The dynamics of diffusion of an electronic platform supporting City Logistics services

(Article begins on next page)

The dynamics of diffusion of an electronic platform supporting City Logistics services

Abstract

The concept of City Logistics (CL) has emerged to reduce social, economic and environmental impacts of last mile freight distribution in urban areas. The case of an innovative ICT platform for CL management is presented here, together with a System Dynamics model developed to explore the dynamics of diffusion of such initiative by three populations of users, namely: municipalities, own-account Carriers and Logistics Service Providers. The model structure and parameters are shaped on diffusion models available in literature as well as participatory focus group sessions with the stakeholders. In particular, during the focus group sessions the stakeholders used the Business Model Canvas building blocks to identify the value propositions delivered by the platform. Results show that routing efficiency, incentives to private operators for sustainable behaviors and advertising campaigns to stimulate the cross-side effect among the stakeholders can stimulate the diffusion of this service. These results highlight a strong demand expressed by the CL stakeholders for ICT services supporting more efficient urban logistics operations, although it also confirms the need for public support for their diffusion.

Keywords

System Dynamics; City Logistics; Simulation Modeling; Technology adoption; Multi-stakeholders platforms

1. Introduction

In recent years, traffic congestion and pollution problems caused by the increasing freight transportation demand within the cities (Gajanand and Narendran, 2013) have led both researchers and public administrations to put their efforts into City Logistics (CL) initiatives. CL fosters the development of integrated logistics systems where all the stakeholders are coordinated to reduce the negative impact of urban freight distribution on the citizens (Taniguchi, 2001). On the one hand, local authorities strive to reduce the pollution and congestion level by implementing public policies that limits the number of vehicles travelling inside the city centre, such as low emission zones (Carslaw and Beevers, 2002) or delivery time windows (Quak and de Koster, 2007). On the other hand, freight carriers play an important role, since they carry out the freight delivering core tasks of the CL process, and their daily activities may be largely influenced by CL initiatives aimed at reducing the negative impact of urban logistics operations (Browne, Allen, et al., 2005; Quak and Van Duin, 2010).

Several CL initiatives have been devised and implemented by municipalities to solve negative externalities of urban freight transport while achieving efficiency for private operators. In particular, some initiatives focused on testing ICT platforms for coordinating stakeholders, managing logistics operations, and provide real-time information to freight carriers in order to optimize the routing and therefore reducing the congestion and pollution level (De Marco, Mangano and Zenezini, 2018). However, such initiatives achieved mixed results in terms of efficiency and environmental benefits, and in some cases (e.g. the Delivery Space Booking in Bilbao and Lyon (Blanco et al., 2012)) could not even propose conclusive results in terms of emissions reduction or better city management by local authorities. As a consequence, the current operational status of most of these ICT platforms after the first trial period is unknown (e.g. the i-Ladezone project in Vienna (AT), the loading/unloading active guide in Barcelona (ES)). In this context, there is a lack of work highlighting the main critical factors for the success of such platforms.

In order to contribute to identify the main factors that might drive the adoption of a CL service focusing on a CL management system, this study presents a model aimed at evaluating the potential diffusion of an ICT platform for supporting the logistics activities in urban areas in the Italian territory by taking into account the three main different populations of potential adopters of the CL service. The present work is part of a national-funded research project, named Urban Electronic and Logistics (URBeLOG), carried out by a consortium of academic and industrial partners including a main ICT operator, a commercial vehicle manufacturer, a logistics service provider, and companies in the automotive, mechanical, electronics, information technology, automation, and energy sectors. The short-term goal of the project is to develop an innovative ICT platform acting as a middleware connecting on-board units and road sensors to manage access of commercial vehicles to the Restricted

Traffic Areas in the city centres of two test bed cities in the North-West of Italy, namely: Torino and Milano. Moreover, it will monitor the state of filling loading/unloading areas, providing valuable routing improvement and planning to freight carriers.

In order to model the diffusion of the URBeLOG platform, a System Dynamics approach is adopted. SD methodology (Forrester, 1961) is used given its proven ability to represent and simulate the behaviour of complex systems like CL ones that involve a lot of factors and stakeholders, such as governments, companies, citizens, and carriers, that interact with each other (Koç et al., 2016). In City Logistics contexts, there are only few available models. A SD approach to CL modelling has been proposed by Thaller et al. (2016), with demand of goods from the population, freight trips demand for transport operators, road mileage and fuel consumption, transport lead time and costs as the main model components. To the best of our knowledge, this is the most comprehensive SD model for CL systems developed so far.

Within the model, the main actors of the City Logistics system adopts the innovation by following the objectives embedded in their Business Model, which has been used by CL scholars to garner insights into the diffusion process of CL initiatives (Björklund et al., 2017). The model is developed based on the interviews with the main stakeholders involved by the projects by carrying out two different participatory sessions of the Business Model Canvas (Osterwalder and Pigneur, 2010) in order to identify the main potential levers of diffusion. The use of the Business Model Canvas as a tool to involve the CL stakeholders in capturing their needs and thus defining the Business Model of a CL solution can be considered a new and innovative approach, and it proves its effectiveness since during the Business Model Canvas sessions all partners involved have the opportunity to highlight their own needs and requirements that are crucial for making the platform interesting and feasible from a commercial point of view.

The paper is structured as follows. An overview of the pertinent literature is presented in Section 2. Section 3 describes the methodology, while the development of the model is presented in Section 4 and its calibration is shown in Section 5. The results of the simulations together with their sensitivity analysis are discussed in Section 6. Finally, the interpretation of the study outcomes is presented in Section 7, while implications, future research, and conclusions are given in Section 8.

2. City Logistics context

CL is defined by scholars and practitioners as the effort of "totally optimizing the urban freight distribution activities by considering economic, social and environmental outcomes of such activities" (Taniguchi, 2001).

The CL concept has been explored and substantiated in many different ways in recent years, and several projects have been tested and implemented. The most widely available in literature among CL projects are urban consolidation centres (Browne, Allen, et al., 2005; van Duin et al., 2016), delivery with alternative vehicles (Arvidsson and Browne, 2013; Pulawska and Starowicz, 2014; Schliwa et al., 2015), satellite terminals inside the city centres where goods are being transhipped from vans to small delivery vehicles (Janjevic et al., 2013; Verlinde et al., 2012), optimization of loading/unloading lay-by areas (Alho et al., 2018; Dezi et al., 2010; Pinto et al., 2019), or off-hour deliveries to retailers (dell'Olio et al., 2016; Holguín-Veras et al., 2016; Marcucci and Gatta, 2017). The realization of CL initiatives occurs because of both private and public undertakings. Therefore, while putting forth a CL project the objectives of private and public stakeholders need to be taken into account (Marcucci et al., 2017).

2.1.Stakeholders' objectives: achieving operational and environmental efficiency

The key stakeholders of the urban movement of goods are shippers, freight carriers, local retailers, residents and local authorities (Macharis et al., 2014). Each stakeholder has distinct points of view because of the different roles played in the system and their sometimes diverging and contrasting objectives.

Residents would like to have a good living environment with low level of pollution, traffic congestion and nuisances generated by freight transportation activities such as noise and road accidents (Macharis et al., 2012; Taniguchi and Tamagawa, 2005). However, citizens do not have a direct impact on city logistics systems decisions, and their objectives are usually shared by the local administration. Local authorities aim at fostering urban economic development and they should coordinate the efforts for the improvement of city logistics systems' efficiency. In fact, in some relevant best practices of CL, local administrations played a major role in resolving conflicting issues and implementing the projects (TRAILBLAZER, 2010).

Shippers outsource the delivery process to transport operators, and thus seek to achieve at the same time low cost deliveries and a high quality reliable service (Awasthi and Chauhan, 2012). Moreover, they may benefit from reliable and timely information on the state of the delivery through effective tracking & tracing systems (Musa et al., 2014). Finally, security and safety of delivery are major requirements for a logistics service (Thompson and Taniguchi, 2008).

Transport operators offer logistics service to shippers and hence are keen on achieving shippers' objectives. In addition, they seek to maximize profits by increasing revenues and decreasing the cost of pick-up and delivery. In fact, last mile distribution in urban areas account for a significant share of delivery costs, that can range from 20% to 40% (Goodman, 2005; Roumboutsos et al., 2014). This relatively large share of cost is due to the congested roads, higher number of vehicles used (i.e. only smaller vans are allowed in most of the cities) high number of delivery points, traffic congestion and other issues such as the first delivery attempt failure when the receiver cannot attend the delivery (Xu et al., 2008). Couriers and express delivery services compose probably one of the most efficient group of transport operators in urban areas. They provide pick-up and delivery services to large shippers, small businesses and local customers. To this end, they have invested large amount of money in warehousing facilities, vehicle technology and ICT systems to reduce operative costs and improve network and operations planning in urban areas (Navarro et al., 2017). As previously mentioned however, local regulations such as limited time windows access to city centres urban areas affect their profitability by putting an additional time pressure on their daily operations. Moreover, local regulations differ significantly from city to city, and these global players find it difficult to cope with this dispersion of policies. A second category of transport operators includes smaller actors who want to sell their goods, own few freight vehicles and organize their own transportation. These own-account carriers do not usually consider transportation activities as part of their core business, have fewer points of delivery in urban areas and less efficient operations than the first group.

The objective of CL efficiency refers to as the improvement of logistic services for final customers, to revenue maximization and to cost reduction for the carriers. In particular, the urban operations' efficiency of LSPs has been found by Cagliano et al. (2017) to be related with the extension of the distribution areas assigned to each driver, the routing and organization of service trips and the vehicle loading policy. In particular, freight carriers can increase their efficiency by optimizing the service delivery network and properly loading vehicles. Consequently, they would use fewer vehicles to perform their service trips. Therefore, it is possible to envision a positive effect on operational efficiency and pollution by setting up ICT tools that improve freight carrier's efficiency and result in a reduction of the total number of service trips in the process with consistent decreases of logistics cost (Yang and Moodie, 2011).

The introduction of a new CL ICT platform should seek to improve the operative conditions of transport operators while reducing the negative externalities generated by their activities. Furthermore, it should take into account the diverse objectives of the major private and public stakeholders, and should aim at solving the conflicts that might arise sometimes between those objectives. As a matter of fact, public stakeholders should aim at reducing the level of pollution and traffic congestion and other nuisances generated by freight transportation activities, as well as foster the efficiency of CL systems. Efficiency is in fact the major objective of private transport operators, and can be either increased by optimizing the service delivery network or diminished with local regulations such as time windows.

