Effects of the realization of a new tram-train system for the regeneration of urban areas. The case of the metropolitan area of Brescia

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Abstract

The present article aims to propose the possible application of a new transport system (tram-train) for the western metropolitan area of Brescia, in compliance with the new national guidelines (issued in April 2013), as an integration to the recently activated automatic light-rail line. The proposed system would upgrade an existing regional railway (the Brescia-Iseo-Edolo line), which at the moment is poorly used and would be an opportunity to redevelop the built-up areas to the west of Brescia, characterized by either residential or disused industrial zones.
Along the line being studied, new stops will be introduced with the aim of improving accessibility to the residential districts and city services.
Different kinds of tram-train systems are analysed here, highlighting the most important technical problems deriving from their application to the Brescia reality and providing a summary estimate of realization/operating costs.

1. Overview of the tram-train system

The tram-train system (TT), conceived in Germany[1] more than 50 years ago, has experienced a significant development in the last decade in Europe (Mantovani, 2011)[2], overcoming many technical and regulatory problems.
The main objective of this kind of transport system is to use light tram-like vehicles on existing poorly used/disused railways, if necessary connecting railways to urban tram lines, in order to create an integrated, flexible and adaptable system that is also able to guarantee low environmental impact (in terms of pollution) thanks to the use of electric light rolling stock.
Italy is characterized by a significant number of poorly used railways, which represent an extremely valuable infrastructure heritage as they are located in urban/metropolitan areas and have favourable features, such as limited slopes, wide radiuses of curvature and their own infrastructure.
In the past, these particular features have often been underestimated and existing facilities have been converted to car parks or used to widen road sections, without considering that reuse of such facilities would have made it possible to avoid considerable economic costs and environmental impact (in terms of land use) for the realization of brand new transport facilities.
The main goals of a TT system can translate into tangible advantages for users and transport companies:

- elimination of the so-called "passengers break-bulks": interoperability on both the railway and tramline network allows direct links between central and suburban zones, offering advantages to travellers in terms of time saving and comfort;
- improvement of accessibility: along a TT line, new tram stops can be realized to offer a more capillary service;
- economic advantages from a realization point of view: the renewal of existing railway facilities makes it possible to reduce initial investment costs;
- economic advantages from a management point of view: the TT system is characterized by flexible operating conditions.

TT systems are especially suitable for metropolitan areas (where there is no interruption between major and minor urban centres) often characterized by considerable mobility problems relating to the management of public transport, such as the critical balance between transport offer/demand and low levels of comfort. As a consequence, individual travel patterns are encouraged, causing congestion phenomena and negative environmental impact in urban centres.

1. The tram-train (TT) system was conceived in the German city of Karlsruhe. Since the post-WWII period the city has shown great sensitivity towards environmental problems and a series of traffic analyses have been carried out in order to exploit the existing but poorly used (or disused) regional railway networks.
The first example of a TT vehicle dates back to 1957, when the local railway line Albtalbahn was re-configured by installing ordinary gauge rails and was connected to the urban tramline, creating a continuous itinerary to the historical city centre. Another similar redevelopment project was undertaken only later, in the second half of the 70s, when a railway line, poorly used only for freight traffic was restored, linking the northern part of the region.
A significant step in TT system development was reached in 1992, when a new kind of service, based on the use of both the tramline rails and the regularly used national railway network (Deutsche Bahn - DB), was implemented.

2. It is not easy to outline a complete state of the art concerning the existing TT systems in Europe, as it is an ever-changing scenario, characterized by different countries that refer to different sets of national laws. In 2002 only two TT systems were already present in Europe: in Karlsruhe (including the Heilbronn T system) and in Saarbrücken. Two other TT systems were under development and 57 new systems were the subject of feasibility studies (Mantovani, 2011). In 2012 (after 10 years) in Europe a total number of 12 TT systems were present, even if not all of them could be considered "strict" TT systems, such as, for example, the one implemented in Zwickau.

2. Regulatory aspects and national guidelines

The regulatory framework concerning rail traffic on the National Rail Infrastructure (NRI) for "light transport" are RFI Provisions 01/2003 "Provisions concerning the regulatory and technical requirements for rolling stock" and 30/2007 "Modification and integration to provision 01/2003 concerning the regulatory and technical requirements for rolling stock".
Current regulations allow for the circulation of TT vehicles on the NRI, though some criticalities emerge, namely:
- the wheel-rail coupling;
- the gauges;
- the kind of power supply;
- the vehicle-platform interface;
- accessibility;
- safety issues.

Recently (April 2013), a work group including various organization representatives (ANFS, ASSTRA, Confindustria, RFI, UNIFER) elaborated the applicable national guidelines for tram-train systems (Molinaro, 2013). The national guidelines aim to provide the essential requirements for the safe circulation of TT vehicles.
The guidelines apply to TT systems and provide technical requirements in compliance with the applicable general legal framework. It should be noted that TT systems "must guarantee a level of safety at least equal to the existing rail/tramways systems, as specified in Legislative Decree no. 162/2007 and Presidential Decree no. 753/1980 [...]. Safety analysis must be carried out in compliance with European Community regulation (EC) no. 352/2009 and standard IEC EN 50126".
The initial section of the guidelines reports the definition of a TT system, which is "a transport system able to integrate railway lines and tramway lines (including high speed tramlines) through the use of vehicles which are specially designed to mainly circulate on tramlines, but also on railway facilities without causing passengers modal change and linking rural territories to urban areas. Such systems can be implemented following consecutive steps, starting from the extension of a tramline service to a disused railway facility and then realizing the actual sharing of different facilities and vehicles".
Therefore, the ultimate definition of a TT system, according to the guidelines, can include TT vehicles, tramway or railway facilities, trams and/or trains.
The guidelines identify three kinds of TT services:
- Tram-train type 1 (TT1): if the railway facility is exclusively used by tram-train vehicles;
- Tram-train type 2 (TT2): if the railway facility is used either by railway vehicles or tramway vehicles running in different time windows;
- Tram-train type 3 (TT3): if the railway facility is used both by railway vehicles and tramway vehicles running in a mixed way.

