AUTOMATED TRANSPORT IN URBAN ENVIRONMENTS: AN INNOVATIVE OPPORTUNITY FOR A HISTORICAL AREA OF ROME

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ABSTRACT

The historical central area of Rome is site of high archaeological and architectural value with great tourist attractiveness, and at the same time, a place of numerous residential and business-related activities. In order to preserve this outstanding and valuable area also assuring the territorial and services accessibility, the provision of innovative public transport modes, alternatives to the conventional ones, can represent a driving force for improving mobility in historical and high-density urban areas.
This paper deals with the results of a preliminary study, carried out by Sapienza University of Rome and Saba Italia, aimed at investigating the opportunities offered by the application of an automated transportation system for connecting the Villa Borghese urban hub to Piazza del Popolo, one of the main Rome historical squares, by a 700 m long link.
In particular, the first research phase focussed on the analysis of individual and tourist collective transportation demand. The second phase has been addressed on the analysis of

the main existing and planned Personal Rapid Transit (PRTs) as well as Automated People Movers (APMs), in order to evaluate the most suitable system for the Rome case.

Keywords: Urban transportation, Automated People Mover systems, Personal Rapid Transit systems, historical sites.

INTRODUCTION

The historical central area of Rome is site of high archaeological and architectural value with great tourist attractiveness, and at the same time, a place of numerous residential and business-related activities. Thus, for this outstanding and valuable area it is essential to assure a continuous balance between the preservation and promotion of the historical and cultural heritage and the accessibility requirements of present day society.
In this context, the improvement of the mobility and the urban dynamics efficiency have to be considered, especially acting on the different components of the transport system, which is mainly aimed at guaranteeing accessibility while reducing and/or limiting the traffic congestion besides the development of public transport and provision of alternative transport modes. The opportunity to provide the Rome historical area with an innovative transport system has been faced by the study proposed in the next sections, which is aimed at investigating the chances offered by the application of an automated transportation system to connect the Villa Borghese (VB) parking to Piazza del Popolo (one of the main Rome historical squares) by a 700 m long link.
This study is included in a wider project which foresees the possibility of transforming the so called Trident Area - a famous area built in Renaissance age including three important roads[1] converging on Piazza del Popolo and where at the moment about 100.000 cars circulate - into a pedestrian zone (Figure 1).

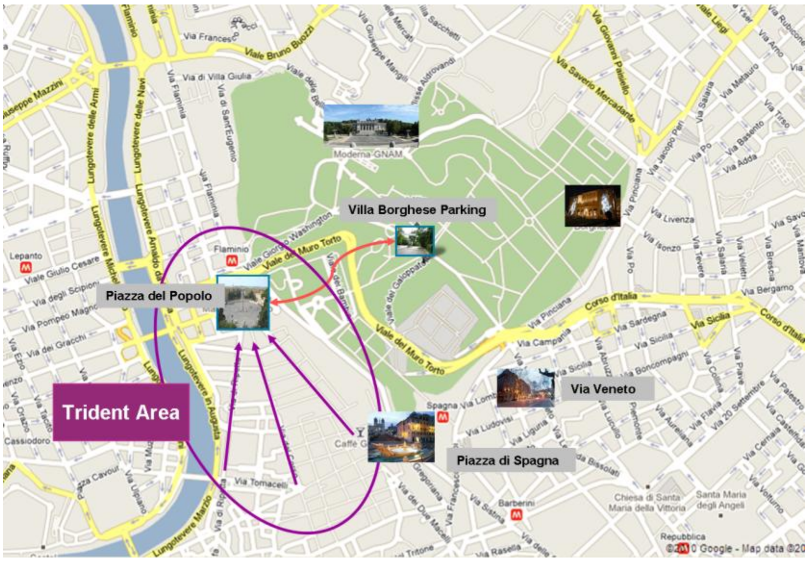

Figure 1 – The Piazza del Popolo – VB parking link and its area of interest

[1] Via del Corso, Via di Ripetta and Via del Babuino

Furthermore, the above study is strictly related to a wider set of measures, aimed at improving the distribution of traffic flows gravitating in the area, and defined as follows:

- the enlargement of the VB parking (> 2,000 car spaces), which has a good potential pedestrian accessibility to Via Veneto and Piazza di Spagna;

- the enhancement of the VB facility, adding the function of integrated urban hub (terminal and depot for electrical mini-buses and terminal for buses and tourist coaches).

In a first phase, in order to foresee potential customers interested in the parking supply offered by the facility as well as possible passengers willing to use a new transport system operating in the Trident Area, the analysis of individual and tourist collective transportation demand was carried out. In addition, some hypotheses about the induced transport demand were, also, suggested.
The second phase was dedicated to the dimensioning and evaluation of the automated transport systems – included in the Automated People Movers (APM) and Personal Rapid Transit (PRT) categories - that could be suitable for the Rome case, both in terms of capacity and layout features. On the one hand, the main automated systems currently in operation as well as those in phase of feasibility and planning study, were presented and critically analyzed. Therefore, with reference to selected automated transport systems, the results of the simulations, depending on different operation models assumptions, were also described. In the light of such simulations, the analysis of performance features of the systems, based on well defined potential strips of demand was also developed. Just by way of an example, it is underlined that the dimensioning of the automated transportation systems was based on the survey results on the potential individual demand [1] also keeping into account the collective demand of tourist data at present available (*Saba, 2006*).

THE POTENTIAL DEMAND ANALYSIS

The individual demand

In order to analyse the potential mobility demand (systematic and non-systematic) of people interested both in use the VB parking supply and the new mechanised link between the parking and Piazza del Popolo, two "stated preference" surveys were planned. The main questions focussed, respectively, on:

- travellers' behaviour in the intervention area;

- knowledge and current use of the Villa Borghese parking structure;

- interest and propensity in using the new automated link;

- interest in a monthly season tickets or in the purchase of a car space in the parking facilities, considering the new link construction.

The questionnaires were administered to a 705 persons sample, interviewed within the catchment area of Piazza del Popolo. In detail, 404 interviews were conducted on persons that carry out systematic trips and 301 interviews on individuals that are directed towards this zone as non-systematic travellers. The survey provided the following results: businessmen and workers come into the zone with an average frequency of 5.8 days/week; more precisely 37% move towards the Trident Area during the whole week (holidays included), 21% for 6 days/week and finally, 37% for 5 days/week (Figure 2).

