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Innovative technologies for the public transportation in the Urban Mobility Plan of Padova

M. Andriollo[1], G. Del Torchio[2], G. Martinelli[3], A. Morini[3] &
A. Tortella[3]
[1]*Department of Electrotechnics, Milan Polytechnic, Italy*
[2]*APS - Azienda Padova Servizi Spa, Padova, Italy*
[3]*Department of Electrical Engineering, Padova University, Italy*

Abstract

The reorganization of Padova public transportation system, established in the Urban Mobility Plan, aims at the development of three main lines along the north-south, east-west e north-south/east directions. The choice of advanced intermediate capacity rubber-tyred transport systems with guided running mode seems to be particularly suitable for Padova town planning, due to their favourable technical and economical characteristics. In fact their supply and traction systems ensure low air and noise emissions, while the inherent flexibility related to both the guidance and the supply modes allows efficient operation even in presence of other vehicles or obstacles along the critical route sections of the lines. Moreover the supply flexibility makes the lines easily compatible with historical-architectural structures. At present the first line is getting into construction and it is expected it will be put into operation by autumn 2003.

1 Introduction

Nowadays the need of urban mobility is satisfied by using various transportation systems with different characteristics and performances according to different utilization demands. In Tab.1 some data are reported, with reference to conventional transportation systems (bus, tram, light rail metro, conventional metro).
The wide ranges of the data reflect a partial overlapping and a substantial

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Table 1: Performance characteristics of conventional transportation systems [1].

	Bus and trolley-bus	Tram[1]	Light rail metro[2]	Conventional metro
Vehicle capacity (passengers)[3]	60 ÷ 120	100 ÷ 200	100 ÷ 250	140 ÷ 280
Transport capacity (phd)[4]	1500 ÷ 3500	2000 ÷ 6000	6000 ÷ 15000	20000 ÷ 45000
Commercial speed (km/h)	5 ÷ 20	12 ÷ 20	18 ÷ 40	25 ÷ 60
Mean stop distance (m)	150 ÷ 300	150 ÷ 300	300 ÷ 600	400 ÷ 1000

[1] in shared lane
[2] or tram with predominant protected lane
[3] 4 standing passengers/m^2 included
[4] passengers per rush hour per direction

continuity in the performance values, due to the variety of operating conditions and specific technological features and infrastructures. In particular, when the transportation demand is within 2000 and 4000 phd (passengers per rush hour per direction), systems based on free drive operation (bus or trolley bus) or fixed guideway (tram) can be convenient.

Nowadays, tramways have got new interest especially if the transportation demand exceeds 4000-5000 phd and the town structure facilitates their application. Anyway tram systems have relatively high investment costs as well as low flexibility. On the contrary, conventional bus and trolley-bus lines sometimes do not meet the favour of passengers for low comfort or poor image, in addition to the reduced transport capacity and - for buses with diesel engine - to pollution problems. As a consequence many local governments of medium sized town (100,000-400,000 inhabitants) are involved in the modernization of the local transportation network by improving its image, ride comfort and efficiency in order to fit the passenger requirements and, at the same time, to reduce air and noise pollution as well as the traffic congestion caused by the increase of private cars.

The necessity of coping with these problems led to the development of new transport systems, different from tram and bus, to get the following targets:

- investment and operating costs lower than costs related to tramway;
- good service efficiency and modern image;
- reduced environmental impact as regards the historical-architectural structure of the town;
- reduced air and noise pollution.

These systems, commonly called "advanced intermediate rubber-tyred transport system with guided running mode", are of particular interest when transportation demand is between 2000 and 4000 phd.

2 Advanced intermediate transport systems

The intermediate systems support different technological solutions, but, in addition to the above-mentioned targets, they share the following features:

- good riding comfort and accessibility;

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- intermediate capacity between tram and bus (2000-4000 phd);
- flexible operation with possibility to choose either guided or free-guided running mode; in case of guided mode, the guidance system can be either of mechanical type (central guiding rail or side kerbs) or of functional type (by means of optical, electronic or magnetic devices);
- electric propulsion with external supply (overhead wire or ground plant) and/or with on board supply (batteries or diesel-electric system);
- realization of an "integrated system" (set of constraints, infrastructures, fixed plants, devices for vehicle running control, devices for customer information and so on) according to the planning of a modern service.

