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EXECUTIVE SUMMARY OF THE THESIS

Innovative tram-based methodology for Last-Mile Delivery: preliminary technical analysis of a Two-level Mixed Logistics System

TESI MAGISTRALE IN MECHANICAL ENGINEERING – INGEGNERIA MECCANICA

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1. Introduction

The thesis work is focused on the presentation and description of an innovative freight delivery method, which integrates the multimodal framework typical of Last-Mile Delivery with the utilization of a tram vehicle. The method proposed is called Two-Level Mixed Logistics System (2L-MLS) and involves the presence of two echelons of operations for performing freight delivery: the first level is characterized by a tram network able to connect several zones of the city, while the second one is composed by a capillary system of vehicles optimized for the transportation of freight from the tramway network to the final customers.

2. Description of the proposed 2L-MLS

The 2L-MLS model proposed is founded on a deep analysis on the current state of art of Last-Mile Delivery (LMD), which is an activity belonging to the last section of the freight delivery service and it represents the most expensive and one of the most pollutant segments of the supply chain of a product [1]. In recent years, the interest on this topic rose abundantly, strongly enhanced by the affirming role of e-commerce in the last decade, which is slowly growing as one of the most competitive and profitable markets. In a perspective of reducing the intrinsic complexity of LMD, the possibility of splitting the logistic service into two levels is gaining increasing consensus among scholars. The main idea is an evolution of the traditional freight distribution system towards a two-level logistics framework, topic of discussion of the thesis work. The main feature of the two-level freight distribution systems is the presence of depots located at intermediate levels to store freight and exchange them between different levels. In a single-level model, depots or Consolidation Centres (CCs) are located in the outer zones of the cities and, once the freight is ready to be delivered, they are taken to their final destinations, which could be business activities, factories and households located in inner districts of municipalities. In the two-level perspective, as reported in Figure 1, there is a whole set of destinations and origins to be acquainted. The origins for the first level are still the CCs, but the destinations are smaller depots located internally to the city known as Distribution Centres (DCs) or satellites. Once goods arrived at the DCs, the first level of the freight distribution system is concluded and other types of vehicles, generally smaller, more efficient and environmental-friendly, deliver the goods from the DCs (which in this moment act as origin for the second level of the delivery process), to their final destinations.

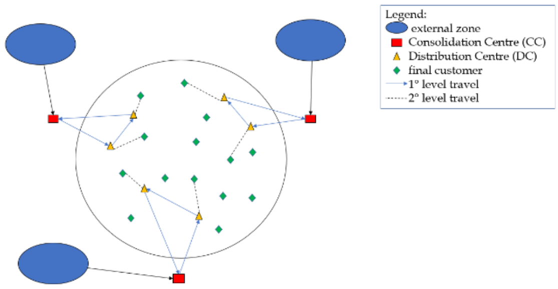

Figure 1: Example of two-level freight distribution system

One of the newest trends of LMD is to use Local Public Transport (LPT) vehicles to perform the 1st level travels of the delivery framework, since they present different advantages. For example, LPT vehicles have an outstanding capacity in terms of available space for people and, in case they will be converted partially or totally to freight service, they will serve as ideal carrier of freight for moving parcel in the inbounds of the biggest cities. Since LPT vehicles are mainly electric, they emit less pollutants with respect to LDVs and HDVs, which could also have limitations in the inner districts of the cities. Moreover, the use of LPT vehicles has minimal impact on congestion and traffic generation, since the vehicles used for moving freight are the one already performing the service, except for particular cases of dedicated vehicles only for freight movement. One of the drawbacks of using the same vehicle for passengers and freight is the creation of an adequate timetable in which fill in both the services, affecting the least the efficiency of passengers' network.

The research focuses on trams and is based on the main European cases of tram applications for freight delivery [2] and from the technical-scientific analysis of the international literature [3] and addresses the advantages and main characteristics of tram systems, providing the reasons behind their utilization for the first level of the system presented. The work focuses on the first level of 2L-MLS, describing the analytical model used for the preliminary technical assessment of the adaptability of an existent tramway line. Further research could be done for the second level of the 2L-MLS, coupled with a Multi-Criteria Analysis which accounts for financial and economic parameters, as well as social and environmental ones.