For each kind of TT system, the guidelines provide the technical requirements concerning the operating phase, the facility, the tramline and the TT vehicle.
The guidelines also provide information for verifying the feasibility of a TT system:
- Annex A - Aspects to consider during the preliminary design phase: the kind of system, kind of railway/tramway, existing tram features;
- Annex B - Aspects to consider during the design phase: expected transport demand/offer features, partners involved, existing facility features and relative programmed interventions, circulation regime and cruise control devices on the tramway/railway facilities, main trams/trains/TT vehicles technical specifications, check of the compatibility between TT vehicles and existing facilities.

3. Technical features and criticalities

The common origin of trams and trains offers important advantages from a technical and operating conditions point of view. However, the shared use of a single facility generates some criticalities.

▪ ***The wheel-rail coupling***

Permanent tramways and railways are based on the same operating principles, but differ in terms of rail geometry and type of switches. The problems deriving from the presence of different kinds of superstructures can be overcome by realizing a particular wheel section, able to adapt to the tramway and railway rails and switches (Alessandrini, 2005).

▪ ***The gauge***

There should be similarity between the tramway and railway gauges to avoid incompatibility problems. If both the tramway and railway have the same gauge or if the tramway is not present (and this is the most frequent situation), the TT system can be implemented without particular gauge problems. On the contrary, if the gauges differ, the technical solution should be evaluated taking into consideration the entity of the difference (Rizzetto, 2009).
In the case of significant differences between the two gauges, a third rail could be introduced in order to allow the circulation of either standard or reduced gauge vehicles.
In the case of slight differences between the two gauges and where a third rail cannot be introduced, it is possible to provide vehicles with variable gauge devices[3].

▪ ***The kind of power supply***

A TT system usually exploits existing facilities, i.e. railways or tramways characterized by different kinds of power supply. Over time this compatibility problem has been solved by re-

3. From a technical point of view, this solution is feasible but quite expensive and in contrast with the principle of economic convenience on which a TT system is based.

alizing vehicles able to adapt to different supplies, such as hybrids or multi-voltage vehicles (Dillig, 2003).

▪ ***Vehicle-platform interface and accessibility***

The original kind of facility exploited by the TT system can be characterized by different vehicle-platform interfaces, as the facility reflects original tramway or railway building standards. As a consequence, there could be two main problems relating to geometry (Novales, Bugarin, 2011): the height of the platform compared to the floor of the vehicle and the gap between the platform edge and the vehicle door.

If the original facility is a railway (without existing/planned urban tramlines) the problem can be solved by purchasing TT vehicles able to fit properly with the platform. On the contrary, when it is not possible to use special TT vehicles or when an urban tramline is present, adaptation work is unavoidable. The extent of work can vary considerably and can generate different costs. A possible solution (even if very expensive and more obtrusive) could be to double the rails and separate the platforms at the station, so that one platform is dedicated exclusively to the train stop and the other to the tram stop. Another solution could consist in aligning the tramway and railway stops linking two platforms at different heights.

Instead, in order to reduce the gap between platform edges and vehicle doors it is possible to provide vehicles with a movable step (paying particular attention to the prevention of malfunctioning) or to realize track bundles at stations so that narrower vehicles can better approach the platform edge.

▪ ***Issues relating to safety***

In the case of railway facilities used both by railway vehicles and tramway vehicles running in a mixed way, collision between trams and trains could occur with serious consequences because of the different kinds of masses and structural types of the vehicles involved, characterized by boxes with different levels of resistance to compression.

This problem can be dealt with by adopting either active or passive safety approaches. In terms of structural resistance to compression, TT vehicles, which are conceived to be light vehicles, will not be as safe as trains. Therefore, the lower level of safety which characterizes TT vehicles compared to trains should be compensated through the introduction of active safety measures, which consist in reducing the likelihood of crashes or malfunctioning through the use of devices, systems or equipment following preventive strategies.

4. The case of Brescia

4.1 The metropolitan area of Brescia

Brescia is a metropolitan city, with about half a million inhabitants and is located in the focal point of a linear metropolitan system (Busi, Pezzagno eds, 2011) called the “Po Valley LiMeS”[4]. The metropolitan area of Brescia requires high-quality transport systems (Maternini, 2000) and the recent activation of an automatic light-rail line (March 2013) goes in this direction, ensuring a high-performance connection between the northern and south-eastern parts of the city.

A possible light-rail line extension was initially provided for in the south-western part of the city, placing the terminus at the exhibition centre to obtain a sort of “backward T”, but the considerable realization costs spent for the first part of the light-rail line deferred the extension project.

The TT system project proposal (which this article focuses on) concerns the western part of the metropolitan area (the same that is the focus of the abandoned light-rail line extension project), which at the moment is covered by a rural railway service (the Brescia-Iseo-Edolo line). This line links the city of Brescia with the Camonica Valley and is characterized by a single track and standard gauge and is not electrified. The line is managed by the company TreNord Spa; it is poorly used but has great potential as its layout runs close to important residential districts and some disused industrial areas, which could be subject to urban regeneration processes, thanks also to the activation of a TT service.

The section of the Brescia-Iseo-Edolo line that is the focus of this redevelopment proposal is located between Brescia central station and Castegnato station and is about 10 km long (Maternini, Riccardi, 2010).

The proposed TT solution envisages 8 stops (of which 4 are existing railway stops), namely:

▪ **Brescia FS (km 0+000) – existing stop**

The Brescia-Iseo-Edolo line has its own terminus on the western platform of Brescia central station from where it is possible to interchange with other railway services (belonging to the national network) or with the urban automatic light-rail line (its stop is located just a few metres from the central station). The location of the terminus at Brescia central station also makes it possible to reach Brescia historical centre in 15 minutes, either on foot or using other urban bus lines.