Therefore, modelling the diffusion of an ICT platform requires a clear understanding of the most important factors that could leverage the attractiveness of a CL initiative for transport operators and local administrations, as well as the interconnections that are embedded in the CL system.

2.2. ICT platforms in urban logistics contexts

So far, just a few ICT platforms for CL purposes have been devised and tested by municipalities participating in EU-funded pilot projects even ICT applications have greatly proved to enhance the efficiency of logistics operations and become crucial enablers of logistics companies' arrangements (Hong et al., 2010). For the MIRACLES project (Hayes et al., 2006) for instance, the city of Barcelona tested a few smart logistics solutions. A loading/unloading active guide was created by the municipality to exchange information on the time slots and location of more congested parking spots, for the benefit of few supermarket operators and carriers operating within a pilot area. The information retrieved during the first trial was used then by the municipalities to target law enforcement activities. A more dynamic approach to information sharing on lay-by areas occupancy was adopted for the i-Ladezone project, carried out in Vienna as one of the BESTFACT solutions (Bohne and Ruesch, 2013). The project covered a smart platform managing an installed base of roadside units (RSU) that real-time monitored the occupancy of lay-by loading/unloading areas. Information on the state of the lay-by areas were then given to drivers in order to optimize their routing; an algorithm for routing optimization was also part of the platform offering to drivers. For the FREILOT project five technological solutions were tested across several European Cities (Gonzalez-Feliu et al., 2013; Pluvinet et al., 2012). Among them, the Delivery Space Booking (DSB) solution tested in Bilbao and Lyon follows the path outlined by the previous projects, integrating it with the possibility of reserving a lay-by area and booking it for 30 minutes. The management system also allowed for a periodic booking of up to 3 months, enabling companies to plan their operations accordingly. Unfortunately, no definite results were shown regarding a significant and positive impact on both the improvement in law enforcement or reduction of emission due to the booking system (Blanco et al., 2012). Moreover, even though there was a slight impact on the traffic, the booking system still resulted in a negligible effect on the route performance. Finally, the city of Lisbon experimented a real-time monitoring system of lay-by areas through the instalment of RSU on the ground, which allows freight vehicles to use the lay-by areas for up to 30 minutes (Posthumus et al., 2014). The objectives of the previously presented ICT platform were twofold. First, generating benefits for private operators by increasing their ability to optimize and plan the delivery routing process by either providing information on the real-time availability of lay-by areas or granting exclusive access to lay—by areas for a specific time window. Second, maximize the occupancy of lay-by areas, drastically reducing the time spent by drivers in search of a parking spot and thus decreasing traffic congestion. However, these projects did not prove to be truly effective in achieving those objectives, and we could not retrieve any information regarding their current operational status.

A privately owned collaboration platform is provided by the RegLog initiative in Regensburg, Germany[1]. The platform enables companies to bundle consignments going into the city from their warehouses located at the freight village of Regensburg. Environmental impacts were achieved, as there were an increase in the vehicle load factor and until August 2007 over 35,000 truck-km in the inner city were saved (Dasburg and Schoemaker, 2007).

Finally, a technological platform for coordinating CL stakeholders, sharing information on logistics issues, optimizing logistics activities and exploiting data on traffic for logistics purpose was devised for the Life CEMD project in Lucca, Italy, as an ITS counterpart to the physical urban consolidation centre (City of Lucca, 2008). This project is still running a share of city logistics operations in Lucca, and even though it has still to reach financial viability it has proved that IT system can be effectively exploited to collect information from transport operations and use them for managing the urban logistics process more efficiently (Björklund et al., 2017).

Table 1 summarizes the CL ICT platforms presented in this section.

Table 1 Existing Deployments of ICT platform for City Logistics

Project	**City**	**Services offered**	**Stakeholders involved**
MIRACLES project	Barcelona (ES)	Exchange information on the time slots and location of congested parking spots	Municipality Supermarket operators

[1] www.reglog.de

			Carriers
i-Ladezone	Vienna (AT)	Real-time monitoring of lay-by areas occupancy Algorithm for routing optimization	Municipality Drivers
Delivery Space Booking	Lyon (FR) Bilbao (ES)	Real-time monitoring of lay-by areas occupancy Booking lay-by areas for 30 minutes Periodic booking of up to 3 months	Municipality Carriers
Real-time monitoring	Lisbon (PT)	Real-time monitoring of lay-by areas occupancy Booking lay-by areas for 30 minutes	Municipality Carriers
RegLog	Regensburg (DE)	Bundling consignments for city delivery	Freight village Logistics Service Providers
Life CEMD	Lucca (IT)	Sharing information on logistics issues Optimizing logistics activities Exploiting data on traffic for logistics purpose	Municipality Logistics Service Providers

There is the need of an ICT platform as a crucial effort to enhance CL. However, these few pilot test bed ICT platforms are still struggling to become largely diffused and well accepted by the community of users and stakeholders. Following is a contribution to understand the factors that might facilitate and spread their diffusion. CL systems can be better managed by ICT platforms that exploit smart sensors deployed on the urban territory to provide services to transport operators. However, these platforms need to strive to deliver value-added services to private transport operators in order to get them on board and achieve long-term financial sustainability. This is possible only if the efficiency of private operators is actually enhanced by the deployment of ICT infrastructure and data-processing middleware platforms. Hence, efficiency factors need to be underlined and understood during the feasibility study phase, as they are the funding aspects of the success of CL ICT platforms.

3. Methodology

The diffusion of a new technology is usually described by an S-shaped curve, with a slower adoption rate at the beginning and an increasing growth rate after the system reaches the "tipping point" (De Marco et al., 2015). Several models were proposed to explore the patterns of diffusion of a product or service by a community of users, such as the Gompertz model (Gutiérrez et al., 2005), the logistic model (Richardson, 1991), the Fisher-Pry model (Fisher and Pry, 1971), and the Bass diffusion model (Bass, 1969). Literature recognizes that there are some founding linkages among key variables related to innovation diffusion (Repenning, 2002). For instance, committing to an innovation has a positive effect on the effort dedicated to using that innovation, and other potential users observe this reinforcing loop taking place and contribute to the diffusion. In addition, companies can have an important role in stimulating the diffusion of a product or a service. According to Maier (1998) and Milling (2002), managers can actually leverage on certain factors to increase the likelihood of a successful diffusion, such as pricing, advertising, product quality, production capacity and investment, or successive substitute products.

Looking at the dynamic pattern of diffusion, models are either homogeneous or heterogeneous in nature. Homogeneous diffusion models are depicted by the two-step flow theory, by which the innovation spreads initially within a small group of individuals as a result of the advertising effect, and then it is transmitted to other potential users by means of word-of-mouth influence (Bass, 1969). However, potential users can present different purposes and needs that induce them to adopt a new product in separate times and under different circumstances or factors. Heterogeneous diffusion models thus include such aspects in the model development (Peres et al., 2010). As previously mentioned, City Logistics is a complex environment where separate class of stakeholders pursue different objectives and their decisions are therefore driven by a wide variety of factors. Hence, different factors will be considered when modelling a CL ICT platform, thus building a heterogeneous diffusion model.

Literature has demonstrated that SD is an appropriate modelling approach to investigate the dynamics of innovation and technology adoption, because it enables modellers to grasp the full complexity embedded in various industry sectors and applications and, therefore, to capture the characteristic behaviour of technology adoption processes. Most of the available contributions share a common trait in the Bass technology diffusion model, which considers the adoption rate as a sum of the adoption rates from both word of mouth and advertising. For instance, SD was used in the energy sector to model the diffusion process of energy efficiency lighting in households (Timma et al., 2015), or the introduction of alternative fuel vehicles (Shen and Ma, 2013) and multi-sided technological platforms for urban mobility (De Marco et al., 2015). Diffusion models for the ICT and telecommunications sector were also developed with a SD approach (Ryan and Tucker, 2012; Tsai and Hung, 2014), and in particular for implementing ICT tools for urban freight distribution management (Cagliano et al., 2014).

The present case study fits in the last research stream and deals with the introduction of URBeLOG, an ICT platform for managing last-mile deliveries in CL environments (Marciani and Cossu, 2014). The project is funded by the Italian Ministry for Education and Research, and sets itself the objective of fostering a better and optimized urban logistics context by coordinating all the stakeholders and retrieving real time information to offer value added logistics services. The platform oversees the process of granting green delivery credits to give entry access to the city centre, as well as providing real-time data on parking spot availability and local regulations to transport operators. A deeper explanation on the technological architecture of the platform is provided by De Marco, Mangano, Zenezini, et al. (2017). URBeLOG integrates together aspects already addressed by previous CL initiatives. For instance, in a similar fashion as the Lucca city platform, URBeLOG connects all the CL stakeholders, and streamlines their operations by integrating the middleware management platform with Road SideUnit, with the aim of measuring the availability and usage of lay-by areas that is a typical critical issue of CL (McLeod and Cherrett, 2011). Finally, the long-term objective of the project is to create and validate a virtuous system that would make last-mile distribution in urban areas more cost-effective, efficient, economically advantageous, and ecologically sustainable, as advocated by many CL scholars (Arvidsson and Pazirandeh, 2017; Harrington et al., 2016; Macharis and Kin, 2017).

To define the components of the diffusion dynamics of the URBeLOG platform, a SD model is developed, based on the suitability of this methodology to explain the complex process of innovation adoption, as discussed earlier in this section.

The authors are directly involved in the development process of the platform, and therefore have the chance to investigate the stakeholders' needs and the platform' requirements by means of several workgroup sessions. These sessions allow including the attributes of the provided service and the stakeholders' requirements. Such attributes are evaluated and extracted using the Business Model Canvas approach (Osterwalder and Pigneur, 2010), that focuses on understanding how a company can create, capture, and deliver value for its customers as well as organize its assets and resources to the task. In particular, three aspects are crucial (Osterwalder and Pigneur, 2010). First, how key components and functions or parts are integrated to deliver value to the customer. Second, how those parts are interconnected within the organization and throughout its supply chain and stakeholder network. Finally, how the organization generates value or creates profit, through those interconnections (Chesbrough, 2007). An organization's business model can provide insight into the alignment of high level strategies and underlying actions that can support strategic competitiveness (Casadesus-Masanell and Ricart, 2010). In particular, the Value Proposition identifies the way a firm deals with the customer's problems and the way the customer's needs are met. It represents the bundle of products and services that create value for a specific customer segment.

