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Conceptual Design of an Integrated Solution for Urban Logistics using Industry 4.0 principles

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Abstract

The paper proposes a conceptual model of an integrated solution for urban logistics and passenger flows to reduce the number of fossil combustion powered commercial vehicles traveling within city, solely for goods transportation, thus contributing to reduce negative effects of urban logistics activities, namely pollution, noise, traffic congestion and accidents. For this solution, a bus network is used to combine the cargo flow with the passenger flow within the cities. After a literature review, a user-centered approach supported by interviews with key stakeholders was followed to define the concept, followed by solution modelling using the Unified Modeling Language (UML) notation. Thus, the high-level requirements will be presented based on a use-cases diagram and the data model based on a class diagram. Also, the automatic order check-in and check-out process on the bus is designed, using Industry 4.0 and IoT principles. This process is relevant since it speeds up the handling of orders in transshipments, reduces the possibility of human error, while at the same time enhancing control and promoting real-time knowledge of the delivery status of orders. The results of this study expand the knowledge in an area with scarce literature. In practical terms this study presents valuable contributions, since it specifies a solution for urban logistics that can have environmental and social impact in the context of urban areas.

Keywords: Conceptual design; UML; Integrated Urban logistics, Urban Logistics 4.0

1. Introduction

The continuously increasing share of population living in urban areas and the rise of online internet sales (e-commerce) reinforce the concern and importance of adopting solutions that help urban areas to improve their life

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quality. Freight and transport have been considered as a significant disturbance to the quality of the urban spaces, especially near areas of historical and artistic value [1].

According to [1] in 1950 only 30% of the global population was living on urban areas, but it is expected that in 2050 this value increases to 66% and in 2100 it reaches 85%, representing an increase of 8 billion of people living is such areas. According to reports by eMarketer (May 2019), annual B2C e-commerce sales reached 3.5 trillion dollars in 2019, 20% more than the previous year, and it is expected to reach 6.5 trillion dollars in 2023. It is important to note that the increase in the transport of goods to the home of consumers instead of conventional retail stores will result in a significant increase in logistics transport vehicles and, consequently, an increase in urban traffic. This increase in traffic contributes significantly to the increase of traffic congestion, noise and environmental pollution, road accidents and the emission of greenhouse gases [2]. Additionally, new services and startups have emerged to respond to the growing market segment where end consumers or companies that buy online intend to receive their goods in less than an hour or two, already representing about 2.5% of all transport within large cities [1]. Also, according to these authors, the increase in this type of instant transport leads to a significant increase in the number of vehicles operating in city centers. Thus, although the main focus of urban logistics is on the main carriers operating in the market, it is necessary to think of a solution for urban logistics that is transversal in the supply chain, making it integrated and sustainable [3].

This paper presents the conceptual model of an integrated solution (SOLFI) for urban logistics. SOLFI is mainly a solution for an environmental-friendly transportation service within cities through the integration of flows of people and goods using, whenever possible, the same transportation network. SOLFI is a new logistics service for the distribution of goods in urban environments, focusing on the use of the bus transportation infrastructure operating in the urban network and the use of environmentally friendly fleets, to ensure the last mile delivery of some types of goods. The new service is particularly suited to the delivery of parcels to shops, private customers or public or private entities [4].

For this study, an exploratory approach has been followed. The research topic emerged from a real problem experienced by practitioners in urban logistics area being the aim of this research is to present a potential innovative solution for that problem. Accordingly to [5] our problem can be classified as “class (2) well-structured problem situations with clear objectives but uncertain user requirements” and the authors suggest that data modelling, process modelling or prototyping are likely to be appropriate methodologies in these situations.

The remaining of this paper is organized as follows. In Section 2 Urban Logistics and the use of advanced technologies are presented. Section 3 briefly describes the integrated urban logistics service proposed (SOLFI). In Section 4 a conceptual model for SOLFI is presented. The paper concludes with Section 5 where the main conclusions of this research are drawn.