As examples of such systems, the four technologies which nowadays have got a good level in experimentation and application are:

- TVR system (Transport sur Voie Réservée), by Bombardier Transport e Spie Enertrans consortium;
- TRANSLOHR system, by Lohr Industrie in collaboration with Parizzi (Alsthom group);
- CIVIS system, by Matra and Irisbus (IVECO group);
- STREAM system, by Ansaldo-Breda.

Their main features are described in the paper, with reference to the present development stage [2-10].

2.1 TVR

TVR (Fig.1) is a transport system based on [3]:

- Dual mode guidance
  - Guided running mode as a conventional tram using a central rail.
  - Un-guided running mode as a conventional articulated transit bus, excluding the rail and the external supply.
- Dual mode supply
  - External supply by overhead contact wire with pantograph-catenary system and the rail as return conductor. The vehicle is arranged to be supplied also by a twin wired overhead line like a trolley-bus.
  - On-board supply for 'off-wire' operation, provided by a 200 kVA diesel engine-electric generator system feeding an inverter at 750 V DC voltage.

The traction equipment consists of two 3-phase induction motors (150 kW each), located in the front and rear of the vehicle and fed by the inverter.
The vehicle is like a tram and consists of three articulated car-bodies, each one mounted on an aluminum frame to which all structural elements are bolted. The main technical characteristics are given in Tab.2.
The TVR technology has been chosen in Nancy to construct three lines (total length 25 km). The first line (11 km and 28 stations) was put into operation on December 2000. The power is supplied by a trolley using the pre-existing twin wired overhead line.

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Figure 1: Bombardier TVR in Nancy [4].

2.2 TRANSLOHR

TRANSLOHR (Fig.2) is a transport system based on [5]:

- Dual mode guidance
  - Guided running mode using the coupling between a 'V' roller system and a central rail placed in a 20 cm deep concrete trench (Fig.3); the roller system drives the axle steering device.
  - Un-guided running mode as a conventional articulated transit bus, excluding the coupling with the rail and without the external supply.
- Dual mode supply
  - External supply by overhead contact wire with pantograph-catenary system and the rail as return conductor.
  - On-board supply for limited 'off-wire' operation, provided by batteries supported by a 5 kW diesel-electric system for their recharging.

Figure 2: TRANSLOHR system [6].

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Table 2: Main technical characteristics of advanced intermediate rubber-tyred transport systems.

	CIVIS	STREAM	TRANSLOHR	TVR
Sizes (m)				
- width	2.55	2.50	2.20	2.50
- height	3.22	2.40	2.89	3.40
- length	12 18	12 18	25 32	24.5
Dual mode guidance	yes	yes	yes[1]	yes[2]
Traction	electric	electric	electric	electric
- external supply	twin wired overhead line	in the roadway	single wire or twin wired overhead line	single wire or twin wired overhead line
- on-board supply	diesel-electric/Euro 3	batteries (3-4 km)	batteries (1 km)[4]	diesel-electric/Euro 3
- bi-directional	no	no	yes	no
Vehicle capacity[3]	70 120	70 120	116 148	145
Per hour capacity (phd)[3]				
frequency 4 min	1050 1800	1050 1800	1740-2220	2175
3 min	1400 2400	1400 2400	2320-2960	2900
2 min	2100 3600	2100 3600	3480-4440	4350
Main performance data				
- commercial speed (km/h)	(20-25)[5]	(20-25)[5]	(20-25)[5]	(20-25)[5]
- maximum speed (km/h)	80	60-70	60-70	70
- maximum acceleration (m/s^2)	1.4	1.2	1.3	1.2
- minimum curve radius (m)	25[6]	12.5	10.5	12
- maximum slope (%)	13	-	13	13

[1] 'off-wire' operation only for short distances (for instance in depot)
[2] Italian road rules don't allow more than 18-m long vehicles
[3] 4 standing passengers/m^2 included
[4] possible integration with 5 kW diesel-electric system
[5] dependent on the length of the protected lane
[6] minimum compatible with optical guidance

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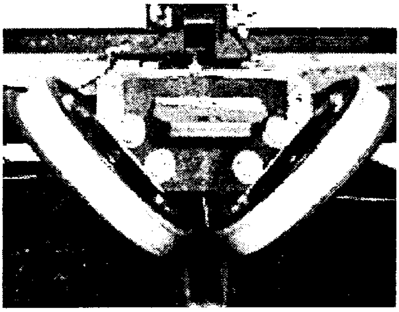

Figure 3: TRANSLOHR guidance system [5].

