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MULTICRITERIA ANALYSIS TO RELAUNCH SANGRITANA S.p.A. RAILWAYS IN THE LANCIANO AREA

SEVKET OGUZ KAGAN CAPKIN
Matricola.1784288

Relatore
PROF. MARIA VITTORIA CORAZZA

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Summary

ABSTRACT

MULTICRITERIA ANALYSIS TO RELAUNCH SANGRITANA S.p.A. RAILWAYS IN THE LANCIANO AREA

CAPKIN, Sevket Oguz Kagan

Transport Systems Engineering Master's Degree Final Thesis

Supervisor: Prof. Maria Vittoria CORAZZA

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The tram-train system is an innovative, at least for the Italian panorama interoperable public transport system, which allows to bond between urban centers and extra-urban zones, by using a single type of public transport vehicle (tram or LRT) adapted or redesigned to operate both on public transport infrastructure (tram lines or LRT lines) and existing railway lines. This is the case of the dismissed Sangritana railway, now under the preliminary phases of rehabilitation in the Lanciano area, as prospective tram-train service. To assess its feasibility, a multi-criteria analysis is carried out, coherently with the operator's approach. For the comparison, three different transport modes, which are tram-train; light rail train; and bike service (according to the possible options in the area), are chosen and the analysis is done concerning criteria focused on the assessment of the environmental effects, operational situations, social acceptance, and economical perspective. The four criteria are weighted (environmental effects-35%, operational situations-25%, social reactions-20%, and economical perspective-35%) according to importance levels. Then, the three transport modes are compared, resulting into a best score for the bike service. Light rail train is the second best option and tram-train service is the third one.

Key Words: Tram-Train System, Multi-Criteria Analysis, Light Rail Train, Bike Service

BACKGROUND

The purpose of the study is by answering the following research questions:

- What is the tram-train service and its concept?
- Which innovative systems have a similar concept to tram-train service?
- What are the Multi-criteria Analysis and its procedure?
- Can the tram-train service be successfully operational in the Lanciano area, in line with the local operators' vision?
- Which transport mode (comparison of three modes which are tram-train, light rail train, and bike service) is better to implement according to multi-criteria analysis concerning four main criteria which are the economic situation, environmental issue, social effect, an operational issue, to assess the relaunch of the rail supply in the study area?

After that, in this study, there are six main parts which are "Introduction, Study Case: Lanciano Tram-Train Project, Technical Approach, Results of Study, Conclusion, and Comments".

First part, which is Introduction, includes the tram-train system's definition; concepts; features; requirements; existing implemented examples around the European Union, light rail train systems' definition; features; requirements; examples of implementation around the World, cargo-tram systems and examples around the European Union, and environmental effects of transportation systems.

The second part, which is Study Case: Lanciano Tram-Train Project, gives some information about Abruzzo Region (Italy)'s geography, existing railway network, existing transport supply services, recent demands, public transport patterns, and environmental situation.

The third part, which is Technical Approach, explains the basic information about multicriteria analysis and its techniques; key features; performance matrix; and advantages. After the information, the study case is evaluated by multi-criteria analysis technique of scoring and weighting according to chosen transport modes (tram-train, light rail train, and bike service) concerning criteria (economic situation, environmental issue, social reaction, and operational issue)

The fourth part, which is the Results, shows the all evaluated scores or each criterion. After that, evaluates the final performance matrix of transport modes and chosen criteria.

The final parts, which are Conclusions and Comments, have recommendations about study outputs and some suggestions about the possible future studies.

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

1. Information about Travel Mode Chosen by The Users

After the Great War (Second World War), European cities almost collapsed. Destruction of mobility services in cities, inhabitants need new services and requirements such as comfort and travel time. Mobility demand has changed, both from the qualitative and quantitative point of view, principally the changed conditions of work and settlement. The economic situation is caused by higher densities cities to get a job opportunity. Besides, the improvements in industry and technology are caused higher population and bigger cities. Higher density city means higher traffic congestion and citizens may change transport mode from private transport to public one because of less loss of time.

At present, journey times have taken on, together with safety and comfort, greater importance, such as the demand of users not only from the suburban areas to the central areas, also from metropolitan areas to the central areas of cities is continuously increasing.

This situation needs some suitable responses from public transportation operators and local administrators, which in recent years has shown a good recovery but this is not enough, however, to supply a better mode choice to private car usage, the transportation systems should answer the citizens' requirements and wants or those which require “breaks of load”. Also, transportation systems’ supply does not require only enough capacity, but also systems should care about economic and environmental sustainability, with integrated visual impact and street furniture. [55][61]

Consequently, this situation appears to be extremely complex for both public/private transportation companies and public administration. Technology and new urban planning help an essential and at the same time a big role in finding better solutions, but decision-makers should have enough knowledge and vision to find a better way for possible delicate problems. Table 1 shows the means of transfers chosen on the basis of urban center. [11]