▪ **Quartiere Primo Maggio (Milan Compartment) (km 1+100) – new stop**

The Primo Maggio district lies south of the Brescia-Iseo-Edolo line, with a population of about 3,000. The new stop would also serve the area just north of the line, where there is a

4. The concept of “Linear Metropolitan System” (or “LiMeS”) has been introduced by the 2007 PRIN national research. “From the metropolitan city to the metropolitan corridor: the case of the Po Valley corridor”, coordinated by Prof. Roberto Busi and funded by the MIUR Ministry. The Po Valley LiMeS, in the north of Italy, consists in a long narrow urban area, which goes from Turin to Trieste and is part of the European Corridor V which crosses Europe from west to east. It presents particular features which makes the Po Valley the main linear metropolitan system in Europe, comparable with the most important LiMeS located in North America, China and Japan.

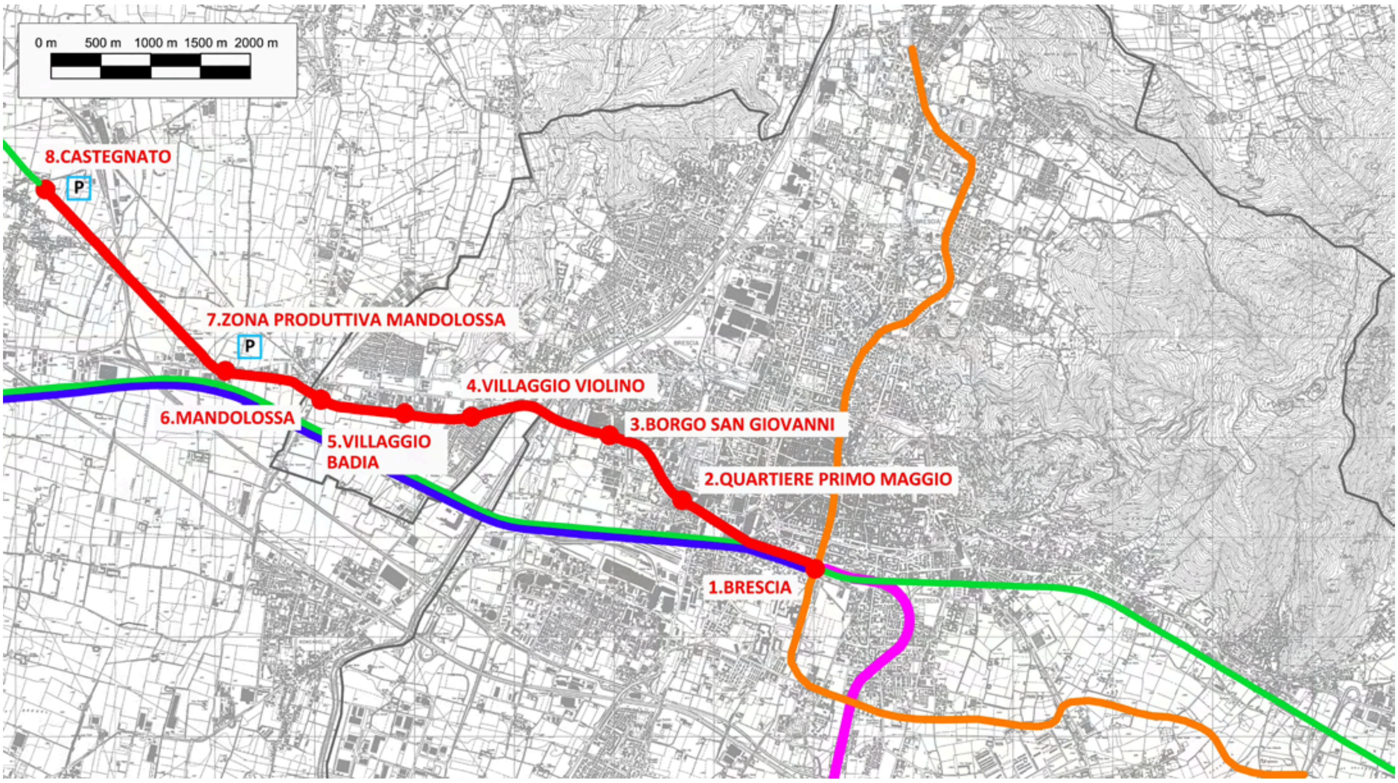

Figure 1 – The Brescia - Castegnato line section that is the subject of redevelopment (red) and the automatic light-rail line of Brescia (orange).

disused industrial zone which will be the subject of urban regeneration, leading to the realization of about 157,000 m^2 of floor space (61,000 m^2 have already been or are about to be built). From this district, with the present bus network, it takes about 6 minutes to reach Brescia central station and the maximum bus frequency (in rush hour) is 12'. The proposed TT system would have the same frequency, but it would take only 1'15" to reach Brescia station.

▪ Borgo S. Giovanni (Fiumicello district) (km 2+500) - existing stop

The Fiumicello district is located above the Brescia-Iseo-Edolo line, around Borgo S. Giovanni station, and has about 7,000 inhabitants.

At the moment a disused industrial area in the district is being redeveloped and a new residential block is under completion. Therefore, thanks to the realization of a TT service, the upgrading of the existing railway stop, which is at the focal point of the district, would make it possible to satisfy present and future transport demands.

From this district, with the present bus network, it takes about 9 minutes to reach Brescia central station and the maximum bus frequency (in rush hour) is 12'. The proposed TT system would have the same frequency, but it would take only 3'15" to reach Brescia station.

▪ Villaggio Violino (km 4+000) – new stop

The Villaggio Violino district is bordered by the Brescia-Iseo-Edolo railway to the north and by the Milan-Venice railway to the south. The district dates back to the 50s and was realized by the so-called "Cooperativa La Famiglia" owned by Father Marcolini. At the moment the district has about 4,000 inhabitants and is served by 2 urban bus lines. The new TT stop would be located close to "S. Anna" shopping centre.

From this district, with the present bus network, it takes about 26 or 35 minutes (depending on the bus line) to reach Brescia central station and the average waiting time (in rush hour) is 7'30" or 10'. With the proposed TT system there would be an average waiting time of 6' and it would take 5'15" to reach Brescia station.