2. Urban logistics: context and challenges

Urban logistics, or city logistics, is an important subject of urban mobility concerned with the activities of delivering and collecting goods in a town and city centers. These activities typically entail the processes of transportation, handling and storage of goods, the management of inventory, waste and returns as well as home delivery services, being of critical importance their support through advanced information systems considering the traffic environment, its congestion, safety and energy savings [6]. [7] define urban logistics as “that part of supply chain management that plans, implements, and controls the efficient, effective forward and reverse flow and storage of goods, services, and related information between the point of origin and point of consumption in order to meet customers’ requirements, as influenced by complex interactions among densely populated social systems and associated infrastructure”.

The problem of urban logistics is characterized by a very high degree of complexity. One of the main sources of complexity is due to the fact that there are several stakeholders with different and sometimes contradictory objectives. On one hand, we have local and central government, urban planners and residents whose main concern focuses on sustainability of cities and quality of life. On the other hand, we have customers, suppliers and distribution companies whose focus is on reducing costs and increasing efficiency. This uncertain and ambiguous environment in city logistics makes decision making evermore challenging [8].

Currently, the distribution of goods in cities is carried out by private companies, typically by logistics operators or by the suppliers of the goods themselves, through a dedicated fleet of vehicles (typically vans and trucks) powered by fuels derived from Petroleum. In this context, the problem is aggravated by the existence of a huge number of small orders (in volume and weight) that must be collected and/or delivered to a large number of customers (private as well as public/private and/or retail services), concentrated in some areas dispersed in the city, which implies a great challenge in the optimization of daily loads, in order to provide a service adjusted to the needs of customers and to optimize the available resources.

On the other hand, passenger transport in the city is mostly provided by a dedicated network, public or private, of buses, taxis, trams and metro. Throughout the daily operation, there are significant variations in the number of passengers using a transport service, although the transport network continues to operate uninterruptedly throughout the day, albeit with less frequency. This situation leads to the system's performance, in terms of capacity utilization, being less than desirable, creating challenges in terms of fleet and driver management. This complex challenge entails the need to minimize the negative impacts associated with the traditional way of distributing goods within cities.

In this context, a new perspective resulting from the integration of passenger flows and freight flows, in order to ensure the distribution of goods in a more efficient and environmentally responsible manner, making use, whenever possible, of the same transport network, is gaining attention. This integration is being reported, in several case studies [9] [10] [11] [12] [13], although the literature in which it is properly studied is almost inexistent. The implementation and operation of these shared/collaborative networks remain a big challenge [14].

This co-modality, the combination of passenger traffic and freight transport, is one of the major dimensions of City Logistics 4.0, along with others such as integrated platforms based on advanced ICT, ITS, IoT and AI systems, and public-private partnerships involving participation of all stakeholders (government, shippers, freight carriers, administrators, residents) for balancing economic growth and environmental friendliness [15], [16].

In the recent literature several advanced technologies are being proposed to support urban logistics activities and reduce its negative impacts. As an example, [17] propose a drone-based parcel delivery using rooftops of city buildings. [18] approach an urban logistics system grounded in networks of smart locker banks as pickup and delivery points in the inner city. Also, [19] introduce the Joint Distribution urban logistics concept, which is an intelligent platform to provide efficient, reliable, high-quality, low-cost and personalized logistics services for the whole process of delivery, using Internet of things, Internet, Cloud computing and RFID. To conclude, [20] use a Cyber Physical System to dispatch urban logistics vehicles.

3. SOLFI: the proposed integrated urban logistics solution

This paper intends to propose a solution to develop an efficient and environmental-friendly transportation service within cities. This new service is based on an intelligent decision support system helping operational planning. To accomplish this, the solution uses bus network of passenger flow and its available capacity to transport goods into the

