ADVANCED TRANSIT SYSTEMS FOR THE INTEGRATION OF INTERCHANGE NODES AND STRATEGIC URBAN POLES

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Abstract

This work is part of an important national scientific research program financed by the Italian Ministry of Education, University and Scientific Research. It focuses its attention on advanced transit technologies characterized by high automation levels, light infrastructures, over a linear distance of a few kilometers and a medium-low transport capacity, in order to determine their potential applications for connecting interchange nodes and strategic urban poles. The main aim of this research work is to carry out a comparative analysis of such systems, following an organized procedure based on quantitative indicators. A reconstructed informative framework concerning the performances supplied by different advanced transit systems can be a useful reference for guiding choices in transport policies.

The work produced a structured and standardized collection of data concerning advanced transit systems at present operating in the world for the integration of interchange nodes and strategic urban poles, as well as systematic methodology for the systems analysis.

From the practical point of view, the paper proposes a short summary of a feasibility study of an advanced transit system connecting the University campus of Reggio Calabria, in Southern Italy, to two strategic interchange nodes, the port and the railway station.

Keywords: Transit systems; Interchange; Strategic planning; Performances
Topic area: A1 Road and Railway Technology Development

1. Introduction

In many cases Public Administrations must select, among the various transit technologies that are available, the one which better satisfies the population's demand for mobility while limiting the negative effects deriving from traffic congestion.

The choice can be quite complex, having to reach varying and often contrasting goals. A procedure is therefore required to help the decision-makers compare, classify and sort out the several available alternatives, in order to draw up an objective and transparent classification.

Generally, the planning of a public transportation line is guided by three main needs:

– to satisfy adequately present demand levels, thus avoiding under- or over-estimating the offer;
– to assure good service levels in order to make the line more attractive than alternative private modes;
– to draw up a budget proportional to a Public Administration's possibilities or to a private operator's interests.

Over the last few decades, poles, characterised by homogeneity and a high user concentration, have developed in many towns: office districts, recreation/cultural areas, University campuses, large commercial centres, health units, etc. They express a strong demand for mobility, which is often widespread, but not always adequately served by public transportation. An efficient connection between this kind of urban structure and the main interchange nodes, such as railway or underground stations, ports and airports, would be desirable in order to rationalise user flows and channel them into transit systems.

Thus, various medium-low capacity transit technologies, which are halfway between traditional buses and tramways, and still proposed under innovative forms by transport industries, can help improve the transportation system structure, as numerous studies have shown (Vuchic, 1981; Strobel, 1982; Neumann, Bondada, 1985; Soulas, 1991; AA.VV., 2003).

The proposal of such advanced technologies is tied to both a better understanding of their potentialities, since a lot of them are only prototypes, and to the nature of the required services.

The work has been developed by the following operative phases:

- research and acquisition of widespread documentation inherent to the function and performances of advanced transit systems connecting interchange nodes and strategic urban poles;
- up-to-date classification of technologies based on different parameters;
- statistical analysis of the function and performances of advanced transit systems that are already operating;
- adoption of a methodological procedure, founded upon the Multi-Criteria Analysis, which allows the comparison of alternative systems.

2. Advanced technologies of public transportation

In order to link strategic urban poles with interchange nodes in an efficient and effective way, it is generally necessary to adopt strong lines of public transportation (adductor lines) which can offer high performances on medium-short distances (not more than 5 km) and have a medium-low line capacity (lower than 10.000 spaces/h per direction).

Among the various transit systems which could be used to link strategic urban poles and interchange nodes the ones chosen as the focus of this paper are the systems with a high level of automation, which are an alternative to traditional buses and to tramway and metro systems; particularly, attention has been focused on ***light automated guideway transit systems***, which can contribute to improve the structure of transport system and the quality of life in towns. Generally, they are characterized by:

- *global automation*: the completely automated driving allows to ensure high levels of reliability, safety and quality of the service;
- *light facilities*: the small size of the vehicles and the reduced physical spaces taken by the road infrastructure allow a better integration of the systems in urban and metropolitan areas;
- *reserved and exclusive lanes*: the separation of the lanes allows to avoid conflicts with private transportation;
- *low environmental impact*: the reduction of polluting emissions allows to safeguard environment and to develop a sustainable mobility.

The typology of the considered systems includes 4 different classes: ***AGT light metros***, ***monorails***, ***funiculars*** and ***ropeways***; such systems are provided with vehicles whose driving is completely controlled by computers replacing the driver and excelling him in ability and reliability.