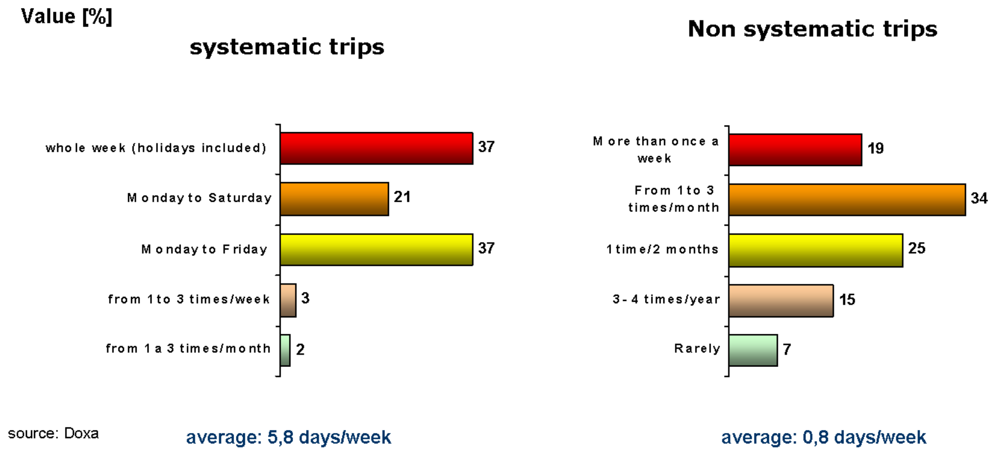

Figure 2 - Trips frequency towards the Piazza del Popolo

Concerning the non-systematic trips, travel frequency is based on an average lower value that is 0.8 days/week. Such results persuades to think that there is a high percentage of exchange population in the zone during the week. Besides, 49% of such demand component comes in this zone for leisure and 20% to meet friends/acquaintances. Furthermore, within the zone the following people almost entirely come from Rome, that is 94% of the workers and 96% of those who choose such destination during free time (amusement, purchases, etc). With reference to transport means used for travel (Figure 3), the survey has emphasized the interviewee's habits. In fact, concerning the systematic trips, 37% of people use a single transport mean while 63% at least two; furthermore, 41% of individuals use private car as drivers but only 22% of these get the final destination (Piazza del Popolo influence area) by automobile.

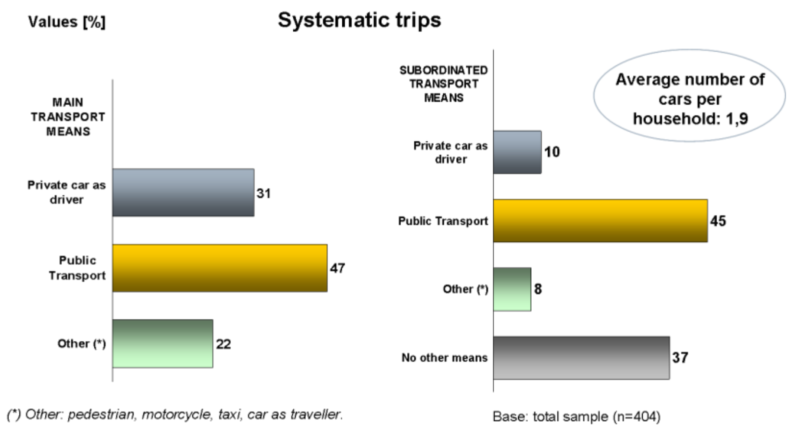

Figure 3 - Transport means used to reach the Piazza del Popolo (systematic trips)

Regarding the non systematic transport demand, 62% of people use only a transport mean and 38% at least two means; on the whole 45% of interviewed people use car as driver and 35% comes into the final destination by car (Figure 4).

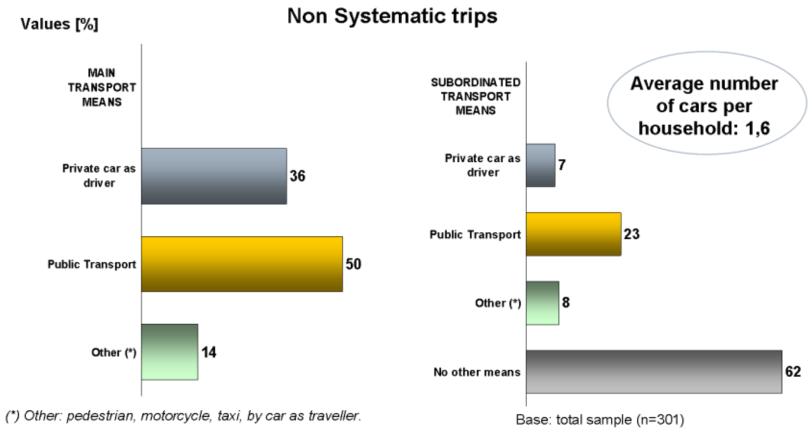

Figure 4 - Transport means used to reach the Piazza del Popolo (non systematic trips)

Moreover, concerning parking habits, the related demand is currently only partially satisfied in the intervention zone by 64% of frequent users and 71% of the occasional people who use the paid-parking supply (i.e. ”blu zones”, garages). Among them, the first represents 12.7% of the systematic users sample whereas the seconds constitute 24.5% of the non-systematic users sample (Figure 5).

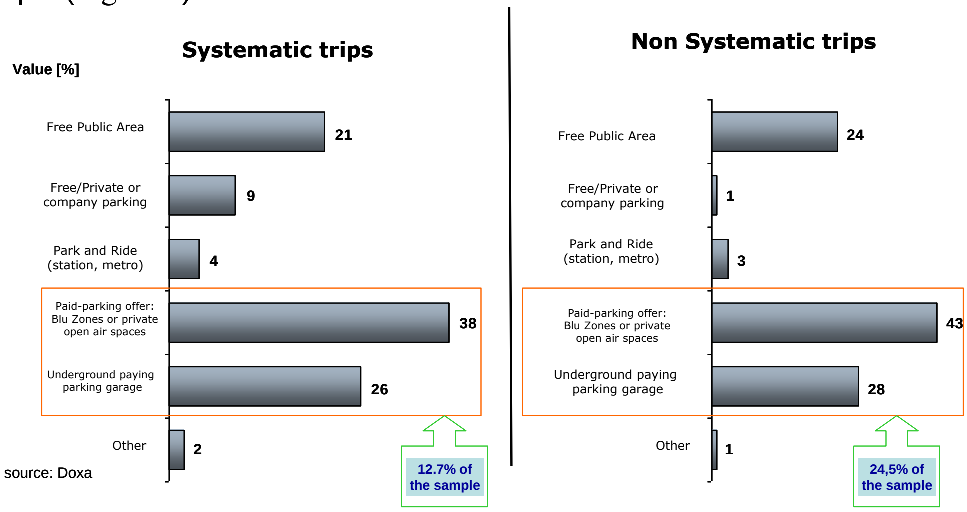

Figure 5 – Parking habits in the intervention area

In order to quantify the mobility demand, a further analysis [2] focussed on the potential catchments area of the VB facility, was taken into account aiming at better estimating the population which, due to different purposes, currently are going to such an area. The achieved results allowed asserting that about 14,200 persons have business activities in the reference zone and, daily, about 20,000 are non-systematic users. As a matter of fact, the attraction capacity only for workers gravitating in the zones of influence was considered as acceptable. In such a context, based on 220 annual working days, the estimated systematic users amount to 4,400 individuals. Concerning, instead, the non-systematic component, the attraction capacity for the 80% of the Trident Area users and only for the adult individuals was considered as acceptable [3]. On account of both the interviews results and the above-mentioned analysis, the potential daily mobility demand is 1,245 trips, of which 220 systematic and 1,025 non systematic.