The traction equipment consists of two 3-phase PM synchronous motors (peak power 220 kW), located in the front and rear of the vehicle, under the driving cabs; the motors are fed by an inverter (input voltage 750 V DC).
The TRANSLOHR vehicle is made up of three or four car-bodies; the main technical characteristics are reported in Tab.2.
Some prototypes have operated in test facilities with satisfactory results; till now no commercial line has been built.

2.3 CIVIS

Unlike the former systems, CIVIS (Fig.4) uses a functional guided running mode.

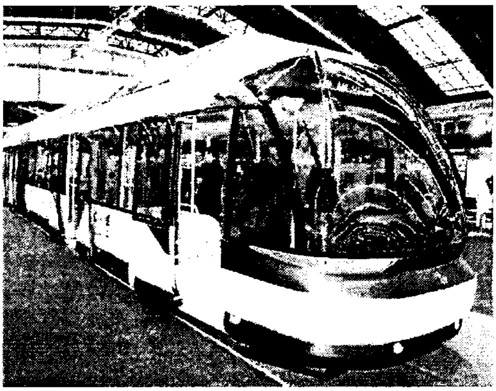

Figure 4: CIVIS vehicle [7].

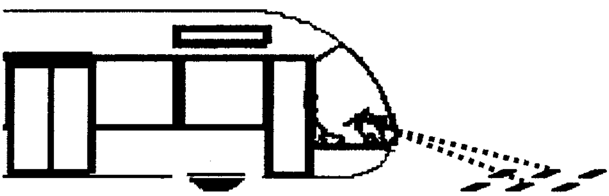

Figure 5: CIVIS optical guidance system [8].

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Its main features are [7,8]:

- Dual mode guidance
  - Optical guidance: the vehicle follows the route thanks to a camera behind the windscreen reading a white dotted double-line on the roadway; the image is processed to detect any course deviation, which is immediately corrected by a motor controlling the steering column [7] (Fig.5). The driver always controls both acceleration and braking and may recover the manual driving at any moment, with a simple movement on the steering wheel. If needed, the functional guidance can be supported by a mechanical guidance based on side kerbs along the route: the contact between the kerb and small wheels (with vertical rotation axis) fixed on all the axles enables to recover the right direction, if vehicle goes outside the path because of adhesion loss or error in the optical guidance.
  - Un-guided running mode as a conventional bus, without optical guidance.
- Dual mode supply
  - External electric supply by twin wired overhead line (750 V DC voltage) like a conventional trolley-bus.
  - On-board supply for 'off-wire' operation, provided by a diesel engine-electric generator or - for limited movements - by batteries or low rate diesel-electric system.

The traction equipment consists of 3-phase induction hub-motors, each fed by a 75 kW converter. The main technical characteristics are given in Tab.2. The 12-m long vehicle (one car-body) uses rear motoring axles; the 18-m long vehicle, with two articulated car-bodies, operates both rear and intermediate driving wheels. The braking action is obtained by means of three independent systems (electric braking, front disk brake, oil bath brake acting on the rear driving wheels).
CIVIS vehicles with optical guidance have operated in test facility routes with satisfactory results; till now no commercial line has been built.

Figure 6: STREAM bus in Trieste [10].

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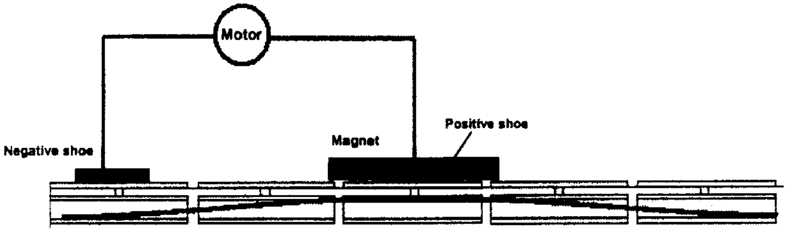

Figure 7: STREAM supply system [10].