2.1. Documentary research

An in-depth study has been carried out about the technical and features and the performances of many light automated guideway transit systems operating in various parts in the world. It has been supported by a wide bibliographic and internet research. Particularly, the research has aimed at the collection of specific information concerning a set of reference variables, such as:

– *general variables* (typology of system; year of opening and of the latest modernization; territorial context of realization; building and managing company, etc.);
– *infrastructural variables* (track length; difference in height; longitudinal maximum slope; medium slope; minimum bending radius, etc.);
– *variables relevant to stations* (number of stations, average interstation distance; safety device at the stations, etc.);
– *variables relevant to vehicles* (model; size characteristics; empty and full-load mass; number of spaces; etc.)
– *variables relevant to engine* (typology of engine; engine power; etc.);
– *operating variables* (typology of service; regime speed; commercial speed; number of vehicles in line; composition of a vehicle; stop time at the station; overall travel time; headway; waiting time at the station; frequency; line capacity; number of operators; work hours during the day; etc.);
– *demand variables* (number of passengers in a day; number of passengers in a year);
– *cost variables* (investment costs; cost per Km of line; vehicle unit cost; cost of the fleet of vehicles; yearly operating cost);
– *revenue variables* (ticket fare; fare revenue).

The research has allowed to get a lot of information on 451 transit systems operating at an international level (23 AGT light metro systems, 44 monorail systems, 92 funicular systems and 292 ropeway systems). The difficulty in finding some interesting full data led subsequently to limit attention on 227 systems (21 AGT light metro systems, 19 monorail systems, 67 funicular systems and 120 ropeway systems).

2.2. Classification

Within the general classification of urban and metropolitan transit systems recently proposed by Gattuso and Meduri (2003.a; 2003.b; 2003.c), light automated guideway transit systems can be differentiated according, firstly, to technological aspects.

In particular, AGT light metro systems can be divided into *rubber-tyred systems* (AGS systems - Automated Guideway System; TGA systems - Transport Guideway Automated; VAL systems - Véhicule Automatique Léger) and *rail systems* (ALRT systems - Advanced Light Rail Transit).

Monorail systems can be classified either as *systems with supported vehicles* (vehicles move supported on the upper part of the guide beam), or *systems with suspended vehicles* (vehicles move hanging by the guide beam, thanks to bogies placed on the upper part of the vehicles and hooked to the lower part of the guide beam) and *systems with laterally suspended vehicles* (vehicles move at the side of the guide beam; supporting elements are at the side of the vehicle and both flanges of the guide beam function as a support).

Funiculars can be divided into *funiculars with a modest slope guideway* (which can work on path with a slope lower than 15%) and *funiculars with a steep slope guideway* (which can go over 15%).

Finally, ropeway systems can be divided into: *open vehicle systems* (where vehicles have an open structure) and *close vehicle systems* (that is gondola ropeways, funitel, aerial tramway where vehicles are made up of close cabin with large windows and sliding doors).

A further classification of the light automated guideway transit systems taken into account can be proposed according to the territorial context in which they are used; in this regard the applications of such systems can be divided into (see Figure 1):

- *nodal applications:* they are carried out inside interchange nodes (some typical examples are the applications in airport terminals), or inside strategic poles (sport centres, recreation parks, hospitals, etc.);
- *extra-urban applications:* they are carried out on an extra-urban area for the effective link between residential areas, strategic poles and interchange nodes; some examples of this kind of applications are the link systems between downtown and airport, or between a built-up area and a dedicated area;
- *urban applications*: they are the applications inside an urban centre aiming at linking residential areas, strategic poles and interchange nodes; some examples are the link systems between downtown and railway station, or between downtown and hospital.

2.3. Statistical analysis

The acquisition of a diffuse documentation concerning the functional characteristics and the performances of 227 light automated guideway transit systems has allowed the reconstruction of an organized database through which it has been possible to carry out some interesting statistical analysis (Gattuso, Meduri, 2003.c).

Later in the paper the results of some general analysis are concisely proposed. In particular, they concern the typology, the year of opening, the nationality and the territorial context of realization of the light automated guideway transit systems taken into account and which can be considered a representative sample.

As to ***the typology of the system***, the analysis shows a greater diffusion of:

- AGS light metro systems (in fact the AGS system, the first having an integral automation, was carried out in 1971, a decade before the creation of the other AGT light metro systems);
- monorail system with supported vehicles;
- steep slope funicular systems (in fact such systems were carried out as from the end of the XIX century in order to get over steep differences in height);
- gondola ropeways and aerial tramway.

The analysis concerning the ***year of opening*** shows that:

- the greatest number of the analized light metro systems was carried out from 1986 to 1990 and then they dropped; in the last decade the most widespread system is the VAL;
- about 40% of the considered monorail systems were carried out in the last five years;
- almost half of the analyzed funicular systems were carried out before 1925; the increase in realizations recorded in the last twenty years shows the renewed attention towards these systems, after decades of loss of interest;
- most of the studied ropeway systems was carried out as from 1950, with a substantial growth in the last 25 years.

As to ***nationality***, it is possible to notice that:

- almost 60% of the analyzed light metro systems concentrate in North America (USA and Canada), where AGS, ALRT and VAL systems have imposed themselves; in Europe the most developed system is the VAL;
- the considered monorail systems are placed above all in Japan and USA; on the whole, 40% of the analyzed systems concentrate in Asian countries and 20% in Europe;
- funicular systems are placed above all in Europe, and particularly in the alpine regions;

– over 80% of the ropeway systems are placed on the European territory and, in particular, in Switzerland (almost 40%).