Another interesting upshot emerging from the survey is the level of fame of the VB parking lot and its utilization rate. The facility is well known from about 95% of the systematic users and 84% of occasional ones that, with smaller frequency, visit the survey zone. Furthermore, 3% of the interviewed people (16% of those who arrive in the historical centre by car) use it regularly and about a third of them get a subscription. Among the non-systematic users, 6% (22% of those who arrive in the historic centre with car) use it to park the car and, of these, 0.9% has a subscription (Figure 6).

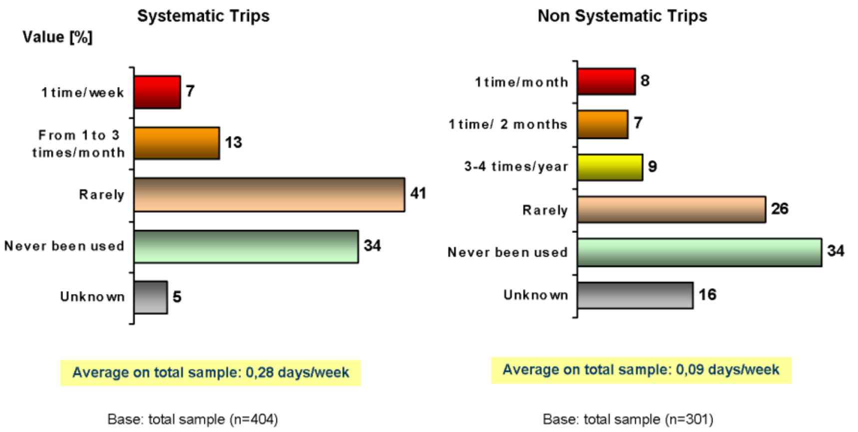

Figure 6 - Utilization rate of the VB parking

With reference to the hourly parking rate of utilization, the profiles of arrival and departure take both on a sinusoidal shape. Bearing in mind that the 82% of the incoming flows are referred to the non-systematic mobility, with reference to the incoming movements of the VB parking, the greater volume of arrivals (142 units) has been obtained in the 9.00 - 9.30 period, showing the same features also in the 9.30 – 10.00 period (Figure 7).

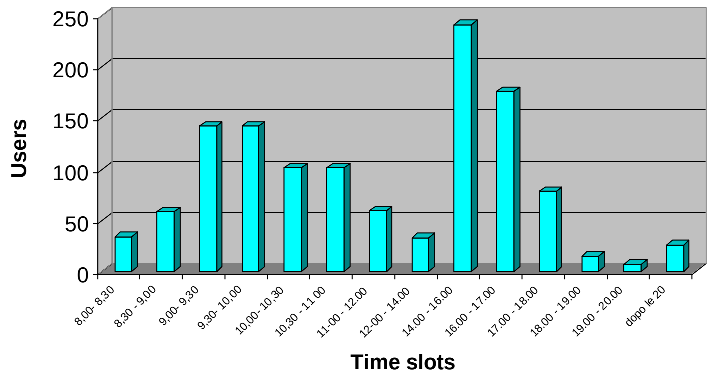

Figure 7 - Distribution of the flows coming into the VB parking (systematic and non)

Therefore, between the 9.00 and the 10.00 in the morning, a peak flow of 284 users/hour was obtained. In the afternoon other two peak values were obtained, the first one being equal to 241 units reached in the 14.00 -16.00 period, the second one, showing a value of

176 users/hour, is related to the 16.00 -17.00 interval. Concerning departures from the VB parking, the important flows (of which only 18% represents the systematic component) start after midday, revealing a first relative peak value (220 users) within the 12.00-14.00 and an absolute peak value of 358 users leaving the parking during the late afternoon (Figure 8).

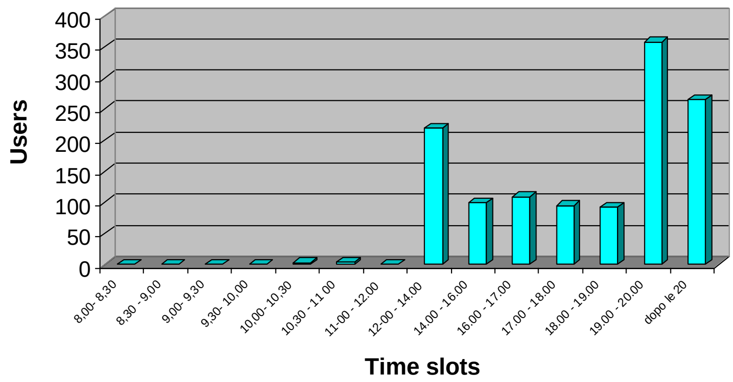

Figure 8 - Hourly distribution of the flows leaving the VB parking (systematic and non)

In synthesis, two potential daily demand peaks can be considered, and more precisely:

- incoming to the parking (9.00 -9.30 time period), a value of 142 users, of which 116 belonging to the non-systematic travellers;

- outward–bound from the parking (19.00 – 20.00 time period), a value of 358 users, of which about 294 assigned to the non-systematic mobility.

However, it is worth mentioning that the morning potential demand value will be increased with respect to the obtained peak value (related to the half-hour); in fact, such a value will be raised to 284 potential users, considering that the capacity offered by the different transport systems, expressed in spaces/hour, will be assessed on hourly base.

Such an analysis needed, however, to be integrated with a important component related to the potential collective demand, in terms of tourists coming by coaches, as well as to the induced transport demand. Such demand components will be analyzed in the next sections.

The collective tourist demand

In order to analyze the potential tourist transport demand interesting the intervention area, the traffic flows of the different tourist coach services, coming in the VB terminal in a standard midweek day [4], have been considered. In particular, the coach services typologies which utilize the VB facility as bus terminal are namely:

- Tourist coaches (international and regional);

- Stop & Go sight seeing service;

- Tourists loading and unloading (as drop-off and pick-up point);

- Overnight parking (arrivals after 8 p.m.).

Moreover, the estimation of the tourist services foresees the presence of about 45 coaches coming in the terminal per half-day. Considering the passengers volumes travelled by tourist coaches, it is plausible that an amount of tourists, once in the VB terminal having left the vehicles, can continue their trip using the new automated link. In this context, since the analysis of available data provides an increasing trend of such tourist services, such increase influences the potential demand: therefore, it is acceptable to consider the main traffic flows related to full-loaded tourist vehicles coming into the terminal.
A slight parking demand increase could be, actually, attributed to the overnight parking service, respect to which, however, the potential demand considers only the number of drivers which leave terminal after having parking their empty vehicles (arrivals after hour 20). Such a component is so slight that does not influence the dimensioning of the transport system; in fact there are about 40 incoming coach drivers, distributed in a large hourly strip, of which only some of these could use the automated system.

In order to assess the whole number of transported passengers and the arrivals distribution calculated on an hourly base, an average coach capacity of 50 seats/vehicle was considered. Moreover, to compare these results to the potential individual demand, the flows coming in to the VB terminal (currently shared out only on a time period three hours long) has been distributed in an hourly period, coherent with the distribution of the individual demand hourly arrivals. Furthermore, two different profiles related to demand coming into the terminal have been considered, in terms of minimum (*Profile 1–P1*) and maximum number (*Profile 2–P2*) of daily coaches arrivals, where the P2 considers an average 8% increase of coaches services both in the morning and afternoon time slots, due to a better tourist demand management. Such a tourist demand was assessed on the basis of the present mobility schemes, assuming that, in both the cases, more than 60% the tourist services users [4] could travel on the Trident Area by using the new automated transport system. Concerning the tourist demand P1, an important concentration of coach arrivals in the first morning strip was registered; with respect to the P2, the coach arrivals distribution is qualitatively comparable with the P1 (Figure 9).