The motivation behind the work proposed is to provide decision-makers of the project with a ready-to-use instrument for the assessment of the technical analysis of the tram system, describing the main feature of trams' infrastructure and configuration for optimizing the distribution of freight along the network. Freight storage facilities such as smart lockers and cargo wagons to unhook from the freight trams are also exploited as an important feature of the project. Particular attention is set on the coexistence of both services of passenger and freight transportation within the same infrastructure, leading the research work towards urbanistic and logistics thematic rather than mathematic and I.T. ones. The literature work on the topic presented is, indeed, focused on mathematical algorithms to solve the intrinsic complexity of arranging such a complex freight delivery framework, lacking a description of the characteristics of the tram systems required for the project.

3. Description of the model

In this chapter, the model for the technical assessment is proposed. The first step of the procedure is dedicated to the selection of the city in which the conditions are most favourable for the 2L-MLS implementation proposed. Once the most suitable city has been chosen, the next step is to select the tramway line of the city for the 2L-MLS operations. A broad evaluation of the characteristics of the tramway service and infrastructure is carried out in this phase, giving estimations about their performances, and classifying them by using marks. The third step of the procedure refers to the selection of the number and the location of the stations along the line to convert into mixed operation stations, according to the indications provided by the municipal authorities and physical constraints related to the installation of auxiliary infrastructures. The last phase of the technical analysis regards the time window in which implement the freight service, namely the time schedule of the freight trams.

In order to choose which are the city and the line that better serve theoretically as actors of the 2L-MLS proposed, the parameters considered in the preliminary technical analysis are ranked by using marks, given to the city/line considered. The marks are the result of a hierarchical clustering analysis, where the number of levels identified is equal to 5: *"Excellent"*, *"Good"*, *"Fair"*, *"Ordinary"* and *"Poor"*, as shown in Table 1. Alternatively, the method used in the model to assess preferences towards parameters, whether is not possible to establish a hierarchical classification for the parameters obtained, is the Delphi method, which is a technique used to address parameters which have not a quantitative definition and can be debated by experts having different points of view on the same issues.

MARK	DEFINITION
$\mathbf{4 \leq X < 5}$	*Excellent*
$\mathbf{3 \leq X < 4}$	*Good*
$\mathbf{2 \leq X < 3}$	*Fair*
$\mathbf{1 \leq X < 2}$	*Ordinary*
$\mathbf{0 \leq X < 1}$	*Poor*

Table 1: Definition of the grades correspondent to the marks

The first step accounts for the predisposition of a pool of candidate cities through the weighted sum of four parameters multiplied by their weights. The four parameters considered are the total length of the network, the coverage with respect to people ρ_P, the coverage with respect to commercial activities ρ_A and the freight flows within the boundaries of the city f_F. To these four parameters, correspondent marks are assigned, based on the position occupied by a city when ranked according to the said parameter. These marks, from 0 to 5 for each of the four measured parameters are respectively indicated with L_N, P_P, P_A and F_F, and summed thanks to the use of calibrated weights, in order to obtain an indication on the value of predisposition C to any city belonging to the pool of candidates for the implementation of 2L-MLS. Note that the definition of marks is related to the relative position between the measurements performed and consequently not proportional to the measured value. This means that the intervals between all the position of the ranking are the same for every position considered. The cities that have scored an aggregate value of C higher than 3 are considered suitable for the 2L-MLS implementation. The computation of the value of C is reported in Equation (1).

$$C = w_1 * L_N + w_2 * \mathrm{P}_P + \\ + w_3 * \mathrm{P}_A + w_4 * F_F \tag{1}$$

The second step of the procedure is rather similar to the one of the choice of the city. Among a pool of candidate lines, the most suitable one is selected, based on a value which accounts for the physical characteristics of the line L. The two parameters considered for the calculation of L are the linear infrastructure of the line I, focusing in particular about the terminals, which could be loop stations, switch-back terminals or a combination of both, and the tram fleet conditions V. The parameters I and V are numbers varying from 1 to 5, correspondent to the least and the most favourable conditions. The two parameters are then weighted based on experts' judgement and summed up to obtain the value of L. The main difference with respect to the choice of the city is that in case of choice of the line the marks assigned to parameters is related to defined characteristics and is not the result of a comparison. Hence, if different lines have the same physical characteristics, they can score the exact same mark for the parameters presented in this paragraph. The main driver for the choice of the line is the potential demand of freight generated by the implementation of the 2L-MLS service. Indeed, the more customers are able to participate in the project and the higher are the revenues for the stakeholders of the 2L-MLS. Even though the demand analysis is performed in the successive phase of the model proposed, being related to the zones in which the station of the tramway line selected are located, it is equally important with respect to the physical characteristics. For this reason, the constraints on the physical conditions of the tramway lines are less tight: unless the mark attributed to the physical conditions of a line L is lower than 2.5 on a scale from 1 to 5, any line could be considered in terms of physical characteristics. For this step of the procedure, the minimum physical conditions of the line are sufficient for the implementation, while the analysis of the stations is the most important driver of the whole process of assessment. Equation (2) shows the procedure for the calculation of L.