As to the ***territorial context of realization***, the analysis shows:

– a greater use of AGT light metro systems in urban contexts and inside airport nodes; the systems in extra-urban contexts are essentially used for the town-airport link;
– monorail systems are used above all in urban contexts, even if there are some applications inside attractive nodes/poles (play parks, zoos, airports) and in extra-urban contexts;
– almost half of the studied funicular systems work in extra-urban contexts, in order to serve areas of landscape interest, or to link built-up centres with attractive poles; moreover there are some applications in urban areas and inside attractive nodes, such as sport facilities;
– ropeway systems work essentially inside sport facilities and in extra-urban contexts; recently, such systems have been successfully used also in some urban contexts.

The statistical analysis which were carried out concerned not only general aspects, but also a set of interesting variables relevant to:

– infrastructures (maximum slope, minimum horizontal bending radius),
– stations (average interstation distance);
– cars and vehicles (length, gross floor area, empty mass, vehicle capacity);
– engine (engine power);
– operational service (frequency, line capacity, commercial speed).

Moreover, the study has aimed at finding significant correlations between particular couples of the above mentioned variables; specifically, the relationships indicated in Table 1 have been deeply analyzed.

Table 1 – Significant relationships between light automated guideway transit systems variables

			1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*
Infrastructures	*Max slope*	*1*											
	Horizontal min bending radius	*2*											
Stations	*Average interstation distance*	*3*											
Vehicles	*Length*	*4*		♦									
	Gross floor area	*5*				♦							
	Empty mass	*6*				♦	♦						
	Vehicle capacity	*7*				♦	♦	♦					
Engine	*Engine power*	*8*	♦			♦		♦					
Operational service	*Frequency*	*9*							♦				
	Line capacity	*10*							♦		♦		
	Commercial speed	*11*			♦							♦	

The following relationship appear of particular interest:

– commercial speed and average interstation distance (Figure 2);
– maximum service frequency and vehicle capacity (Figure 3);
– maximum service frequency and line capacity (Figure 4).

In the first case it is possible to observe how the commercial speed maintained by light automated guideway transit systems tends to increase when the average interstation distance, following an approximately linear trend; the interstation distance being equal, the system which can ensure the highest commercial speed are AGT light metros and monorails.

From the analysis of the second relationship it emerges a decreasing trend of the service frequency tied to the vehicle capacity, even if in the case of monorail systems such a trend appears less marked. In the particular case of AGT light metros, funiculars and ropeways, it is possible to observe how the envelope of the points representing the above mentioned relationship follows a qualitatively hyperbolic trend. Moreover Figure 3 underlines a distinctive feature of ropeway systems, which can ensure high frequency even using low capacity cages.

Finally, from the study carried out it emerges an increasing trend of the line capacity tied to the maximum service frequency; particularly, in the case of funicular and ropeway systems it is possible to find, considering the vehicle load capacity, some suitable classes of systems where the above mentioned tie is linear.

