Last Mile Logistics in Smart Cities: An IT Platform for Vehicle Sharing and Routing

Emanuele Guerrazzi

Abstract Due to the current remarkable growth of e-commerce, the *last mile* logistics has become a relevant problem. In this paper, the main issues of the *last* mile logistics in a smart city context are introduced. We propose a solution based on a shared Information Technology (IT) platform that needs no material investments. The principle of resource pooling is applied to the sharing of heterogeneous vehicles in the urban network. In particular, an IT platform powered by an optimization algorithm is proposed to allow couriers to make their deliveries more efficiently, that is, to reduce the total distance covered by the vehicles. This was achieved through the development of four software modules: an ETL, an optimizer, a web application and a map displayer. First results are promising, but further investigations should be done in order to evaluate more accurately the expected benefits and the possible positive externalities such as improvement of air quality in the city.

Keywords Last mile delivery · Logistics · Smart city · Vehicle sharing

1 Introduction

In the recent years, business practices worldwide have been shaped by the remarkable rise of e-commerce. The rapid e-commerce growth has resulted in the steady increase of parcel delivery and returns volumes, which has accentuated the pressure on last mile delivery actor and has created a demand for new solutions [1].

Globalization and the web market have led to exponential growth in transport, allowing the development of an open market: products can be purchased anywhere; goods travel around the world; and most of the goods are delivered to cities. The topic of the last mile delivery is dealt with innovative modes thanks to the development of Information and Communication Technologies (ICT), Information Transport Systems (ITS), Industry 4.0 and new transport vehicles [2].

E. Guerrazzi (✉)
University of Pisa, 56121 Pisa, PI, Italy
e-mail: emanuele.guerrazzi@gmail.com

A. Lazazzara et al. (eds.), *Exploring Digital Ecosystems*,
Lecture Notes in Information Systems and Organisation 33,
https://doi.org/10.1007/978-3-030-23665-6_18

In this context, a *Smart City* is defined as "A ICT enabled development which extensively uses information as a way to improve quality of life for its citizens and population at large" [3]. It is well known that transportation is one of the main contributors of CO_2 emissions [4]. Thus, public authorities are encouraging companies to collaborate in order to increase sustainability. They not only aim at reduced emissions of harmful substances, but also on reduced road congestion, and noise pollution.

Urban areas require a massive quantity of goods, services and resources, which are causing many problems for citizens. Transportation systems are often influenced by unexpected conditions that affect their performance, with inconveniences for citizens due to the lack of interoperability among the various transport operators [5]. Studies indicate that freight vehicles represent no more than 15% of total traffic flow in urban areas [6], but due to their size and frequent stops for deliveries have a more significant impact than passenger vehicles.

Sii-Mobility Project, co-founded by Italian Ministry of Education, University and Research, aims to create an ICT platform for the introduction of smart solutions for urban mobility, the optimization in the use of public and private resources and the reduction of traffic and pollution impacts in urban areas, improving the concept of "*smart city*" as a solution to face the increasing problems related to traffic and pollution and the growing demand for sustainable mobility and quality of services [7]. In this context, we focus on a typical city logistic scenario, where there are a certain number of *couriers* and a much bigger number of *last-mile operators* (aka "*masters*") that are accountable for delivering and picking up small packages in the urban and extra-urban environment. These operators have exclusive agreements with couriers, and they are responsible for picking up packages at the logistic centres and for visiting the final addressees. This transportistic organization leads to a redundant presence of vehicles of different couriers, even at the same addresses or in the same areas in the same day, resulting in an increase of urban traffic, an increase of delayed deliveries and an increase of pollutant emissions, as well as all the indirect consequences.

The main objective of this work is to provide couriers with a tool that allows them to organize more efficiently their last mile distribution, through the shared use of vehicles and Information Technology (IT) platform in a *smart city* context. The core of the designed IT platform is powered by an optimization algorithm in order to make the distribution of goods in the last-mile delivery more efficient.

