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Railways as an urban transport system: roles, technologies and analysis tools

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1. Introduction

Railway is the most effective, safest and most economical mode of transport that allows large amounts of people to travel inside urban areas. Moreover, the use of electric traction makes the railway an urban transport system that is "clean" in terms of the severe problem of air pollution. Unfortunately, building new metrorail systems is often unfeasible, due to huge obstacles of economic and environmental nature. In view of these considerations, there is currently a growing interest in the possibility of utilizing the existing railway lines, both state-owned and licensed.

Actually, in most cases, railway lines go through medium and large Italian cities; however, only in few cities do railway lines play a key role in urban transport.

2. The role of railway in urban transport: the Italian situation

The exploitation of railway lines as a support for city traffic, at least in the main directions of traffic, is encountering many difficulties.

Although each city must face specific problems, nevertheless, it is possible to define some situations typical for many Italian cities. An important factor is represented by the dependence of the direction of railway lines on the shapes of the urban areas they go through. In this context, it is possible to distinguish three types of cities:

a) coastal cities with a linear expansion, through which railway lines are in the direction of length, with many stations inside urban areas (e.g. Genoa, Bari, Naples, Reggio Calabria);
b) cities about circular in shape, tangent to railway lines, with one or two stations in urban areas (e.g. Bologna and many cities of medium dimensions);

c) cities of various shapes, with terminal stations in central areas and some transit stations in urban areas (e.g. Turin, Milan, Florence, Rome, Palermo).

Type a) cities are of course the most suited for the use of existing railway lines as support lines for urban traffic. At present, in all the aforesaid cities of this type, trains of Italian Railways are already utilized for urban services. In these cities, the requirements for the development of train services concern the addition of new stations and an increase in the traffic capacity of railway lines, along which goods trains and passenger trains of all categories run according to daily schedules.

In type b) cities, the development of regular urban railways services is difficult, as railway lines are located in fringe areas with respect to urban areas. In such cities, there is a greater interest in regional-metrorail projects. Significant examples of such undergrounds are in the Emilia and Veneto regions.

In type c) cities, the presence of terminal stations favours the penetration of railways lines into central areas. On the other hand, the development of urban services imposes constraints on train traffic and requires connections among the various transit stations. Such connections are currently under construction in Turin, Milan and Rome.

In order to contribute effectively to solving urban-traffic problems, railways services should exhibit particularly attractive characteristics for potential users. In more detail, they should offer [1]:

- a high frequency of runs, as for metrorail systems; otherwise if such a frequency is impossible or unsuitable due to traffic requirements, it is at least necessary that, during the different daily periods, trains should follow one another at constant intervals so that users are not obliged to consult railway timetable or to remember train schedules;
- capillarity on the territory, that is, several stops are required, at short distances (typically, 1 km long); moreover, urban-service trains should always stop at all stations;
- particular fares (i.e., different from those specific for usual railway services), with the possibility of integrating the fares for the different urban-transport systems.

It is useful to compare the characteristics of urban railway services in Italy versus the afore aid standard requirements. The existing services can be classified as follows:

1) Underground-like services of Italian State Railways.

The train schedule of Italian Railways (FS) includes 16 lines officially used for underground-like urban services. Both urban-services trains and trains of other types (even long-route ones) run on these lines. Urban-service trains are classified as metro-trains, with particular fares. Such lines are described in Table 1.In addition to these lines, Italian Railways offer, on the lines Genoa Voltri - Genoa Brignole and Fiumicino Aereoporto - Rome Tiburtina-Monterotondo , services at exactly 15 min. and 20 min. intervals, respectively. Though these services are not included in the official 1993-1994 train schedule as

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underground-like services, nevertheless, they exhibit many characteristics of such services.

Table 1 - Underground-like services of Italian State Railways

	L	T	(a)	(b)	H
Napoli Gianturco - Pozzuoli	17	27'-29'	yes	yes	7'-9'
Palermo Centrale - Giachery	10	19'	yes	no	-
Palermo Not. - S.Tommaso N.	10	12'-20'	yes	no	-
Venezia S.L. - Mestre	8	10'-11'	no	no	-
Enziteto C. - Torre a mare	25	(+)	no	no	-
(*) Ciampino - Roma Termini	14	12'-18'	no	no	-
S.Maria delle Mole - Roma Termini	18	17'-23'	no	no	-
Cesano di Roma - Roma Ost.	27	30'-45'	no	no	-
Monterotondo - Roma Tib.	21	25'	yes	yes	20'
Lunghezza - Roma Tib.	15	21'-32'	yes	no	-
(*) Colle Mattia - Roma	26	20'-23'	no	no	-
Pomezia - Roma Term.	24	14'-25'	no	no	-
Ponte Galeria - Roma Tusc.	19	26'	yes	yes	20'
Torre in Pietra - Roma Term.	41	35'-45'	no	no	-
Pantanella - Roma Term.	19	20'-28'	no	no	-

(*) In the council of Rome there is an integrated fare system.