The adopted approach proves to be effective and exhaustive: all the partners of the projects, together with a public authority have taken part to the organized plenary sessions so that all the aspects of the ICT CL platform that can foster its adoption could come up. These features are then translated into factors that make up the diffusion model together with state variables and feedback loops, adopting the Bass (1969) diffusion model approach with three different population of users.

Then, the calibration of the model is performed by defining the parameters of the system from multiple internal and external sources.

Finally, different scenarios are simulated and the resulting implications are drawn.

4. The System Dynamics Model

Among the models to study innovation diffusion, the Bass model (Bass, 1969) is chosen in the present work because of its simplicity but high predicting capabilities compared with other methods (Daim and Suntharasaj, 2009) as well as its wide diffusion also to investigate the adoption of new technologies that can be also exploited in CL environment (Cagliano, Carlin, et al., 2017). Furthermore, SD literature offers a well-consolidated representation of the Bass Model (Sterman, 2000).

The proposed SD model is inspired by previous contributions such as Ardila and Franco (2013), Gorbea et al. (2011), Seitz and Terzidis (2014), Shepherd et al. (2012), as well as by the SD representations of the Bass model by Sterman (2000). It is structured into three interconnected populations:

- “Municipalities”: represents the dynamics of the diffusion of the URBeLOG platform among the Italian municipalities;
- “LSP”: describes the behaviour of diffusion for the main logistics service providers operating in Italy;
- “OAC”: refers to the adoption of the ICT platform by the own account carriers.

As previously mentioned, the Business Model Canvas is used to frame the diffusion levers of URBeLOG. The Business Model Canvas divides an organization’s business into nine interconnected components: Value Proposition, Customer Segment, Customer Relationships, Channels, Key Resources, Key Activities, Partnerships, Costs Structure and Revenues Stream.

In particular, the Value Proposition identifies the way a firm deals with the customer's problems and the way the customer's needs are met. It represents the bundle of products and services that create value for a specific customer segment. The first value proposition is a better management of the access restrictions. Thanks to the data gathered, URBeLOG can be an interface for dealing with the green credits that are given to logistics service providers and own account carriers, from carrying out their activities. In this sense, Green credits as value proposition, represent a lever that might stimulate the diffusion of the ICT platform. They can be defined as fiches that are acquired or lost according to the adoption of green strategies such as the use of low impact vehicles, or optimized routings policies. When the amount of credits is out, they can be purchased back through URBeLOG. The platform also supports the development of dynamic policies such as the management of reserved lanes. Another service of URBeLOG is the real time monitoring of lay-by areas and the vehicle fleet, which allows for an enhanced scheduling of the routings. URBeLOG will then enable the planning of national logistics policies in order to standardise the different local regulations. The purpose of URBeLOG is to present herself as a unique interface among the different stakeholders involved in the CL processes, optimize the logistics processes and reduce the delivery times. In the developed model this value proposition is associated with two levers of diffusion, namely the Efficiency in Distance and the Efficiency in Service Time that show the improvements gathered by using URBeLOG in terms of Km travelled and time required for completing the routes. Thus, the identification of the Value Propositions have allowed defining the main potential levers of diffusion for the populations under study.

4.1 Municipalities Sub-Model

Figure 1 represents the diffusion of the URBeLOG platform among the Italian Municipalities that deal with a Restricted Limited Area (224 in total). The choice of taking into account just this subgroup of municipalities coaches on the idea that they are the ones more focused on congestion, logistics and mobility issues, and in turn more interested about the services that URBeLOG can offer.

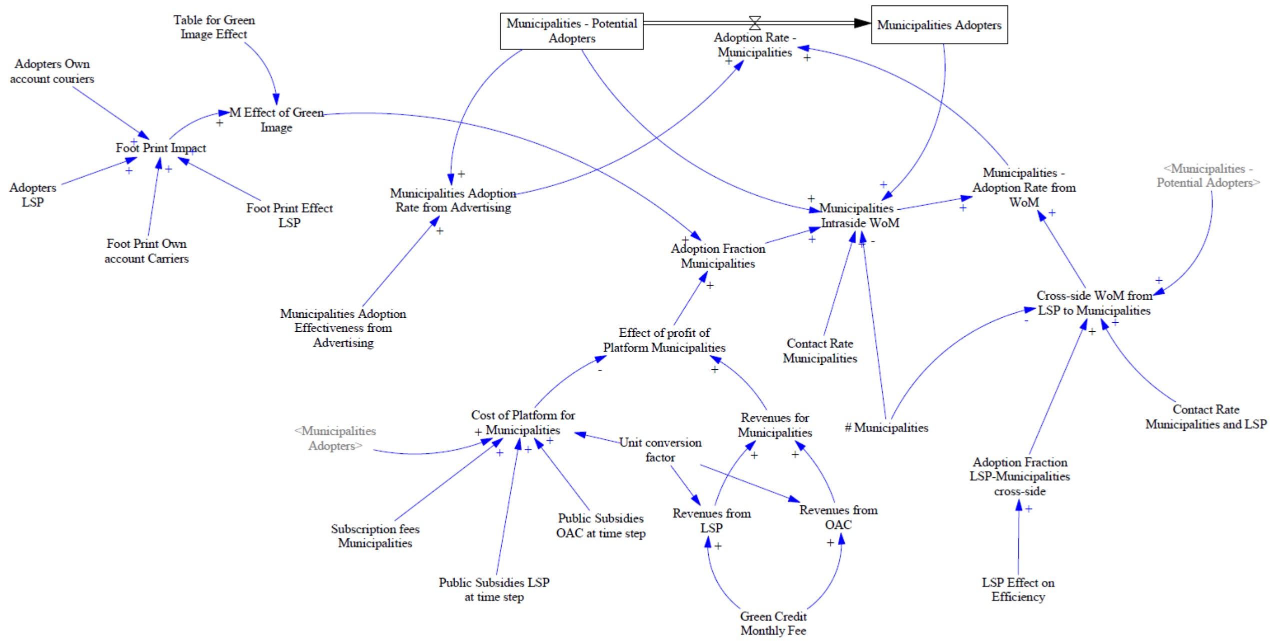

Figure 1 Municipalities Sub-Model. Shadow variables (i.e. variables present more than once in the model) are represented in grey.

Municipalities are likely to adopt URBeLOG as a service for better defining their city logistics strategies and for better dealing with the mobility green credits. In particular, there is a first adoption lever associated with the effect of Green Image. This is driven by the positive effect of the Foot Print Impact that is increased by the number of freight carriers (both OACs and LSPs) that by adopting URBeLOG are able to generate positive effect in terms of CO_2 emissions. Another lever of diffusion is the Effect of Profit, made up of two different components. On the one hand, there is the holding back effect of the cost that a Municipality has to borne for joining the platform. On the other hand, the Revenues for Municipalities represents the income cash flow coming from LSPs and OACs that buy Green Credits through URBeLOG for carrying out their urban logistics processes. When the revenues are greater than the cost, the profit will be positive with a consequent positive influence on the Adoption Fraction. The last lever is made up of two different words of mouth (WOM). The WOM among Municipalities depending on the Adoption Fraction, expressing the amount of contacts that becomes a real adoption, and the Contact Rate that is the frequency of contact between a Municipality that has already adopted and a potential adopter. The other WOM takes into account the Municipalities and the LSPs. It depends on the contact between two different populations (Contact Rate Municipalities and LSP) and on the Adoption Fraction Municipalities cross side that represents the number of municipalities that after a contact with an LSP decides to adopt URBeLOG.

4.2 Logistics Service Providers Sub-Model

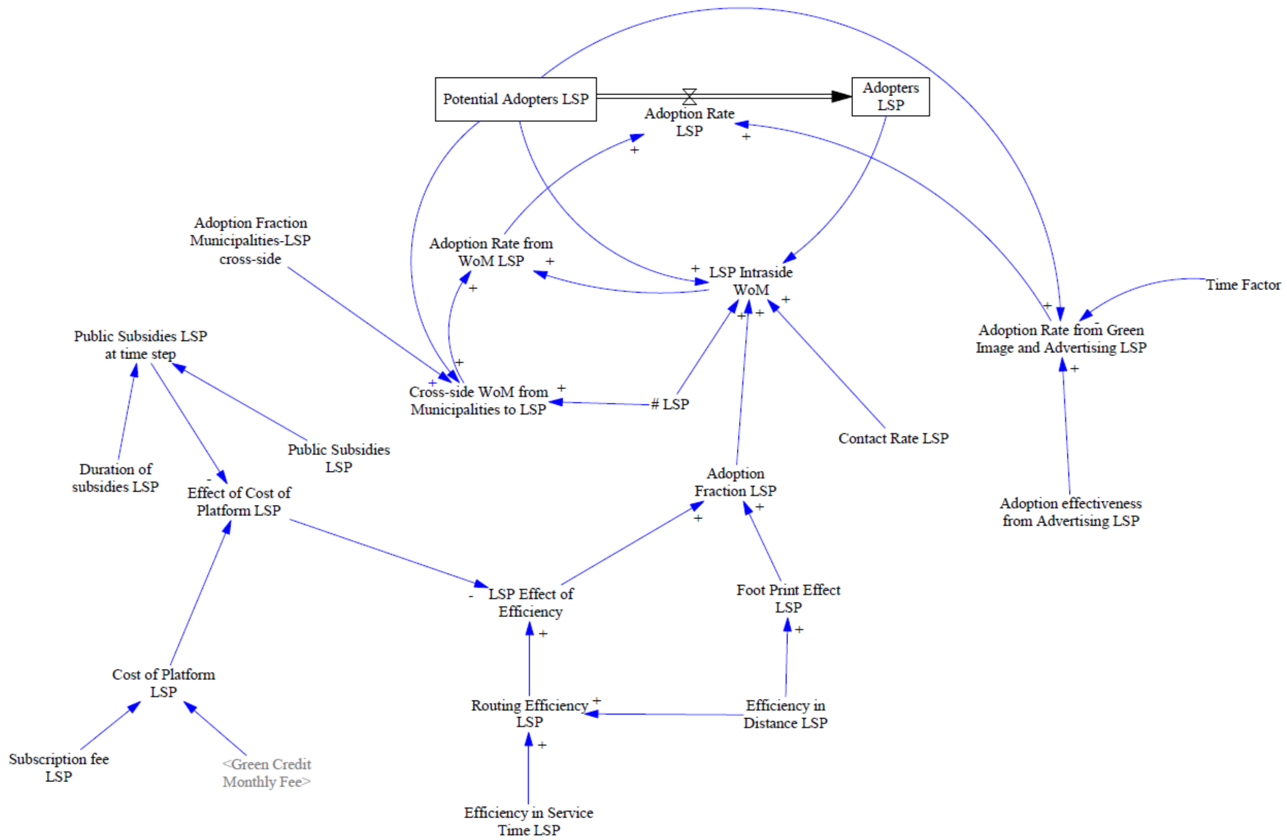

Figure 2 Logistics Service Providers Sub-Model. Shadow variables (i.e. variables present more than once in the model) are represented in grey.