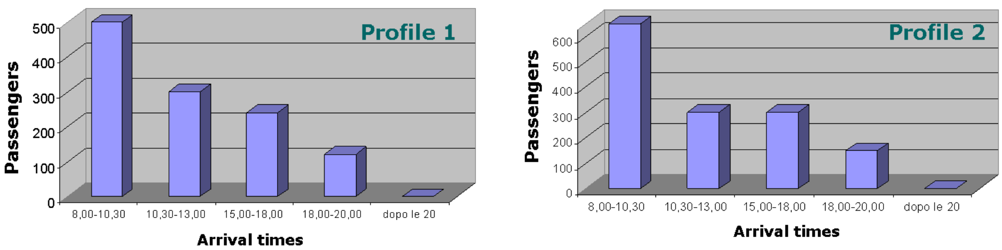

Figure 9 - The tourist aggregate demand (P1 and P2 profiles)

Therefore, distributing the aggregated demand on an hourly base and assuming regular headways between successive arrivals, with reference to *P2*, a peak demand of 300 passengers/hour related to the first morning slot was obtained. Such a value, which is 120 passengers/hour in the late morning time slot, get the volumes, respectively, of 120 and 75 passengers/hour in two afternoon time slots for *P2* and of 96 and 60 passengers/hour for *P1* (Figure 10).

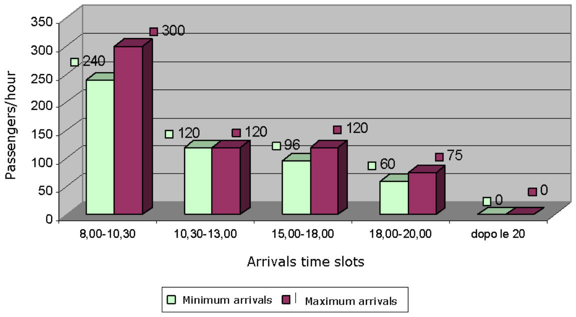

Figure 10 - Hourly transport demand (P1 and P2 profiles) distributed on time slots

Therefore, adding the potential tourist collective demand to the individual (for both the systematic and non users), the following peak periods (with the *P1* coach arrivals profile) were obtained: 524 passengers/hour in the time slot 9.00-10.00 that decreased to 260 passengers/hour in the 16.00-17.00 afternoon period (Figure 11).

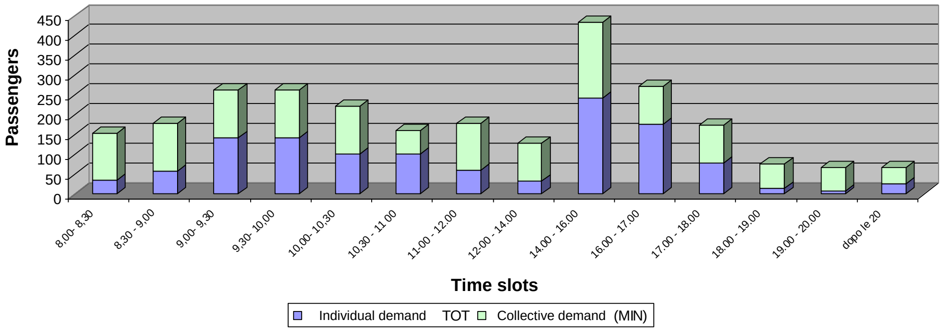

Figure 11 - Total potential demand (Profile 1)

Considering the potential tourist demand associated to the *P2* coach service and, then, adding to this the estimated total individual demand, a peak of 584 passengers/hour, in the 9.00-10.00 time period was obtained; a second relative peak of about 290 passengers/hour, was also marked in the 16.00-17.00 time slot (Figure 12).

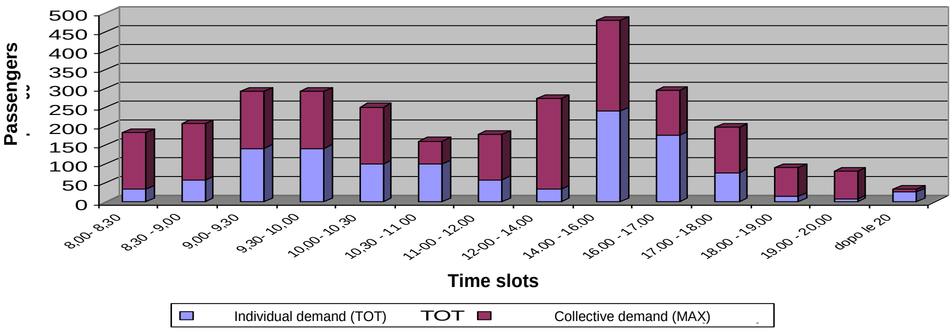

Figure 12 - Total potential demand (Profile 2)

The total potential demand

Some hypotheses on the induced mobility demand were also assumed, in terms of potential users that, although are not interested in use the VB parking, could be willing to use the new automated transport system for moving in the Trident zone. According to comparable fields studies, such a propensity in using the innovative transport system, can be quantitatively translated in an 5%-7% average range. Consequently, with the aims to consider in a more proper way such demand modulations, two induced demand growth scenarios were defined, named respectively *Low*, related to a 5% increase and *High*, related to a 7% increase. In such demand component was also included who, living in the influence area and being an owner of a private car place in the VB parking, could become a potential user of the new transit system, using it for his individual home-parking and parking-home trips, more times during the day[2].

Finally, cumulating the results of the all transport demand components, the evaluation of the total potential demand provided the morning rush-hour values comprise between 538 passengers/hour (Figure 13) in a *realistic scenario* (low induced demand and *P1*) up to 604 passengers/hour (Figure 14) in an *optimistic scenario* (high induced demand and *P2*).