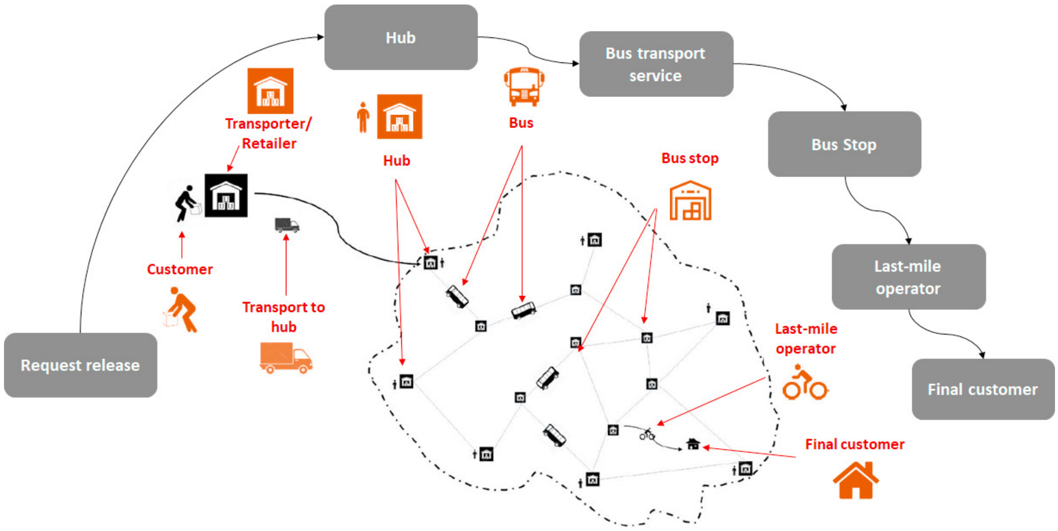


Figure 1 - Main steps of SOLFI - integrated urban logistics solution

city center. This solution also considers a last-mile operator, with an environmental-friendly fleet, to deliver the volumes from the bus to the final customer. The main steps of the proposed solution are illustrated in figure 1.

The key pieces of the solution can be briefly described as follows:

- **Request release** - The customers/sender of this service are any type of entity that intends to send goods to a location within the city, typically a logistics company, a retailer, or a private customer. Each customer places the order in the system providing the initial address, destination address, quantity, time window for delivery to the final customer and release time. This customer/sender is responsible for deliver the order at the hub indicated by the intelligent decision support system.
- **Hub** - Place where bus routes start and where orders are left by customers/senders. Subsequently, orders are organized and each one is assigned to a bus route.
- **Bus transport service** - The arrival time of each bus service to the respective hub and the transportation time between the hub and each stop of the route are known. Buses have capacity constraints that must be considered to maintain the service level of the passenger flow.
- **Bus stop** - Each bus stop is characterized by its unloading capacity and the time needed to unload the goods last-mile operator. It is assumed that goods cannot be loaded into the buses at the bus stop but only on respective hubs.
- **Last-mile operator** – logistic operator to deliver goods from the bus stop to the final destination. This entity is responsible to guarantee the delivery time window at the final customer.
- **Final customer** – The entity that receive and confirm that the order has been delivered at the right location.

4. The conceptual model for SOLFI - integrated urban logistics solution

The following subsections describe the system through Unified Modeling Language (UML) models [21], [22]. The UML models provide information about static structure and dynamic behavior of the system through diagrams that are windows or views unto UML models. The UML diagrams can be divided in two main categories: structural and behavioral. The structural group describes the components of the system and their relationships such as package diagrams, component diagrams or class diagrams and the behavioral category describes the behavior of the system over time, for example, activity diagrams or use case diagrams. The next subsections present the UML use case diagram to illustrate the functional requirements of the system and its representation from the user's point of view and also the UML class diagram as a data model to represent the main information objects, and relationships, to accomplish the functional requirements. In this project and after a literature review, a user-centered approach supported by interviews with key stakeholders was followed to define the conceptual model. These interviews were non-structured and exploratory interviews that were performed with key partners of the project, such as, public transportation enterprises, last mile operators and logistic operators, contributing to design the concept for this solution.

4.1. Functional requirements of the solution

The high-level use case diagram illustrates the main functional requirements of the system, the use cases as ellipses and the actors in the system as human figures. The figure 2 shows a use-case diagram illustrating the main functionalities and actors of the SOLFI system.