The adoption of the nine LSPs operating in the Italian market is firstly associated with the green image and the advertising. In addition, the enhancement of the routings with the consequent improvements of the efficiency and of the foot print positively impact of the Adoption Fraction and in turn on the Intra-side WoM. The other WoM taken into account is the WOM between

Municipalities and the LSPs. On the contrary, the Cost of platform is considered as a negative factor of diffusion. Its effect could be mitigated by Public Subsidies that could be corresponded for a certain period for stimulating the diffusion of the proposed solution.

4.3 Own Account Carriers Sub-Model

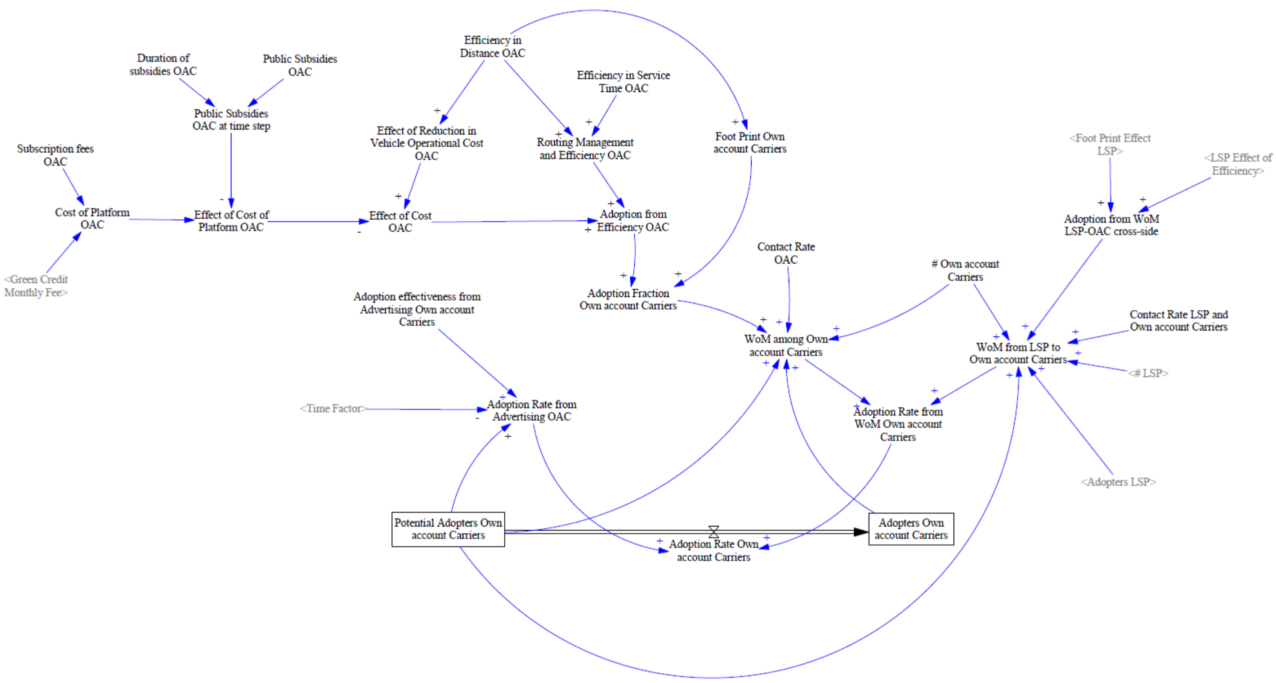

Figure 3. Own Account Carriers Sub-Model. Shadow variables (i.e. variables present more than once in the model) are represented in grey.

The 2688 Own Account Carriers (OFC) operating in the sample of Municipalities of the analysis is the third population studied. The diffusion levers considers are the same ones analysed into the LSP sub-model. Thus, the Advertising and the WoMs are the main aspects taken into account.

In the model, some balancing and reinforcing loops can be observed. In particular, Municipalities Effect of Green Image positively affects the Adoption Fraction Municipalities and in turn on the Adoption Fraction Municipalities that consequently increases the number of Adopters Municipalities. This has an effect of the Cross Side WoM from Municipalities to LSPs that increases the Adopters LSP, with positive effects on the Foot Print Impact and thus on the Municipality Green Image, closing the reinforcing loop. The same behaviour can be noticed for the OACs. In this case, there is also the effect of the Cross Side WoM from LSP to OAC that gives a positive contribution to the OACs adoption. On the contrary, the Cost of Platform generates balancing loops. For instance, the Cost of Platform Municipalities determines lower Effect of Profit of Platform Municipalities, with negative effect on the adoption by Municipalities, that jeopardize the effect of WoM both intra-side and cross side for OACs and LSPs and in turn of the adoption by OACs and LSPs. The full list of equations can be requested by contacting the authors.

5 Model Calibration

The numerical values of the input variables to carry out simulations are gathered from a variety of sources as follows, all of them relying on the knowledge of experts operating in the CL context.

The values of the parameters associated with the Municipalities sub-model (Table 2) are set together with the representatives of a Municipality based on the participatory sessions of the Business Model Canvas, where attendees were also asked to share their opinions about the quantitative aspects characterising the potential adoption of the URBeLOG platform.

Table 2 Municipalities sub-model parameters

Parameter	Range	Value	Units
Municipalities Adoption Effectiveness from Advertising	0-1	0.0015	1/month
Subscription Fees Municipalities	0-50	25	€/month
Contact Rate Municipalities	0-1	0.004	1/month
# Municipalities	-	224	users
Contact Rate Municipalities and LSP	0-1	0.005	1/month

The values of the parameters included in the LSP sub-model (Table 3) are obtained through semi-structured interviews carried out with an international LSP operating in the Italian territory and with the managers of the Municipality partner of the pilot, based on their either direct or indirect knowledge on initiatives similar to the URBeLOG one.

Table 3 LSP sub-model parameters

Parameter	**Range**	**Value**	**Units**
Adoption Fraction Municipalities-LSP Cross-side	0-1	0.005	dmnl
Contact Rate Municipalities and LSP	0-1	0.005	1/month
# LSP	-	9	users
Contact Rate LSP	0-1	0.11	1/month
Adoption Effectiveness from Advertising LSP	0-1	0.008	dmnl
Subscription Fee LSP	0-30	10	€/month
Duration of Subsidies LSP	0-48	12	month
Public Subsidies LSP	0-30	0	€/month
Efficiency in Service Time LSP	-	0.07	dmnl
Efficiency in Distance LSP	-	0.18	dmnl
Green Credit Monthly Fee:	0.1 -2	0.5	€/month

Finally, the values of the OAC sub-model parameters (Table 4) are obtained through semi-structured interviews carried out with several freight carriers operating in the Italian territory and with the managers of the Municipality partner of the pilot. In particular, the first ones provided numerical values according to their average service levels, while the second ones assessed the parameters based on their understanding and experience about promoting and supporting CL initiatives.

Table 4 OAC sub-model parameters

Parameter	Range	Value	Units
Contact Rate LSP and Own Account Carriers	0-1	0.008	1/month
# OAC	-	2.688	users
Contact Rate OAC	0-1	0.054	1/month
Adoption Effectiveness from Advertising Own Account Carriers	0-1	0.008	dmnl
Efficiency in Service Time OAC	-	0.12	dmnl
Efficiency in Distance OAC	-	0.2	dmnl
Public Subsidies OAC	0-30	0	€/month
Duration of subsidies OAC	0-48	12	month
Subscription fee OAC	0-30	10	€/month
Green Credit Monthly Fee	0.1 -2	0.5	€/month

In the base case, the variables Public Subsidies LSP and Public Subsidies OAC equal zero because in the reference context policy makers are not currently planning to encourage the use of new ICT technologies for the City Logistics arena. These parameters are changed during sensitivity analysis (Section 6) in order to evaluate the impact of some forms of public contribution in the diffusion of the project among the populations under analysis.

6. Simulation Results

6.1. Base Case

In the initial configuration of the system with no public incentives for the two population of carriers and a cost of the green credit equal to 0.5, 66 out the 224 Municipalities adopt the proposed solutions. Therefore, the market of the Municipalities with a time span equal to 200 months is not saturated.

This means that the social benefits are strongly compensated by the cost that a Municipality has to born for exploit the services of the platform. This is dramatically true, especially in a period of bad economy with strong financial distress for public authorities. On the contrary, the market of the LSPs is completed saturated and 2.550 out of 2688 OACs join the proposed solution. This result is very important and it shows the attention that freight carriers pose to CL initiatives aimed at improving the urban operations activities.