L = *section lenght in km;*
T = *time to cover the whole section in minutes;*
(a) = *regular stops for all trains at all stations;*
(b) = *constant headways between underground-like trains;*
H = *headway time;*
(+) = *no links for the whole section.*

2) Urban services of Italian Railways

In addition to the previous sections, there exist sections of Italian Railways (typically shared by several lines) that connect various stations in the same city. On these sections, services are more or less frequent, and trains have heterogeneous characteristics, come from different places, and fall into different categories. Intervals between trains are not constant, event though they are quite short at some times of day. All these characteristics are typical for the following sections:

- Milan Certosa - Milan Porta Garibaldi, terminal section of the Milan Rho line: it is shared by the lines towards Turin, Arona, Luino e Varese;
- Milan Greco Pirelli - Milan Porta Garibaldi, terminal section of the Monza - Milan line: it is shared by the lines towards Como, Lecco, Bergamo;
- La Storta - Rome Tiburtina, terminal section of the line towards Viterbo;
- Reggio Calabria Catona - Reggio Calabria Pellaro, urban section shared by the Tyrrhenian and Ionian Lines.

Similar services, with intermediate characteristics between urban and suburban services, are offered on the sections Turin - Chivasso and round Florence.

3) Urban services not belonging to Italian Railways

Various licensed railway lines or those managed by a State government official offer urban services [2]. They are indicated in Table 2. In the cases of the Perugia P.S.G. - Perugia S. Anna and Cosenza FS - Cosenza Centro lines, trains run mainly on urban sections; in the other cases, trains run on the terminal sections of wide-range railway lines.

Overall, the conditions that should make a railway service meet the standards typical for undergrounds (i.e., constant headways, uniformity of schedule times) are fulfilled only in very few cases. Nevertheless, on some lines, the frequencies of train-runs are very high (in Naples and Milan, trains run at intervals of only 3 minutes).

Table 2 - Urban services not belonging to Italian Railways

	L	T	(a)	(b)	H
Napoli Gianturco - Pozzuoli S.	17	27'-28'	yes	yes	7'-8'
Cesano di Roma - Roma Tiburtina	40	50'-60'	no	no	-
Palermo Centrale - Giachery	10	19'	yes	yes	25'
Palermo Notarbartolo - Tommaso N.	9	9'-15'	yes	no	-
Venezia S.Lucia - Mestre	8	9'-11'	no	no	-
Bari S.Spirito - Bari Parco Sud	15	20'-30'	no	yes	30'

L = *section lenght in km;*
T = *time to cover the whole section in minutes;*
(a) = *regular stops for all trains at all stations;*
(b) = *constant headways between underground-like trains;*
H = *headway time.*

3. Limitations related to railway-line potentialities

To analyse the difficulties concerning the use of existing railway lines as underground-like lines, it is necessary to divide railway lines into two categories:

1) under-utilised (or even closed to regular traffic) railway lines;
2) over-utilized railway lines.

The former are represented by terminal sections of branch lines and by side-tracks (either industrial or harbour ones) present in various cities, even in central areas, and often little utilized, as compared with traffic capacity. The recent recoveries, in Genoa and Palermo, of tracks previously used for harbour traffic and now utilized for the development of underground-like services are quite significant. Moreover, in various cities of medium dimensions, limited

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changes might allow suburban sections of branch lines to become suited for a passenger service of the underground type. As they are mostly single-track railway lines, the frequency of train-runs is mainly linked to the number and the positions of passing points. Possible changes concern a partial track doubling (which is suitable where no urban restrictions nor natural obstacles exist), the building of new passing points, the applications of an electric axle-counter block and of a remote-control system.

The use of underground-like trains on high-traffic lines seems more critical. Studies on traffic capacity show how the presence of slower trains (stopping at all stations) and of fast trains on the same line leads to a non-optimal utilization of the traffic capacity of the line [3]. It is often difficult to add new trains because the existing ones utilize the line to its capacity limits; therefore, the residual traffic capacity is zero or insufficient.

The insufficiency of residual traffic capacity, can be faced by two different approaches, which can be defined as an infrastructural solution and a technological solution. The former consist in the building of new infrastructures (new lines, doubling of existing lines). This solution is in conflict with notable territorial restrictions. In many cases, the narrow space between existing railways lines and the surrounding urban space does not allow the laying of parallel tracks. Even in the absence of urban restrictions, the cost of new railway structures in urban areas is very high and the realization times are very long. This holds true for underground structures, too.

An alternative (though partial) to the realization of new infrastructures is represented by the application of technological measures to existing lines, for the purpose of increasing traffic capacity. Such measures concern the rolling stock and traffic control systems. As to the former, it is worth noting that underground-like trains of Italian Railways and of some licensed railway lines have already been built with specific material. Moreover, new trains will be added. Therefore, local trains are becoming more and more similar to those of actual undergrounds. By contrast, concerning traffic control systems, the presence of trains with different characteristics has so far prevented the application of specific control systems for underground-like traffic to ordinary railway lines.