This model starts with the customer/sender performing a use case which is "request order quotation". Then the system calculates the final quotation and performs planning, using algorithms and optimization models, to transport the respective order and returns the information to the customer who requested the quotation. Note that the use cases that are performed by the system are represented in blue, in order to distinguish them from the use cases performed by the other actors. The customer is also notified by the system of the distribution plan for his/her order. After receiving notifications from the system with the final quote and the order distribution plan, the customer decides whether to register the order or not. In case of customer proceed with the order placement, it is necessary to confirm the order, which will authorize the system to create notifications and send them to all actors involved in the order distribution process. These notifications include the distribution plan with details for each of the actors who will interact with the order such as the estimated time when the order arrives to each part in the delivery process. Thus, the customer is notified of the location and times that the order must be dropped off at the hub and then the order is checked-in on the respective urban transport, notifying the last-mile operator this check-in was successful.

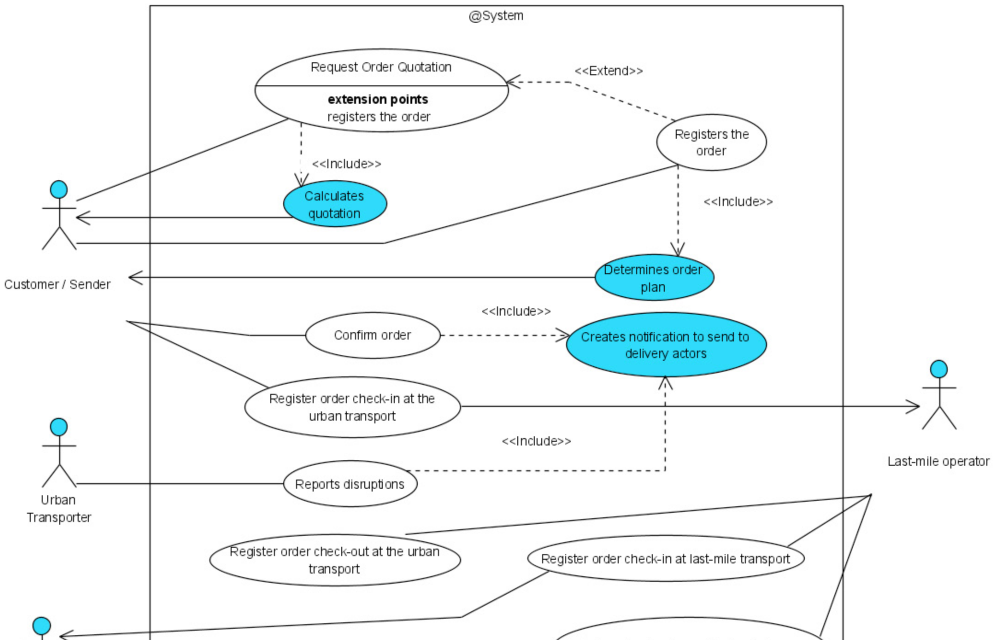


Figure 2 - Use-case diagram representing the main functionalities and actors of the SOLFI system

The urban transporter is responsible for transporting the order along its route and communicating any disruptions in transport, such as traffic accidents, breakdowns, etc. When the bus arrives at the stop where the order has to be unloaded, a last-mile operator must be present to make the transfer between the bus for his/her vehicle. In order to minimize the stopping time for urban passenger transport, the last-mile operator performs the check-out of the order from the bus and automatically the check-in in his/her last-mile vehicle. When the check-in of the last-mile operator is carried out, a notification is sent to the final customer informing the status of the order as well as the estimated delivery time at the destination address. When the order is delivered to the destination address, the last-mile operator checks out the order from last mile transport. The final customer also has a use case that confirms receipt of the order.

