CONSLUSIONS

CS is an emerging trend that is expected to reduce the externalities caused by UTF. Currently manifold of startups around the globe have entered the market. However, modelling the CS services, predicting their market share and their effect in the network is not a trivial task. CS matches the demand created by freight transport companies with the available capacity offered by passengers. To achieve an efficient modelling of CS decisions such as WTP from the demand side and WTW from the supply side need to be included. Real-time matching of the senders and receivers is also necessary. Currently a gap exists in the literature on the models that manage to integrate all three aspects, accurate prediction of the supply and demand and real-time matching. To fill this gap we propose a theoretical methodological framework that incorporates the WTW, creates a fleet of available crowdshippers and then real time matches it with the parcel demand.

Given the peculiar nature of crowdshipping, where travelers (who are usually regarded as travel demand in econometric models and simulation) are actually the supply fleet, exploring public preferences to participate to a CS initiative or conduct a single CS trip is an important element of an integrated study and simulation of crowdshipping. One of the innovations of the presented approach has to do with the design of an SP experiment to explore user preferences, willingness-to-participate and time/cost elasticities of CS service participation. Additional exploration of type of parcel, safety and security, deviation from original trip will provide useful information to a researcher or modeler attempting to simulate CS as a distinct transport service in a model and quantify its effects on the transport system.

On the other hand, the demand is still represented in a more simplified way since it does not include the WTP for crowdshipping services. Aggregated household data are applied to calculate the parcel demand. Currently a part of the demand is randomly assigned to crowdshippers since only the OD pair is known for each parcel. Future versions of the simulator will take include additional choice models which will help identify the actual demand for CS services.

The matching in the operational level is done with in tailored way. Based on the WTW and the TTT parcels are assigned to crowdshippers. This matching assignment is the most integral part of the framework and it applies strategies that will balance business objectives (TTT) and social impacts (environmental, congestion in the network).

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