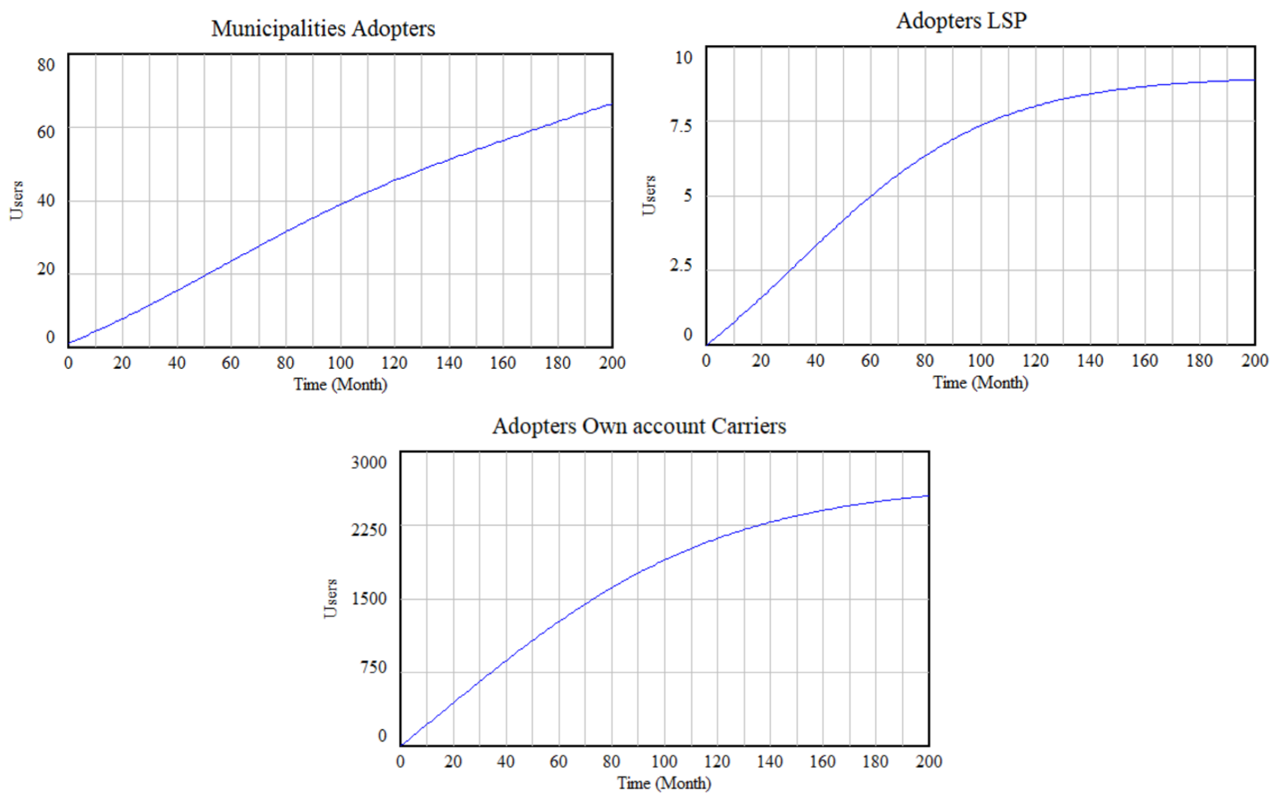

Figure 4. Adoption Curves

6.2 Sensitivity Analysis

The sensitivity analysis helps not only to understand the dynamics of the diffusion process and highlight the most important stimulating factors, but also to validate the robustness of the SD model (Sterman, 2000). The Vensim® DSS dedicated tool is used. Figures 5 and 6 show the confidence bands where the output values can be found with probabilities equal to 50%, 75%, 95%, and 100% as the selected input parameters change.

8.2.1. Multivariate Sensitivity Analysis on Public Subsidies OAC and LSP

This analysis investigates the change in the adoption as the parameters "Public Subsidies OAC and Public Subsidies LSP vary according to a random uniform distribution between 6 and 9 €/month. Public subsidies are crucial variables in the sense that they typically heavily affect the financial feasibility of CL initiatives.

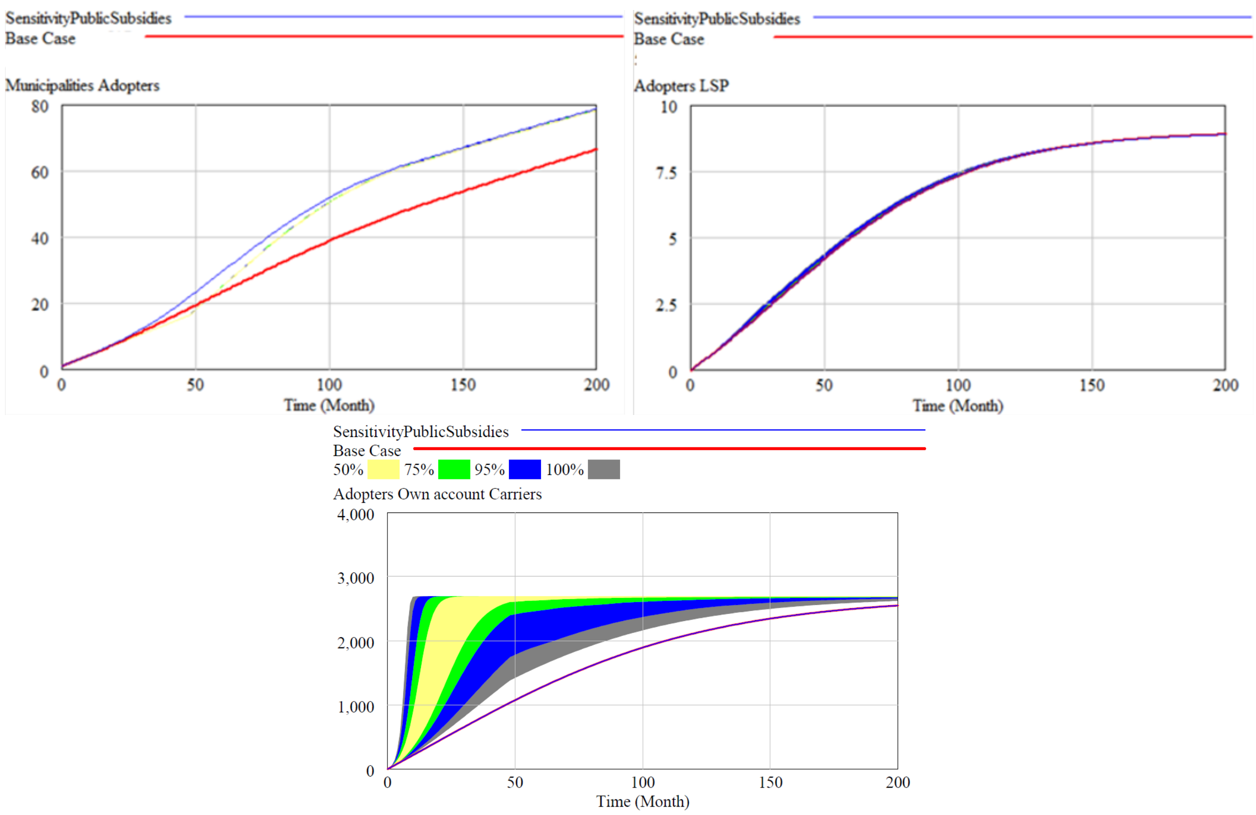

Figure 5. Sensitivity Analysis on Public Subsidies OAC and LSP

Figure 5 presents the number of adopting OACs, LSPs and Municipalities. For OACs, the adoption dynamics is very sensitive to an increase of the subsidies, since they balance the effect of cost. This population is more willing to adopt, and in the time span considered 2679 OACs out of a whole population of 2688 join the URBeLOG platform. Similarly, Municipalities adopt URBeLOG earlier. In this case, the higher expense for corresponding the subsidies is balanced by the higher incomes related to the green credits that are both by the new OAC adopters.

8.2.2 Multivariate Analysis on Efficiency in Time LSP and OAC

This sensitivity analysis explores the effects on the adoption when the efficiency measured in time changes according to a random uniform distribution between 0 and 0.20.

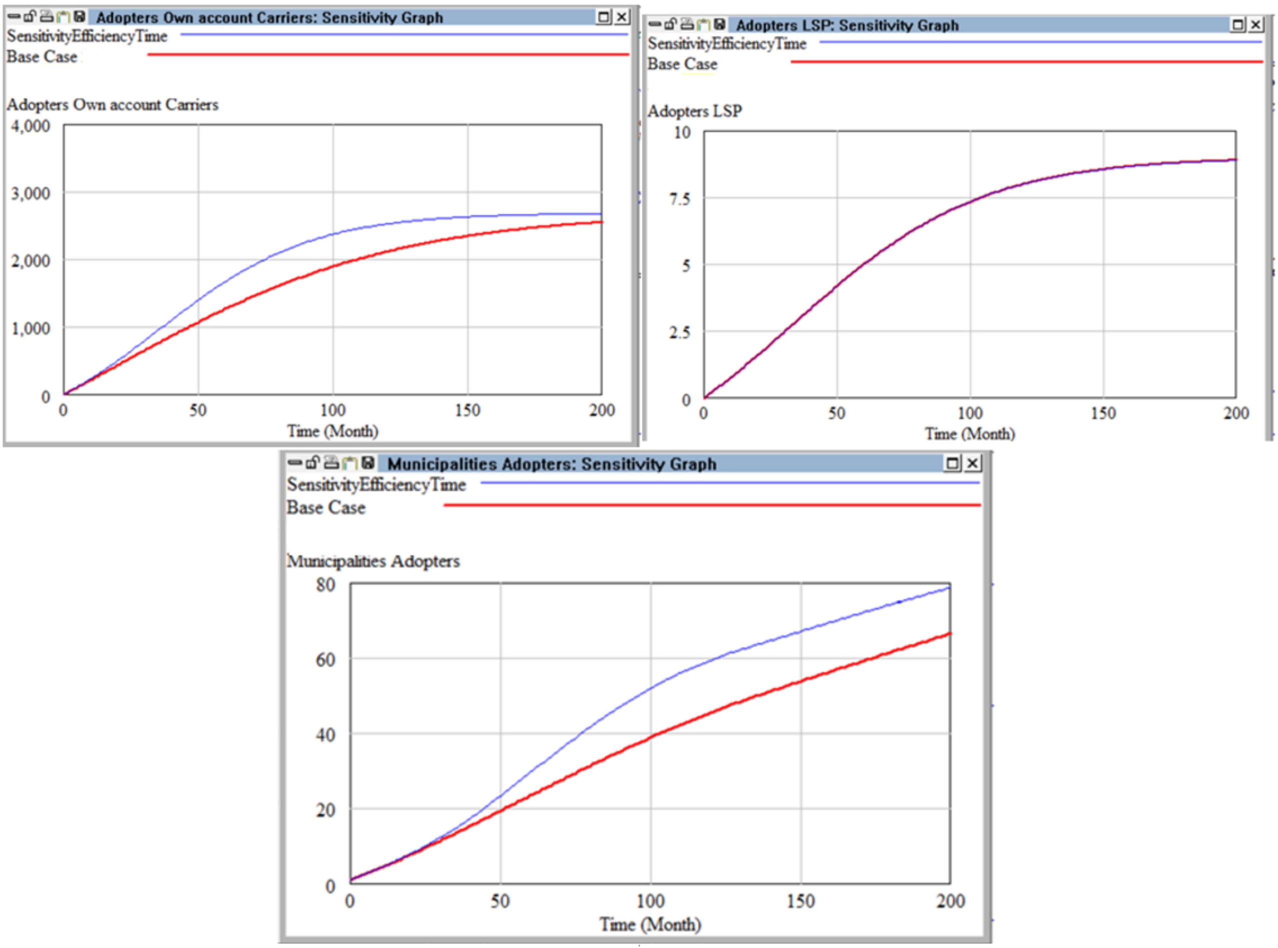

Figure 6. Sensitivity Analysis on Efficiency in Time for OACs and LSPs.