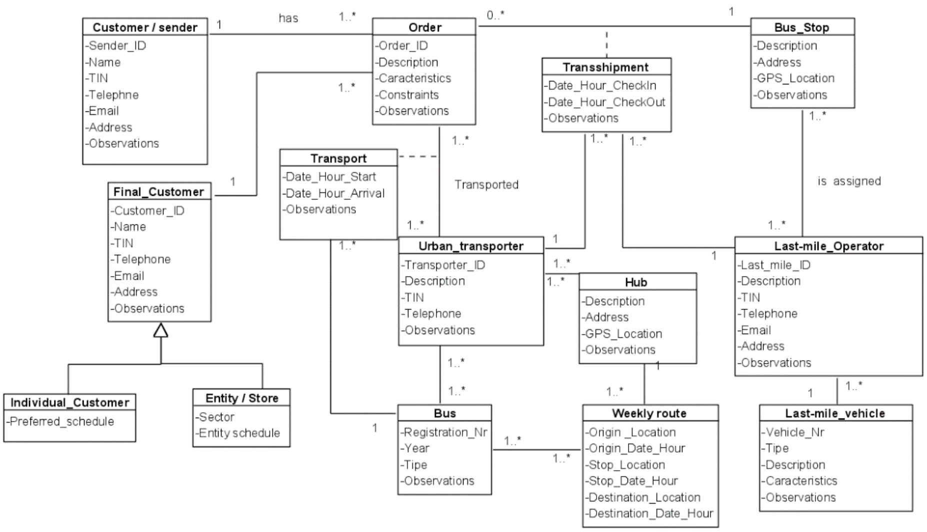
This model is a high-level model that illustrates the macro operation of the system as well as its requirements, step by step, throughout the order distribution process, in a scenario where everything goes well.

4.2. Data model of the solution

The UML class diagram is a representation of the structure and relationships between classes as well as their attributes. This type of diagram allows to represent in a simple and graphical way the functioning of the system. A class is represented by a square divided into 2 sections: the upper section represents the name of the class, the lower section its attributes. Between classes there are relationships that are represented by a line. The figure 3 illustrates the general class diagram of the system.

This diagram represents the general structure of the SOLFI solution as well as the main relationships between the key elements. The diagram starts with a sender who wants to send an order. These two classes, with their respective attributes, are related in a way that each sender can have one or more orders to send and each order can only be sent by one, and only one, sender. Then the final customer class is presented, ensuring that each order has one and only one final customer and that each final customer can have one or more orders. The order class is related to the urban transport class in which the relationship is many to many. This relationship results in the transport, which represents loading of the order to urban passenger transportation vehicle and its transportation, characterized by the date and start and arrival time. This transport is related to one and only one bus, and it can have one or more transports. The bus can have one or more weekly routes, and vice versa. Each route is associated with one and only one Hub. Each order is associated with one, and only one, bus stop for unloading. This relationship results in transshipment which represents the unloading of the order from the bus order to one, and only one, vehicle of the last-mile operator. Each last-mile operator is associated with one or more transshipment and one or more bus stops. Each last-mile operator is associated with one and only one vehicle type, but each vehicle type can be used by one or more operators.Figure 3 – General UML class diagram for SOLFI

4.3. Intelligent process of check-in and check-out using Industry 4.0 technologies



This subsection presents a use-case diagram developed to represent the interface between the order and the bus. The aim is to develop an automatic method to perform the check-in and check-out of the order volumes form/to the bus automatically, through the usage of specific tools such as sensors, authentication cards or other type of technology. This method will require some adjustments on the bus structure to perform check-in and check-out automatically and on real time. This automatic approach to update the order status on the system delivers some advantages, once the human interface with the system itself is minimized, avoiding potential errors or delays during the process. These delays are even more important on the step previously named as "transshipment", where the bus stops to unload the goods to the last mile operator and has to be quick to be possible to continue his/her route and accomplish his/her schedule. The figure 4 represents a use case diagram focused on this automatic method.