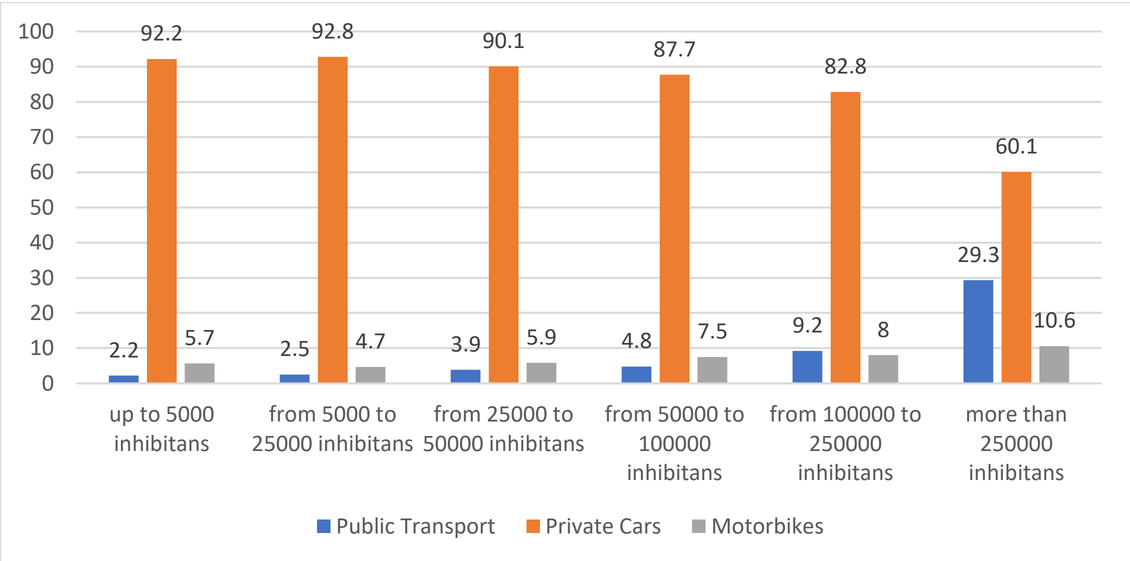


Table 1: Means of transfers chosen on the basis of the urban center (ISFORT) (Italy, 2017)

The new trends, for public transportation, in progress are various. First of all, revival of the old tramway systems as a common chosen method and better exploitation for city transportation plannings, which are being redesigned through it. In more detail for Italy, Italian citizens appears to the usage of private cars which are two or four wheeled. According to EUROSTAT data, Italian cities have the highest motorisation rate in the European Union (EU), with 625 cars per thousand inhibitants in 2016, passed only by Luxembourg (670 cars per thousand inhibitants in 2017) (Figure 1). [28]

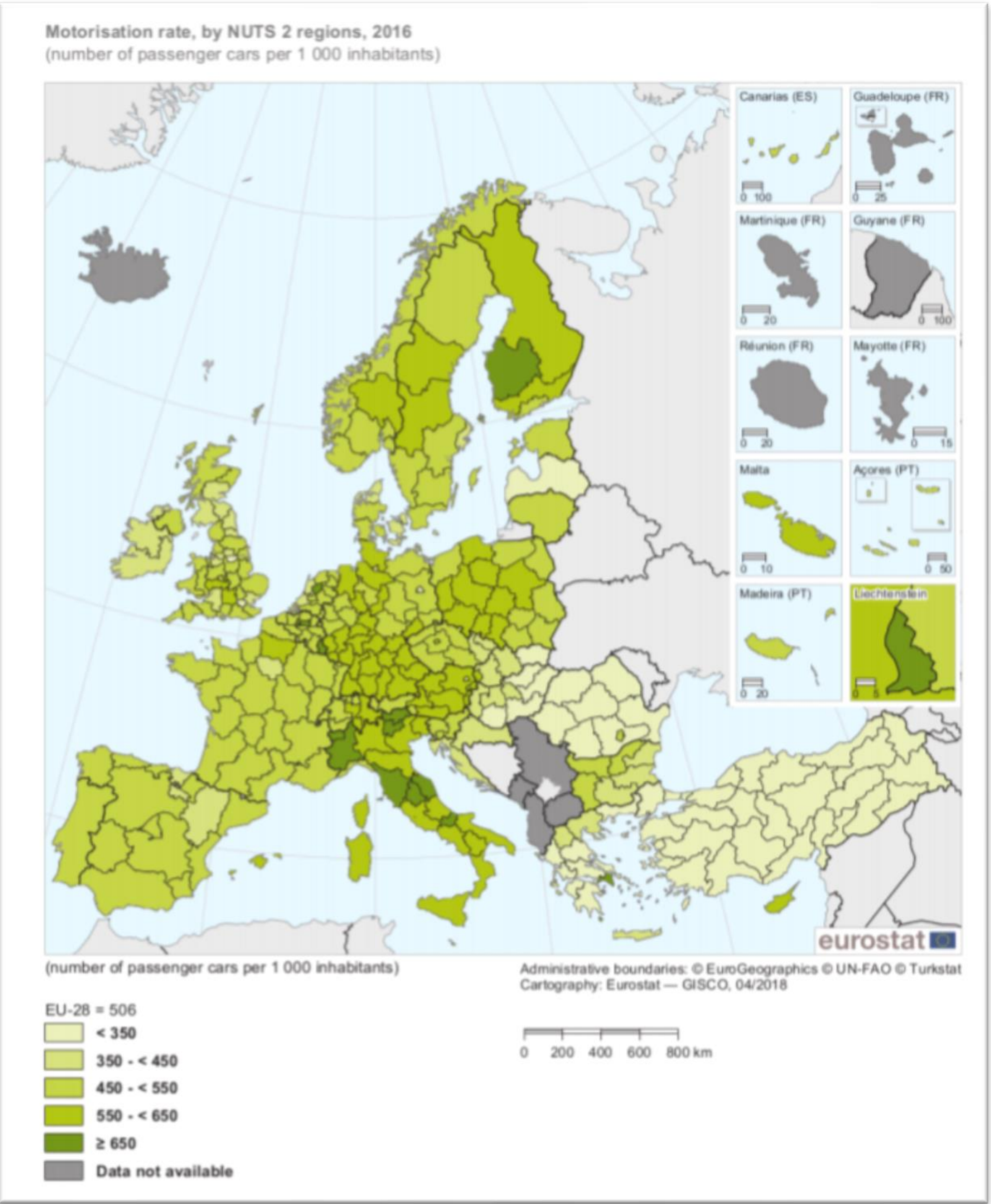


Figure 1: Motorisation rate in European regions 2018 (EUROSTAT)