2.4 STREAM

STREAM technology (Fig.6) utilizes an original electric supply system, innovative with respect to the other intermediate transport systems.
Its main features are [9,10]:

- Dual mode supply
  - External electric supply by a contact line installed in a trench (30-cm deep, 60-cm wide) along the roadway. The trench is formed by pre-fabricated box modules with the power conductor in the bottom and covered by insulated metal segments about 50-cm long. The contact line is normally connected to the ground: as a magnet, placed under the vehicle, passes over a metal segment, a force is performed which raises the power conductor from the trench bottom, so that it is put into contact with the metal plate (Fig.7). A collector, consisting of two sliding shoes with opposite polarities, supplies the traction energy: the current flows from the positive shoe to a passive metal segment through the negative shoe. The power is delivered by AC/DC converters placed along the line with output voltage of 500 V DC.
  - On board supply provided by batteries; for short distances (3-4 km), the vehicle can instantly and automatically disconnect the line and continue by using the on-board supplied energy.
- Dual mode guidance
  - Functional guidance system, based on the self-centring action of the current collector on the contact line; this enables to correct the vehicle path by steering the front wheels by means of an hydraulic cylinder.
  - Un-guided running mode when the vehicle is supplied by the on-board electric sources.

The 12-m long vehicle is propelled by two 80 kW induction motors in the rear wheels; the 18-m long vehicle by four motors placed in the rear wheels and in the middle axle. The main technical characteristics are reported in Tab.2.
A project based on STREAM technology is under experimentation in Trieste.

3 New public transportation system in Padova

In order to manage the mobility problems from a global point of view, Padova worked out an Urban Mobility Plan (PUM) [11], in which all the components

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involved in public mobility are analyzed and a new efficient integration among them is studied. In particular the following aspects are considered:

- different components of the public transportation network (regional railway system, urban and suburban lines, extra-urban lines and so on);
- interchange junctions between public transportation and road network;
- parking system;
- road network and its control model;
- sub-systems for non-motorized mobility: cycle tracks and pedestrian areas;
- public and private transport information system;
- public transport monitoring and regulation.

Such plan will be carried out step by step, taking into account both the present territorial scenery and the future developments within ten years, in terms of road infrastructures and town planning projects.
The PUM starting point is the re-design of the public transport system to get better service quality by means of innovation and re-qualification [1].
At present the public transportation network consists of 21 urban and suburban lines, with 7,5 millions vehicles km per year. In addition, extra-urban services develop a traffic of 1.05 millions vehicles km per year (1999). The main data of urban and suburban lines are reported in Tab.3.

Table 3: Main data related to the public transport in Padova.

Number of urban and suburban lines	21
Number of weekday trips	2336
Mean service frequency in primary lines (trips/hour)	10
Mean service frequency in auxiliary lines (trips/hour)	4
Rush hour commercial speed (km/h)	15.2
Daily commercial speed (km/h)	16.8
Number of operating vehicles	203
Mean transfer time from origin to destination (min)	17.2

The transport network has a radial configuration and most of the routes flows into two corridors which cross the downtown area, the first from north to south and the second from east to west. The 80 per cent of the urban lines converges towards the railway station: 13 routes reach directly the station square, 4 are located in close proximity. A third corridor, covered by a number of users lower than the other ones, links the station to the University scientific departments and to the hospitals.
The new public transportation system (just approved in the first stage of the PUM) is based on the following main features:

- Choice of innovative rubber-tyred systems with transport capacity intermediate between tram and bus and able to combine the features of both the conventional systems: guided running mode, low air and noise emissions, operating flexibility, easy insertion into the urban structure.
- Determination of three central corridors passing through the downtown area and in which a network of three main lines ("lines of force") is put

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into operation. The routes, operated by intermediate transport systems with partially protected lane, are:

a) north-south (Pontevigodarzere-Guizza), at present involving most of the users;
b) east-west (Ponte di Brenta-Sarmeola di Rubano), connecting the areas in which the future development of Padova is expected;
c) north-south/east, linking the railway station to the University scientific departments and to the hospitals.

The layout and the length of the lines, crossing each other at the railway station, are shown in Fig.8 and Tab.4, respectively.

- Integration of the main lines with secondary ones; these lines, with lower traffic intensity, can run, totally or partially, in the central corridors.
- Interchange parking (park & ride), located near the lines of force in strategic positions with respect to the main vehicular flows (Fig.8).
- Interchange nodes, located on the corridors, to allow the integration among the urban public network, the extra-urban public system and the regional railway transport service.