As can be seen from the interactions represented in the figure 4, this starts when the urban transporter enters his credentials in the system through the scanning of his personal identification card or even his/her fingerprints, assuring a fast and reliable log-in process when compared to a manual method for the same goal. The system, then, analyze the credentials and perform the authentications for the respective user. Once again, the use-cases that are performed by the system are represented with blue. After this log-in is performed successfully, the urban transporter puts the order into an available slot of a dedicated container present on the bus. This container has to be equipped with technology that can identify the presence of the order into the respective slot to confirm the check-in. After this, the system will notify the last-mile operator about the check-in status with information about the bus and slot where the order is stored. When the bus arrives to the unloading bus stop, the last-mile operator enters on the bus and insert his/her credentials in the system, through the same method used previously by the urban transporter. The system will then perform the authentication and only allows the logistic operator to access and open the slots that were assigned to him to avoid wrong order pick-ups from the bus. When the last-mile operator picks the order from the slot, the system will automatically perform the check-out of the order and update its status on the system. When the last-mile operator closes the trunk of the bus, the system registers the check-in (in the last mile operator) and at the same time notify the final customer with information about the state of the order and respective location. The system instantly updates the slot status to "empty" so it can receive and store more orders on the next iteration. During all the process, only the authorized users can access the parcels since these are enclosed into the containers.

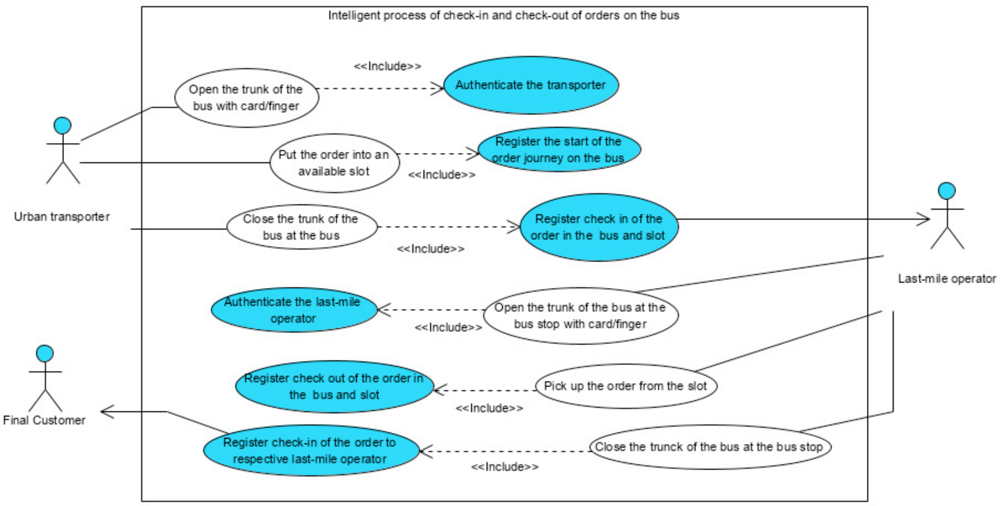


Figure 4 – Use-case diagram reporting automatic process of check-in and check-out of the orders

5. Conclusions

This paper presented the conceptual design of an integrated solution for Urban Logistics using Industry 4.0 principles, more specifically in the check-in and check-out processes. The main results of this study are the behavioral and structural modelling of the system that were documented by a set of UML diagrams, designated as use case diagram and data model. The conceptual design presented on this study has provided a better understanding of the real problem, since it allowed to define the actors on system, their relationships and the limitations on their actions. The models described on this study also provided some deeper insights on how the interface with the IT system should be performed to answer stakeholders' requirements.

These results were based on the literature review and the feedback from key stakeholders of this project about their needs and concerns through non-structured interviews.

The final solution presented on this work implies some adaptation and investment to the bus fleet to integrate technology that enables the IoT potential and the cargo safety and, consequently, the intelligent processes of check-in and check-out. These intelligent processes are truly important for the safety, speed and flexibility during the cargo transshipments.

It is important to emphasize that studies addressing solution that integrates urban passenger and goods flows are scarce in the literature so, this conceptual design is a valuable theoretical contribution for the field. Also, this work reported in this paper is part of a larger project that is under development and so, as limitations, next steps are required to test and validate the conceptual designed system proposed. The prototype of this solution will be test in a real and controlled scenario to evaluate its executability and suitability, performing some practical contribution for the field. This pilot will be performed in a near future contributing for this investigation with practical insights about the implementation of this concept in a real-world scenario. Also, structured interviews and questionnaires are being developed and will be performed on key stakeholders on the next iteration of the project, to detail and define the current concept at a lower level.

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