According to ISFORT (Istituto Superiore di Formazione e Ricerca per i Trasporti), Table s shows a survey results, which are conducted between 2004 and 2006, with regard to the satisfaction expressed by the citizens of medium and large cities with respect to public transportation, especially by bus and tram (graph on left) and by underground (graph on right). As it is possible to say that the satisfaction (very satisfied and quite satisfied) of the underground service is continuously increasing if compare the results of 2004 and 2006 (76.3% and 84.1%). For the bus and tram service, it is possible to see, the satisfaction (very satisfied and quite satisfied) is continuously decreasing between 2004 and 2006 (71.5% and 65.2%). This comparison shows citizens prefer faster and more comfortable systems which go on railways . Rail systems are more acceptable and preferable for citizens if compare the road systems. [43]

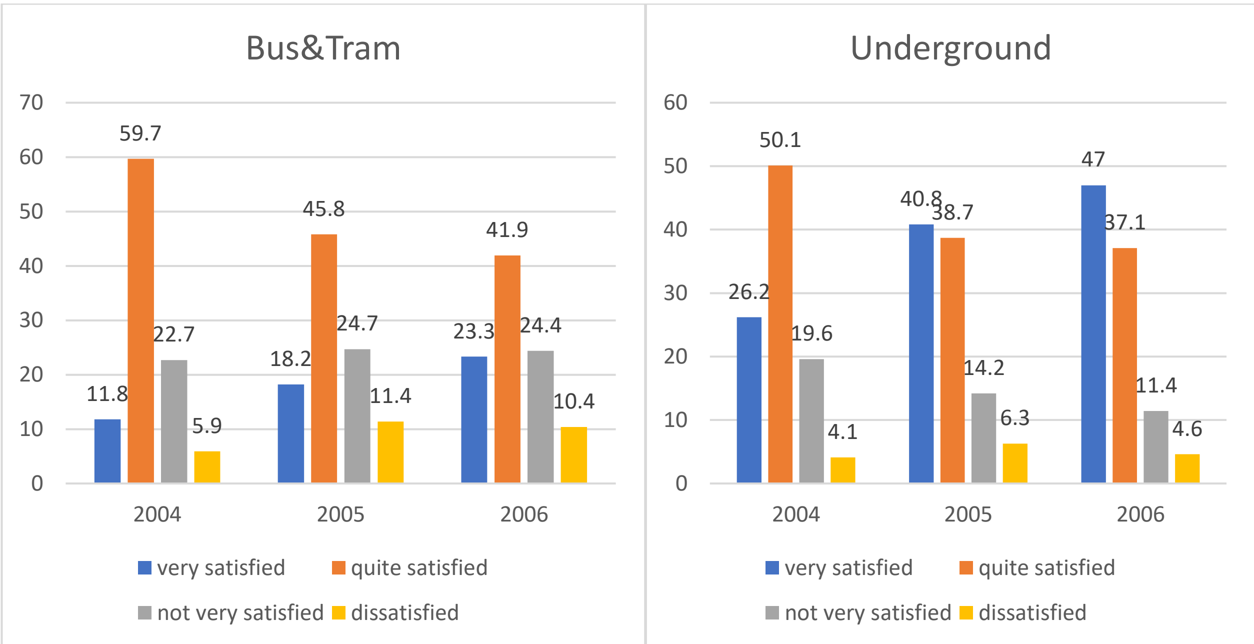


Table 2: Satisfaction expressed by citizens in medium and large cities for the public transportation (ISFORT)

However, the population of small or medium cities seem to create no sufficient demand to have a mass rapid transportation system. Mass rapid systems, such as rail systems, are not applicable into small and medium cities because of low demand, but interoperable systems (such as tram-train) available to apply. Interoperable systems allow using the existing lines or infrastructures with technology by more than one transportation systems and drastically reduce the breaks of load. [65]

2. Public Transportation in Italy

To understand public transportation in Italy, focus on the worst one which is Rome's transportation. Rome is the capital of the Italian Republic. The metropolitan city of Rome has almost 3 million inhabitants and the city have the highest private car usage rate if it is compared to other biggest cities in the European Union. Rome has lots of problems such as high congestion and air pollution. They are results of high private transportation and diesel motorized public vehicles. This means Rome is in a transportation crisis. To solve these types of problems, the Italian government and local authorities attend and support sustainable and environmental opportunities that are developed with new technology. In Italy, public transportation buses have diesel engines. It causes emissions means air pollution. [9][11]

The fundamental reasons for the disaffection of public transportation are both due to social and technical issues. Indeed, the significant complaints in the public transport journey in Italy, the points of major critically are, in order of importance in the users' perception:

- journey times considered non-competitive compared to those of the private means and often very difficult to quantify with certainty in advance;
- accessibility of the public means (understood as ease of use) is lower than the private means, and the need for breaks of load;
- poor capillarity of the service;
- insufficient level of comfort, mainly attributable to overcrowding but also to parameters now assessed as fundamental, such as the level of cleaning, the efficiency of the air conditioning plant, the level of safety and the difficulty of entering the carriage due to the survival of vehicles with the floor not lowered;
- correspondence of the service with the real needs, with particular reference to the frequency of the service, the design of the routes and the networks (Epifanio and Malandrino).