$$L = \alpha I + \beta V \tag{2}$$

The sequence of operations for the procedure for identifying the number and the position of the mixed stations along the line, which compose the third step of the model proposed, is the following:

1) Identification of the ideal number of mixed stations S_0 for the line analysed;
2) Selection of the business activities through the use of isochrones;
3) Classification of the business activities and calculation of the priority generated by the customers;
4) Extraction of priority index of the zones, based on the cumulated priority generated by the customers;
5) Choice of the stations to include in the conversion process, based not only on demand analysis but also on physical constraints;
6) Conversion of the stations from passenger only to mixed operations of passenger and freight services, according to the physical constraints.

The first operation is the definition of the ideal number of mixed stations along the line S_0, considering that having freight stations distributed over short distances is detrimental for the flow of the network, other than being redundant for the customers. The number of freight stations must be high enough to justify the investment of the 2L-MLS on the chosen line and low enough to allow a fluid circulation of both passengers' and freight vehicles. It is up to the agreements discussed between decision-makers and local authorities to define the exact number of mixed stations along the line, according to the already discussed physical and logistical limitations. Isochrones are used for the assessment of the number of business activities to consider in the analysis, using the stations of the line as centroids. The priority generated by the customers is a value between 1 to 5, from the least priority generated to the highest, as shown in Figure 2.

DEMAND ANALYSIS OF THE ACTIVITY		QUANTITY OF PRODUCT [KG/DELIVERY]		
		HIGH	MEDIUM	LOW
PROMPTNESS OF DELIVERY [DELIVERY/MIN]	HIGH	5	4	3
	MEDIUM	4	3	2
	LOW	3	2	1

Figure 2: Freight demand analysis

By analysing all the business activities of the zone, a priority index can be extracted for any station of the line. The successive operation is to study the feasibility of the conversion of the stations from passengers' activities only to mixed operations, according to the demand generated and physical constraints such as the possibility of installing secondary rails for cargo wagons, the proximity to points of interest (shopping malls, restaurants, hospitals, …) and the localization of the stations in which potentially perform freight service, to distribute them optimally along the line.

The fourth and last phase of the model proposed regards the choice of the time period in which perform freight activities. Three periods are considered: peak hours, off-peak hours and night hours. For each period a value of favourability is calculated, based on the number of freight vehicles that could be utilised per hour per direction, according to the restrictions caused by the presence of passengers' dedicated vehicles. As a matter of fact, the synchronization between passengers' and freight vehicles is the most arduous task for a successful implementation. In case of night operations, the problem of sharing the network with passengers' vehicle is no more considered, but new limitations arise, such as the presence of

Distribution Centres in which storing temporarily the freight that cannot reach the final customer until the next morning, and the regulations that are needed for running the service during night in the most populated zones of the cities. Considering all the constraints mentioned, the values of T_{Peak}, $T_{Off-peak}$ and T_{Night} are calculated. According to the values obtained, it is possible to understand which is the best solution for the period in which performing freight service.

4. Application of the model over an Italian horizon

The model proposed is successively applied to an Italian context to identify on one hand the predisposition of the tram cities towards the 2L-MLS implementation and on the other hand its validity and efficacy. Thirteen Italian cities are considered for the analysis, the ones having a functioning tram system. From the application of the model, it emerges that the city having the highest score according to the predisposition of the city C in which implement the 2L-MLS is Milan, with a value equal to 5. Consequently, for the Italian application, the municipality of Milan is selected as case-study. The city of Milan has an historical tradition of tram services, consequently the majority of the lines of the city fulfil the minimum requirement for being considered as suitable for 2L-MLS implementation.
Among the lines of the city, Line 4, reported in Figure 3, represents an interesting candidate for the implementation of the 2L-MLS project because it crosses the most central and flourishing zones of the city, like Piazza Garibaldi and Piazza Castello, over a distance of 7 kilometres and serving 21 stations in total. The conformation of Line 4 suggests that the demand, either for passengers or freight, could be potentially high enough to justify the investment. The area in which Line 4 operates is also a good candidate because of the presence of Hospital Niguarda.