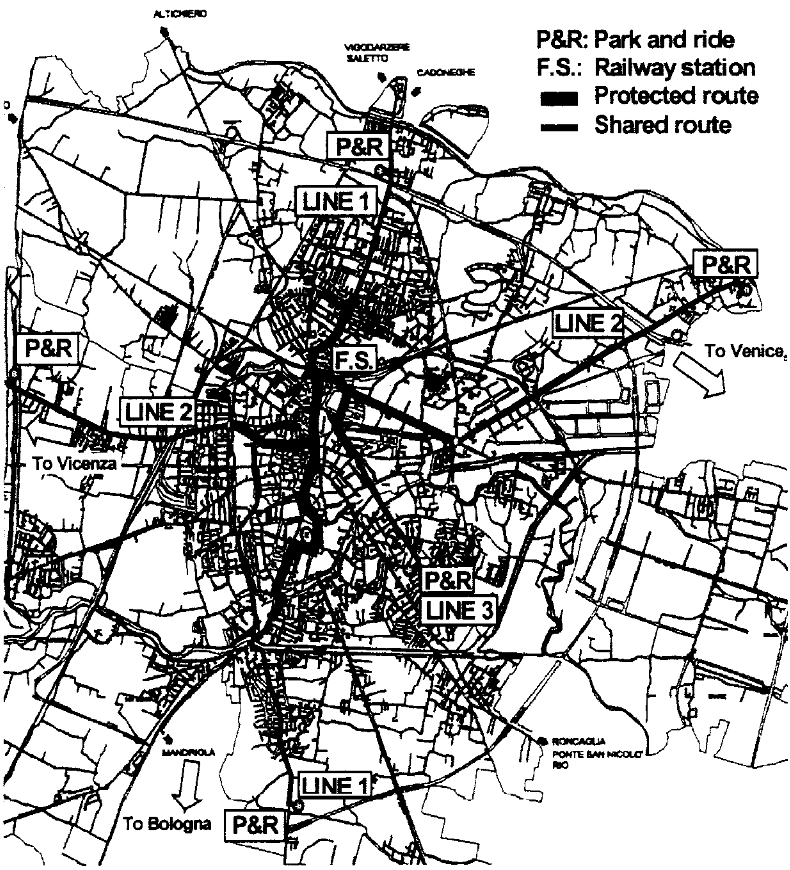

Figure 8: New Padova transportation network: layout of the lines of force.

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Table 4: Length of the lines of force.

	Line #1	Line #2	Line #3	Total length
Route	Pontevigodarzere-Guizza (north-south)	Ponte di Brenta-Sarmeola di Rubano (east-west)	Railway station-S.Antonio Hospital (north-south/east)	
Length (km)	9.3	12.9	3.2	25.4
Protected length (km)	5.3 (57%)	4.2 (32%)	2.0 (62%)	11.5 (45%)

The problems related to the impact on both the historical-environmental peculiarity and the road systems as well as the technical, economical and organizing aspects of the network management introduce some constraints in the definition of the requirements of the lines of force:

- Need of dual mode supply to reduce - on the one hand - air and noise emissions (external electric supply) and, on the other hand, to attenuate the visual impact in downtown area or to run on routes outside the main corridors (on-board supply).
- Need of dual mode guidance for guided and free-guided operations. The guided mode is requested mainly to get accurate alignment at platforms for non-level passenger access and, where possible, to limit the lane width in some sections of the corridors. On the other hand, as normal operation in routes shared with other vehicles is required, the possibility to disconnect the guided mode allows maximum flexibility to overcome obstacles or to run outside the lane; furthermore the free-guided operation, together with on-board supply, is useful to move to and from the depot areas.
- Exigency to integrate, in the system design, both the trackway and the vehicle technology. The aim is to insert the new transportation system into the urban configuration, by re-planning the whole image of some urban areas and the system accessibility; this can be carried out by acting on the lane differentiation, on the fittings of the lane protection, on the architectural structure of stops and interchange junctions.
- Exigency that the vehicle layout reflects the innovation in the service and offers travel comfort in accordance with the updated technological progress (on-board, for both passengers and staff, as well as during the boarding or getting off operations).
- Need of central control of the system including the following capabilities:
  - radio link;
  - monitoring;
  - auto-location;
  - service management;
  - user information;
  - interface with the control system of traffic lights;
  - interface with the information system of the transport company.

In the PUM a technical-economical comparative analysis has been performed to evaluate the advantages deriving from the application of the described intermediate systems to the network of Fig.8 and Tab.4.