The graphs shown in Figure 6 highlight that an increase of the efficiency brings positive effects on the adoption. In particular, OACs anticipate the adoption of URBeLOG. This result highlights the demand for enhancing the urban logistics operations and demonstrates that small freight carriers lack dedicated enabling technologies. It is important to underline that the positive influence on the adoption by OACs, consequently affects the Municipalities that thanks to higher incomes for green credits adopt earlier. These results demonstrate that the incentive to adopt is not merely related to economic aspects, but also to effects on the operations. Results do not change for LSPs. This is likely due to the small sample size, but also to the fact the big companies have been already implemented tools and devices aimed at improving the operational efficiency.

7. Discussion of Results

This study shows that an ICT platform to manage the CL system can be feasible in today's urban environment. As a matter of fact, the whole LSP market of is saturated, together with most of the OAC one. Furthermore, 30% of the population of the Municipalities adopt the proposed solution in the considered time span. The green image together with advertising, the enhancement of the routing efficiency, and the WoM both within a population and cross-side populations have proven to be significant drivers of diffusions. The green image effect shows that there is an increased awareness about environmental issues in urban areas, especially in recent years when more and more people are moving to live in cities. The impact on the diffusion of the improvement of the efficiency for routings demonstrates that even if there are many optimization routings already used especially by LSPs that often develop their own systems, there is still a high demand for operational efficiency. In particular, OACs can be more interested in this solution, since they are less likely to have the capability for implementing these ICT optimization softwares. The WoM has proved its important effect especially in the present model wherein such a lever has not only been merely considered within a single population but the cross-side effect has been also taken into account. This appears to be particularly interesting since it highlights the crucial role of communication among different populations of stakeholders. Moreover, an economic contribution for purchasing the platform (even if corresponded for a certain period) is able to significantly hasten the diffusion. This result points out the key role of public authorities as promoters of initiatives that are aimed at improving the sustainability in cities. Forms of public subsidies represent a cost for Municipalities, which is balanced by the increased level of adoption by freight carriers that by buying the green credits consequently increase the incomes for public authorities. This virtuous mechanism is very important and it underlines the goodness of investing in initiatives related to urban operations processes.

Thus, based on this study, it can be stated that the diffusion of such an initiative should be pursued though structured campaigns aimed at addressing sustainable issues and stimulating the cross-side effects among the main stakeholders of CL processes. These programs should stress the enhancement of the efficiency in carry out the urban operations and should promote forms of public contributions that represent a crucial lever of diffusion. Moreover, the platform should leverage on competitive factors that drive the decision-making of CL stakeholders regarding their Business Models.

8. Implications and Conclusion

The proposed analysis investigates the diffusion dynamics of an innovative ICT platform for CL systems. This study extends the literature on the modelling of innovation diffusion, which typically takes into account the diffusion of new technologies within one population, by exploring the cross-side effects across three populations of potential users.

Results show that, with the proposed parameter configuration, there is a concrete interest in adopting the proposed ICT platform within the simulation time frame, highlighting the demand by different stakeholders for projects aiming at carrying out more efficient urban logistics operations.

The proposed research addresses both theoretical and practical implications. From a theoretical point of view, this work contributes to the modelling of approaches for ex-ante evaluation of CL projects, by proposing an innovation diffusion model of a new CL technology. Moreover, it introduces aspects in the innovation diffusion modelling in the CL arena not enough considered in the already existing literature, such as the effects of word-of-mouth across different populations. This is particularly important since in CL the relationships among heterogeneous groups of stakeholders are crucial to gain their commitment and ultimately to stimulate the success of initiatives. In addition, the present work contributes to the existing modelling efforts about both the evaluation of CL projects and innovation diffusion by introducing the Business Model Canvas as an approach to identify and explore the levers of diffusion from the actors' perspective, by bringing out the actual value they give to innovative urban logistics services. This appears to be very relevant, since there is a clear positive relationship between the perceived value of a product or a service and the willingness to adopt it. Moreover, the participatory Business Model Canvas sessions allow uncovering the different requirements of the multiple populations of prospective adopters. In this way, all the potential diffusion levers are taken into account, and consequently their global effects on the adoption of the URBeLOG platform are considered.

From a practical point of view, this work aims to highlight the most important levers of diffusion for a more proper uptake of CL initiatives, in the light of the different requirements by the CL stakeholders and the value they are willing to recognize to innovative urban logistics services. Identifying the correct levers of diffusion might drive the strategies of the stakeholders proposing CL initiatives, in terms of resource allocation, marketing efforts, and value proposition.

As a matter of fact, the model shows that a correct integration among stakeholders' requirements can foster an effective implementation of innovative CL projects.

From a methodological point of view, the present contribution might also serve as a guideline for decision makers about how to adopt the Business Model Canvas with the aim of identifying the actual needs of the future users of CL services as a driver to set out the most appropriate features such services should have. Also, the participatory nature of the Business Model Canvas suggests that a shared design of CL initiatives together with the key stakeholders facilitates their first implementation and the consequent scaling up. In addition, the developed SD model provides a framework that can be potentially adopted by decision-makers to explore the cause and effect relationships among the different aspects characterising a CL system and thus to anticipate the effects of innovations at both an operational and a strategical level.

Finally, the proposed study can be exploited by public authorities for exploring the feasibility of public policies related to new technologies, such as the green delivery credit proposed in the case study. Additionally, the public subsidies theme discussed in this work, together with its beneficial effect on the platform diffusion, might help public authorities to ponder alternative forms of their involvement in actions to improve CL.

However, this work suffers from some limitations. In particular, aspects related to the utility that could be generated by the adoption of the URBeLOG platform are not considered in the model. Also, the value of the efficiency considered is an average value. In some cities, that value could be significantly higher, and in other ones wherein the CL issue is more mature could be lower. For this reason, future research will be addressed towards the introduction of more accurate depiction of the utility aspects related to the adoption of the platform and the development of sub-models that group the municipalities according to their level of maturity and familiarity with CL. Such improvement could provide more detailed insights on the diffusion dynamics of innovative CL projects.

Acknowledgements

This work was developed under funding by the Italian Ministry for Education, University and Research (MIUR), project titled URBeLOG, n. SCN_00200, awarder of call for proposal under funding scheme Smart Cities and Communities.

References

Alho, A.R., e Silva, J. de A., de Sousa, J.P. and Blanco, E. (2018), "Improving mobility by optimizing the number, location and usage of loading/unloading bays for urban freight vehicles", *Transportation Research Part D: Transport and Environment*, Elsevier, Vol. 61, pp. 3–18.

Arvidsson, N. and Pazirandeh, A. (2017), "An ex ante evaluation of mobile depots in cities: A sustainability perspective", *International Journal of Sustainable Transportation*, Vol. 11 No. 8, pp. 623–632.

Awasthi, A. and Chauhan, S.S. (2012), "A hybrid approach integrating Affinity Diagram, AHP and fuzzy TOPSIS for sustainable city logistics planning", *Applied Mathematical Modelling*, Vol. 36 No. 2, pp. 573–584.

Bass, F.M. (1969), "A new product growth for model consumer durables", *Management Science*, INFORMS, Vol. 15 No. 5, pp. 215–227.

Björklund, M., Abrahamsson, M. and Johansson, H. (2017), "Critical factors for viable business models for urban consolidation centres", *Research in Transportation Economics*, Elsevier, available at:https://doi.org/10.1016/J.RETREC.2017.09.009.

Blanco, R., Garcia, E., Gonzalez-Feliu, J., Pluvinet, P., Gardrat, M., Sartre, V., Salanova, J.M., et al. (2012), *FREILOT. Urban Freight Energy Efficiency Pilot. D.FL.4.2 Final Evaluation Report*.

Bohne, S. and Ruesch, M. (2013), *Best Practice Handbook 1- BESTFACT Deliverable D2.2.*, available at: www.bestfact.net.

Browne, M., Allen, J. and Anderson, S. (2005), "Low emission zones: the likely effects on the freight transport sector", *International Journal of Logistics: Research & Applications*, Vol. 8 No. 4, pp. 269–281.

Browne, M., Sweet, M., Woodburn, A. and Allen, J. (2005), *Urban Freight Consolidation Centres Final Report*, available at: http://ukerc.rl.ac.uk/pdf/RR3_Urban_Freight_Consolidation_Centre_Report.pdf.

Cagliano, A.C., Carlin, A., Mangano, G. and Rafele, C. (2017), "Analyzing the diffusion of eco-friendly vans for urban freight distribution", *The International Journal of Logistics Management*, Emerald Publishing Limited, Vol. 28 No. 4, pp. 1218–1242.

Cagliano, A.C., Carlin, A., Mangano, G. and Zenezini, G. (2015), "System dynamics modelling for electric and hybrid commercial vehicles adoption", *6th International Conference on Theoretical and Applied Mechanics (TAM '15)*, WSEAS Press, pp. 171–180.

Cagliano, A.C., De Marco, A., Mangano, G. and Zenezini, G. (2017), "Levers of logistics service providers' efficiency in urban distribution", *Operations Management Research*, available at:https://doi.org/10.1007/s12063-017-0125-4.

Cagliano, A.C., De Marco, A. and Rafele, C. (2014), "Understanding the Diffusion of a Mobile Application for Supply Chain Management: A System Dynamics Approach", *Mathematics and Computers in Science and Engineering Series*, WSEAS Press, Vol. 34, pp. 360–369.

