Modelling Urban Logistics Business Ecosystems
An Agent-based Model Proposal

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Abstract: Urban Logistics (UL) faces several issues arising from e-commerce and population growth, and it is undergoing a series of technological and systemic innovations. However, most of these innovations fails to scale up, and high is the need to grasp the overall operational and economic aspects that drive UL stakeholders to accept such innovations. To this end, proper modelling and assessment methodologies need to take into account these aspects and the heterogeneity of objectives and decision-making of stakeholders. This paper aims at filling this gap by proposing an agent-based model based on an existing theoretical framework depicting UL systems from a business model perspective. A computational experiment is presented to retrieve more insights into the topic.

1 INTRODUCTION

Urban Logistics (UL) is facing several issues that arise from e-commerce and population growth. In particular, logistics service providers (LSP) are faced with the challenge to increase the speed of delivery (Savelsbergh and Van Woensel, 2016), which has become a major value proposition (VP) for e-commerce customers *et al.*, 2016). At the same time however, UL is dealing with technological innovation that might enhance the optimization capabilities by LSPs (Mena and Bourlakis, 2016).

From a systemic perspective, the traditional hub-and-spoke delivery network is being reshaped and improved by existing and new players. For instance, automated parcel locker stations consolidate parcels at the delivery point, reducing the uncertainty of the home delivery process (Morganti, Dablanc and Fortin, 2014). Despite their relatively large diffusion, UL initiatives often fail to take up after a first pilot implementation, or lag at a low scale for years after their introduction (Zenezini and De Marco, 2016). Reasons for failure ranges from a lack of profitability, too many stakeholders involved or too complex schemes to be introduced (Rooijen, Guikink and Quak, 2017). If initiatives are implemented without a proper assessment of their commercial attractiveness then private operators may not be willing to invest their resources (Cagliano *et al.*, 2016).

This paper aims to contribute to the research area of UL project evaluation by providing an agent-based model (ABM) oriented at the business model of UL stakeholders, taking into consideration both business and operational aspects. The ABM proposed here is a follow-up work to the theoretical framework by Zenezini *et al.* (2017), which depicts UL systems as business ecosystems where companies can play different roles. In this paper, we present the development of the model and a computational experiment on a parcel locker installation case study.

The paper is structured as follows. After a literature review section, the model development phases are outlined inn section 3. Then, the computational experiment is presented. Simulation results from this experiment are shown in section 5, and discussions and conclusions are drawn in section 6.

2 LITERATURE REVIEW

Scholars of Urban Logistics have only recently turned to ABM to model and simulate various aspects of the topic. The main goal of the majority of ABM papers in UL literature is to depict the interaction among agents through flows of money and goods, and then to evaluate the introduction of policy measures in terms of economic and environmental impacts. In one of the first

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conceptualizations of ABM in UL contexts, Taniguchi and Tamagawa (2005) simulate traffic flows, and include for the first time stakeholders' behaviours and objectives in the evaluation. In a similar effort, a combined approach agent-based with vehicle routing problem is proposed by Teo, Taniguchi and Qureshi (2014). Adaptive agents learning from previous experiences are modelled in Tamagawa, Taniguchi and Yamada (2010) using a Q-learning algorithm to compute the value function of an agent, namely the profit, including the expected values of the agent's future states and behaviours, and a learning rate through which agents adapt their behaviour. However, the calibration of parameters in this previous work is not proposed. The decisions of agents in the previous models are mostly driven by costs and only basic transportation services are exchanged among them. van Heeswijk, Mes and Schutten (2016) integrate operational decisions with strategic ones, such as cooperation and collaboration among agents.

Only Roorda *et al.* (2010) introduce the concept of business model within their conceptual framework for modelling urban supply chains, to identify business and operational decisions behind the exchange of logistics services among entities.