This article is organised as it follows. In Sect. 2 the state of the art about last mile delivery and vehicle sharing is presented. Section 3 shows more in detail the objectives and the methodology used for this work. In Sect. 4 preliminary results are shown. Finally, the discussion and conclusions, including future developments, are presented in Sect. 5.

2 State of the Art and Empirical Background

Ranieri et al. [2] provides a review of the last mile logistics innovations in an externalities cost reduction vision, classifying the innovative contributions into five categories:

(1) Innovative vehicles
(2) Proximity stations or points
(3) Collaborative and cooperative urban logistics
(4) Optimization of transport management and routing
(5) Innovations in public policies and infrastructures.

Particularly, this work deals with issues 3 and 4.

The cooperative urban logistics concept is based on the sharing of the resource and the revenue in the last mile delivery. An interesting application can be found in [8], in which the delivery of small- and medium-sized packages is carried out using public transport means. Liakos and Delis [9] propose an interactive freight-pooling service using a *trustee* (i.e. a city authority) to orchestrate the process by specifying constraints (i.e. changing time windows). In this work a *cluster-first route-second* heuristic has been used in order to optimize the cost of the last-mile delivery, supposing that the cost depends on the time the freight remains engaged to a hired carrier and suggesting a fair pricing policy that encourages the participation of couriers.

We mention also Juan et al. [10] that discuss a backhaul-based cooperation among couriers, comparing cooperative and non-cooperative scenarios. Results show that cooperation leads to a lower distance overall covered, even if the technique is limited only to the backhaul route.

For what it concerns the optimization of transport management and routing we cite the work of Kin et al. [11], where a mathematical model is developed to calculate the costs of alternative distribution set-ups for the last mile transportation in urban areas. This work suggests four different set-ups (direct, cross-dock, direct with small vehicles, urban consolidation centre) depending on the volume of transported items and distances covered.

Zhou et al. [12] introduce a city logistics problem in the last mile distribution involving two levels of routing problems (depots-satellites, satellites-customers), proposing a hybrid multi-population genetic algorithm.

Actually, routing problems in logistics are modelled as variants of the VRP, and they are often solved by heuristics [13], especially when applied to the real-world.

As concerning the empirical background, in the EU area, a number of innovative experiences about city logistics have been implemented in the last decades. The most important are reported here following (for a more detailed description see [14]):

- On street package collection and delivery stations (Germany)
- Coventry's zero-emission postal service (UK)
- Delivering goods by cargo tram in Amsterdam (Netherlands)
- Electronic vehicles for companies in Stavanger (Norway)
- Utrecht's sustainable freight transport (Netherlands)

- Smart packaging solutions for cleaner urban freight in Berlin (Germany)
- Padova Cityporto: a success model for urban logistics (Italy)
- Distripolis: a new city logistics solution in Paris (France).

3 Objectives and Methodology

3.1 Objectives

The main objective of this Sii-Mobility solution is to allow multiple couriers to optimize their last-mile delivery using a shared pool of vehicles. In order to achieve this purpose, it is necessary to accomplish the following objectives:

(1) Allow data integration and sharing among all couriers and masters. In particular, couriers have to share their transportistic requests and masters have to share the information about their vehicle fleet.
(2) Make the overall distribution more efficient, in terms of:
    a. Reducing couriers' logistics costs
    b. Reducing air pollution in the urban context
    c. Reducing traffic jam
(3) Show the route to drivers, using a suitable displayer.

Main benefits expected from such a solution are:

- sharing the logistics resources for pickup and delivery
- optimizing the use of the available resource in order to reduce cost
- reducing urban mileage and consequently reducing pollution and traffic
- improving the quality of services.

3.2 Methodology

The proposed solution is IT platform that enables the centralization and processing of info from several couriers and *masters* in order to optimize the pickup and delivery processes of goods.

An overall vision of the IT platform is reported in Fig. 1.

In the following, each part of the system will be described.

ETL Module This module implements ETL processes in order to retrieve information from external and heterogeneous sources and to store them on a shared Data Warehouse (DW).