Carslaw, D.C. and Beevers, S.D. (2002), "The efficacy of low emission zones in central London as a means of reducing nitrogen dioxide concentrations", *Transportation Research Part D: Transport and Environment*, Vol. 7 No. 1, pp. 49–64.

Casadesus-Masanell, R. and Ricart, J.E. (2010), "From strategy to business models and onto tactics", *Long Range Planning*, Elsevier Ltd, Vol. 43 No. 2–3, pp. 195–215.

Chesbrough, H. (2007), "Business model innovation: it's not just about technology anymore", *Strategy & Leadership*, Vol. 35 No. 6, pp. 12–17.

City of Lucca. (2008), *Center for Eco-Friendly City Freight Distribution (CEDM) Project-TECHNICAL FINAL REPORT*.

Dasburg, N. and Schoemaker, J. (2007), *Quantification of Urban Freight Transport Effects II-BESTUFS Deliverable Report 5.2*, available at: www.bestufs.net.

dell'Olio, L., Moura, J.L., Ibeas, A., Cordera, R. and Holguin-Veras, J. (2016), "Receivers' willingness-to-adopt novel urban goods distribution practices", *Transportation Research Part A: Policy and Practice*, available at:https://doi.org/10.1016/j.tra.2016.10.026.

Dezi, G., Dondi, G. and Sangiorgi, C. (2010), "Urban freight transport in Bologna: Planning commercial vehicle loading/unloading zones", *Procedia-Social and Behavioral Sciences*, Elsevier, Vol. 2 No. 3, pp. 5990–6001.

van Duin, J.H.R., van Dam, T., Wiegmans, B. and Tavasszy, L. órán. A. (2016), "Understanding Financial Viability of Urban Consolidation Centres: Regent Street (London), Bristol/Bath & Nijmegen", *Transportation Research Procedia*, Vol. 16, pp. 61–80.

Fisher, J.C. and Pry, R.H. (1971), “A simple substitution model of technological change”, *Technological Forecasting and Social Change*, Elsevier, Vol. 3, pp. 75–88.

Forrester, J.W. (1961), *Industrial Dynamics*, *Harvard Business Review*.

Gonzalez-Feliu, J., d’Arcier, B.F., Grau, J.-M.S., Hervé, T., Zubillaga, F., Jeftic, Z., Thebaud, J.-B., et al. (2013), “The deployment of urban logistics solutions from research, development and pilot results. Lessons from the FREILOT Project”, *Städtischer Wirtschaftsverkehr-Commercial/Goods Transportation in Urban Areas-Transports Commerciaux/Marchandises En Ville. Dokumentation Der Internationalen Konferenz 2012 in Berlin*, Deutsches Institut für Urbanistik, pp. 104–121.

Goodman, R. (2005), “Whatever You Call It, Just Don’t Think of Last-Mile Logistics, Last”, *Global Logistics & Supply Chain Strategies*, Vol. 9 No. 12.

Gorbea, C.E., Lindemann, U. and de Weck, O.L. (2011), “System Dynamics Modeling of New Vehicle Architecture Adoption”, *DS 68-10: Proceedings of the 18th International Conference on Engineering Design (ICED 11), Impacting Society through Engineering Design, Vol. 10: Design Methods and Tools Pt. 2, Lyngby/Copenhagen, Denmark, 15.-19.08. 2011*.

Gutiérrez, R., Nafidi, A. and Sánchez, R.G. (2005), “Forecasting total natural-gas consumption in Spain by using the stochastic Gompertz innovation diffusion model”, *Applied Energy*, Elsevier, Vol. 80 No. 2, pp. 115–124.

Harrington, T.S., Singh Srai, J., Kumar, M. and Wohlrab, J. (2016), “Identifying design criteria for urban system ‘last-mile’ solutions – a multi-stakeholder perspective”, *Production Planning & Control*, Vol. 27 No. 6, pp. 456–476.

Hayes, S., Ros, L., Roselló, X., Ramón, J.G., Vilar, E. and Perez, J. (2006), *REPORT ON EVALUATION RESULTS Annex 3 – 2nd Implementation Report for Barcelona-MIRACLES Project Deliverable D 4.2*.

Holguín-Veras, J., Encarnación, T., González-Calderón, C.A., Winebrake, J., Wang, C., Kyle, S., Herazo-Padilla, N., et al. (2016), "Direct impacts of off-hour deliveries on urban freight emissions", *Transportation Research Part D: Transport and Environment*, available at:https://doi.org/10.1016/j.trd.2016.10.013.

Janjevic, M., Kaminsky, P. and Ndiaye, A.B. (2013), "Downscaling the consolidation of goods-state of the art and transferability of micro-consolidation initiatives", *European Transport - Trasporti Europei*, No. 54.

Koç, Ç., Bektaş, T., Jabali, O. and Laporte, G. (2016), "The impact of depot location, fleet composition and routing on emissions in city logistics", *Transportation Research Part B: Methodological*, Vol. 84, pp. 81–102.

Loch, C.H. and Huberman, B.A. (1999), "A Punctuated-Equilibrium Model of Technology Diffusion", *Management Science*, Vol. 45 No. 2, pp. 160–177.

Macharis, C. and Kin, B. (2017), "The 4 A's of sustainable city distribution: Innovative solutions and challenges ahead", *International Journal of Sustainable Transportation*, Vol. 11 No. 2, pp. 59–71.

Macharis, C., Milan, L. and Verlinde, S. (2012), *STRAIGHTSOL-Deliverable 3.2: Report on Stakeholders, Criteria and Weights*, available at: http://www.straightsol.eu/deliverables.htm.

Macharis, C., Milan, L. and Verlinde, S. (2014), "A stakeholder-based multicriteria evaluation framework for city distribution", *Research in Transportation Business & Management*, Vol. 11, pp. 75–84.

Maier, F.H. (1998), "New product diffusion models in innovation management—A system dynamics perspective", *System Dynamics Review*, Wiley Online Library, Vol. 14 No. 4, pp. 285–308.

Marciani, M. and Cossu, P. (2014), "How the URBeLOG Project Will Enable a New Governance

Model for City Logistics in Italian Metropolitan Areas", *Procedia - Social and Behavioral Sciences*, Elsevier, Vol. 151, pp. 230–243.

De Marco, A., Giannantonio, R. and Zenezini, G. (2015), "The diffusion mechanisms of dynamic ridesharing services", *Progress in Industrial Ecology*, Vol. 9 No. 4, pp. 408–432.

De Marco, A., Mangano, G. and Zenezini, G. (2018), "Classification and benchmark of City Logistics measures: an empirical analysis", *International Journal of Logistics Research and Applications*, Vol. 21 No. 1, pp. 1–19.

De Marco, A., Mangano, G., Zenezini, G., Cagliano, A.C., Perboli, G., Rosano, M. and Musso, S. (2017), "Business Modeling of a City Logistics ICT Platform", *41st Annual IEEE Computer Software and Applications Conference (COMPSAC)*, Vol. 2, IEEE, pp. 783–789.

Marcucci, E. and Danielis, R. (2008), "The potential demand for a urban freight consolidation centre", *Transportation*, Vol. 35 No. 2, pp. 269–284.

Marcucci, E. and Gatta, V. (2017), "Investigating the potential for off-hour deliveries in the city of Rome: Retailers' perceptions and stated reactions", *Transportation Research Part A: Policy and Practice*, available at:https://doi.org/10.1016/j.tra.2017.02.001.

Milling, P.M. (2002), "Understanding and managing innovation processes", *System Dynamics Review*, Wiley Periodicals Inc., Vol. 18 No. 1, p. 73.

Musa, A., Gunasekaran, A. and Yusuf, Y. (2014), "Supply chain product visibility: Methods, systems and impacts", *Expert Systems with Applications*, Elsevier, Vol. 41 No. 1, pp. 176–194.

Navarro, J.L.A., Ruiz, V.R.L. and Peña, D.N. (2017), "The effect of ICT use and capability on knowledge-based cities", *Cities*, Elsevier, Vol. 60, pp. 272–280.

Osterwalder, A. and Pigneur, Y. (2010), *Business Model Generation: A Handbook for Visionaries, Game Changers, and Challengers*, John Wiley and Sons Inc., New York, USA, available at:https://doi.org/10.1523/JNEUROSCI.0307-10.2010.

Peres, R., Muller, E. and Mahajan, V. (2010), “Innovation diffusion and new product growth models: A critical review and research directions”, *International Journal of Research in Marketing*, Elsevier, Vol. 27 No. 2, pp. 91–106.

Pinto, R., Lagorio, A. and Golini, R. (2019), “The location and sizing of urban freight loading/unloading lay-by areas”, *International Journal of Production Research*, Taylor & Francis, Vol. 57 No. 1, pp. 83–99.

Pluvinet, P., Gonzalez-Feliu, J., d’Arcier, B.F., Gardrat, M., Basck, P., Ambrosini, C. and Routhier, J.-L. (2012), “Methodology, evaluation, simulation and assessment for the analysis of the deployment of DSB and EEIC systems of the FREILOT project Contribution of LET”, Laboratoire d’Economie des Transports.

Posthumus, B., Eris, B., Balm, S., Moolenburgh, E. and Quak, H. (2014), *Business Models for Innovative and Sustainable Urban-Interurban Transport-STRAIGHTSOL Deliverable D5.3*, available at: www.straightsol.eu.

Quak, H. and Van Duin, J.H.R. (2010), “The influence of road pricing on physical distribution in urban areas”, *Procedia - Social and Behavioral Sciences*, Vol. 2, pp. 6141–6153.

Quak, H.J. and de Koster, M.B.M. (2007), “Exploring retailers’ sensitivity to local sustainability policies”, *Journal of Operations Management*, Vol. 25 No. 6, pp. 1103–1122.

Richardson, G.P. (1991), “Feedback thought in social science and systems theory”, *Waltham, MA: Pegasus Communications Inc*.

Roumboutsos, A., Kapros, S. and Vanelslander, T. (2014), “Green city logistics: Systems of Innovation to assess the potential of E-vehicles”, *Research in Transportation Business & Management*, Vol. 11, pp. 43–52.

Ryan, S.P. and Tucker, C. (2012), “Heterogeneity and the dynamics of technology adoption”, *Quantitative Marketing and Economics*, Springer, Vol. 10 No. 1, pp. 63–109.