In summary, extant literature focuses on evaluation of the impact of policy measures on UL systems, and fails short of addressing the business model of UL agents as a comprehensive tool to identify business and operational factors and assess the exchange of services and the success of UL initiatives. The objective of this work is to contribute to existing literature by providing a business model view of the UL system, similarly to Roorda *et al.* (2010). Hence, UL agents are characterized by their business model, in terms of a specific set of resources, a limited set of decisions, and the exchange of logistics services with other agents. To this end, new agents that are nowadays striving in UL systems and were not recognized previously need to be introduced.

3 MODEL DEVELOPMENT

The model development of this UL system agent-based model is based on the methodological steps identified by van Dam, Nikolic and Lukszo (2013) namely: i) problem statement, ii) concept formalization, iii) model formalization and iv) model verification. This paper attempts at operationalizing the theoretical framework presented in Zenezini *et al.* (2017) focusing on a specific case study in UL systems. In particular, in problem statement we outline the case study at issue by identifying agent types and the agents' environment. Then, concept formalization focuses on providing a conceptualization of two major elements that compose a UL system under the lens of the business model: the value proposition exchanged between a provider and a set of potential users, and the metrics used to evaluate that value proposition exchange. Model formalization represents the model narrative, meaning the activities performed by the agents, the major events and the rules that triggers them. Finally, this section explores the issue of model verification.

3.1 Problem Statement

The model aims to simulate two different service configurations related to the introduction of automated parcel locker stations in office buildings. For the first configuration, the locker operator only installs parcel lockers, and builds the managing ICT infrastructure. For the second one the locker operator consolidates goods at the warehouse on top of installing and managing the parcel lockers and organizes the last-mile delivery. Hence, it is assumed that in the second scenario the PLO would require more resources and consequently offer a higher price to the customer.

3.1.1 Problem Owner

UL promoters are faced with the issue of involving other stakeholders without a complete knowledge of the potential outcomes of such projects. Therefore, the major problem owner of the proposed ABM is the stakeholder, or group of stakeholders, that comes up with an idea of an innovative UL solution and intend to design it, plan it and implement it. New business ventures in UL are shaping their business model or striving to scale up. These private ventures need to generate value for old and new customers of logistics services.

3.1.2 Agents

Agents in this model belong to two types: provider and user of logistics services. Entities that decide to become providers aim at delivering a value proposition including tangible and intangible benefits that are valued by their potential customers (Zenezini *et al.*, 2017). Such value proposition is assembled as a bundle of logistics services with attributes such as price and service quality. In this view of UL systems agents, perform activities, use resources and take business and operational decisions.

Parcel Locker Operators: besides installing parcel lockers, Parcel locker operators (PLOs) take on some activities related to last-mile delivery process such as cross-docking and fleet allocation. Moreover, they have an interface with both the final customers and the express couriers. The activity and resources of PLOs are shown in Table 1.

Table 1: Activities and resources of PLOs.

Activities	Resources
Parcel lockers	Urban Distribution Centres
installation	Logistics personnel
Cross-docking	Marketing personnel
Parcel delivery	ICT Equipment
ICT support	Light commercial vehicles

PLOs have a set of strategic and operative decisions to take (Table 2).

Table 2: Business and operative decisions of City Logistics providers.

Strategic Decisions	Operative decisions
Value Proposition setting	Fleet allocation
Level of service provided	Vehicle routing
Pricing scheme	Demand allocation
Budget allocation	
Resource acquisition	

Facility Managers: Facility managers are employees in charge of managing large complex buildings such as office buildings, malls or large condominiums. They need to cope with the increasing number of parcels being delivered at the desk reception. Therefore, some UL innovations target these managers by offering them solution for reducing the efforts spent doing this non-core activity. Activities and resources of facility managers are outlined in table 3.

Table 3: Activities and resources of Facility Managers according to the role played.

Activities	Resources
Inbound operations	Storage
Payment for delivery	capacity
Evaluation of level of service	Inbound
Evaluation of intangible benefits	Personnel

Facility managers have to take certain decisions, mainly related to the adoption of the service offer, the evaluation of the level of service and intangible benefits obtained with the service. It is assumed here that after adopting the service, there will be no decisions taken on the operative level by facility managers.