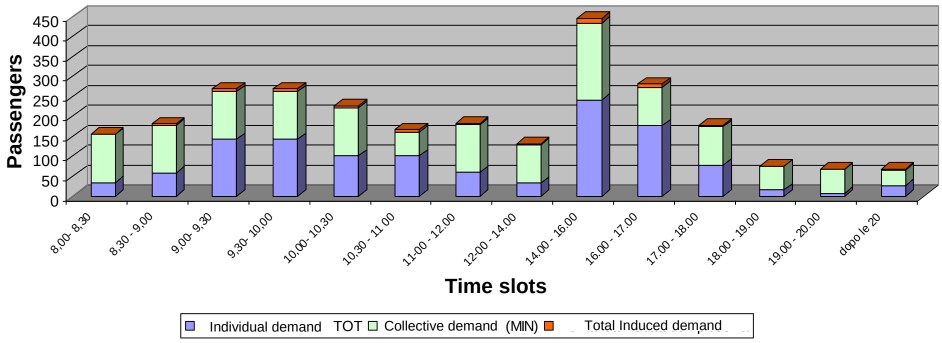

Figure 13 - Total potential demand in the realistic scenario

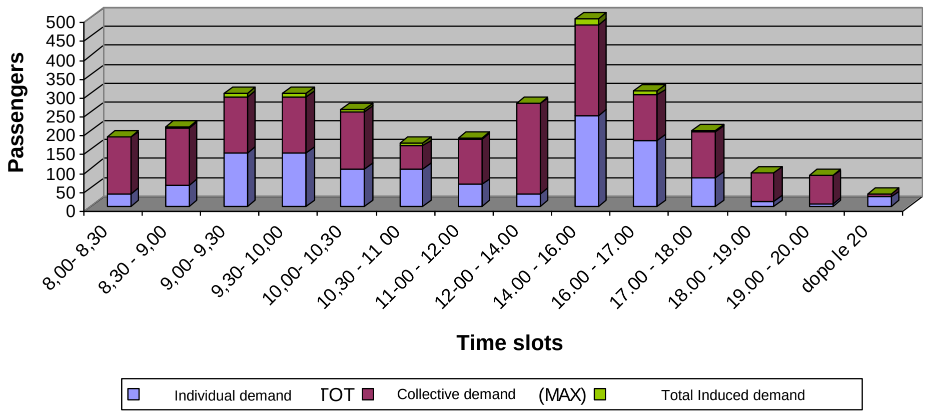

Figure 14 - Total potential demand in the optimistic scenario

[2] It has chosen to introduce such further contribution in the induced demand because of the negligible impact developed from such users typology on the transport system dimensioning.

AUTOMATED TRANSPORT SYSTEM DIMENSIONING AND EVALUATION

After having analysed the transport demand, it has been possible to draw the basis for the analysis and evaluation of the main automated transport systems, currently in operation or in the design/under construction phase, in order to evaluate the most suitable system for the Rome case. The main manufacturers of Automated People Mover (APMs) are essentially three: *Poma*, *Leitner* and *Doppelmayr* (even if the French-based Poma is currently owned by the Italian company Leitner Technologies and the Poma Italia has recently changed its company name in *Agudio*). During the years, each of these companies has realized systems technologically more and more advanced, producing different design solutions - mainly in terms of vehicles typology and capacity, line capacity and rail track layout - aimed at developing such systems in heterogeneous environmental contexts (urban centres, airports, amusement parks, etc.) as well as to satisfy different customers requirements.
In the next sections an overview of the main systems will be presented, in order to provide a framework of the current trend in the passengers rapid transit, in satisfying low and medium level of mobility demand and guaranteeing, at the same time, high performances and an excellent level of service.

An overview on the main automated transport systems currently in operation

The automated transport systems can be generally classified in two macro categories well-defined in the reference literature as Personal Rapid Transit (PRT) and Automated People Mover (APM), being both fully-automated and grade-separated transit systems.
In particular, a PRT is a narrow gauge system which runs on limited network by small vehicles (4-8 seats/vehicle). Such a system reaches very high frequencies (up to 60 trips/hour on average) and is generally designed for providing non-stop or on-demand services. The stations are usually off-line, that is to say located out of the rail track. The APM systems, instead, have a larger range since they include systems with different train configurations, obtainable by adding two or more vehicles. Such vehicles, in turn, can be also different in terms of car capacity (from 10 to 130 spaces/vehicle) providing, therefore, a set of heterogeneous systems depending on the maximum line capacity (variable from 600 up to about 6000 spaces/hour/direction). Such systems can be equipped, without distinction, with off-line as well as on-line stations.

In order to focus the analysis only on systems that in a reasonable manner could be operated on the Villa Borghese – Piazza del Popolo link, the selection has privileged those with a basic track layout (linear, absence of circuits and intermediate stations) and a capacity able to satisfy a transport demand not greater than 1500 passengers/hour/direction. Special attention has been mainly paid to the last generation of ropeway systems, featured by fully-

automated operations, which have achieved an high spread level in different environmental contexts[3].
A list of the several APM systems that are currently in operation is showed in Table 1.

Table 1 - Several APM systems in operations

BUILDER	YEAR	SITE	LENGTH [m]	STATIONS [number]	TRACKS [number]	VEHICLES CAPACITY [spaces/vehicle]	TRAIN COMPOSITION [vehicles /train]	FREQUENCY [trip/hour]	MIN. HEADWAY [min]	MAXIMUM CAPACITY [spaces/hour/direction]
Leitner	2008	**Perugia** (Italy)	3,015	7	2	50	1	60	1	3,065
Poma	1999	**Milan** (Italy)	682	2	1	34	3	14	4,3	1,430
Poma	1989	**Laon** (France)	1,500	3	2	33	3	27	2,2	891
Poma Otis	2003	**Zurich Airport** (Switzerland)	1,138	2	2	92	2	24	2,5	4,416
Poma Otis	2004	**Oeiras** (Portugal)	1,200	3	1	53	2	15	4	1,590
Doppelmayr	2007	**Mexico City** (Mexico)	3,025	2	1	26	4/6	5	12	540/806
Doppelmayr	2003	**Birmingham Airport** (UK)	585	2	2	27	2	30	12	1,600
Doppelmayr	1999	**Las Vegas** (USA)	838	4	2	32	5	10	6	1,300
Doppelmayr	2006	**Toronto** (Canada)	1,473	3	2	25	6	15	3,4	2,150

Furthermore, in Table 2 a list of several transport systems, which are in design or under construction phase, is also showed. Such systems are based on two different building technologies that use electric (ATS, Robosoft) or funicular traction (Doppelmayr) cars.

Table 2 - APMs and PRTs currently in phase of design study or under construction

BUILDER	TYPE	SITE	LENGTH [m]	STATIONS [number]	TRACKS [number]	VEHICLE CAPACITY [spaces/vehicle]	TRAIN COMPOSITION [vehicles/train]	FREQUENCY [trips/h]	MIN. HEADWAY [min]	MAXIMUM CAPACITY [spaces/h/direction]
ATS	PRT	**Cardiff** (prototype)	1,400	2	2	4	1	600	0,1	2,400
ATS	PRT	**Heathrow AIRPORT** (UK)	3,900	2	2	4	1	600	0,1	2,400
Robosoft	APM	**Rome NUOVA FIERA (prototype)**	1,617	13	2	20	1	15	1	900*
Doppelmayr	APM	**Las Vegas** (USA)	650	4	2	33	4	20	3	3,266
Doppelmayr	APM	**Venice** (Italy)	870	3	1*	50	4	15	3,5	3,000

* assuming a 6 cars fleet
** single track bypassed system (with 2 trains and 2 switches)

Dimensioning of the transportation system

With reference to the above-mentioned systems, considering the different line capacity (spaces/hour/direction) in function of the link length, some elements can be outlined (Figure 15). For example, for links up to 1.500 m and for whatever line capacity, there is a wide use of the Poma and Doppelmayr systems, many of those analysed (excepted Laon and Oeiras)

3 Such systems are equipped with a classical ATC - Automated Train Control architecture, structured in the following subsystems: ATO: Automated Train Operation (related to running and stopping phases, braking, etc.); ATP: Automated Train Protection (related to vehicle safety running) and ATS: Automated Train Supervision (to manage data transmission to the head control centre, communication audio-video with passengers, etc).

were installed in airports, hospital poles and theme parks. This can be deduced by the distribution of the single points arranged in a sort of "rectangular lower" strip.