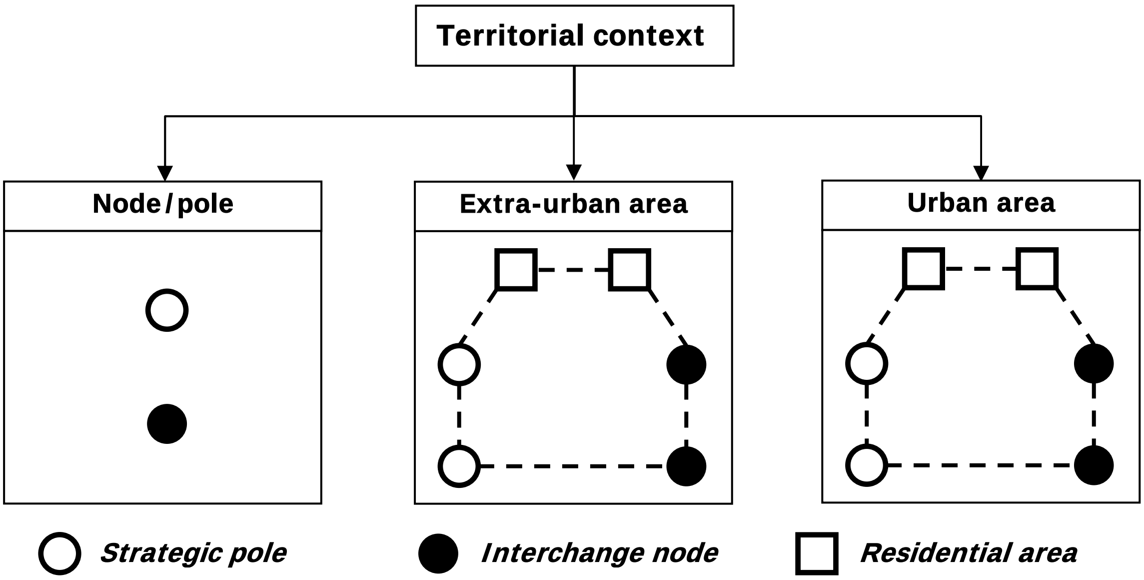

Figure 1– Application contexts of light automated guideway transit systems

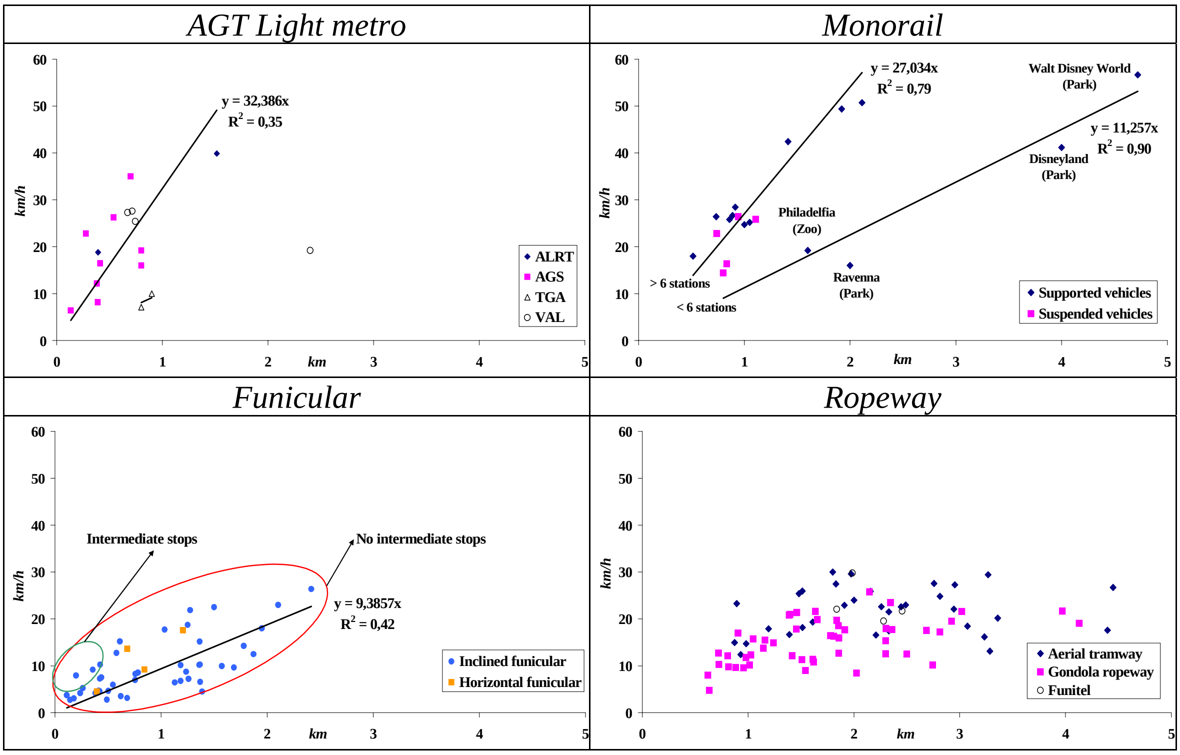

Figure 2 – Relationship between commercial speed and average interstation distance