4. Technological solutions to increase traffic capacity

The traffic capacity of a double-track railway line depends on the systems used in the stations and on the signalling system, which determines the minimum distance between two trains running one after the other in the same direction. Some underground-like or *people mover* systems use sophisticated signalling systems, at high automation level, that allow very reduced headways (1 minute long) between trains, while meeting all safety and time requirements.

It seems reasonable to wonder whether the use of such signalling systems on an existing railway line may allow so reduced headways also in the presence of other trains. This possibility would lead to an extremely efficient utilization of existing infrastructures, at a lower installation cost than the one required by an infrastructural solution. Moreover, it is interesting to analyze the conditions that make a technological solution preferable to an infrastructural one.

The difficulties that oppose the transfer of signalling technologies from undergrounds and *people mover* to urban sections of ordinary railway lines are linked to the presence of trains (both passenger and goods ones) that are not used for an underground-like service.

Replacing, on urban sections, common signalling systems of Italian Railways with different systems, typical for undergrounds and suitable for shorter headways between trains, poses the following problems:

- Unless they are limited, headway reductions for long-route trains, in accordance with train speeds or train compositions, might turn out to be unsafe.
- The benefits, in term of traffic capacity, resulting from shortened headways might be nullified by lower traffic capacities inside station areas; such capacities are related to the number of platforming tracks and to the arrangement of station layout.
- A replacement involves modifications to the station-plan regulations not only of underground-like trains (for which specific regulations might be accepted) but also of long-route trains running on urban sections.

In general, the possibility of modifying operation regulations encounters obstacles and difficulties that increase with the number of elements that are in contrast to current regulations. Neglecting such conflicts is not a sound design philosophy because it involves the risk of specific, though very accurate, investigations that are not likely to lead to short-term practical applications.

Therefore, it seems more advisable to associate a new signalling system (aimed at reaching a higher frequency of trains) with the existing one, without need for replacing it. Moreover, a new system should not influence the running of trains not used for urban services; such trains could even ignore the new signalling system. For instance, this can be accomplished by using the technique of coded-current track circuits, that is, by adding codes that may be picked up only by underground-like trains provided with suitable cab-signal devices.

To sum up, to obtain the increase in traffic capacity, required for an increase in urban services, some technological solutions can be adopted, which can be applied, in the long term, to urban sections of high-traffic railway lines provided with automatic block systems.

Such solutions are:

- shortening of headways;
- modifications to station layout;
- adding to existing track circuits new special-frequency circuits and/or colour-light signals only for underground-like trains (as an alternative cab-signal system based on electromagnetic transmission points).

Moreover, it is necessary to explore the possibility of predicting the traffic of underground-like trains with free schedules. Such trains might better exploit the intervals of time between long-route trains by adapting themselves to the various schedules in a dynamic way. If free-schedule traffic, already present on urban railway sections to meet service requirements (e.g., isolated locomotives),

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might be combined with a high frequency of trains runs, it would make a railway service (from the user's stand point) entirely similar to an underground service.

5. Computer simulation as an analysis tool

In general, the construction of new infrastructures ensures a greater increase in traffic capacity than technological modifications to existing railway lines. The availability of four tracks instead of two allows different traffic flows to be separated, hence it also allows a high traffic capacity, even when technologically simple traffic-control systems are used. However, a comparison between the two situations should be made in terms of a cost/benefit analysis. A technological solution offers a smaller increase in traffic capacity, but the cost and time requirements may be much smaller. Therefore, if the benefit-to-cost ratio is considered, a technological solution may turn out to be preferable in many cases.

To make sound investments, it is important to use, in addition to usual tools for an economic analysis, a specific tool able to predict, in technical terms, the benefits resulting from alternative solutions, typically, in forms of traffic capacity (i.e., number of passengers carried in the unit time).

Traffic capacity does not depend only on the headway system on a line but also on layout conditions and on station systems. The complexity of station yards and the related restrictions may impose long headways. Due to the large number of factors involved, it is difficult to evaluate by analytic methods the traffic capacity that might be obtained, for instance, by innovative signalling system, or by utilizing free-schedule trains. For traffic-capacity evaluations, the use of computer programs specific for the simulation of train running is much more effective than analytic approaches (necessarily simplified), as it combines a good precision with high flexibility [6]. In other words, many running situations or design alternatives may be simulated by simply inserting new input data, with a notable saving in time, as compared with analytic methods.

6. Conclusions

The paper has pointed out that, in many cities, suitable structural or technological modifications (sometimes of limited cost) can make existing railway lines suitable for being utilized for urban transport. This has already been achieved in some Italian cities, but further evolutions, both quantitative and qualitative, of underground-like urban services are possible. Moreover, the article has stressed the usefulness of computer simulation, which represents an analysis tool that can be employed as an aid to decisions concerning the choice of investment targets.

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