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EXECUTIVE SUMMARY OF THE THESIS

Sustainable Urban Logistics in Milan: Train, Electric Vehicles and Cargo-Bicycles as alternatives to traditional deliveries

TESI MAGISTRALE IN MANAGEMENT ENGINEERING – INGEGNERIA GESTIONALE

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1. Purpose of the Study

The context on which this study focuses on is the one of last-mile deliveries and specifically deliveries related to e-commerce orders, which consist in the most of the last-mile deliveries performed and is a continuously growing phenomenon. Considering the Italian market, the value of e-commerce reached in 2021 an aggregate value of 39.4 billion with 578 million deliveries of products, growing in value and orders respectively 21% of 20% compared to 2020 (B2C eCommerce Observatory, Politecnico di Milano 2021). Last mile deliveries networks have some common aspects that effects their efficiency and make them expensive compared to aggregate deliveries. Indeed, customers need to be served singularly also demanding a high service level, making last-mile deliveries a complex and inefficient activity. Moreover, given the time needed for the actual delivery, the number of parcels delivered per tour is lower than its capacity and vehicles used are therefore unsaturated, which increases overall impact of deliveries activities.

Overall, inefficiencies bring to low optimization of emissions and costs, and it was proved how last-mile delivery is the most significant component of the whole parcel delivery costs, corresponding to 50% of it (Martin Joerss et al., 2016). Given the relevance that door-to-door deliveries have already and are always more obtaining, exploring more sustainable ways to perform them is quite a hot topic and need for metropolitan societies in particular.

The purpose of this thesis work is therefore to propose an innovative solution to perform last-mile deliveries, capable of acting on both economic and environmental impact of urban logistics for the company's sake on one side and the environment and people health and life quality on the other.

2. Extant Literature

The first step of the study was to perform a systematic literature review in order to deepen, understand and classify the studies already performed on the topic of our interest and identify possible research gaps present that our study may aim to fulfill. The methodology of the literature review followed R. Mangiaracina et al. (2015). The first main phase consisted in the Papers selection, which were gathered through online libraries on the topic of "Urban logistics sustainability" and then selected in different steps according to their content and relevance, bringing from 668 initial papers to a research corpus analyzed of 64 papers. The second phase was then the review itself.

The first step of the review was to analyze geographical and temporal distribution of the studies, highlighting how the contribution in the literature about this topic is something whose relevance increased a lot in the recent years and that is studied in developed countries much more than in developing one. Then the most spread research fields and methods were identified, realizing that most of the publications performed on Logistics & Supply Chain journals and using Analytical methods and Simulations, but also many Case studies. Given the practical topic we are investigating, indeed, many studies are related to real application case or else evaluation of potential implementations.

Going to the content and the classification of the papers, two classification axes have been used:

- Solution proposed: Regulations, Stakeholders' Collaboration, Non-Road Transportation, Alternatively Powered Vehicles, Cargo Bicycles, Autonomous Vehicles.
- Impact analyzed: Economical/Operational, Environmental, Social.

On the first classification axes, what emerged was that many different networks can be set up, using different types of vehicles and strategies. The most common solution analyzed is the usage of Cargo-Bicycles, given the very high emissions savings achieved and their affordable-price, while also maintaining good operational performances. The other most common solutions consider the usage of Alternative Powered Vehicles, which means Electric Vans (EVs) or hybrid ones, and Non-Road Transportation, which means tramways, railways, and waterways.

In general, three classes of vehicles used can be identified:

- Heavy Non-Road Vehicles, with high capacity and low costs and emissions per parcels but also low accessibility and flexibility, particularly suited for long movements without stops.
- Medium Road Vehicles, electric and hybrid vans, with medium capacity and huge accessibility and flexibility but also higher costs and emissions per parcel, particularly suited for medium-distance and weight moved tours.
- Small Road Vehicles, Cargo-Bicycles and Autonomous Vehicles as robots and drones, with lower capacity but huge accessibility and flexibility with however lower cost than vans, particularly suitable for the last-mile.