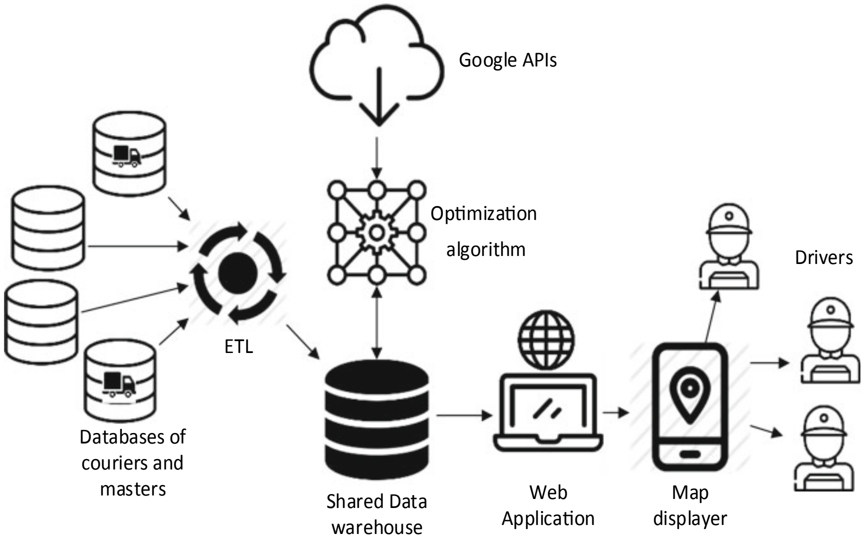

Fig. 1 Representation of the proposed IT platform

These ETL processes have two objectives:

1. To acquire and manage static data provided by couriers and *masters*, (i.e. the capacity of the vehicles)
2. To acquire and manage dynamic data provided by couriers, in particular data about the deliveries/pickups.

This is achieved by implementing the following phases:

- *Phase 1*: extracting data from outside sources (Ingestion phase). This phase includes data retrieval, the processing, the selection and the internal storage of data, interacting (in different ways) with external sources.
- *Phase 2*: transforming data to fit operational needs which may include improvements of quality levels (Data Quality Improvement phase). This phase allows to preliminary analyse data in order to identify attributes of interest, how they are made and, if necessary, acting to improve their quality. For example, a "name" could be trimmed, an "email" could be checked, an "address" could be uppercased and so on.
- *Phase 3*: loading data into the data warehouse (or another end target such as a database or a data mart).

Optimization Module This module is the core of the entire algorithm and it solves a variant of the popular *Vehicle Routing Problem* (VRP) called *Multi-Depot Pickup and Delivery Heterogeneous Capacitated VRP with Time Windows* (MDPDHCVRPTW) that can be stated as it follows: given a certain number of heterogenous vehicles that are at disposal of various depots, we have to make the optimal assignment of packages in order to satisfy the transportation requests of customers within their required arrival time, minimizing the overall distance covered by the vehicles.

This is a generalization of the VRP, that is already a NP-hard problem [15].

We decide to specify the objective function as it follows: to reduce the total distance covered by vehicles through a coordinated and optimized management of the vehicle pool and of the transportation requests (pickups or deliveries).

Indeed, this typically would lead to the benefits cited in 3.1.

Besides, the use of more ecological vehicles is more appreciated than old trucks, and the module takes in account this.

More operatively, this module has to provide:

- The optimal allocation of packages to the vehicles
- The optimization of the route of each vehicle.

in order to reduce the total distance covered by the vehicles.

An implementation of the *Tabu Search* metaheuristic has been developed, the details of its mechanism are reported in Appendix.

This module reads data from the DW and write into an appropriate table the resulted solution, that consists in the assignment of packages to the selected vehicles, indicating the sequence of the visit to each customer and to each courier's warehouse.

The module integrates data from Google APIs, in particular it gets geographical coordinates, distance matrix and time matrix from it.

These data are essential in order to make the algorithm work correctly.

Web Application Module This module is a Web application that has to show for each vehicle:

1. The *warehouse pickup* list, that states which packages the vehicle has to pick up at which courier's depot (it could be more than one)
2. The *pickup and delivery* list Which packages the vehicle has to deliver or pickup at customers' addresses.