▪ Villaggio Badia (km 4+600) – new stop

The Villaggio Badia district is located north of the Brescia-Iseo-Edolo railway and has about 3,500 inhabitants

At the moment the district is served by 1 urban bus line. The new TT stop could be placed near the disused level crossing in Via Colombaie, so that not only Villaggio Badia, but also the Villaggio Violino district would be served.

From this district, with the present bus network, it takes about 24 minutes to reach Brescia central station and the average waiting time (in rush hour) is 10'. With the proposed TT system, with an average waiting time of 6', it would take only 6'40" to reach Brescia station.

▪ Mandolossa (km 5+500) - existing stop

Mandolossa is located between Brescia South ring road and

the provincial road "SpBs11 (former SS11) Padana Superiore". It is crossed by the Brescia-Iseo-Edolo railway, where a stop already exists. It has a population of about 1,300 inhabitants and an urban bus line is present.
From this district, with the present bus network, it takes about 20 minutes to reach Brescia central station and the average waiting time (in rush hour) is about 10'. With the proposed TT system, with an average waiting time of 6', it would take about 8' to reach Brescia station.

▪ **Zona Produttiva Mandolossa (km 6+500) – new stop**
The hypothesis of realizing a new stop in the industrial estate of Mandolossa derives from the need to have an interchange car park where the rural bus lines can have their terminus (at the moment their terminus is at Brescia Central Station). With this solution, users would have to make a modal change, but would reach Brescia station more quickly as existing bus lines cover a highly congested itinerary, especially during rush hour.
The interchange car park could also serve commuters from the west and from the South ring road, linking the motorway toll booths.

▪ **Castegnato (km 9+000) – existing stop**
The TT line terminus would be at Castegnato station. This station would serve Castegnato town, with 8,000 inhabitants. Thanks to a new interchange car park, this stop would easily serve users from the other neighbouring Franciacorta towns and also commuters using their own private vehicles from the provincial road SpBS510 Sebina Orientale.
The new stops have been positioned taking into account not only the geometric layout of the line, but also by assessing the amount of space required for lay-bys and platform adaptation, aiming to reduce on-line train crossing as much as possible.
The realization of a TT service in the western metropolitan area of Brescia aims to improve accessibility to the city, provide an interchange between private and collective transport modes, reduce travel time and improve travel comfort.
The main advantages of TT service implementation consist in its economic convenience[5] and its moderate environmental impact.

5. In order to implement a TT service only limited interventions are required on the infrastructure, such as for example the adaptation of existing platforms, the realization of new tram-like stops and the introduction of lay-bys for train crossing. Interchange parking at Castegnato and Mandolossa stations and a depot (for night-time vehicle parking and ordinary maintenance operations) should also be realized. The introduction of a TT service would lead to transport service optimization and the reduction of operating management costs thanks to the elimination of overlapping bus lines.

4.2 Design alternatives

4.2.1 Tram-train type 3: mixed circulation of tram and trains between Brescia and Castegnato

A first design alternative consists in introducing a light tram-like transport service running on the existing railway line between Brescia and Castegnato with a mixed circulation of trams and trains to create the so-called TT3 system.
This hypothesis generates some criticalities, mainly relating to safety and the management of traffic and level crossings.

4.2.2 Tram-train type 1: exclusive circulation of trams between Brescia and Castegnato. Railway terminus at Castegnato station

Under this alternative, the railway terminus would be located at Castegnato station (instead of Brescia central station), isolating the link through the exclusive circulation of tram-like vehicles. This kind of solution would be characterized by reduced safety problems and favourable operating conditions, but would be disadvantageous to commuters from the Camonica Valley and Lake Iseo: as a matter of fact, commuters would experience modal change delays in reaching the city of Brescia, therefore, the modal interchange should be studied thoroughly.

4.2.3 Tram-train type 1: exclusive circulation of trams between Brescia and Castegnato. Train circulation deviated to the Milan-Venice railway at Castegnato Station

Under this alternative, the TT system could run exclusively on the existing facility between Castegnato and Brescia, while the regional railway service (Brescia-Iseo-Edolo regional line) could exploit the existing facility up to Castegnato station and then be deviated to the Milan-Brescia railway line for the last part of the itinerary.
The forthcoming HS/HC line will decrease the traffic on the old Milan-Brescia line; therefore the deviation of trains to this line would not cause relevant overloading problems. The deviation could be made between Castegnato and Mandolossa stations, where the two railway lines run parallel. The main limit of this configuration consists in the fact that regional trains from Brescia to Iseo would cross the opposite track on the Milan-Venice line, in order to join up with the Brescia-Iseo-Edolo line. Crossing could be done through a switch (causing potential safety problems) or through the realization of a flyover (with a consequent increase in costs).

4.2.4 Tram-train type 1: exclusive circulation of trams between Brescia and Iseo. Train circulation deviated to the Milan-Venice railway through the upgrading of the Bornato-Rovato Borgo line

Under this alternative, the new TT system could have its terminus at Iseo station. Trains going to Brescia could be deviated to the existing regional line Bornato-Rovato Borgo and

then deviated again onto the Milan-Brescia line changing at the Rovato station.
The TT service between Iseo and Brescia would be characterized by high frequencies. This solution seems to be the most expensive, as it implies the purchase of new vehicles, the installation of a power supply for about 25 km and the almost complete upgrading of the Bornato-Rovato line, which at the moment is used only for freight.