According to Italian National Transport Account (ISFORT), the data is shown in table 3, from which an imbalance between supply of and demand for public transport in 2007. There are two divided zones which are urban area and suburban area. This imbalance is more understandable and visible if compare the urban one (71.1 billion places per km supplied against 11.6 billion passengers per km transported in 2007) and extra-urban one (70.4 billion places per km supplied against 18.1 billion passengers per km transported in 2007). [11][12]

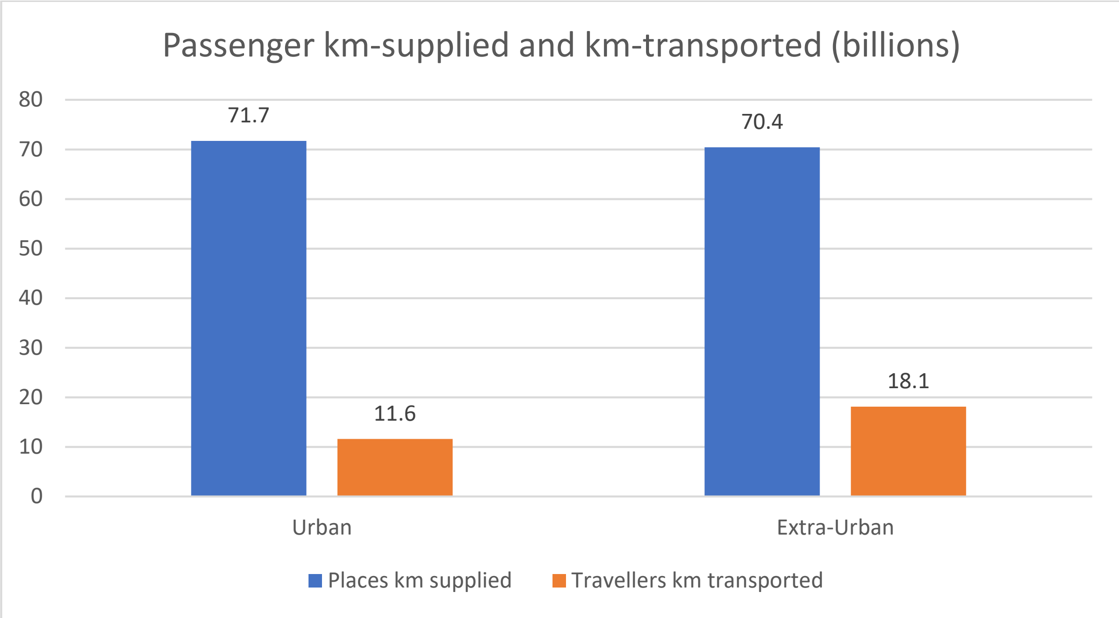


Table 3: *Comparison between passenger km-transported and km-supplied in 2007 (ISFORT)*

Both extra-urban and urban zones have lower coverage rates, and this means less economic efficiency. Even though, the appreciable result of the coverage of the places does not seem to like this data for the covering of the cost or for the satisfaction with the public transport service.

The population of the city is a parameter, which causes higher density and traffic congestion, and directly affects the mode choice of the users. Table 4 shows the comparison of cities which have a different number of inhabitants. [11][55]

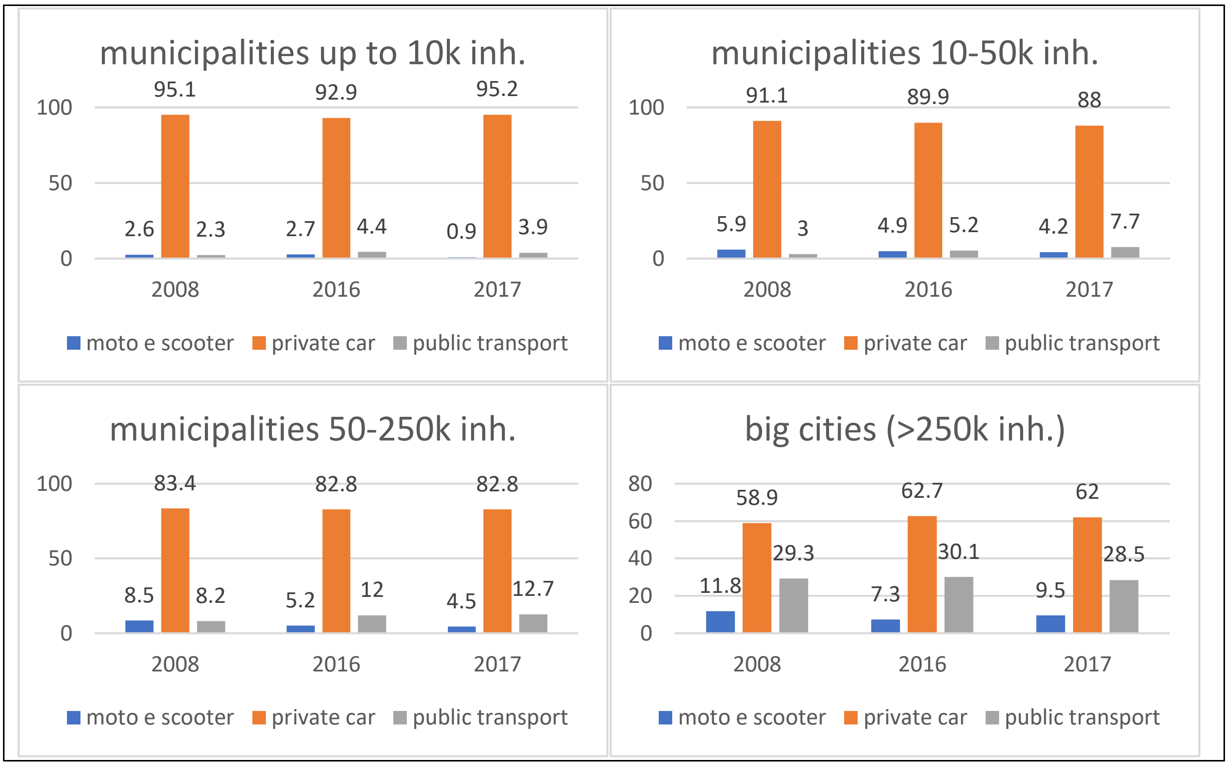


Table 4: *The distribution of motorized urban movements by geographical area (%) (ISFORT)*