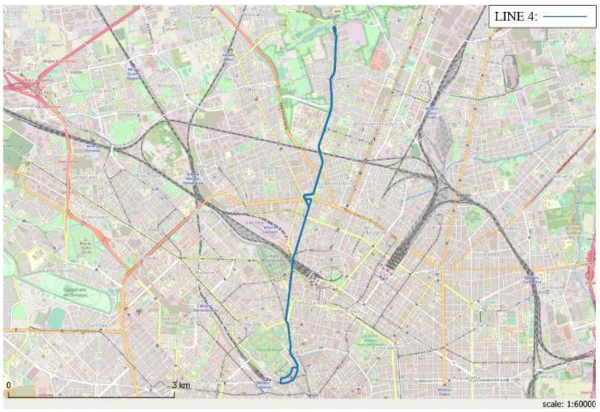

Figure 3: Tramway Line 4 of Milan

The value attributed to the physical characteristics of Line 4 is equal to 3.5, high enough to justify the choice of the line selected and proceed with the analysis. For the definition of the number of mixed stations along the line, it has been decided to introduce as input a number of stations equal to 5. Then the zones around the stations, using 10-minutes isochrones, are analysed for defining the priority index of all the 21 stations of the line. For this application of the model, the activities considered are restricted to gastronomy activities, big retailers and hospitals. After having observed the stations one by one to assess whether they can be converted into mixed operation stations, a total number of 8 stations along the line are defined suitable. Since the input value is equal to 5, the first 5 stations of the 8 suitable, classified according to the priority index generated, are selected to become mixed operations stations. The disposition of the mixed operation stations along the line is reported in Figure 4.

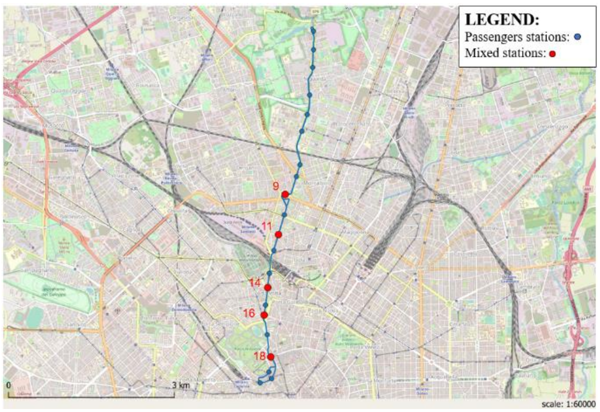

Figure 4: Disposition of mixed stations along Line 4

The last step of the model is the definition of the values of T_{Peak}, $T_{Off-peak}$ and T_{Night} for the freight operations. Form the analysis undergone, it emerges that both off-peak and nightly operations can be selected, while performing freight operations during peak hours is strongly discouraged. The obtained results are reported in Table 2 and confirm the validity and the applicability of the model as instrument for decision-making support for the assessment of the presented case-studies. The comparison shows off that Milan is the best solution to implement the tram-based 2L-MLS, and the detailed analysis on one specific tramway line of the city, Line 4, shows good results in terms of possible application of 2L-MLS.

PARAMETER	VALUE [1-5]
C	5
L	3.5
S	5
T_{Peak}	1
$T_{Off-peak}$	3.4
T_{night}	4.4

Table 2: Results of the case-study

The outcome of the application of the model is that, considering the first level of 2L-MLS using trams as vehicles for performing the delivery activities, Line 4 of the city of Milan represents a good candidate, and five stations can be converted into mixed stations.

5. Conclusions

To conclude, the strongest characteristic of the model proposed resides in its level of applicability. The model can affirm whether a city can be considered for the implementation by comparing it with other candidates, then is able to select the suitable tramway line of the city which has the sufficient conditions for the implementation of 2L-MLS, regardless of economic and financial parameters. One of the keys of the application of the model proposed is the presence of a reliable source of data able to address for different characteristics of the cities and the tramway lines using parameters that can be compared between different alternatives. The gather of data represents a crucial activity for the model, since in absence of a consolidated source of data able to classify parameters for any of the city considered in the analysis, is impossible to assess the predisposition of the cities considered.

6. Bibliography

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