Networks with both only one vehicle type or more are presented, however, no solutions consider the possibility of using more than two vehicle classes assigning to each a piece of the supply chain and also no papers consider the whole path from outside of the city to the customers locations.

On the other side, considering the impacts studied, almost every paper in the corpus considered analyzes the economical/operational dimension of the solution proposed, many the environmental one and only few the social one. Indeed, the first two are easier to be computed mathematically, which is harder instead in the case of social impact.

Our study wants to fulfill the gap identified, designing a network in which many vehicles are used, assigned to each the task that it can perform at best, to optimize cost generated and emissions produced for last-mile deliveries.

3. Methodology

Given the outcomes of the analysis performed on the academic literature and the purpose of the study, the research questions formulated are the following.

- RQ1: Is it possible to design an integrated network of different green vehicles from out-of-cities to customers' homes?
- RQ2: What is the Economic and Environmental savings that can be achieved in this way with respect to traditional networks?

To answer our research questions a Simulation model has been developed from the point of view of an express courier that exploits the benefits of using railways, EVs, and Cargo-Bicycles in a new and green integrated network simulated in the city of Milan.

The development and implementation of the model has been performed on ArcGIS, a geographical information system (GIS) that allows to perform geostatistical simulations. This choice allowed us to have different benefits given by the nature of simulation models such as being capable of randomizing customers on the real map of the

city of Milan, to assess variability in different scenarios and to consider real time and distances needed and covered for performing each route.
Given some inputs, the model optimizes the routing of the different vehicles in order to serve all customers minimizing total distance covered and time needed. Then, through costs or emissions parameters, per unit of time or distance, total costs and emissions produced in a day of operations are computed. The same process is done also for the traditional deliveries network, which considers only Internal Combustion Engine Vans (ICEVs), and finally the economic and environmental performances of the two networks are compared to evaluate benefits and drawbacks.
At first, one case is analyzed and compared to the traditional one, which is defined as Base Case, based on real volumes delivered in 2021 and some assumptions made in terms of network settings. Then, through a sensitivity analysis, the robustness of the model and the outcomes in different settings are evaluated, understanding if and how the results would change varying some of the inputs.
The activities considered for the assessment are the handling of parcels in the different infrastructures, the transportation of goods performed by vehicles and the delivery activities. Previous activities related to goods consolidation and sorting are not considered because not differential between the innovative and traditional networks, and also not significant on the overall costs and emissions produced.
For computation of Costs, we started from the framework used in R. Mangiaracina et al. (2019) adapting it a bit according to our goal. The final cost evaluation defined considers costs related to drivers and to vehicles, the last of which composed by Feeding and Rental one, which also includes maintenance. Moreover, a daily toll for ICEVs assessing the city center of Milan is included. Different is the case of the Train in which the service is performed by a Railway Operator and therefore paid as a service on the base of distance and weight moved.
As regards emissions, similarly to most papers studied, as Carbon dioxide equivalent (CO_2e) is adopted, in which all emissions coming from the different Greenhouse Gases produced are expressed in reference to CO_2, using the Global Warming Potential (GWP) of each. For the method used the choice fell on the Well-To-Wheel analysis, in which emissions are computed considering the fuel production (Well-To-Tank) and the vehicle use (Tank-To-Wheel). What is therefore missing in this perspective is the emissions produced during the production of the vehicles, which is out of the scope of this thesis work, focused instead on operational results, costs and emissions.

4. Model Development

4.1. Model design

The network developed considers an express Courier that delivers through the innovative solution proposed the whole flow related to e-commerce delivers on the area inside the ring-road of Milan.
The starting point is a Courier Hub outside the city of Milan were the goods to be delivered are consolidated and sorted per delivery tour. From there two flows are delivered differently, according to the weight they have:

- Parcels over 2kg will be delivered by EVs directly from the Courier Hub.
- Parcel within the band 0-2kg will be delivered by Cargo-Bicycles starting from some Micro-Hubs located in the City Center.