Looking at the graphs, as the population of the city increases, the usage of private transportation decreases due to the increase in traffic congestion. At the same time, the preference of other mode choices (such as a scooter, moto, etc.) increases. Between 2008 and 2017, it has been observed that the usage of public transportation has increased in 50-250k municipalities over the years. It is easier to say that this type of cities' inhabitants accepts and use public transportation, which is less crowded and more efficient, comfortable. [69]

On the other hand, despite the intense urbanization processes that characterize the global scenarios, also affecting Italy, the fact remains that the cities with over 250,000 inhabitants absorb no more than 15% of the total population, a percentage which doubles by adding all the municipalities of the metropolitan cities. About 2 Italians out of 3 live instead in municipalities with less than 50,000 inhabitants, falling or not in metropolitan areas; these citizens move very little by public transport even when they have to move towards the major poles. [65]

In urban areas, private transportation (auto and powered two wheelers - PTW) rate decreases because of more traffic congestion and higher public transport conditions over years. Table 5 shows the distribution of urban movements by the mode of transport used by inhabitants. Between 2008 and 2017, walking and bicycle usage increases due to improvement of sidewalks and bicycle lines. At the same time, choice of public transport increases by citizens between 2008-2017. Also, travel by public transport with motorized vehicles, which consume fossil fuels, is important. [67]

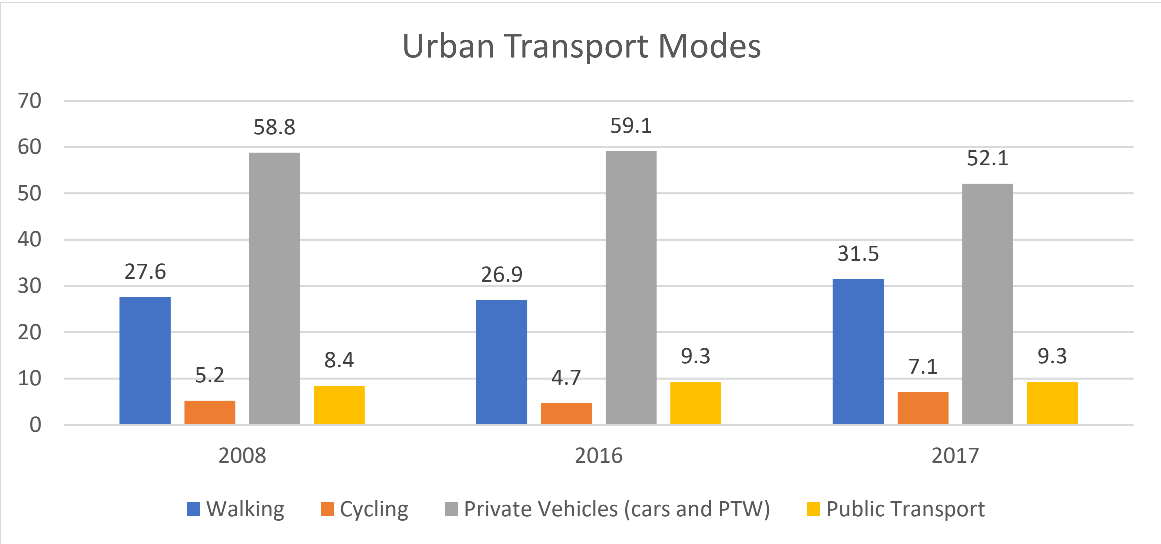


Table 5*: The distribution of urban movements by the used transport modes (%) (ISFORT)*

Table 6 shows private transportation (auto and moto) is so high in extra-urban areas. At the same time, public transportation is cheaper to travel from suburban areas to central areas for the citizens of these municipalities. However, a non-effective time schedule and less route choice cause decreasing the usage of public transportation. In suburban zones, inhabitants csonsider the comfort and duration because of distance or travel time between suburban areas and urban centers.

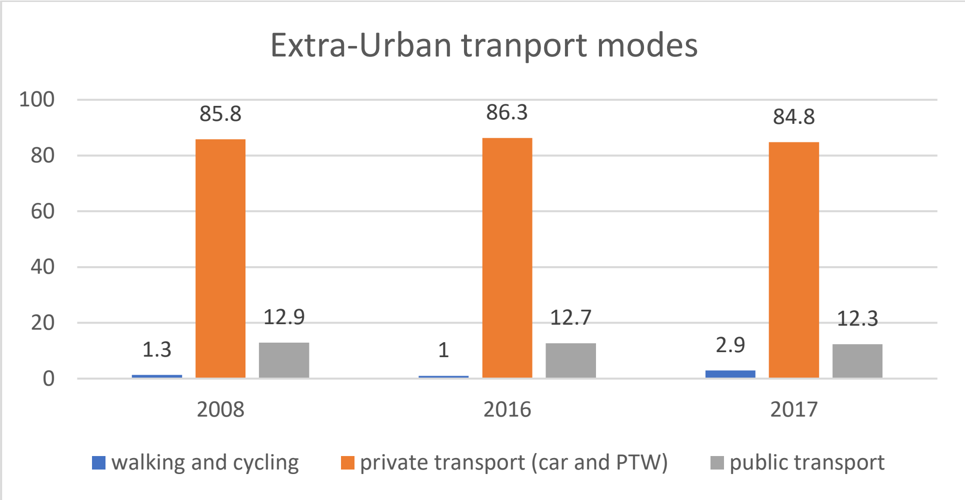


Table 6: The distribution of extra-urban travels by the used transport modes (%) (ISFORT)