4.3 System design

4.3.1 Estimate of the maximum peak-hour passenger flows

The introduction of a new rapid transport service such as a TT system, characterized by a dedicated permanent way, could bring to a modal split relating not only to existing collective means of transport but also individual ones, thanks to the possibility of saving travel time during peak hours.
The attraction of the new system mainly relies on its features: punctuality, operating speed and frequency are fundamental conditions for its success against other alternatives. Another essential feature is the high level of comfort on board, which should push users to choose collective systems instead of passenger cars.
Existing urban bus lines, which overlap the new TT system (three in the western metropolitan area of Brescia), will be properly modified.
Brescia Mobilità Spa, Brescia's transport company, provided data concerning bus passenger flows. In particular, focusing on the bus stops situated close to the TT line, analysis of passengers transported by the three existing bus lines during the morning rush hour on a typical working day showed that a total of about 650 passengers/hour*direction could be diverted to the new TT service.
In addition to this flow, passengers from the existing Brescia-Iseo-Edolo regional railway (characterized, in the Castegnato-Brescia link, by 140 passenger/hour*direction) should be taken into consideration, reaching a total of about 800 passenger/hour*direction at peak times.
Alongside this, we should consider that a new potential flow of passengers could be generated by the ability of the TT system to attract new users, such as non-systematic users who would choose the new system because of its performances. Similarly, former passenger car users living by the stops or the interchange car park could find the new system more competitive than individual means of transport and then be diverted onto the TT system. It can be estimated that this component would increase the passenger flow calculated so far by 20%, to about 960 passenger/hour*direction.
If the terminus of the rural bus lines was set outside the city at the Zona Produttiva Mandolossa TT stop, it would be possible to further increase by 320 passenger/hour*direction the passenger flow estimated so far, reaching a total (for the TT3 system) of 1,280 passenger/hour*direction during rush hour.
This approximate estimate is based on the present situation. In the future, with easy interchanges between light-rail and TT system and after the regeneration of disused areas, considering also new residential loads, the estimated value could even increase.
Another future scenario, capable of increasing the estimated number of passengers transported, is represented by the extension of the TT system southwards towards Montichiari Airport.
Finally, the possible evolution of the initial TT3 system to a TT1 could bring to a total estimate of about 1,500 passenger/hour*direction.

4.3.2 Definition of the service

Definition of the service is based on the estimate of the maximum passenger load described in the previous paragraph.
The length of the vehicles is strongly related to the estimated number of passengers: in the Brescia-Castegnato link the selected vehicles are 35-40 m long and are able to carry up to 300 passengers.
Floor height will be selected depending on the platform layout: in the link in question, considering there is no tramline in Brescia, we do not recommend using completely depressed floor vehicles[6], as the platforms are mainly railway-like.
The minimum number of vehicles required refers to the worst operating conditions, i.e. to the peak hour of a typical school/working day. The number of vehicles able to satisfy transport demand can be estimated by analysing the service throughout the day, evaluating the time required to cover the complete itinerary of the line and then assessing where it is necessary to insert lay-bys.
For each link between two adjacent stops, as an initial approximation, the motion diagram is characterized by a trapezoidal shape and is composed of an initial acceleration phase[7], a constant motion phase and a final deceleration phase which equals the acceleration one, without considering the coasting phase, during which the vehicle moves thanks to its inertial force and progressively decelerates without using the braking system. Resistance to acceleration (which should be increasing rather than constant) was not considered, even if present, while the physical constraints to speed were taken into consideration.

6. The ideal solution would be to have vehicles with a floor 55 cm above the track surface. Doors should be numerous and wide, in order to make it easier to get on/off the TT vehicles.

7. Acceleration values for TT vehicles were set at 1.1 m/s^2 for speeds up to 40 km/h and at 0.5 m/s^2 for speeds up to the maximum permitted speed. The acceleration value for trains was set to 0.4 m/s^2 up to the steady-state speed value.


Figure 2 – The tram-train service in Kassel.
Source: http://railforthevalley.wordpress.com/

Stop duration time strictly depends on the kind of vehicle: in the case in question the stop lasts about 30 seconds. The stop at the terminus lasts about 4 minutes, considering the time the driver needs to reach the cabin in the opposite direction, the drivers' break time and any recovery of delays. The minimum lap time is therefore 2'016.8 seconds, corresponding to about 34 minutes. According to these assumptions, the commercial speed v_c and operating speed v_e are 44.44 km/h and 32.30 km/h, respectively.

Transport demand analysis led to the estimate of 1,280 passengers/hour*direction and it is plausible to allocate all of them to the section with the heaviest load. Assuming the TT vehicles' maximum capacity of 300 passengers, we can calculate the following amounts:

N of trains/h = (Maximum flow)/(Vehicles capacity) =
= (1'280 p/hd)/(300 p/veh) = 4.3 veh/h

Time separation between vehicles = (One hour)/(N of trains/h)=
= (3'600 s)/(4.3 veh/h) = 837.2 s

N of vehicles in line = (Lap duration)/(Time separation between vehicles)=
= (2'016.8 s)/(837,2 s) = 2.4

Rounding up the number of vehicles on the line, the minimum value is 3, with a frequency of about 11 minutes during rush hour. The effective time separation between vehicles is then re-calculated as follows:

Actual time separation between vehicles =
= (lap duration) / (rounded N of trains/h) = (2'016.8)/(3) = 672.2 s

In order to offer a regular frequency of vehicles, it should also be taken into consideration that the lap time duration should be a whole multiple of the interval between the different runs. A regular frequency is very important for users, especially when the interval between the different runs is more than every 5-6 minutes. Alongside this, timetables should be easy to remember for users. Therefore, under the hypothesis of setting the frequency to 12 minutes, the number of transits increases to 5 per hour. As a consequence, lap duration should be increased up to the smallest whole multiple of 12 minutes (corresponding to 720 seconds), i.e. 36 minutes, corresponding to 2'160 s. The difference between this last lap duration and the one previously calculated (144 seconds) can be used to increase the duration of the terminus stop or to recover any slight delays along the links. So, the actual capacity of the system described above is slightly higher than the estimated one at 1,500 passenger/hour*direction. During off-peak time windows the interval between transits can be increased.