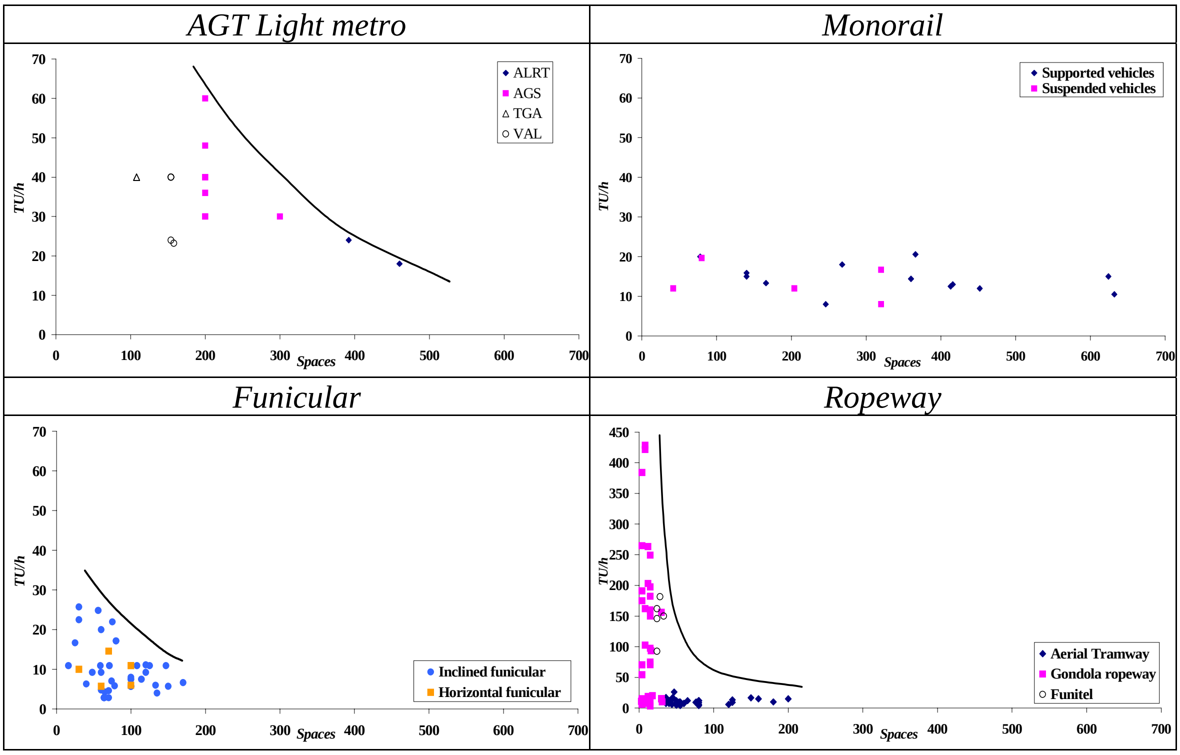

Figure 3 – Relationship between maximum service frequency and vehicle capacity

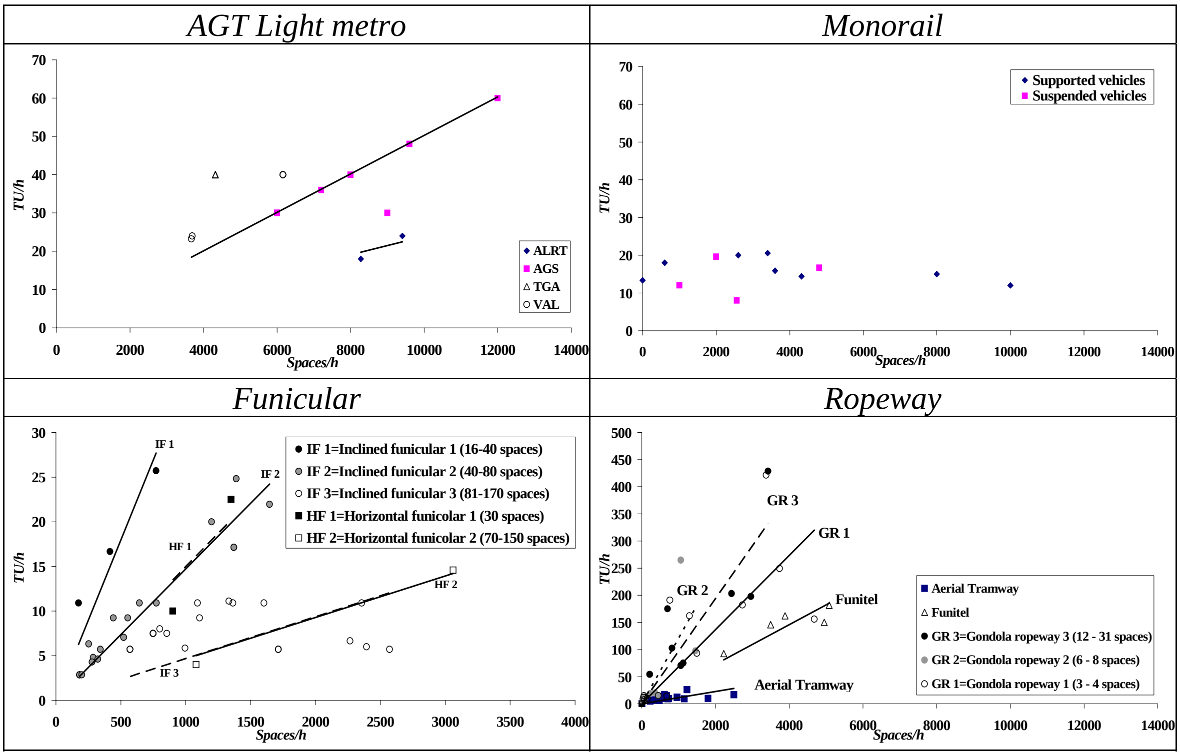

Figure 4 – Relationship between maximum service frequency and line capacity

3. Evaluation of transit advanced technologies

Generally, the choice of a transit system is strictly connected with the performances of the various transit technologies, with the present and future mobility demand of the area to serve, with other parameters of evaluation expressing the needs of the different social components. Later in this paper a reconstructed informative picture, concerning the performances offered by the considered light automated guideway transit systems, is proposed as well as a methodological procedure, based on the Multi-criteria analysis and allowing the comparison of various alternative systems taking into account several variables.