Seitz, C. and Terzidis, O. (2014), “Market Penetration of Alternative Powertrain Concepts in Heavy Commercial Vehicles: A System Dynamics Approach”, *32nd International Conference of the System Dynamics Society July*, pp. 20–24.

Shen, F. and Ma, T. (2013), “System dynamics modeling of diffusion of alternative fuel vehicles”, *International Conference on Knowledge Science, Engineering and Management*, Springer, pp. 241–251.

Shepherd, S., Bonsall, P. and Harrison, G. (2012), “Factors affecting future demand for electric vehicles: A model based study”, *Transport Policy*, Elsevier, Vol. 20, pp. 62–74.

Sterman, J.D. (2000), *Business Dynamics: Systems Thinking and Modeling for a Complex World*, *Business Dynamics: Systems Thinking and Modeling for a Complex World*, Vol. 53, available at:https://doi.org/10.1057/palgrave.jors.2601336.

Taniguchi, E. (2001), “City Logistics”, *Infrastructure Planning Review*, Japan Society of Civil Engineers, Vol. 18, pp. 1–16.

Taniguchi, E. and Tamagawa, D. (2005), “Evaluating City Logistics Measures Considering the Behavior of Several Stakeholders”, *Journal of the Eastern Asia Society for Transportation Studies*, Vol. 6, pp. 3062–3076.

Thaller, C., Clausen, U. and Kampmann, R. (2016), “System Dynamics Based, Microscopic Freight Transport Simulation for Urban Areas”, *Commercial Transport*, Springer, pp. 55–72.

Thompson, R.G. and Taniguchi, E. (2008), “City logistics and freight transport”, *Handbook of Logistics and Supply-Chain Management*, Emerald Group Publishing Limited, pp. 393–405.

Timma, L., Bariss, U., Blumberga, A. and Blumberga, D. (2015), “Outlining innovation diffusion processes in households using system dynamics. Case study: energy efficiency lighting", *Energy Procedia*, Elsevier, Vol. 75, pp. 2859–2864.

TRAILBLAZER. (2010), *O2.1 CASE STUDY - Bristol, UK. Consolidation of Deliveries to Bristol City Centre*, available at: http://www.trailblazer.eu/content.php.

Tsai, J.-M. and Hung, S.-W. (2014), "A novel model of technology diffusion: System dynamics perspective for cloud computing", *Journal of Engineering and Technology Management*, Elsevier, Vol. 33, pp. 47–62.

Verlinde, S., Macharis, C. and Witlox, F. (2012), "How to Consolidate Urban Flows of Goods Without Setting up an Urban Consolidation Centre?", *Procedia - Social and Behavioral Sciences*, Vol. 39, pp. 687–701.

Appendix – System Dynamics Model Equations

LSP = 9

Units: Users

Municipalities= 224

Units: Users

Own account Carriers= 2688

Units: Users

Adopters LSP= INTEG (Adoption Rate LSP, 0)

Units: Users

Adopters Own account Carriers= INTEG (Adoption Rate Own account Carriers, 1)

Units: Users

Adoption effectiveness from Advertising LSP= 0.008

Units: Dmnl

Adoption effectiveness from Advertising Own account Carriers= 0.008

Units: Dmnl

Adoption Fraction LSP = LSP Effect of Efficiency + Foot Print Effect LSP

Units: Dmnl

Adoption Fraction LSP-Municipalities cross-side = Foot Print Effect LSP+LSP Effect of Efficiency

Units: Dmnl

Adoption Fraction Municipalities = min (max (Effect of profit of Platform Municipalities + M Effect of Green Image, 0), 1)

Units: Dmnl

Adoption Fraction Municipalities-LSP cross-side = 0.005

Units: Dmnl

Adoption Fraction Own account Carriers = Adoption from Efficiency OAC+Foot Print Own account Carriers

Units: Dmnl

Adoption from Efficiency OAC = Effect of Cost OAC*Routing Management and Efficiency OAC

Units: Dmnl

Adoption from WoM LSP-OAC cross-side = Foot Print Effect LSP+LSP Effect of Efficiency

Units: Dmnl

Adoption Rate – Municipalities = max (0, Municipalities Adoption Rate from Advertising+ Municipalities - Adoption Rate from WoM)

Units: Users/Month

Adoption Rate from Advertising OAC = (Potential Adopters Own account Carriers*Adoption effectiveness from Advertising Own account Carriers)/Time Factor

Units: Users/Month

Adoption Rate from Green Image and Advertising LSP = (Potential Adopters LSP*Adoption effectiveness from Advertising LSP)/Time Factor

Units: Users/Month

Adoption Rate from WoM LSP = LSP Intraside WoM+ Cross-side WoM from Municipalities to LSP

Units: Users/Month

Adoption Rate from WoM Own account Carriers = WoM among Own account Carriers+WoM from LSP to Own account Carriers

Units: Users/Month

Adoption Rate LSP = max (0, Adoption Rate from Green Image and Advertising LSP+Adoption Rate from WoM LSP)

Units: Users/Month

Adoption Rate Own account Carriers = max (0, Adoption Rate from Advertising OAC+Adoption Rate from WoM Own account Carriers)

Units: Users/Month

Contact Rate LSP = 0.11

Units: 1/Month

Contact Rate LSP and Own account Carriers = 0.008

Units: 1/Month

Contact Rate Municipalities= 0.004

Units: 1/Month

Contact Rate Municipalities and LSP = 0.005

Units: 1/Month

Contact Rate OAC = 0.054

Units: 1/Month

Cost of Platform for Municipalities = (Subscription fees Municipalities*Municipalities Adopters*Unit conversion factor) + Unit conversion factor*(Public Subsidies LSP at time step*Adopters LSP + Public Subsidies OAC at time step*Adopters Own account Carriers)

Units: €/Month

Cost of Platform LSP = Subscription fee LSP + Green Credit Monthly Fee

Units: €/Month

Cost of Platform OAC= Green Credit Monthly Fee + Subscription fees OAC

Units: €/Month

Cross-side WoM from LSP to Municipalities = Adopters LSP* Municipalities - Potential Adopters *Contact Rate Municipalities and LSP * Adoption Fraction LSP-Municipalities cross-side/(# LSP + # Municipalities)

Units: Users/Month

Cross-side WoM from Municipalities to LSP = Municipalities Adopters*Potential Adopters LSP* Adoption Fraction Municipalities-LSP cross-side *Contact Rate Municipalities and LSP/(# LSP + # Municipalities)

Units: Users/Month

Duration of subsidies LSP = 12

Units: Month

Duration of subsidies OAC = 12

Units: Month

Effect of Cost OAC = max (Effect of Reduction in Vehicle Operational Cost OAC-Effect of Cost of Platform OAC, 0.001)

Units: Dmnl

Effect of Cost of Platform LSP = (Cost of Platform LSP-Public Subsidies LSP at time step)/Cost of Platform LSP

Units: Dmnl

Effect of Cost of Platform OAC= (Cost of Platform OAC-Public Subsidies OAC at time step)/Cost of Platform OAC

Units: Dmnl

Effect of profit of Platform Municipalities = (Revenues for Municipalities-Cost of Platform for Municipalities)/Revenues for Municipalities

Units: Dmnl

Effect of Reduction in Vehicle Operational Cost OAC = Efficiency in Distance OAC

Units: Dmnl

Efficiency in Distance LSP = 0.18

Units: Dmnl

Efficiency in Distance OAC = 0.2

Units: Dmnl

Efficiency in Service Time LSP = 0.07

Units: Dmnl

Efficiency in Service Time OAC = 0.12

Units: Dmnl

Foot Print Effect LSP = Efficiency in Distance LSP

Units: Dmnl

Foot Print Impact= Adopters LSP*Foot Print Effect LSP+Adopters Own account Carriers*Foot Print Own account Carriers

Units: Users

Foot Print Own account Carriers= Efficiency in Distance OAC

Units: Dmnl

Green Credit Monthly Fee = 0.5

Units: €/MonthLSP Effect of Efficiency = max ((Routing Efficiency LSP-Effect of Cost of Platform LSP) , 0.001)

Units: Dmnl

LSP Intraside WoM = (Adopters LSP*Potential Adopters LSP*Contact Rate LSP*Adoption Fraction LSP /"# LSP")

Units: Users/Month

M Effect of Green Image = Table for Green Image Effect(Foot Print Impact)

Units: Dmnl

Municipalities - Adoption Rate from WoM = Municipalities - Intraside WoM + Cross-side WoM from LSP to Municipalities

Units: Users/Month

Municipalities - Intraside WoM = Municipalities - Potential Adopters *Municipalities Adopters*Adoption Fraction Municipalities *Contact Rate Municipalities/# Municipalities

Units: Users/Month

Municipalities - Potential Adopters = INTEG (- Adoption Rate - Municipalities, # Municipalities)

Units: Users

Municipalities Adopters= INTEG (Adoption Rate - Municipalities, 1)

Units: Users

Municipalities Adoption Effectiveness from Advertising = 0.0015

Units: 1/Month

Municipalities Adoption Rate from Advertising = Municipalities - Potential Adopters *Municipalities Adoption Effectiveness from Advertising

Units: Users/Month

Potential Adopters LSP= INTEG (-Adoption Rate LSP, "# LSP")

Units: Users

Potential Adopters Own account Carriers= INTEG (-Adoption Rate Own account Carriers, # Own account Carriers)

Units: Users

Public Subsidies LSP = 0

Units: €/Month

Public Subsidies LSP at time step = Public Subsidies LSP - STEP(Public Subsidies LSP,Duration of subsidies LSP)

Units: €/Month

Public Subsidies OAC= 0

Units: €/Month

Subscription fees OAC = 10

Units: €/Month

Subscription fee LSP=10

Units: €/Month

Time Factor = 1

Units: Month

Unit conversion factor = 1

Units: 1/Users

WoM among Own account Carriers = (Potential Adopters Own account Carriers*Adopters Own account Carriers*Adoption Fraction Own account Carriers*Contact Rate OAC /"# Own account Carriers")

Units: Users/Month

WoM from LSP to Own account Carriers= Potential Adopters Own account Carriers*Adopters LSP*Adoption from WoM LSP-OAC cross-side *Contact Rate LSP and Own account Carriers/(# LSP+ # Own account Carriers)

Units: Users/Month