With respect to the graph, which is shown in Table 7, motorized public transport vehicle usage increase in urban areas over the years (12.6% in 2008 and 15.2% in 2017). However, motorized public transport vehicle usage quite non-changed over years (12.6% in 2008 and 12.6% in 2017). [69]

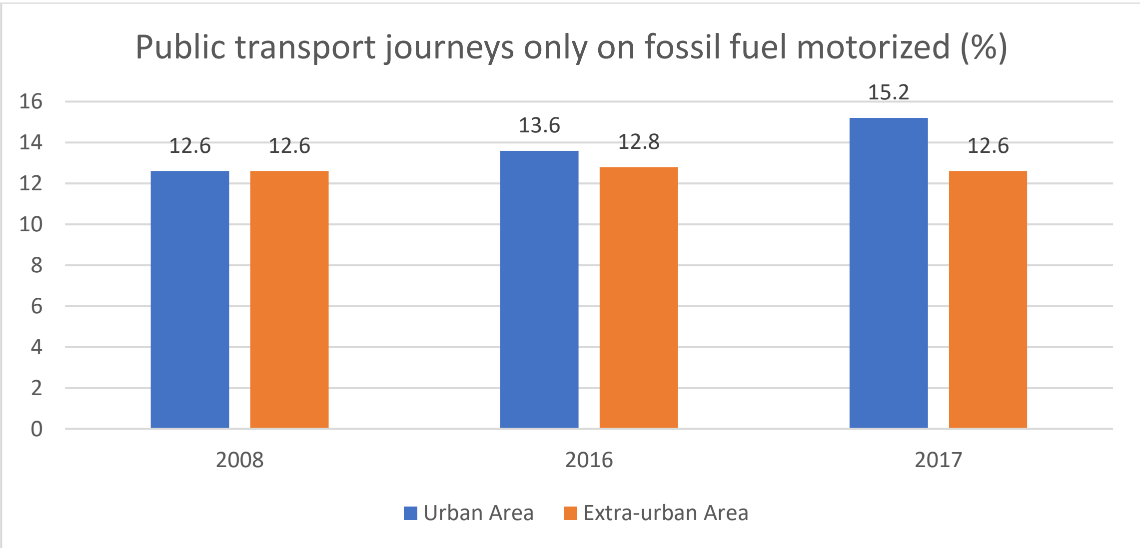


Table 7: Public transport journeys on motorized vehicles that consume fossil fuel (ISFORT)

The choice of means of transport tends to segment significantly on a territorial basis. With respect to the territorial constituency of the interviewees, the means public exhibit higher modal shares in the regions of the North West (12.8%) and in those del Centro (12.4%), where the weight of large metropolitan areas is very incident, while values lower than about one third are observed in the North East and the South. Differentials very high characterize the use of the bicycle, with a share of around 8% in the North and less in the middle to the south. The choice of private transportation is appreciably lower in the North West (54.2%) compared to the rest of the country (around or above 60%). Finally, the movements of walking seem to be a little more common in the South, especially compared to regions of Central Italy (but the gaps are not so wide). [11] [65]

As for the other traditional territorial segmentation parameter, or the breadth demographic of the municipalities, the differences in values confirm the very fault lines deep already drawn. In fact, those who live in smaller municipalities (up to 10,000 inhabitants) tend to use much more private transportation (almost 70% of all journeys) and much less the most sustainable means, the public transport in particular (modal split less than 5%).

After all of this, authorities should attend sustainable and economical innovations. The number of lower density cities is much in European Union member states. Reduction of private transportation and low emission, public transportation should be more efficient, comfortable and economical. Innovations in public transport systems and new urban planning provide the satisfaction of users and local authorities. To improve urban life quality, transportation systems can reduce congestion by private transport traffic and air pollution. If public transport systems provide the satisfaction of environmental parameters and user satisfaction, both the liveability of cities and economic sustainability will be increased.

3. Definition of Tram-Train

"Tram-Train" is an innovative, at least for the Italian panorama interoperable public transport system, which allows to bond between urban centers and extra-urban zones, while eliminating the necessity to change the respective waiting times, public transport vehicles (tram or LRT) adapted or redesigned to operate both on public transport infrastructure (tram lines or LRT lines) and existing railway lines. On the other hand, tram-train system means a tramway vehicle is able to operate two different existing infrastructures requires overcoming some technical barriers which depend on both safety and geometric requirements between two different railway systems (such as heavy rail or LRT). [61]

There are three types of tram-train service according to the classification shown in Figure 2.

Figure 2: Tram-Train classification schema by Naegeli, Weidmann and Nash

- **Type A** tram-trains run on the tram tracks in mixed operation with conventional trams and on the heavy rail track in mixed operation with conventional heavy rail trains. Examples include Karlsruhe and RegioTram Kassel (Germany).
- **Type B** describes a system in cities without an existing tram network. The tram-trains do not run in mixed operation with heavy rail trains on the heavy rail tracks. An example is the Saarbahn in Saarbrucken (Germany).
- **Type C** includes other systems, for example, those in which the tram-train has its own exclusive tracks in the city center or the regional area and therefore does not run in mixed operation in one or both of these areas. Examples include the line T4 in Paris (France) and the Randstad Rail in The Hague (Netherlands). [61]

The purpose of this public transport system is to re-run the tram-LRT vehicle on existing-disusing or poorly using infrastructures, bonding railways between the urban center and extra-urban areas, and create integrated, flexible and adaptable public transport system. Also, these systems guarantee higher environmental issues, especially air quality, and lower energy consumption.

In Italy, the country has a significant number of poorly using railway infrastructures, which has extremely valuable issues, such as they located in urban centers or extra-urban zones and have sufficient features. Over the years, these infrastructures (railways) have been underestimated and they have been converted to road sections or car parks. Re-using of these existing railways, avoiding considerable economic issues (infrastructure costs) an environmental impact (less land use and lower emission).