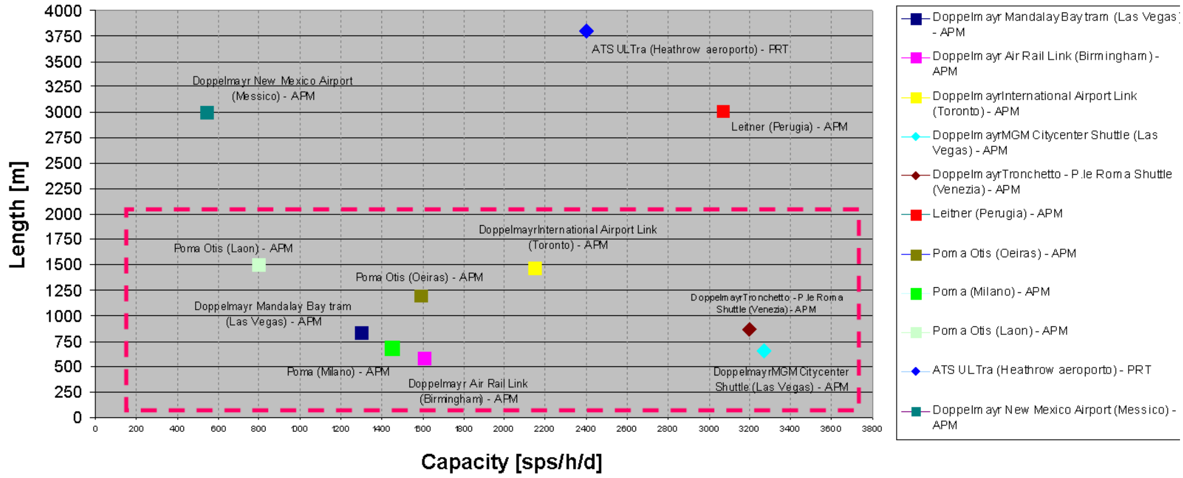

Figure 15 - APMs capacity in function of link length

A specific case is represented by the Minimetro system, developed by Leitner and currently in operation in the Perugia city (Figure 16), which is an isolated point in the above graph respect to the lower strip of values. Concerning the Minimetro system, the available data are referred only to this specific site, where a larger line capacity is requested on a longer track line respect to the other listed systems. Nevertheless, due to its performance and undoubted flexibility in vehicles capacity and train composition, the Leitner system would be comparable with the proposed ones and, therefore, able to satisfy small as well as medium transport demand.

Figure 16 - Perugia Minimetro system (source: www.leitner-lift.com)

Furthermore, an innovative case is represented by the Ultra system (Figure 17), developed by Advanced Transport Systems Ltd (ATS) and British Airport Authority (BAA) and designed for connecting, within the London Heathrow airport, a business parking area to the T5 terminal by a 3,9 km link length. The Ultra system, belonging to the PRTs category, consists in a "pod cabs" fleet of battery powered and driverless vehicles, with a capacity of 4 seats/cab, traveling along an at-grade and elevated guideway. Despite the very small car capacity, but in virtue of its frequency (providing a sort of no-stop service) and depending on fleet availability, the Ultra system can serve up to 2,000-2,600 passengers/hour. Compared to the APMs, such a system runs on narrow gauge (guideway cross-section) link, with smaller turning radii and, due to its limited vehicles size and battery-powered, it produces lower environmental impacts (pollution, noise and visual). Currently, such a innovative system is working still as trial at the Heathrow airport and its fully operation is foreseen by 2010.


Figure 17 – The Ultra system

Possible transportation systems for the Rome case

According to the scope of such a study, the field of the simulations was limited to the following 4 manufacturers: *Leitner*, *Poma*, *Doppelmayr* and *ATS*. As a matter of fact, the *Poma* system was considered in virtue of its numerous and famous word-leading applications, and with technical features and services able to satisfy the demand expected for the Rome case. In fact, such a system can be easily associated with the *Leitner* (both belong to the *Seeber Group* and currently known as *Leitner-Poma*), as well as the *Agudio Company*, known as *Poma Italia* (builder of the Milan APM), envisaging different train configurations.

A synthesis of the main average main quantitative parameters of the analysed systems, accounted as average values, are shown in Table 3, where a travel time of about 1,3 -1,5 minutes to cover the project distance with a commercial speed variable from 29 to 32 km/h were considered (including waste of time at stations and acceleration/deceleration phases) [4].

Table 3 - Range of performance features of the transport system

TYPE	TRACTION SYSTEM	ENGINE	SAFE CONTROL COMMAND	VEHICLE CAPACITY [spaces/vehicles]	TRAIN [vehicles /train]	OPERATIONAL SPEED [km/h]	FREQUENCY [trip/hour]	MINIMUM HEADWAY [minutes]	MAXIMUM CAPACITY [sps/h/d]
PRT	Electric traction	Electric-drive	ATO	4	1	30	300	0,2	1,200
APM	Rope traction	Electric-drive	ATO	50 - 67	2	29 - 32	15 - 17	3.5 - 4	1,700 – 2,000

[4] The systems features, in some cases, were directly provided either by manufacturers or have been derived from data provided by the same companies.

Dealing with such data - meaning *frequency*, *operational speed*, *headways* and *maximum capacity* and strictly connected with the quality of service – several simulations were carried out considering a guideway 700 m long. Different operating models were obtained by changing the design configurations (1 or 2 tracks), train composition, vehicles capacity as well as service frequency (varying from 6 to 17 trips/hour for the APMs and up to 300 trips/hour for the PRT).

In detail, the APMs (Figure 18) were considered with a single track configuration (as a shuttle service) with trains composed both from one and two cars (with a vehicle capacity of 50 spaces). For each train typology, service frequencies included between 8 (7.5 minutes of headway) and 17 trips/hour (a train every 3.5 minutes) were considered. Depending on train length, results provide respectively a maximum capacity variable from 400 spaces/hour/direction to 1,500 spaces/hour/direction according to a Round-trip Time (RTT) of 3.5 minutes and an operational speed of 32 km/h (all the phases of non-uniform motion included).

System: **Automated People Mover**	Service: *shuttle*										
LINK LENGHT [m]	**STATIONS [number]**	**TRACKS [number]**	**TRAIN [vehicles/train]**	**VEHICLE CAPACITY [sps/vehicle]**	**UNIT CAPACITY [spaces/train]**	**OPERATION SPEED [km/h]**	**TRAVEL TIME [minutes]**	**RTT [minutes]**	**FREQUENCY [trips/hour]**	**HEADWAY [minutes]**	**MAXIMUM CAPACITY [sps/h/d]**
700	2	1	1	50	50	32	1,31	3,5	8	7,5	**400**
700	2	1	1	50	50	32	1,31	3,5	10	6	**500**
700	2	1	1	50	50	32	1,31	3,5	12	5	**600**
700	2	1	1	50	50	32	1,31	3,5	15	4	**750**
700	2	1	1	50	50	32	1,31	3,5	17	3,5	**850**
700	2	1	2	50	100	32	1,31	3,5	8	7,5	**800**
700	2	1	2	50	100	32	1,31	3,5	10	6	**1.000**
700	2	1	2	50	100	32	1,31	3,5	12	5	**1.200**
700	2	1	2	50	100	32	1,31	3,5	15	4	**1.500**

Figure 18 - Results of the APM systems simulation

Maintaining the same shuttle service, by using increased capacity cars (i.e. 67spaces/vehicle) and an operational speed of 29 km/h, for such a train, frequencies included between 6 trips/hour (10 minutes of headway) and 12 trips/hour (a train every 5 minutes) were assumed. The achieved results provided an operation model based on a maximum capacity variable from 400 to 1,608 space/hour/direction, with a RTT of 4 minutes (Figure 19).