3.1. Performance parameters of the light automated guideway transit systems

Generally, the performance parameters of interest in transit systems are numerous; among the most common there are: vehicle capacity; minimum headway; maximum frequency; line capacity; regime speed; commercial speed; productive capacity; maximum slope; minimum horizontal bending radius; average interstation distance. The numerical ranges of the above mentioned parameters are shown in the table below (Table 2) and refer to the 227 studied light automated guideway transit systems (AGT light metros, monorails, funiculars and ropeways).

Table 2 – Numerical ranges of the light automated guideway transit system performance parameters

	AGT light metros	*Monorails*	*Funicolars*	*Ropeways*
Vehicle capacity (spaces)	50-100	4-160	16-170	4-200
Minimum headway (min)	1-6	3-10	2-25	0.13-16
Maximum frequency (TU/h)	10-60	6-20	2-26	3-430
Line capacity (spaces/h per dir.)	2000-14000	500-9500	180-3000	24-4700
Regime speed (km/h)	40-80	25-85	5-43	9-43
Commercial speed (Km/h)	6-40	12-57	3-29	5-30
Productive capacity (spaces*Km/h^2)	25000-330000	7250-474000	745-61000	120-145000
Maximum slope (%)	8-10	4-8	12-123	15-104
Minimum bending radius (m)	>20	>20	>12	n.d.
Average interstation distance (Km)	0.13-2.4	0.5-4.7	0.1-2.4	0.6-12.5

3.2. Choice procedure through Multi-Criteria Analysis

The choice of a specific transit technology is very complex because it must achieve different and often conflictual objectives; it needs a preselection of the evaluation variables as well as a procedure useful for an objective comparison of the different alternatives.

In order to compare different transit technologies a set of representative and not redundant evaluation variables is proposed as follows:

– demand/line capacity ratio;
– commercial speed;
– surmountable maximum slope;
– allowable minimum bending radius;
– vehicle durability;
– cost of the fleet of vehicles;
– cost per Km of line;
– air pollution;
– noise pollution;
– visual interference.

Once the values assumed by the above mentioned evaluation variables are found, it is necessary to provide people responsible for the final choice (decision-makers) with a procedure helping them to compare, classify and organize the various alternatives available, as to obtain an objective and transparent final classification. In literature, there are many methods for the comparison of alternative hypotheses. This paper focuses on the Multi-Criteria Analysis techniques (Roy, 1976; Haimes, Chankong, 1985). In its most general formulation, Multi-Criteria Analysis presupposes the transformation of the various objectives achieved by the decider into evaluation criteria, that is into quantitative and qualitative variables. Each criterion m is given a weight $w_m \geq 0$ measuring its importance. The value assumed by the generical criterion m in relation to the alternative j can be expressed by a variable x_{mj}. The matrix of the elements x_{mj}, having a number of lines equal to the evaluation criteria and a number of columns equal to the alternative hypotheses, is defined as "evaluation matrix". In order to avoid distortions deriving from the use of different scale factors, it is suitable to replace the values $x_{mj.}$ with normalized values $l_{mj,}$ that is, values belonging to the interval [0,1]; in that way the "standardized evaluation matrix" is obtained. In the Multi-Criteria Analysis the construction of the above mentioned matrix is actually just the starting point, because the formulation of judgements, expressing the prevalence of an alternative rather than another, implies the interpretation of the matrix itself through suitable Multi-Criteria Analysis techniques (IPA – Ideal Point Approach, ELECTRE methods, WSA – Weighted Summation Approach, etc.). In particular, the "Weighted Summation Approach " in based on the assumption that the utility u_j, produced by an alternative j, can be expressed as a linear function of the normalized measures l_{mj}, that is: $u_j = \sum_m (w_m \, l_{mj})$. The order of preference of the alternatives is established taking into account the utility indices; the most favourable alternative is the one maximizing u_j.

4. Hypothesis of a light automated guideway transit system for the city of Reggio Calabria

Over the last few years the need to relieve congestion of important universities has led in many towns to the building of new university complexes. Where possible, pre-existing infrastructures, often situated in town centres have been used, but more often, there has been a preference for the construction of new universities in suburban areas.

Universities are places that have high user concentrations, characterised by systematic "home-university" commuting; as a result, if universities are not connected to its surrounding territory by means of regular and integrated transit systems, it may become difficult to reach them not only for resident users, but above all for non resident ones. The scarcity, or even the lack, of university-user-oriented public transport services means, on the one hand, often unsustainable general entrance and exit times and costs at universities, on the other hand, the frequent resort to private means of transport. The most obvious consequences of such a phenomenon include the congestion, especially during the rush hour, of university routes and the systematic saturation of parking areas within or in the vicinity of the campuses.

The Mediterranea University of Reggio Calabria presents all the above-mentioned problems. Its buildings are all concentrated in the northern part of the town, about 2 km away from the town centre.