The main aim of tram-train service allows the connecting between tram lines and existing heavy rail lines, without high train traffic density, submits lots of benefits for the rail operators and the users. Indeed, rail operators or local authorities minimize the investment costs by using existing railways, bonding urban centers' and extra-urban areas' public transport systems and provide effective regional train services without interchanges.

Furthermore, running on regional rail lines by light rail vehicles, with higher acceleration and braking performances than other railway vehicles, easily reach higher commercial speeds during operation, this provides higher operation frequency of the transport service and this allows additional new intermediate stops/stations in regional rail lines, which are in suburban zones, with quite similar travel time. For example, the Saarbrücken-Sarreguemines cities have tram-train service running on between these two cities in 30 minutes with 14 stops. However, the old system, which only operated with regional trains, at the same time, served only 7 stops. [61][65]

The well-known tram-train service, the foundation of tram-train service, is "Karlsruhe Model" and it has two main characteristics:

· The system running with tram or light rail vehicles

· The operation is mixed of tram or light rail "dual-mode" vehicles with regional transport vehicles, such as heavy trains, in existing railway lines

There are some tram-train concepts such as planned in Karlsruhe/Saarbrucken and Kassel. However, some other public transport systems called "tram-train". For instance, in some European cities (as Croydon and Aulnay-Bondy), have low heavy train traffic density, have been completely changed to light rail services, but in the Zwickau (Germany) extra-urban area units operate together with tramway vehicles.

4. Features of the Tram-Train Systems

Speed and Network Coverage

The maximum speed of the tram-train service depends on two important issues which are physical characteristics and safety requirements of the infrastructure and vehicle. Concerning the International Union of Railways, the body stiffness standard of heavy rail vehicles much more than tram-train service vehicles. This body stiffness provides passive safety and supports the train in a crash situation.

Because of the reduced body stiffness (reduced passive safety) in tram-train service vehicles, the operational active safety has to be increased to obtain sufficient safety levels in interoperable operations. If the service is new and innovative, there should be new rules and requirements. After Karlsruhe tram-train system in Germany, German authorities published guidelines for lightweight rapid transit rail vehicles.

The guidelines set the maximum speed for operations of tram-train vehicles at 90 km/h (56 mph). However, the maximum speed of a tram-train vehicle can reach 100 km/h (62mph) if additional requirements are satisfied. The average speed of a tram-train vehicle, during the operation, is 35 to 40 km/h (22 to 28 mph), because the service has both features of conventional regional trains and urban tramways. At the same time, users don't want to spend much time on their journeys. So, there is an assumption for travel time that maximum commuting time per day and direction is 1h, the maximum system infrastructure radius is 35 to 45 km (22 to 28 mi) from the urban center.

Capacity and Capability

In the urban centers, the tram-train vehicles run on the streets and interact with other vehicles or pedestrians. Therefore, tram-train vehicles have the same rules and requirements when they run on the urban centers, such as German Bau und Betriebsordnung fur Strassenbahnen. According to the German example, the maximum dimensions of tram-train vehicles are 75 m (246 ft) in length and 2.65 m (8.7 ft) in width. Other European countries have similar regulations for tram-train vehicle dimensions.

For the point of users' view, comfort is the main parameter. Concerning the users' comfort, a tram-train vehicle has a limit for capacity which guidelines allow about 112 passengers (base on occupying 95% of seats and 20% of the standing room). Generally, trains operate in double traction (the allowed maximum length is 75m) as similar to tram-train vehicles. So, capacity reaches about 225 passengers. Table 10 shows different public transport capacities.

In the extra-urban areas, heavy rail track's operational capacity has a limit because of the other train services traffic and technical regulations of the vehicles. Basis of requirements such as available slots on heavy rail tracks and infrastructure capacity, the maximum operational passenger capacity is about 1400 passengers per hour per direction. Table 8 shows the comparison of different public transport systems' capability and Table 9 shows public transport systems characteristics and performances. [6*]

Transport System (Vehicle)	Transport Capability [pass/h per direction]	Infrastructural Costs [k€/km]
Tramway	4000 – 6000	5000 – 10000
Light Rail (LRT) (*)	8000 – 12000	20000
Underground (**)	8000 – 30000	12000 – 50000
Tram-Train (*)	3000 – 5000	Typically Existing

Length and power referred to single unit, (*) multiple coupling up to three units, (**) multiple coupling up to eight units

Table 8: *Comparison of different public transport systems (Rozzo, Genova and Ballini)*

	Bus and Trolleybus	Tramway	Light Rail Metro	Conventional Metro
Vehicle capacity [passengers]	60 – 120	100 – 200	100 – 250	140 – 280
Transport capacity [passenger/hour]	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

Table 9: *Public transport systems characteristics and performances (Pede and Agostini)*

	Vehicle Capacity (seats+standing)	Practical line capacity with 5min headway (passenger per hour)
BUS – Standard Bus	80	960
BUS – Articulated Bus	120	1440
LRT – Hannover (28m)	150	1800
LRT – Kassel (28m)	180	2160
LRT – Vienna Type A (24m)	150	1800
LRT – Vienna Type B (35m)	230	2760
LRT – Karlsruhe (36.5m)	220	2640
LRT – Bremen (35m)	220	2640
LRT – Sheffield (34m)	250	3000
Heavy Rail – Munich (metro, 110m)	870	10440
Heavy Rail – Zurich (bilevel S-Bahn, 99m)	600	8200
Heavy Rail – Rhein-Main (S-Bahn, 217m)	1380	8280
Heavy Rail – ET 426 Hannover (regional train, 10 min headway assumed)	1500	9000

Table 10: *Vehicle capacity and practical capacity of public transport modes (Kaiserslautern University)*

City Size

The European cities, which have successful performed tram-train services, have inhabitants between 100,000 and 300,000. The tram-train service typically operates between regional areas and metropolitan areas if these are strongly related to each other for working, shopping, recreational facilities, health issues, governmental and higher education activities. This strong relationship between the extra-urban and urban centers causes centralized traffic flows. [9]

However, this type of cities has lower passenger demand not sufficient to provide standard regional railway services in which users transfer to other services at a central station. Tram-train systems are more attractive for these cities because of lower costs (lower capacity requirements) and direct connection to the urban center's public transport services.