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Table 5: Comparison of different solutions for the urban transport system of Padova [1].

Quantities	Unit	Present situation	Projects for the urban transport system		
			Tram	Intermediate system with functional guidance	Intermediate system with rail guidance
Length of the routes	km	-	6.5	25.4	25.4
Investment costs	billions ITL/km	-	18.1	8.3-11.1	17.7
Offered transport volume	thousand seats-km/day	1813	2277	2133	2240
Daily passengers	passengers/day	102,000	110,300	122,000	122,000
Travels with transfers	% of the total	11	56	22	22
Mean travelling time	minutes	17.2	18.4	16.2	16.2
Rush hour commercial speed	km/h	15.2	15.3	15.7	15.7
Daily commercial speed	km/h	16.7	16.9	17.3	17.3
Rate of protection of the routes	%	-	76	45	45
Per unit operating cost	ITL/passenger-km	377	329	282-296	311
Total operating costs (except amortization)	billions ITL/year	47.6	50.1	44.2-46.3	47.9
Total receipts	billions ITL/year	20.1	21.7	24.0	24.0

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The analysis - reported in Tab.5 - compares the proposed scenery with the present arrangement in the public transport as well as with a tram-based network [1]. The tram option was foreseen in a previous project for the route Pontevigodarzere-Guizza (even if shorter in length) and later rejected for the following problems [1]:

- probably overestimated transport demand;
- lack of integration with a global project of the urban mobility (in particular it didn't take into account the planned developments of the east and west quarters of Padova);
- penalization on the private traffic and on the access to the trading and residential buildings, because of the barrier effect due to the rail;
- negative impact on historical-architectural areas of Padova;
- investment costs too high if compared with the expected benefits.

With reference to Tab.5, the criteria for the evaluation of the intermediate systems have considered range of values for some parameters (e.g. investment and operating costs) in order to take into account the different level of complexity of the examined technologies. On the contrary, the assumptions about the length of the protected routes and the mean operating speed are the same for all the technologies; the same transport capacity is obtained by assuming a different number of daily trips.
The advantages due to the introduction of rubber-tyred intermediate systems with guided running mode are:

- improvement in the daily service with an increase of about 20% in terms of offered seats;
- increase of the commercial speed;
- decrease of the mean travel time;
- decrease of the operating costs.

It's worth to notice that the mean travelling time related to the intermediate systems is lower than the one related to the tram, because the latter is applied only in north-south corridor and then a higher number of transfers is required.
As regard the realization of the three main lines, the beginning of the construction of line #1 is imminent, since a state co-financing of about 31 millions euros was assigned; for the other lines a state contribution has just been requested.
The announcement of a competition was published on the Official Journal of the European Community on May 11, 2001, by APS - Azienda Padova Servizi Spa, the company which manages the public urban transport of Padova. The contract includes the design and the realization of line #1, by means of a rubber-tyred intermediate system with mechanical or functional guided running mode; it requires the supply of both the rolling stock and the guidance system, the construction of the external supply system, the construction of the infrastructures and the system maintenance according to a "global service" principle.
The contract will be awarded to the most convenient tender with respect to the contract base-price (58,359,629.60 euros + VAT), on the basis of the projects

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which will be presented by January 31, 2002. The foreseen maximum period for the construction of the line is 540 days. In addition to the economical conditions, other aspects will be considered, such as the technical quality, the performances and the experimentation level of the proposed technology, the time required for the realization, the impact of works on town life, the features and the quality of the inside of the vehicle, the vehicle stylistic design and the architectural and environmental impact.

4 Conclusion

The reorganization of the public transport system of Padova, elaborated in the Urban Mobility Plan, recommends a solution based on a network of three main lines ("lines of force") as the most promising to meet the user demand and the most feasible from a technical and financial point of view.
The choice of rubber-tyred intermediate systems with mechanical or functional guided running mode and 18-m long vehicles seems to be very attractive for operating the three routes. The flexibility in the use of the guided mode - typical of these systems - enables the running even if other vehicles or obstacles are on the lane; a temporary disconnection from the guided mode enables also to run easily in presence of connections with other lines or if critical route sections are placed along the line. In addition, the flexibility due to the dual supply system ensures low impact on historical-architectural areas.
At present the first line is under its realization phase and it is expected it will be put into operation by autumn 2003.

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