Once the number of vehicles, frequency and the travel times are known, it is possible to realize the service motion diagram. In addition to the hypothesis described above, another constraint is represented by the need to make vehicles meet and cross at the existing Borgo S. Giovanni station (where a lay-by is already present) and at two other stops. "Odd" TT vehicles (running in the direction Castegnato-Brescia) cover the course in 12.8 minutes, considering maximum speed/acceleration/deceleration values and stops lasting 30 seconds. Instead, "even" vehicles (running in the direction Brescia-Castegnato) cover the same distance in 15.8 minutes, considering longer stops at stations (45 seconds instead of 30 seconds). The stop at the line terminus is 4.4 minutes (both at Castegnato and Brescia stations), therefore the whole course duration is of 34 minutes.

The regular railway service, whose circulating trains cover the whole distance in 7.5 minutes, means it is necessary to introduce 2 other lay-bys (at the Villaggio Violino and the Zona Produttiva Mandolossa stops) allowing a single train transit every 12 minutes or a couple of trains (running in opposite directions) every 36 minutes. Once the TT system is in operation, the ordinary train timetable will inevitably be subject to change.

It is also necessary to consider the availability of reserve TT vehicles, both to promptly substitute them of necessary and to better manage ordinary vehicle maintenance operations without affecting the service. The number of reserve TT vehicles depends on many factors, such as their initial number, their maintenance requirements, etc. In the proposed system, it is assumed that maintenance operations are carried out on one vehicle at a time. In addition to this, as an 'active reserve' another TT vehicle would be necessary (corresponding to 15% of the fleet). Only an accurate analysis of the rolling stock and of operating conditions will lead to the final decision to purchase just one reserve vehicle, reducing investment costs and assuming a reasonable level of risk (corresponding to two vehicles out of order at the same time).

5. Some project characteristics

The preliminary design of a TT transport system, such as the one in the case study, implies the analysis of some fundamental elements, namely: the need to renew the existing facility, the power supply adaptation, accessibility to the service (in particular platform-vehicle interface and track pedestrian crossings at stations) and level crossings. The present document did not take into consideration the issues relating to safety and the signalling systems.

▪ ***Lay-bys***
Under the TT3 hypothesis, the service analysis highlighted the need to have four lay-bys located at four stops along the TT line: Borgo S. Giovanni, Villaggio Violino, Mandolossa and Zona Produttiva Mandolossa. Borgo S. Giovanni station does not require the realization of a lay-by[8] as it already exists (a three-track bundle is present) while new lay-bys should be realized at the other stops. TT vehicles are intended to use the deviated rails segments when a train is present at the station, in order to limit delays to the ordinary railway service.
The evolution of the initial TT system configuration from a TT3 to a TT1 could reduce the number of lay-bys from 4 to 2.

▪ ***Platforms***
The project foresees the realization of four new stops and the adaptation of existing ones.
Platforms are 80m long, corresponding to two coupled TT vehicles, in order to make it easy to get on/off the vehicles safely.
In order to increase accessibility, where a lay-by is not necessary, the platform should be realized on the side characterized by the highest passenger inflows.
The platform height[9], in compliance with railway standards, will be set at 55 cm at every stop. As a matter of fact, the present platforms are only 35 cm above the track surface and do not facilitate boarding operations.
On the contrary, there could be problems with the distance between the longitudinal side of the vehicles and the platform edges, as reported in figure 3. As a matter of fact, depending on the kind of vehicles circulating on the line, doors are placed at different distances from the platform edge and the distance is particularly considerable for TT vehicles (29.25 cm). In order to tackle this safety problem, a possible solution could be the use of movable steps.

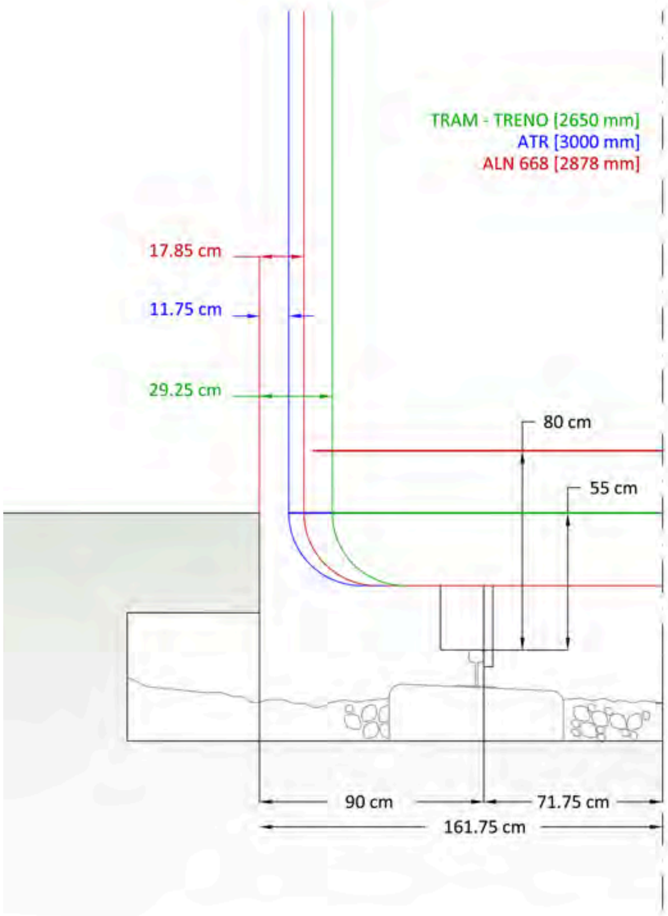

Figure 3 – Distances between the longitudinal side of the vehicles and the platform edge per type of circulating vehicle.

▪ ***Power supply***
Providing the line with an electrical power supply represents an important evolution of the existing facility and could increase line potential: as a matter of fact, the power supply can improve the overall performances of the system, such

8. Double-tracks are realized using deviators characterized by a radius of 170 m, in compliance with railway standards. The length of the deviators is about 30 m each, to which a useful length of 80 m is added (as the minimum length for the second track), reaching a total length of 140 m.