3.1.3 Environment

In the business-model oriented UL system, agents change the way they evaluate a Value Proposition based on the dynamics of the environment surrounding them, meaning that the perception of a UL innovation changes when more and more agents start adopting it. Moreover, relationships between agents are the result of interaction, and each agent can encounter a set of other agents and deliver the Value Proposition. In this context, the environment decides which agents are actually part of the subset of potential users. The availability of resources from the UL business ecosystem environment determines the capability of a company to perform. In particular, new UL companies gain access to external funding from investors, which are not modelled explicitly. The modeller decides whether a new business entity can have access to a specific amount of monetary resources. The role of the environment is also to include parameters defined by the modeller to establish the cost of the interaction among the agents and the success of such interactions. In fact, the UL system implies the generation, promotion and execution of logistics services. Thus, each provider-user encounter as well as each logistics contract signed has a cost. This cost is borne by the provider.

3.2 Concept Formalization

3.2.1 Logistics Value Proposition

To quantify a value proposition, Töytäri and Rajala (2015) propose to link the elements of such VP to key performance indicators that the customer is seeking after. The VP evaluation is then regarded likewise a qualification step for the supplier selection problem, where the supplier performance/attributes have to rank above a minimum threshold. Moreover, innovative companies have to overcome the afore-mentioned risk of committing to them by providing a “premium” in terms of the desired service attributes. If the components of value proposition yield higher value than the target requirements then the user decides how much demand to allocate.

The value proposition offered by PLOs is composed of four components, or decision-making criteria. The first criterion is the logistics cost for receiving parcels. A second criterion is related to intangible benefits, such as cost reduction, availability and convenience, better, flexible and customized service or plain innovativeness and status from product superiority or design. The third criterion is the environmental sustainability of the delivery process. A fourth criterion is added to take into account the risk related to adopt an innovative solution ever tested before, which is related to the credibility of the company the scope of the service.

The overall value proposition is an aggregated function dependent on the four attributes of value highlighted (Eq. 1).

$$VP_i = f(Price_i, Intangible_i, Sustainability_i, Risk_i) \quad (1)$$

3.2.2 Metrics

Metrics are assigned to the targets set by entities, which refer to their objectives. Primarily, entities need to achieve economic benefits from their relationships with other entities. Providers for instance need to make profit by selling their logistics services to users. Then they aim at maximizing other objectives, which are better represented by the intangible benefits created and exchanged during the execution of the roles. Metrics are relevant because performance measurement can steer the decisions of UL companies.

Table 4 highlights the evaluation metrics of the model.

Table 4: Evaluation metrics.

Agent type	Metrics
Provider	Profit
	Number of customers
Receiver	(Un)loading time (Un)loading cost

3.3 Model Formalization

The model narrative focuses on the value proposition exchange between provider and user.

As anticipated, entities first make strategic decisions. Providers for instance need to design their value proposition in terms of price and service quality. Then, the first allocation of the budget in Research and Development (R&D) and marketing should take place. In the case presented, the provider sets a specific number of customers (i.e. market penetration) as a target, and thus calculates the size and number of parcel lockers stations according to this target. This decision nonetheless ensues from both the target for market penetration and the budget allocated to R&D in terms of capacity building. Consequently, the size of the lockers station will also determine an estimation of the total costs.

Entities that are potential users of this service will receive the service offer. The spread of the service proposal to potential customers is a function of the marketing action set up by the service provider. From a modelling standpoint, this configures as a message sent by the service provider to a potential customer. This message bears a cost, that is a reflection of how difficult it is to get in touch with a company. Providers can make a contact with the employer only once, and it is assumed that employers are reached by only one provider and later on cannot be reached by a second provider.