System: **Automated People Mover**	Service: *shuttle*										
LINK LENGHT [m]	**STATIONS [number]**	**TRACKS [number]**	**TRAIN [vehicles/train]**	**VEHICLE CAPACITY [sps/vehicle]**	**UNIT CAPACITY [spaces/train]**	**OPERATION SPEED [km/h]**	**TRAVEL TIME [minutes]**	**RTT [minutes]**	**FREQUENCY [trips/hour]**	**HEADWAY [minutes]**	**MAXIMUM CAPACITY [sps/h/d]**
700	2	1	1	67	67	29	1,45	4	6	10	**402**
700	2	1	1	67	67	29	1,45	4	8	7,5	**536**
700	2	1	1	67	67	29	1,45	4	10	6	**670**
700	2	1	1	67	67	29	1,45	4	12	5	**804**
700	2	1	2	67	134	29	1,45	4	8	7,5	**1.072**
700	2	1	2	67	134	29	1,45	4	10	6	**1.340**
700	2	1	2	67	134	29	1,45	4	12	5	**1.608**

Figure 19 – Results of the APM systems simulation (use of increased car capacity)

The simulations for the PRT system (Figure 20), considering a double-track configuration and a loop service typology, takes into account the vehicle capacity (4 seats/car) and assumes a wide variation in the frequencies set, from 15 (4 minutes headway) up to 300 trips/hour (a trip every 12 seconds). In such a way, the capacity range is extremely variable, starting from 60 to 240 spaces/hour and, finally, arriving up to 1,200 spaces/hour, feasible with a trip every 12 seconds.

System: **Personal Rapid Transit**	Service: *double-track*										
LINK LENGHT [m]	**STATIONS [number]**	**TRACKS [number]**	**TRAIN [vehicles/train]**	**VEHICLE CAPACITY [sps/vehicle]**	**UNIT CAPACITY [spaces/train]**	**OPERATION SPEED [km/h]**	**TRAVEL TIME [minuti]**	**RTT [minutes]**	**FREQUENCY [trips/hour]**	**HEADWAY [minutES]**	**MAXIMUM CAPACITY [sps/h/d]**
700	2	2	1	4	4	30	1,40	4	15	4	**60**
700	2	2	1	4	4	30	1,40	4	20	3	**80**
700	2	2	1	4	4	30	1,40	4	30	2	**120**
700	2	2	1	4	4	30	1,40	4	60	1	**240**
700	2	2	1	4	4	30	1,40	4	100	0,6	**400**
700	2	2	1	4	4	30	1,40	4	120	0,5	**480**
700	2	2	1	4	4	30	1,40	4	150	0,40	**600**
700	2	2	1	4	4	30	1,40	4	180	0,33	**720**
700	2	2	1	4	4	30	1,40	4	200	0,30	**800**
700	2	2	1	4	4	30	1,40	4	220	0,27	**880**
700	2	2	1	4	4	30	1,40	4	240	0,25	**960**
700	2	2	1	4	4	30	1,40	4	250	0,24	**1.000**
700	2	2	1	4	4	30	1,40	4	280	0,21	**1.120**
700	2	2	1	4	4	30	1,40	4	300	0,20	**1.200**

Figure 20 - Results of the PRT system simulation

The performances indicators – namely *car capacity*, *train length, maximum line speed, travel time, RRT, frequency, headway and maximum capacity* - were also associated to the following four ranges of mobility demand: 600, 800, 1,000 and 1,200 passengers/hour. These ranges were selected in order to be consistent with the order of magnitude of the capacity required for the Rome case, after assuming next development phases of the system and surpassing the transient state in terms of customers' awareness. Such a further analysis, based on the calculation of the mean values of the performance indicators, allowed reaching some further evaluations .

In particular, with reference to a potential demand of 600 passengers/hour (Table 4), it can be outlined that travel times of all analysed APMs have the same order of magnitude (variable between 1.30 to 1.70 minutes); furthermore, assuming a mean waiting time equal to half headway and a constant distribution of the arrivals (10 passengers/minutes), the APMs waiting times are comparable and all included in an period of about 3 minutes. The PRT system provides the lowest waiting times at stations (about 12 seconds) and it was expected also in virtue of its operation that, at limit, provides a no-stop service.

Table 4- Potential demand of 600 passengers/hour: average service performances

	APM	PRT
Tracks [number]	1	2
Average car capacity [spaces/vehicle]	50	4
Train length [vehicles/train]	1	1
Average Maximum line speed [km/h]	39	30
Average Travel Time [minutes]	1.30	1.40
Average RTT [minutes]	4	4
Average Frequency [trips/hour]	11	150
Average Headway [minutes]	6	0,40
Average Maximum capacity [spaces/hour]	**600**	**600**

Anyway, in order to satisfy such a demand, the PRT system requires 11 cars and, therefore, some additional surfaces, properly designed, have to be arranged in order to allow cars depot and stop as well as parking activities during the lower demand periods.

With reference to a potential demand of 800 passengers/hour and if compared to the previous configurations (Table 5), the APMs should increase their frequencies from 11 to 14 trips/hour, allowing a consequent reduction of the headway (from 6 to 4.5 minutes) and, therefore, of the average waiting time at stations that decreases from 3 to about 2 minutes. The PRT system, instead, should increase frequency from 150 to 200 trips/hours, also reducing its average waiting time at 9 seconds, with a consequent increase of the needed cabs (from 11 to 14).

Table 5 - Potential demand of 800 passengers/hour: average service performances

	APM	PRT
Tracks [number]	1	2
Car capacity [spaces/vehicle]	50	4
Train length [vehicles/train]	1	1
Average Maximum line speed [km/h]	39	30
Average Travel Time [minutes]	1.30	1.40
Average RTT [minutes]	4	4
Average Frequency [trips/hour]	14	200
Average Headway [minutes]	4.5	0.30
Average Maximum capacity [spaces/hour]	**820**	**800**

In case of a potential demand of 1,000 passengers/hour (Table 6), the APMs, if compared to the previous case, need to change its train configuration adding a second car; however, the frequency decreases from 14 to 12 trips/hour, causing the headway (from 4.5 to 6 minutes) and the station waiting time increase (from 2 to 3 minutes). The PRT system should increase its frequency from 200 to 250 trips/hour, also increasing the fleet (from 14 to 17 cars) in order to guarantee a satisfying level of service. In such conditions, the average waiting time steps down to 7 seconds.