This module gets data from the Optimization Module in order to show the required outputs. Every next modification can be requested by couriers or *masters* through this module.

This web application arranges a user interface to access:

- Static data about couriers, *masters*, vehicles, drivers and depots
- The *warehouse pickup* and *pickup and delivery* list
- Info about the delivery status of the packages.

In this way both couriers and *masters* can customize the assignments suggested by the algorithm according to their necessities (i.e., reassigning a package from a vehicle to another one). Once the manual reassignment has been done, it is possible to ask again the algorithm a new optimized solution, without changing the packages that have been manually reassigned.

Map Displayer Module This module is an APP developed in order to display on the map the info about the warehouse pickup and pickup and delivery lists.

It also provides an interface that allows the drivers to point out all the info useful to track the package (i.e., delivery status, interruption on the itinerary).

4 Preliminary Results

In order to validate the system, a local *master* of the city of Pisa has been contacted and 3 real instances have been tested.

Note that in this case an instance consists in a set of transportation requests that have to be accomplished in a specified day. Every transportation request includes the customer's address, the weight of the item, the requested arrival time, the type of transport (pickup or delivery) and all the info about the origin of the item.

Besides, as it would not be possible to use all the features of the algorithm with the original data of the *master,* these have been slightly modified in order to test the full potentiality of the algorithm and its main applications.

Results are shown in the following table:

Instance type	CD_m (km)	CD (km)	S (%)	C	P	ET (s)
MDPDHCVRPTW	267	201	24.7	68	72	38
PDHCVRPTW	200	148	26.0	66	69	34
MDHCVRPTW	268	243	9.3	107	123	126

where:

- CD_m is the covered distance (km) by *master* solution
- CD is the covered distance (km) found by our algorithm
- C is the number of customers (i.e., the number of distinct addresses visited by the vehicles)
- P is the total number of packages
- ET is the total execution time of the algorithm (s)
- S is the saving percentage in distance, computed as: $S\,(\%) = \frac{CD_p - CD}{CD_P} \cdot 100$.

5 Discussion and Conclusions

The problem of the last-mile distribution has been faced, and a tool that allows couriers to manage more efficiently their deliveries has been designed, using an optimization algorithm that relies on the resource pooling principle and that is based on a modified version of the tabu-search metaheuristic.

First results show that there is a possibility for couriers to have the daily total distance covered by their trucks reduced.

Besides, there are some limitations that must be taken in account:

- It could be impossible to couriers to share their information due to privacy and perceived risk/issues.
- Google APIs restrict the algorithm's capacity to handle a large number of customers because there is a limit on the free daily queries [16].

Further investigations should be conduct in order to study possible positive externalities such as:

- The improvement of air quality
- The effective reduction in the transportation costs of the couriers
- The time saving of the planner

Also, a complete instance involving real data from more than one courier should be used to further test the proposed solution.

In the context of smart-city, such a shared IT platform could enable a disruptive change in the business model of couriers and masters. As an addition, it could provide local authority with a tool to support environmental policies.

Finally, we remind that the modular nature of the algorithm allows future adjustments to the algorithm itself can be done (i.e., considering the fairness among vehicles).

Acknowledgements This work has been supported by a yearly research contract between T.I.M.E. S.r.L. and the University of Pisa, Department of Computer Science. This work is part of the Sii-Mobility project, which is funded by MIUR.
The author desires to thank prof. Antonio Frangioni and prof. Laura Galli, both of the Department of Computer Science of the University of Pisa, for their precious contribution to the development of the optimization algorithm.
The author thanks also Mirco Manciulli, Alice Carminati and Daniela Landucci, of T.I.M.E. S.r.L., for the suggestions received during the year.

Appendix: Optimization Algorithm Details

In this appendix is reported more in detail how the algorithm works.

The optimization algorithm is a modified implementation of the popular *tabu-search* technique, and it can be divided in four phases:

(1) *Clustering of the customers*: through the geographical coordinates of the customers, is it possible to apply a simple K-Means algorithm in order to get the desired K clusters. K is an integer computed through the cost of the Minimum Spanning Tree of all the nodes (customers and courier's depots). Every cluster is then ordered, or rather, every customer of the cluster is sorted in an ascending manner according to a distance-time function that takes in account both the

geographical distance from a customer to another one and its requested arrival time.