Potential users then evaluate the VP according to the value of the four VP components. We adopt a multi-criteria assessment for the VP evaluation, which include monetary and non-monetary aspects. The multi-criteria evaluation depends on the relative importance assigned to the different criteria, which is expressed as a subjective judgment by the user. Multi-criteria methods have already been used in transport problems, and are suitable to the problem at issue. For the proposed ABM, it is assumed that evaluating the VP means giving a quantitative outcome as a weighted linear combination of the service (Eq. 2). In particular, the VP of provider *i* to potential user *j* is as follows:

$$VP_{ij} = w(p)_j Price_i + w(i)_j Intangible_i + w(s)_j Sustainability_i + w(r)_j Risk_i \quad (2)$$

This evaluation method is associated with a simple additive weighting (SAW) method (Afshari, Mojahed and Yusuff, 2010). Triantaphyllou and Mann (1989) state that SAW “gives the most acceptable results for the majority of single-dimensional problems” and is the most used multi-criteria methods for its simplicity.

The decision to adopt the service does not change over time even if a better solution for the customer might be present in the system. This is because it is not cost-effective for an employer to look for other solutions, and thus the first solution to provide overall benefits will be chosen (technology lock in). On the contrary, a negative evaluation will end the evaluation process and no agreement will be signed between user and provider. However, users can change their minds if conditions change. In this case, there will be no need for a second contact and the user will only re-evaluate the value proposition. When a contract is signed among the parties, the lockers are installed and then a payment is issued

each month by the user to the provider, according to the size of the locker.
The providers therefore can sum up all the profits accrued during the previous months and calculate their costs, including marketing budget spent for reaching new customers and R&D budget spent in improving the capacity. Table 5 summarizes the events and rules that triggers them for each agent type.

Table 5: Events, rules and agents of the model.

Agent type	Event	Rule
Facility manager	VP received	Random choice by software engine
	VP accepted	Positive comparison between alternatives
	Change of criteria weights	Market share threshold
	Payment issued	Once per month
PLO	Parcel locker installed	VP accepted
	Payment received	Payment issued

3.4 Model Verification

Verification of ABM often poses some challenges to modellers. For model verification we adopt the approach by Walters and Lancaster (2000). The first verification step takes place during problem formulation and model building, and is grounded on the adoption of the theoretical framework (Zenezini *et al.*, 2017) that provides with the model components. Moreover, first-hand verification with stakeholders involved is used to verify that the mechanisms in the model resemble the ones in the real life case. Finally, given that only synthetic data are available, the second and third validation stages are carried out by performing a robustness analysis on the main assumptions and hypotheses regarding the performance indicators of the model.

4 COMPUTATIONAL EXPERIMENT

Through the computational experiment we investigate two different service offering configurations related to the installation of parcel lockers inside office buildings. The aim is to garner insights into the service diffusion across potential users, in relation with the allocation of the initial budget and the type of service configuration.

To model the providers, interviews with the founder from one company and the Director of product design of a second company supported the quantification of the value proposition of the two competing services, and provided a realistic value for operational parameters.

Concerning the facility managers, we consider three types of employers, namely small, medium and big entities according to the number of employees. Small companies have less than 50 employees, medium between 51 and 250, and big companies have more than 250 employees. Such companies differ in decision-making criteria as will become clearer later on. Facility managers have to choose between three alternatives: i) Business-As-Usual (BAU), where no parcel lockers is installed, ii) first configuration with only parcel lockers management, and iii) second configuration with parcel lockers management and parcels consolidation.

Software implementation is performed on NetLogo. NetLogo is used for its simplicity and for its ability for rapid prototyping and developing proof-of-concept models (Anand, 2015).

4.1 Parameters and Variables

As mentioned above, data on infrastructure costs were collected through interviews with a PLO, data on marketing instead are a speculation based on the assumption made for the two scenarios.