At present, in the absence of an integrated local university-user-oriented transit system, the most common means of transport used to reach the university are private: over 65% of journeys that start or end at the Faculties take place by car or motorbikes. The high number of vehicles attracted or generated by the university campus contributes to the increase in traffic congestion in the urban area and in accident risk, causing queues and waiting during the rush-hour.

These considerations have led to the idea of creating an integrated transit system for the Mediterranea University of Reggio Calabria, with the aim of satisfying the ever growing demand for student mobility, and of reducing the effects of private transport (Gattuso, Meduri, 2003.d).

After studying the transit system that is now serving the university campus as well as the possible future trends deriving from the absence of public transport solutions, a hypothesis regarding the creation of a transit system connecting the University campus in Reggio Calabria to two strategic interchange nodes, i.e. the town's port and railway station has been developed in broad outline. A series of analyses relating to the performance of the various possible transit system technologies, have focused their attention on certain high-quality systems characterised by performances that are congruent with the expected demand levels. In particular, thanks to a Multi-Criteria Analysis attention has been restricted to light automated guideway systems.

The hypothetical system consists of a line in elevation along a sea-mountain route, with its lowest point in the vicinity of the Reggio Lido railway station and its highest point at the University campus. There should be four intermediate stops (the port, Piazzale Libertà, San Brunello, the Faculty of Architecture). The main dimensions of the track (see Figure 5) are:

- total length: 1.86 km;
- average interstation distance: 372 m;
- difference in height: 85 m;
- maximum slope: 10%.

System operational service has been dimensioned in relation to:

- three different light automated guideway transit systems: a funicular with 30 spaces vehicles, a gondola ropeway with 8 spaces cabins and a monorail with 120 spaces vehicles supported by a guide beam;
- two different demand scenarios: a basic-demand scenario where it is assumed that the expected regular demand is estimated on the basis of opportune SP (Stated Preferences) surveys, and a high-demand scenario, where it is assumed that the expected regular demand is twice the basic one. On a strategic scale one must consider a high-demand scenario in virtue of certain specific factors such as the assimilation of a number of users presently classified as pedestrians, the attraction of a number of local users who are not motivated by the University, a greater frequency in the use of the new system, an eventual integration with urban transport fares. For both hypothetical demand scenarios two time references have been taken into consideration: the rush hour, and moderate flow times.

On the basis of kinematical parameters (regime speed, service acceleration and deceleration) of light automated guideway transit systems already operating in other territorial contexts, it has been estimated that the total time required by the funicular to cover the whole distance between the lowest and the highest stations is about 7.5 minutes (the corresponding commercial speed is 14.6 km/h); similarly, the time required by the cableway to cover a one-way trip is about 8 minutes (with a commercial speed of 14 km/h), while the time required by the monorail is about 9.5 minutes (the corresponding commercial speed is 11.8 km/h).

The traffic flows along the busiest section during the rush hour, the number of vehicles required for the three hypothetical systems and their corresponding line capacities have been calculated for each hypothetical demand scenario. With reference to the morning rush hour (8 to 9 am), in order to satisfy peak traffic load (450 users), the basic demand scenario requires a funicular system with two vehicles made up of two 30 spaces cars (in such conditions, the system's frequency is equal to 8 TU/h and its line capacity is 480 spaces/h), or a gondola ropeway system with fifteen 8 spaces cabins (reaching a frequency of 56 TU/h and a line capacity of 450 spaces/h), or, in alternative, a monorail with two 120 spaces vehicles, each one made up of two cars (reaching a frequency of 6 TU/h and a line capacity of 720 spaces/h).

Finally, the work presents an economic analysis of the hypothetical projects, estimating two cost components, investment costs and operating costs. The former cover the construction of the infrastructures, network structures and purchase of rolling stock. Operating costs, for an average year, cover the cost of various components in operating and maintaining the system. Moreover, the revenue from fares has been estimated.

This economic analysis has shown that the profits are rather modest compared to operating costs; one must bear in mind, however, that the operating costs include the rate of depreciation of infrastructures, stations, network structures and vehicles. Thus, in a strictly financial analysis, the operation would not be worthwhile.

In the case of an economic and social analysis, and in consideration of the concept of sustainable development, estimations are quite different; in fact, a variety of factors must be included and well-pondered, such as safety, air pollution, noise pollution, visual interference, town image factor, effects of traffic congestion on circulation quality, effects of traffic congestion on urban life quality, changes in land values.

Clearly, all these factors can assume great value in guiding the decision-maker.

In order to simulate the operation of the proposed systems and to visualize their interaction with the surroundings a 3-D dynamic virtual representation of the three hypothesis has been made exploiting the potentials of the Computer Graphics. Figures 6 and 7 show two images of the simulated proposed systems.

5. Conclusions

Among the various transit systems which could be used to link strategic urban poles and interchange nodes the ones chosen as the focus of this paper are the light automated guideway transit systems (AGT light metros, monorails, funiculars and ropeways), which are characterized by high automation levels, light infrastructures, over a linear distance of a few kilometers and a medium-low transport capacity.