The network related to Cargo-Bicycles deliveries is visualized in Figure 1.

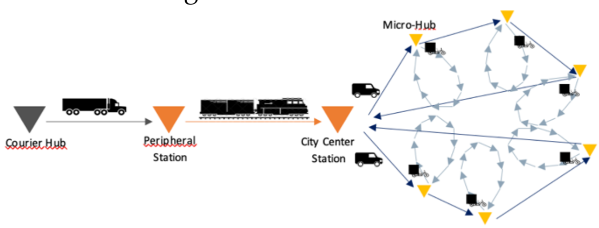


Figure 1: Cargo-Bicycles deliveries network

To move the goods from the Courier Hub to the Micro-Hubs, these are transported by a Truck to a nearby train station, and then by a Train towards a train station located into the city center. Here some other EVs, initially located in a parking spot near the City Center, collect the parcels and bring them to the Micro-Hubs from where the Cargo-Bicycles start their tour. At the end of their tour the Cargo-Bicycles leave the parcels related to failed deliveries and returns performed at the Micro-Hubs and an additional EV performs a tour to collect these parcels and bring them back to the Courier Hub.

4.2. Data

Considering the whole computational process, five different categories of data are involved:

- Input data: market data about deliveries and parcels dimensions inserted into the model.
- Context data: vehicles and activities data based on the application context of the study.
- First Output data: results of the simulation model in terms of distance travelled and total time required by each mean of transportation.
- Consumption data: costs and emissions factors needed to compute the total impacts starting from operational results.
- Final Output data: total costs and emission produced.

4.3. Simulation model design

As regards the actual definition of the network, after defining the activities included into the scope of the analysis, the model was built on ArcGis.
While the location of the Courier Hub and the train stations are consistent to the existing infrastructures, the Micro-Hubs locations, which are specifically 6, are obtained through a Location-Allocation problem resolution with the customers to be served as reference points and a group of 38 points as candidates for the hubs.
The final setting of the model on ArcGis is displayed in Figure 2.

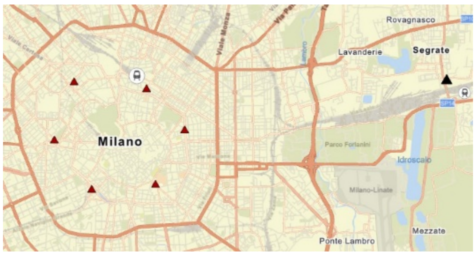


Figure 2: Problem Setting on ArcGis

The solution of the problem is based on different Vehicle Routing Problem, one per each mean of transportation and task performed, each considering the specific vehicle characteristics, infrastructures used, and points served. Solving the VRPs the routes are defined, and operational results obtained for all vehicles apart from the Train, for which instead the distance is obtained through a measurement tool and time spent is not relevant. In Figures 3, 4 and 5 are shown tour examples of respectively an EV that fulfills the Micro-Hubs, a Cargo-Bicycle and an EV that performs deliveries.

Given the complexity of the model, the many vehicles used and the interdependencies between their flows and activities, intermediate steps are performed between the different VRPs. For example, based the results of the Cargo-Bicycles the parcels to be moved to each Micro-Hub is defined, which is an input of the EV Fulfilling VRP.
These computations are performed on Microsoft Excel where also the final outputs are computed.

Figure 3: EV Fulfilling

Figure 4: Cargo-Bicycle

Figure 5: EV Deliveries

The model related to the Traditional Network is much simpler and consist in just one VRP with ICEVs delivering to customers directly starting from the Courier Hub.