Some variables shape the system. To manage the parcel lockers, PLOs build up their IT capacity, which is directly dependent on the share of budget allocated to R&D. The values for marketing cost are set so that realistically all employers are reached in a sufficient period of time, to avoid that a small share of the budget devoted to marketing is enough to reach all market in few simulation steps. Marketing cost is furthermore assumed to be related to the degree of innovation, and thus the marketing cost for provider 1 is half the same cost for provider 2. In other words, solution 1 is “easier” to understand and thus it can reach a wider market. Hence, the marketing effort is modelled by explicitly stating the cost for reaching one customer and thus the share of the market that can be reached with the marketing budget.

Furthermore, more resources are necessary to organize the last-mile delivery, thus the cost for each unit of capacity is higher for provider 2. To organize the last-mile, PLOs compute their handling capacity as (*Parcel handled per m2) x (Handling area*).

From the facility manager point of view, handling cost is as follows:

Handling cost = (Cost of handling cost per parcel per unit of time) x (Handling Time) x Employee per company x Monthly demand per employee (3)

Table 7 synthetizes the parameters of the model.

Table 6: Parameters of the model.

Actor	Parameter	Value
Both PLOs	ITcapacity	r&dbudget / 1000 €
	Cost of infrastructure	100 €/lockerstation
	Cost of maintenance	50 €/lockerstation
PLO (first configuration)	Marketing cost	2500 €
	Fixed cost	150 €/locker station
PLO (second configuration)	area	100 m2
	Parcel handled per m2	3
	Marketing cost	5000 €
	Cost of transportation	10 €/lockerstation
	Cost of handling	150 € / lockerstation
	Fixed cost	200 €/locker station
Facility Managers	Cost of handling	0.33 €/minute/parcel
	Handling time	5 minutes

4.2 Criteria Weights and Values

The alternatives are ranked using four criteria. Some criteria need to be further detailed according to the information given by the companies. The criterion related to the intangible benefits is represented by the hassles connected with having to face the delivery process, determined with the amount of people external to the employer that are involved in this process. The criterion of sustainability is assumed to have the highest value for the second configuration, since it consolidates the deliveries and therefore reduces the number of vehicles-km. Finally, the risk criterion is assumed to be higher for the PLO that organizes the last-mile and consolidates goods, which is the more extensive solution in terms of service offering among the three ones and therefore the more risky for customers.

To calculate the values for each criterion and convert them for the multi-criteria method their value are computed and then converted into an ordinal scale signifying their relative values. A traditional Likert-scale 1-5 has been used to the task. To this end, thresholds need to be identified for criteria C1 and C2. For criteria C1, information from online retails reports is used (Wallace, 2017). Computing the cost of receiving parcels by using the parameters identified previously and the average number of monthly deliveries per employee, it is assumed that the median employer usually spends in average circa 5 €/ employee: this value is equivalent to 3 in a Likert scale. For criteria C2, it is assumed that one delivery person per day in average is still manageable by the company, whereas 5 represents a situation where having to deal with multiple persons entails a strain on daily operations. This is especially true if express couriers should change the drivers very often.

To assign the weights, companies are profiled based on their characteristics and size. The results of this profiling are not presented here for space reason. In practical terms, smaller companies are less interested in consolidation value because they are less likely to face a lot of deliveries and are also more risk averse because installing locker station require an investment which might be too large to sustain for them. Larger companies instead care less about price but more for sustainability and consolidation, and are less risk averse.

4.3 Sensitivity Analysis

To validate the results of the evaluation phase and check the robustness of the model, a sensitivity analysis is performed on the criteria weights. The objective of the sensitivity analysis is to identify the change in criteria weights needed for diverging from the first ranking, assessing the impact of those changes on the final ranking of alternatives. This work can be performed by making pair-wise comparisons between two non-dominated alternatives, and observe the change in the criteria weights needed to reverse the total weighted value of those alternatives by a predetermined amount. A least-square procedure (Barron and Schmidt, 1988) is applied on the weights assigned to the companies, showing that the evaluation results holds quite well after manipulating the criteria weights.