9. Alongside this, recently introduced trains circulating on the Brescia-Iseo-Edolo railway (ATR) are characterized by a floor that is 55cm high; therefore, platforms should be adapted in order to allow on-the-edge boarding operations. There are also more dated trains (ALn 668) still circulating on the line, which have a floor height of 80 cm which are likely to be out of use by the start-up of the TT system.
The selected TT vehicles are 55cm high; therefore they are compatible with the new platforms.

as acceleration, commercial speed, the possibility to partially recover energy during the braking phase, reduction of noise and pollutant gas emission and economic advantages during the operating phase of the service.

The only disadvantage consists in high initial investment costs, which do not vary depending on mileage (on the contrary, diesel-powered vehicles are characterized by operating costs which are proportional to mileage).

The choice of whether or not to electrify the line or keep the existing facility depends on economic consideration: to provide electricity to the line is justified only if a given mileage is reached during the steady-state service. According to the estimated passenger flow, the frequencies and the overall performances of the TT system that are the subject of the present project, electrification of the line should be more than justified.

If a 750V DC voltage tramway was installed, there would be a higher compatibility with any electrified lines within the urban area. Instead, if a 3kV DC railway voltage power supply was installed, it would be possible to limit potential drops along both the feeder and the contact power line, reducing the number of electricity substations. The rural context would allow higher voltages than the urban one and the potential future extension of the Castegnato-Brescia line to Montichiari Airport, exploiting the existing 3kV railway facility, would ensure compatibility of the rolling stock.

▪ ***Depot***

The depot will be located east of Castegnato station. The building will have three terminal tracks to house the whole TT vehicle fleet and a workshop for ordinary maintenance work will be realized. For extraordinary interventions the existing depot/workshop near Iseo station will be used and vehicles will be pulled by diesel-powered locomotives (as the Brescia-Iseo-Edolo railway from Castegnato to Edolo is not electrified).

▪ ***Level crossings***

There are 9 level crossings along the existing railway between Brescia and Castegnato. With the introduction of the new TT service, the level crossings could be managed based on different scenarios, depending on the kind of TT system.

A possible solution (for TT1 and TT3 systems) could be the realization of underpasses[10], in order to eliminate interferences with motorized traffic, even if this kind of intervention would require a more detailed analysis of the overall dimensions.

- Under the scenario of a mixed circulation of TT vehicles and trains, as it is not possible to use level crossings with gates for trains and with traffic lights for TT vehicles at the same time (the law does not allow such heterogeneous solutions for safety reasons), the existing gates are kept all along the line. Therefore, in order not to excessively affect the circulation of motorized traffic, it is necessary to reduce gate timing. The TT system guidelines establish that, in the case of TT3 systems, gate timing at level crossings can be differentiated depending on the kind of approaching vehicle and maximum speed or braking systems. In order to do that, automatic identification systems can also be used. As regards the line that is the subject of study, an automatic identification system could theoretically be introduced, considering that, at the same time, the track open sign should be placed at a distance that allows rolling stock to stop safely in the event of gate malfunctioning (in compliance with standard UNI 11117). In practice, the gate closure period would be too long because of the high frequency of vehicles, making the TT3 scenario unadvisable compared to a TT1 one.
- Under the scenario of the exclusive circulation of TT vehicles, level crossing management would be easier than in the previous alternative. According to standard UNI 8379, which defines binding transport system features, the TT1 system proposed for Brescia is treated as a rapid tramway. For this kind of service, standard UNI 8379 allows for level crossings with signals or level crossings with gates. The best configuration for Brescia would be the presence of crossings with signals, featuring traffic lights regulated on board by approaching vehicles. The "track closed" signal timing for motorized traffic would be about 30 seconds, for a total closure time of 5 minutes per hour.

10. Underpasses can be realized mainly in two ways: interrupting the service or maintaining operation of the service during the work. In the first case, for each underpass, a total expenditure of about 1,500,000.00 € (amount to be put out to tender); in the second case, in addition to the costs of the underpasses, the cost for Essen bridge technology application should also be considered (about 250,000.00 €).

5.1 Initial considerations about investment and operating costs

The most significant advantage of a TT system, from a realization point of view, consists in its economic convenience. An initial summary evaluation of the realization costs of the proposed solution for Brescia, expressed as the amount to be put out to tender (excluding VAT), excluding costs relating to control-command and signalling systems, safety devices and design costs, includes the following:

- civil work (realization of 4 new stations and redevelopment of 4 existing ones, realization of 1 underpass). Investment costs range from 3,500,000.00 € to 9,500,000.00 €;
- permanent way (realization of 3 90m-long lay-bys using UNI 50 rails, 2 s60/170/0, 12 switches for each lay-by). Total expenditure is 550,000.00 €, including ballasts, concrete sleepers, small parts and labour;
- electrification (for the whole line between Castegnato and Brescia, including 2 power substations). Investment costs are about 6,000,000.00 €;

- rolling stock (purchase of 4 vehicles). Total expenditure of 14,000,000.00 €;
- depot (depending on the selected technical solutions mentioned above). Expenditure ranging from 4,600,000.00 € to 6,100,000.00 €.

Thus final expenditure ranges from 28,650,000.00 € to 36,150,000.00 € (excluding VAT) for initial investment costs. Therefore, kilometric costs range from 3.2 to 4 million €.

It is important to highlight that the level of service offered by the newly designed TT system is comparable to the automatic light-rail system, but implies initial costs (in relation to kilometric costs) which are about 20 times lower.

Considering similar experiences, the estimate of annual operating costs is about 3,440,000.00 € -4,730,000.00 €,

Operating revenues can be estimated at 0.30 €/passenger, considering both ordinary and season ticket fares and setting the present TPL fare at 1.20 €/ticket. The estimated number of passengers per year varies between 1,200,000 and 2,500,000, therefore total revenue varies between 360,000.00 € and 750,000.00 €. In addition to the operating revenues described above, the savings deriving from the adaptation of the entire existing PT network should also be considered, namely: about 500,000.00 € could be saved by reducing overlapping urban bus lines; about 1,000,000.00 € by locating the terminus of rural bus lines outside the city at the Mandolossa TT stop. Finally, as a qualitative consideration, the introduction of a TT1 system (moving the terminus of the regional railway from Brescia to Castegnato) could bring further savings in terms of km covered by trains (about 120,000 km/year).