The acquisition of a diffuse documentation concerning the functional characteristics and the performances of 227 light automated guideway transit systems operating in different countries in the world, has allowed the reconstruction of an organized database through which it has been possible to carry out some interesting statistical analysis and to find out significant correlations between some couples of variables (commercial speed and average interstation distance; maximum service frequency and vehicle capacity; maximum service frequency and line capacity).

In order to compare different transit technologies, a set of representative and not redundant evaluation variables is proposed and a methodological procedure, founded upon the Multi-Criteria Analysis, is adopted.

From the practical point of view, the paper proposes a short summary of a feasibility study of an advanced transit system connecting the University campus of Reggio Calabria, in Southern Italy, to two strategic interchange nodes, the port and the railway station.

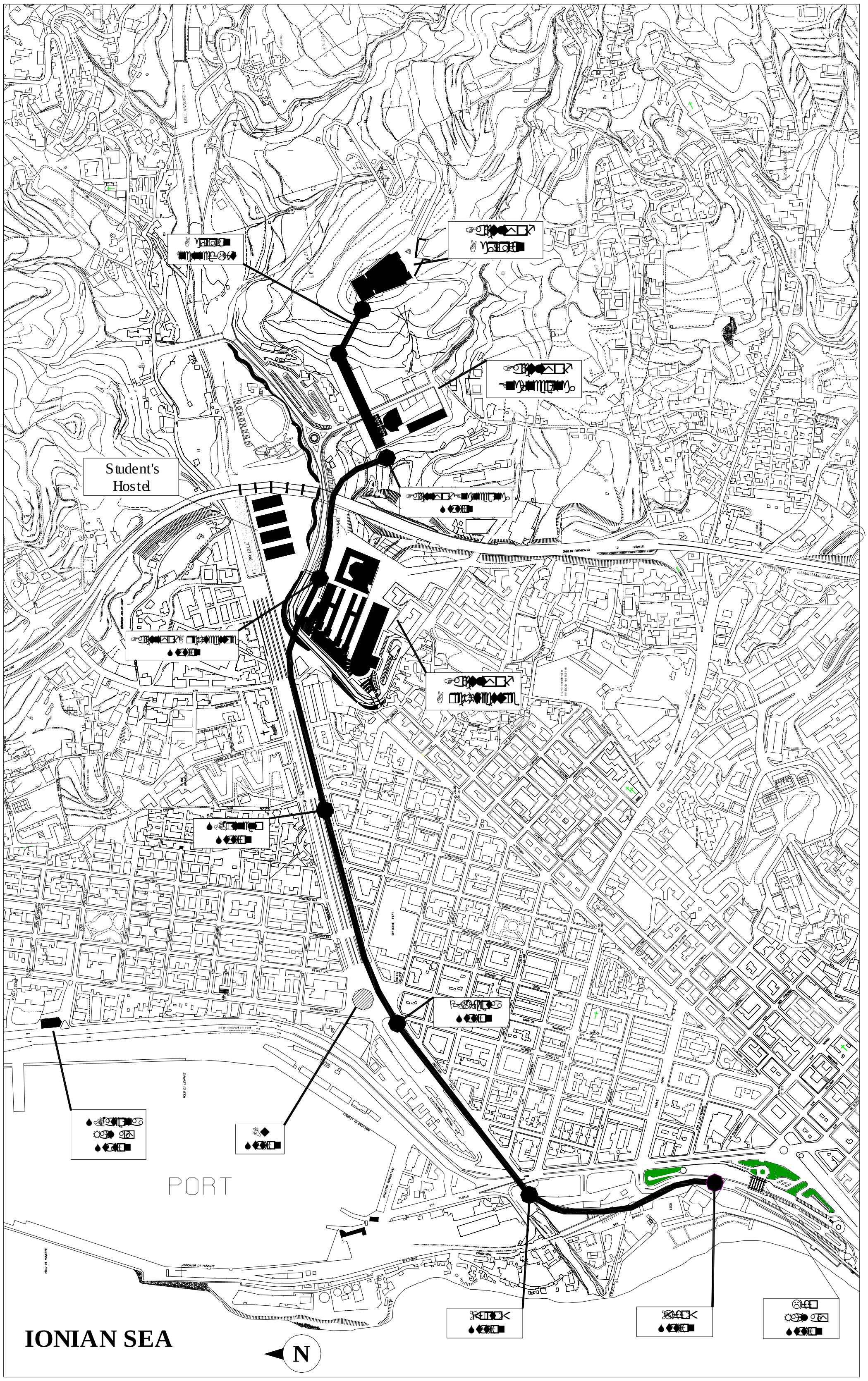

Figure 5 – Route planimetric pattern

Figure 6 – 3-D image of the proposed funicular system

Figure 7 - 3-D image of the proposed gondola ropeway system

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