Table 6 - Potential demand of 1,000 passenger/hour: average service performances

	APM	PRT
Tracks [number]	1	2
Car capacity [spaces/vehicle]	50	4
Train length [vehicles/train]	2	1
Average Maximum line speed [km/h]	39	30
Average Travel Time [minutes]	1.30	1.40
Average RTT [minutes]	4	4
Average Frequency [trips/hour]	12	250
Average Headway [minutes]	6	0,24
Average Maximum capacity [spaces/hour]	**1,064**	**1,000**

Regarding a demand of 1,200 passengers/hour (Table 7) the APMs ask for a little frequency improvement that should pass from 12 to 13 trips/hour, guaranteeing a maximum capacity of 1,350 spaces/hour, obtained with almost 5 minutes headway. Finally, the PRT system should increase the frequency up to 300 trips/hour, with a consequent enlargement of the vehicles fleet (needed cars pass from 17 to 20) and an average waiting time reduction at 6 seconds.

Table 7 - Potential demand of 1,200 passenger/hour: average service performances

	APM	PRT
Tracks [number]	1	2
Car capacity [spaces/vehicle]	50	4
Train length [vehicles/train]	2	1
Average Maximum line speed [km/h]	39	30
Average Travel Time [minutes]	1.30	1.40
Average RTT [minutes]	4	4
Average Frequency [trips/hour]	13	300
Average Headway [minutes]	4,7	0.20
Average Maximum capacity [spaces/hour]	**1,350**	**1,200**

Evaluation of the simulations results

It being understood that the quantitative results presented in the previous section and in order to select the most suitable automated transport system for the Rome case, some critical considerations aimed at supporting and addressing the decision-making process were developed. However, it is important to underline that the evaluation of the system to be adopted in Rome can not ignore the knowledge of the necessary unit costs for the design, building, maintenance and running costs of the system, in terms of permanent way and vehicle fleet (typology and sizing).

In synthesis, the main evaluations findings are listed below.

The PRT system represents a “niche” transport system whose operating development at international level was however little significant. In fact, only few PRT systems, realized in middle of the seventies, are at present fully-operated (i.e. Morgantown and Las Colinas) but several new systems are in a testing phase (i.e. ULTRA system at *Heatrow* airport, Cybercar at *Nuova Fiera di Roma*). In the past, the lack of its widespread application is probably due to the high operating costs, caused by the need to guarantee high-quality services (in terms of frequency and travel comfort) compared to the existence of rather slight volumes of transport demand that not necessarily allow to cover the investment costs foreseeing a complex operating system that, however, is not the case of the Villa Borghese project. However, in such a current panorama the PRT system is proposing as an extremely innovative system, that is finding a proper role in the reference market, likely supported from appropriate on-site testing phases, able to rebuild, with a good reliability, the real operating conditions.
According to the simulation results, the PRT is more flexible depending on the demand fluctuations, offering ranks of capacity and frequency extremely variable, from 240 seats/hour (1 trip/minute) to 1,200 seats/hour (5 trips/minute). A demand up to 1,200 passengers/hour asks for a fleet of 15 – 20 cars with consequent need of further spaces for depots and holding bays dedicated to the parking of non-used cars during the off-peak hours. However, in the VB project it seems easily obtainable; besides, the running costs could possibly be very competitive considering the Rome projects layout and operating set up.
Obviously, such system performances will be better validated only after the evaluation of the first outcomes related to the next put in operation in the Heathrow airport, which could enhance the system spreading, which is supported by a good service flexibility, low

maintenance costs as well as unusual and well-integrated placement within the historical urban centres and/or pedestrian zones.

Concerning the APM systems, whatever is the manufacturing company, are all comparable systems, provided traction funicular, for which there is both the possibility to operate on a one-track configuration (as shuttle service) and with similar train composition (1 or 2 cars for train) according to the variability of the transport demand. In particular, frequencies from 8 to 12 trips/hour and a line capacity between 800 and 1,200 spaces/hour are fitting values for the Rome case (easily achievable in the medium term), also considering that such configurations can be assured by a fleet of only one train (2 cars).
The fully-operations of the APMs in various contexts is also a strength factor in terms both of high effectiveness in providing excellent Level of Service in any intervention area as well as distinctive element in the environment where it is built. So, the investment and operating costs become the main discriminating factors in orienting the selection process.

Finally, the automated systems were also evaluated by a qualitative way, employing five brief indicators (Table 8) in terms of: *comfort level on board* (seats/total spaces); *cost-effective time* (including the average waiting time at station), *noise level*, *number of similar systems at present fully-operated* and *robustness of the used technology* (level of maturity).

Table 8 - Qualitative analysis of the automated transport systems

	On-board comfort [%]	**Cost-effective time** On board time/Total Travel Time* [%]	**Noise level** at 10 m distance [dBA]	**Fully-operated systems**	**Technology** [maturity level]
APM	15	36,7+	50-55	5**	High
PRT	100	90,3 + +	45	0	In testing

*considered a capacity of 800 spaces/hour
** only systems operating in context comparable to the Rome case (in terms of track length and layout) were considered;
+ a trip every 5 minutes (fleet: 1 train)
+ + a trip every 18 seconds (fleet: 14 cars)

It is worth mentioning that, even if the PRTs seem to be more convenient in terms of level of service (comfort and cost-effective time), such values are reached with a large vehicle fleet (14 cars instead of 1 APM train). In any case, such considerations have to be stressed in the selection process, as they suppose a different approach for the dimensioning and maintenance of the system and, therefore, important differences in the total cost.

CONCLUSIONS

Dealing with the achieved results, some functional considerations for the selection of the more suitable transport system for connecting VB terminal to Piazza del Popolo can be drawn. For the system dimensioning, the analysis of the potential transport demand was essential. Such a demand was assessed taking into account, respectively, individual demand data collected during the on-site survey (Doxa survey, January and March 2009) and the tourist demand travelling by coaches that, using the VB as terminal, could be potential users

of the new automated link; in addition also two different growth scenarios related to the induced transport demand were suggested.
On the basis of the cumulate demand analysis, the main automated transport systems, currently in operation and/or under a construction phase, and able to satisfy the demand expected for the Rome case, were analysed. To this end, several simulations were elaborated considering different operating models, applied on a guideway 700 m long, obtained by changing the design configurations (one or two tracks), in terms of train composition, vehicles capacity and service frequency, varying from 6 to 17 trips/hour for the APMs and up to 300 trips/hour for the PRT system.

It being understood that every analysed system assures excellent technical and operating performance, in order to finalize the decision making process, the knowledge of the investment, operating and maintenance costs cannot be ignored. However, at the moment, data capturing are in progress so, a further period is required for concluding the overall assessment.

As things stand, as the link VB terminal – Piazza del Popolo is included in a wider project, focused on the improvement of public and tourist transport and the optimization of intermodal related services supply (mainly Park and Ride), the selection process should probably be oriented towards a solution that foresees gradual steps of transport capacity development, according to:

1. the first outcomes of the fully operations of the Villa Borghese urban hub (after surpassing the transitory state);
2. the process of spatial reorganization related to the Trident Area pedestrianization;
3. the growing public transport demand derived from the changing accessibility patterns in the whole influence area of Trident zone.

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