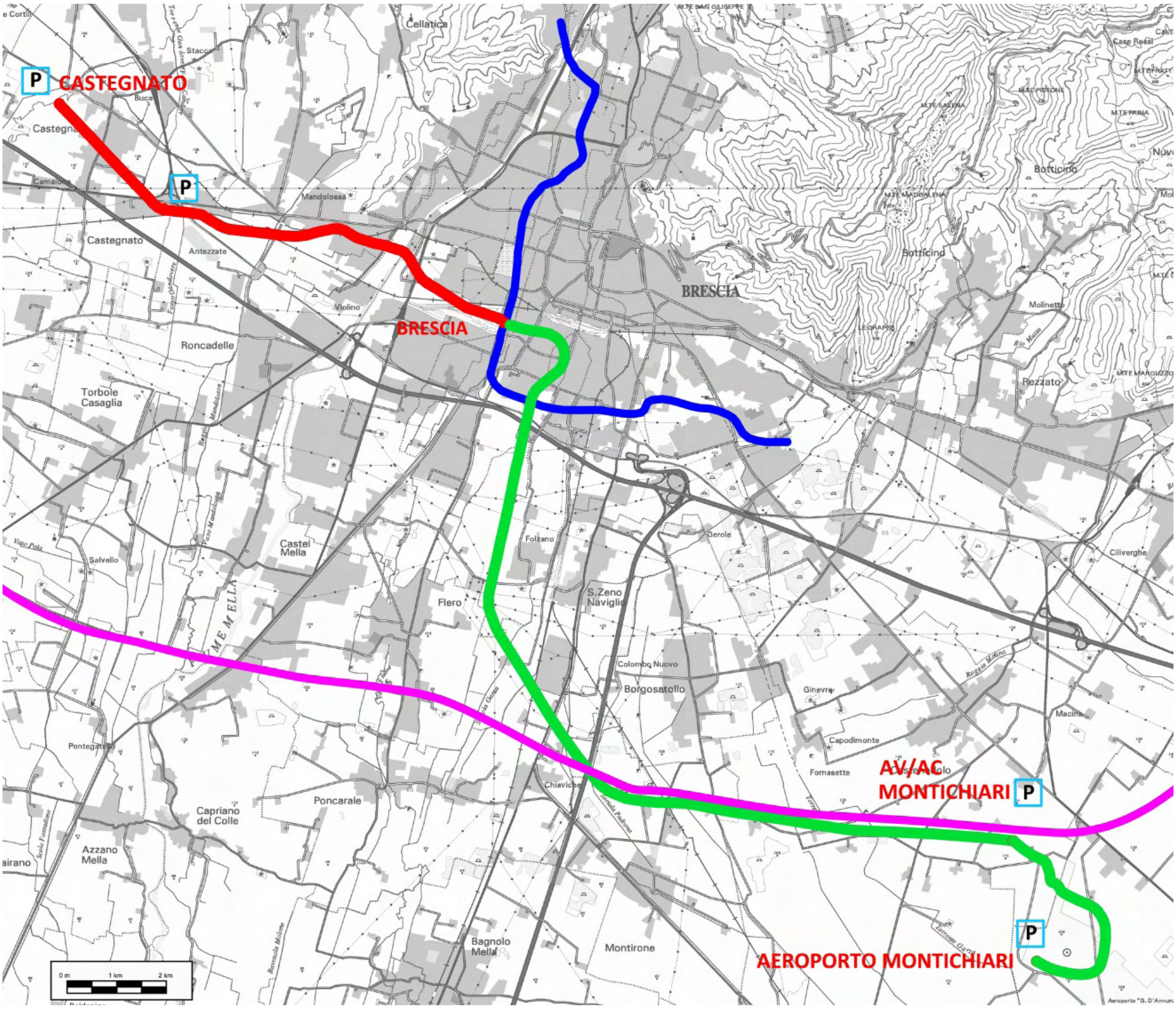

Figure 4 – The new Brescia - Castegnato TT line (red line) and its possible extension connecting Brescia and the High Speed/High Capacity (HS/HC) Montichiari station (green line). The map also shows the new light-rail line (blue line) and the HS/HC line (magenta line).

6. Conclusions

The existing railway facility linking Brescia to Iseo and Edolo represents an important resource for the territory, which unfortunately, at the moment, is not sufficiently exploited. The recent guidelines on TT systems allow for the use of this line through the introduction of tram-like vehicles and by increasing the number of stops, such a system would provide a capillary service able to serve the western metropolitan area of the city of Brescia. In addition, after a necessary reorganization of the PTL network, the TT system would be well interconnected to the brand new automatic light-rail line (activated in March 2013), offering a high-quality integrated transport system, able to reduce the congestion problems of the area involved and improve service accessibility.
The TT solution which could be easily adapted to the Brescia reality is the TT1, which foresees the exclusive circulation of tram-like vehicles on the section of line between Brescia and Castegnato. This configuration would guarantee a maximum load of about 1,500 passengers/hour*direction in rush hour, reaching a total of 2,500,000 passengers per year. Other TT configurations, such as for example the TT3 solution, would guarantee a lower passenger load (about 1,200,000 per year).
A further development of the proposed system could be represented by the extension of the TT line from Brescia central station to Montichiari Airport where a new HS/HC station is planned, covering also the south-eastern area of the Province of Brescia (see figure 5). The extension proposal derives from the need to link the airport to the main cities in the north of Italy through a rapid, efficient and high-quality transport system such as the TT. The extension envisages the reuse of two existing (but poorly used) railway lines (namely, Brescia-Cremona to San Zeno Naviglio station and Brescia-Parma to Borgosatollo station) and the realization of a new permanent line adjacent to the HS/HC line and provincial road SP19 to the airport.
Finally, as already mentioned, during the design phase, particular attention should always be paid to analysis of accessibility to the stations, in particular for non-motorized users (especially vulnerable road users), in order to increase the likelihood of success and development of any new transport system.

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