5. Results

5.1. Base Case

According to the results of the model benefits can be achieved implementing the proposed solution in both emissions and costs.
On the emission side, it was expected, being the transition to green vehicles the basis of the network definition. Specifically, only 54.7 kgCO2e/day are produced with the innovative network, versus the 998.9 kgCO2e/day generated in the traditional network, with savings of 94.5%. The vehicles employed are indeed not comparable at all in terms of environmental sustainability, with 307.4 gCO2/km produced by ICEVs, 57.2 by EVs and 2.3 by Cargo-Bicycles. Therefore, even if the number of total vehicles is slightly higher, in the green network emissions are sensibly reduced.
Going on costs, instead, the solution proposed generates an overall cost of 21,589€/day versus the 23,146€/day produced by the traditional network, giving 6.7% of cost savings. Since our model also considers vehicle cost, this was not a certain

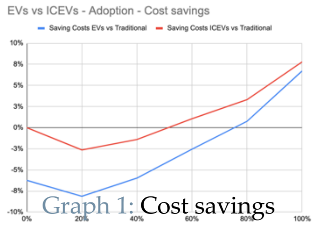
outcome, being the EVs more expensive than ICEVs, not off-setting with lower fueling and maintenance cost the higher vehicle cost. However, also in this case, Cargo-Bicycles, which are 84 out of the 110 vehicles used, play the fundamental role of decreasing vehicles cost so to offset the higher total driver cost of the network given by the increased number of total vehicles.
Deepening the contributions of the different transportation mean on emissions and costs, interesting outcome are obtained as well. On emissions, EVs Deliveries, even if are only the 16% of the vehicles, produce the 71.5% of the emissions, followed by the Train with the 11.3% and EVs Fulfilling with 8.9%. All the other vehicles account for around the 3% each, but what need to be noted is again how the Cargo-Bicycles, 76% of the vehicles, produce only the 3% of the emissions. Different is the role on costs, in which the main cost is given by the Driver cost, and therefore it is more aligned with the amount of vehicles per type. The 97.5% of the cost is therefore generated just by Cargo-Bicycles and EVs Deliveries, with the other EVs, the Train and the Truck being not significant.

5.2. Sensitivity Analysis

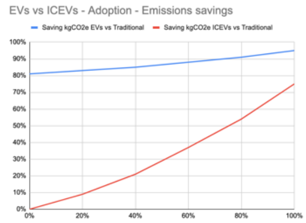
Different sensitivity analyses were performed to evaluate the robustness of the solutions obtained to the variability of some inputs and also to compute the performances of different scenarios.

Adoption rate

The first one is about the adoption rate of the innovative network, considering that initially there could be a partial adoption and what would be the effects. Rates considered are 20%, 40%, 60% and 80%, also compared with the Base Case as 100% and Vans only as 0%. Each scenario was evaluated considering as vans both EVs or ICEVs. Graph 1 and Graph 2 respectively present Costs and Emissions savings in all scenarios evaluated compared to the traditional network.
For low percentages of adoption, the network is not convenient from an economical point of view, and according to the usage of EVs or ICEVs, for the solution to become more convenient than traditional deliveries respectively 80% or 50%.
Emission savings increases in both EVs and ICEVs cases as the adoption increases, as expected but additional interesting outcomes are that even with 0% of Adoption EVs implementation would bring to more than 80% of emissions savings, while the 100% of adoption with ICEVs around the 75% of savings is achieved.



Graph 1: Cost savings



Graph 2: Emissions savings

Cargo-Bicycles weight range

The threshold considered for the assignment of parcels to Cargo-Bicycles choses was 2kg, however, it was worth to evaluate the effects and the feasibility of a higher threshold, which is specifically 10kg. Results in this case showed a halving of the emissions produced compared to the Base Case and a 3% decrease in cost generated, increasing its benefits compare to the traditional network.