(2) *Choice of vehicles and assignment of packages*: once the K clusters are obtained and ordered, K vehicles are chosen from the pool. The algorithm chooses first the most ecological vehicles, then those ones that have larger capacity. Once the vehicles are selected, all the packages are sequentially assigned to one of the vehicles according to the same distance-time function of step 1), that is a package is assigned to the nearest vehicle. If no vehicle is available, or one or more constraints are violated, (i.e., overload of the truck, customer not served in time) then another vehicle is chosen from the pool.

(3) *Local search*: once a first constructive solution is obtained, five local search moves are applied sequentially so that only improvements to the current solution are allowed. Some of these moves are well-known moves used for the Travelling Salesman Problem, such as 2-opt or Or-opt, while others are a modification of classical moves.

(4) *Tabu search*: after the local search, a tabu search based on the same moves is started. It is possible to choose how many iterations of the tabu search the algorithm has to run. We remind that this technique is used in order to escape eventual local minima found in 3.

References

1. Vakulenko, Y., Hellström, D., & Hjort, K. (2018). What’s in the parcel locker? Exploring customer value in e-commerce last mile delivery. *Journal of Business Research, 88,* 421–427.
2. Ranieri, L., Digiesi, S., Silvestri, B., & Roccotelli, M. (2018). A review of last mile logistics innovations in an externalities cost reduction vision. *Suistanibility, 10,* 782.
3. Mamkaitis, A., Bezbradica, M., & Helfert, M. (2016). Urban enterprise: A review of smart city frameworks from an enterprise architecture perspective. In: IEEE International Smart Cities Conference (ISC2) (pp. 1–5). Trento, Italy: IEEE. September 12–15, 2016.
4. Ballot, E., & Fontane, F. (2010). Reducing transportation CO_2 emissions through pooling of supply networks: Perspectives from a case study in French retail chains. *Production Planning & Control, 21*(6), 640–650.
5. http://www.sii-mobility.org/index.php/il-progetto.
6. European Commission: Study on Urban Freight Transport. Technical Report, April 2012.
7. Nesi, P., Po, L., Viqueira, J. R. R., & Trillo-Lado, R. (2018). An integrated smart city platform, IKC 2017. *LNCS, 10546,* 171–176.
8. Chatterjee, R., Freulich, C., Edelkamp, S. (2016). Optimizing last mile delivery using public transport with multi-agent based control. In Proceedings of the 2016 IEEE 41st Conference on Local Computer Workshop. Dubai, United Arab Emirates, November 7–10, 2016.
9. Liakos P., Delis A. (2015). An interactive freight-pooling service for efficient last-mile delivery. In 16th IEEE International Conference on Mobile Data Management.
10. Juan, A. A., Faulin, J., Pérez-Bernabeu, E., & Jozefowiez, N. (2014). Horizontal cooperation in vehicle routing problems with backhauling and environmental criteria. *Procedia—Social and Behavioral Sciences, 111,* 1133–1141.
11. Kin, B., Spoor, J., Verlinde, S., Macharis, C., & Van Woensel, T. (2018). Modelling alternative distribution set-ups for fragmented last mile transport: Towards more efficient and sustainable urban freight transport. *Cases Studies on Transport Policy, 6,* 125–132.

12. Zhou, L., Baldacci, R., Vigo, D., & Wang, X. (2018). A multi-depot two-echelon vehicle routing problem with delivery options arising in the last mile distribution. *European Journal of Operational Research, 265,* 765–778.
13. Crainic, T. G., & Sgalambro, A. (2014). Service network design models for two-tier city logistics. *Optimization Letters, 8*(4), 1375–1387.
14. http://www.eltis.org/discover/case-studies.
15. Dantzig, B., & Ramser, J. H. (1959). The truck dispatching problem. *Management Science, 6,* 80–91.
16. https://developers.google.com/maps/documentation/javascript/usage.