5 SIMULATION RESULTS

An experiment has been run to provide insights into the effect of the parameters initial population, initial budget and marketing budget of the two providers on the number of customers reached. In particular, the ranges of the parameters are as follows:

Table 7: Parameter *settings* for the run experiment.

Parameter	Range
Initial Market	15-90
Marketing budget provider 1	2500-10000 €
Marketing budget provider 2	5000-15000 €
Initial Budget provider 1	20000-30000 €
Initial budget provider 2	20000-30000€

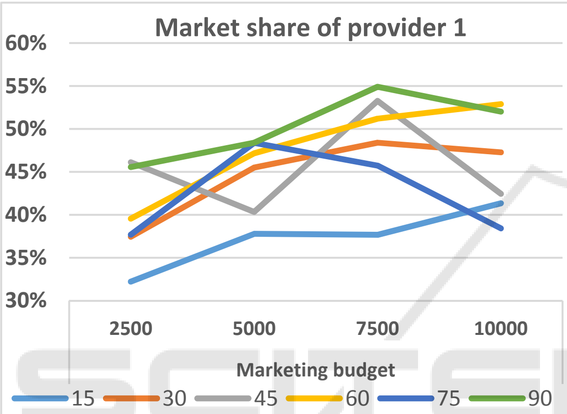

Figure 1 Market share of provider 1 with different levels of marketing budget by provider 2 and different initial population size.

One simulation run has been performed for each setting of the parameters, generating 1440 total runs. Figure 2 shows that only for selected initial population of employers the average market size reached by provider 1 increases with the marketing budget.

For population size equals to 75 the market share of provider 1 decreases with marketing spending. For a population of 45 moreover, the average market share is lower with a marketing budget of 10'000 € than with a marketing budget of 2'500 €. From an experiment with total market of 60 employers, provider 1 can reach 50% of the market with either a lower initial or marketing budget than provider 2 in more than one third of the simulation runs (i.e. 36.25%).

These results further confirm that it may be counterproductive to increase marketing spending as well as the overall budget, and that a decision from one provider affects the success of the other provider.

Another experiment has been conducted on profits, with the same range of parameters. To compare fully the profits with market share it is necessary to apply normalization to the profits, as these are evidently influenced by the size of the market. Hence, the average profit per initial customers is used to check for correlation between market share and profits. These simulations show that the maximization of the profit per initial customer for all marketing budgets does not take place with the highest market share (i.e. with population of 30 customers). Similarly, we find that one of the lowest profit per customer corresponds to the highest market share (i.e. with population of 90 customers).

6 DISCUSSIONS AND CONCLUSIONS

This paper provides a first modelling and simulation tool for assessing the implications of business model decisions for UL systems.

The model simulation provides insights into a specific case study that has become relevant in city logistics, namely the parcel locker operator. The model enables to assess the profitability of the solution by assigning a business model to all stakeholders involved. The model is designed on a service offering and evaluation basis, where service providers bear costs to reach customers and deliver their value proposition, which is then assessed using multiple criteria. Two different configuration of the same innovation are modelled, ac-cording to the specifics emerged during interviews with the administrators of two parcel lockers companies. The main strategic levers for the success of the business model are the initial budget and the share of the budget allocated to the marketing effort, which enables the two providers to reach their customers.

Results show that in some cases a higher marketing spending turns into smaller market share reached and consequently lower profits. This counterintuitive result originates from the fact that a higher spending dries out the budget for one provider, making it impossible to contact other customers and thus leaving the completely “untouched” market to the other provider. Hence, it is clear that the outcome for each provider is strongly influenced by the decisions taken by the other providers.

This study has some limitations that will be addressed in future research. In particular, the calculation of the metrics by the agents should lead to further decision-making and reassessment of their initial decisions. This reassessment should consider the actual performance of the service delivery by the providers, and it would then require the implementation of a realistic operational model in the existing ABM. By doing so, it would be feasible to embed other metrics such as customer satisfaction, reliability and efficiency in the evaluation by the agents.

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