Number of Micro-Hubs

The number of Micro-Hubs included in the network may vary and mainly depends on space availability. It was assumed to be 6, as a reasonable value given the area covered of around 30km^2. Effects of having between 2 and 6 Micro-Hubs, or 10 of them were studied and between 2 and 6 costs savings compared to traditional network increase from 6% to 6.7% while going to 10, no changes are present. On emissions side, the solution are all quite equal, with slight growth when increasing the Micro-Hubs to 10.

E-Commerce Volumes

The results obtained in terms of sustainability of the solution may be influenced by the relevant dimension of the deliveries volume considered. Therefore, scenarios with -20% and -40% of volumes were studied, to understand if the proposed network would still be worth. What emerged is that in both cases there is a contraction of the convenience of the network with respect to the traditional one, especially on cost going from 6.7% of savings to 5.8% in both reduced volume scenarios, while emissions savings are almost the same.

5.3. Discussion on the results

As regards the impacts generated, the solution designed and proposed in this study was proved to bring benefits in both costs and emissions, with respectively 6.7% and 94.5% of savings achieved compared to traditional deliveries network.

Cargo-Bicycles proved to be a very competitive vehicle for deliveries in city centers given the very high proximity of customers and therefore no need of vans speed, while neither needing its capacity.

Performing some sensitivity analyses more insightful outcomes were obtained. Looking at the adoption rate results, it's clear that even low adoptions bring huge benefits in terms of emissions produced, while for cost savings certain threshold of adoption must be overcome. Considering the 0% and 100% cases as well, the main outcome is that using EVs instead of ICEVs in the traditional network or implementing the Cargo-Bicycles network at 100% without migrating to EVs, both can help in achieving around 80% of emission saving, while with their combination almost 95% is achievable.

The benefits achieved, both on monetary and environmental terms can be even increased if exploiting more the potential of Cargo-Bicycles, assigning to these not only parcels until 2kg but 10kg. Specifically, emissions would be halved, achieving 97% of savings compared to traditional network, while on costs savings would increase from 6.7% to 9.5%

The number of Micro-Hubs was then proved to bring some differences in the operational costs generated but considering that we are not including infrastructures costs and we are assuming their availability, a lower number of Micro-Hubs may be considered without having significant decrease in performances.

Lastly, the solution proved to be very robust also to variations of the demand, with neither 1% of difference of savings in both costs and emissions compared to traditional network.

6. Conclusions

The main purpose of this thesis, correlated to the request questions formulated, was to design an integrated delivery network from out-of-cities to customers' homes through green vehicles. Once designed its performances needed to be assessed, to evaluate benefits and drawbacks with respect to traditional deliveries. The main benefit expected were significant reduction of environmental impact, which declined significantly, reaching almost 0 in case Cargo-Bicycles are exploited delivering parcels until 10kg. Moreover, the implementation of the innovative network deliveries proved to be, if at least 50% of adoption is set, also cheaper than traditional one.

This thesis work represents a step forward in the attempt to significantly reduce the impact of urban logistics on the environment in general and on the quality of life in cities more in detail, focusing on the networks preforming e-commerce deliveries.

The main originality is given by the number of vehicles considered and the fact that to each is assigned the activity in which it is one of the best vehicles to perform it. Truck and Train are used for high-volume movements, EVs for medium volumes and deliveries of big parcels and Cargo-Bicycles for most of the deliveries to customers.

Potential limitations on the model may be given by the assumption performed, even if most of these are coming from discussion with the couriers or other studies analyzed. Moreover, each of the most relevant assumptions, for example the definition of the fixed delivery time, is affecting both the proposed innovative network and the traditional one. Being the comparison performed always comparing to the two networks, and given the sensitivities performed on the inputs, the results are therefore considered quite robust.

As last remarks, a very insightful study we consider could be performed with a view on the future could be based on autonomous vehicles. These indeed, drones or robots, not needing any driver, once regulated and operatively feasible, will bring a huge disruption in the field of last-mile deliveries.

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