Type A tram-train service is more applicable for the cities which have their existing tramway services (most of the European cities, which have 100,000 to 300,000 inhabitants, have their tram systems). The other cities, which have no tram systems, Type B tram-train system more feasible by building a new railway track in these cities. As it is, the relationship between a regional train and an urban tram means more passengers use the railway system.

The implementation in Saarbrucken is a good example of it. Table 11 shows the reachable users along the tram-train service zone in Germany. [86]

Regional Track	Length [km]	Reachable Inhabitants	Persons/km	Frequency[min]
Saarbrucken Brebach – Sarreguemine	14	27,400	1,960	30
Saarbrucken Malstatt – Walpershofen	8	19,100	2,390	15
Saarbrucken Malstatt – Limbach	19	39,400	2,080	15
RT3 Kassel Vellmar – Warburg	36	35,000	980	30
RT4 Kassel Oberzwehen–Wolfhagen	25	29,400	1,180	60
RT5 Kassel Oberzwehen–Melsungen	20	30,000	1,500	60
RT9 Kassel Vellmar – Treysa	52	47,000	900	60
550 Chemnitz – Stollberg	16	26,100	1,630	30
Zwickau Maxhuette – Zwotental	48	46,200	1,160	60
Zwickau Maxhuette – Plauen	40	46,200	1,160	60
S1 north, Hochstetten–Karlsruhe Neu	11	27,300	2,480	20
S1 north, Karlsruhe–Rupuerr–Bad H.	18	42,100	2,340	30

Table 11*: Population density and reachable inhabitants along the German tram-train service line corridors*

Requirements of Tram-Train Systems

The tram-train system has features of both a tramway system and a light rail system. On the other hand, the tram-train system is a modified light rail system. In the circumstances, tram-train vehicles are not changed to work on regional railways or urban centres. They were changed for a better organization to work in both areas. Urban tramway services run on promiscuous or separated railways from urban road traffic. Vehicles operate with low speeds in the meantime they need high acceleration and braking. After all, vehicles have light structures. The opposite way around, the extra-urban network vehicles, such as light rail train, usually operate on separated zones, means there is no interaction with road traffic, vehicles don’t have to work with high acceleration and braking because of a smaller number of stops. [21]

The interoperable service, such as tram-train, have some optimization problems which are;[9]

▪ rail and wheel compatibility: a fundamental situation for the running of tram-train service is rail-wheel compatibility. The wheelset dimensions (such as tire width, coning angle, flange distance) of regional service and urban centre networks' vehicles are variable because tram services have a narrow and shallow groove to protect inhabitants (as pedestrians, moto riders, bicyclists) and vehicles (as cars) of cities from possible hazards. Tram vehicles can derail when they run on conventional rail lines. Because of this, a new wheel type, which operates together on tram and conventional lines, should be implemented. Table 12 illustrates the geometrical differences between Rome tramway wheels and regional heavy railway wheels.

	Rome Tramway			Regional Railways		
	standard	min	max	standard	min	Max
Track gauge [mm]	1445			1435	1432	1470
Wheel profile width [mm]	84	--	--	135	130	140
Distance between inside faces of wheel profiles [mm]	1392	--	--	1360	1357	1363
Distance between outside faces of wheel flanges [mm]	1439	--	--	--	1410	1426
Wheel diameter [mm]	680	--	--	--	700	1250

Table 12*: Vehicle's wheel's geometrical differences in Rome's service (RFI)*

▪ electric supply system (tram and regional line vehicles use different voltage): This is a quite bigger problem for interoperable systems because generally tramway vehicles operate with 750V DC while regional trains run with 15kV to 25kV AC (data from Ferrovie dello Stato Italiane). Existing tramway catenary wires allow enough clearance requirements for regional train vehicles' electrical power supply without any technical problem. However, this situation is a barrier for possible new train operators, which want to use the same lines, and the line owners may refuse to approve this new electrification. The existing devices, that supply the power for traction, may be modified to dual voltage but this is not so simple. Vehicles with diesel engines can be more suitable if a running corridor is longer, traffic density is less and separation from road traffic is higher. The modification of dual voltage is performed in Karlsruhe and it is the best available solution. The voltage changing happens automatically when the vehicle changes the line. Also, there is another opportunity that allows interoperability vehicles with dual voltage.

A vehicle can have both dual traction power supplies that are diesel and electrical. When the vehicle runs on the tram line, the electrical engine works and when it runs on regional lines, diesel engine works such as Kassel's system. [65]

▪ vehicle shape (track and structure gauges): For track gauge, tram-train runs both on the tram and regional railways. Therefore, these networks have to be compatible. For the solution to this situation, there are some opportunities, such as building a third rail or a fourth rail. In the main Italian cities (such as Roma, Milano, Bari, L'Aquila) have different track gauges between urban tram and regional railway. Concerning the different vehicle gauges in Italian cities (1435 mm for regional railways and 1445 mm for urban tram vehicles), adding a third rail on existing networks or operates with dual gauge wheels are not suitable solutions (for instance, implementation of Zwickau project). As a consequence, some modifications should be implemented in system vehicles. The tram-train modified vehicles, which have dual bogies, can run on both 1435mm and 1445mm track gauges in Italian cities. For structure gauge, tram service vehicles car-bodies are narrower than regional rail vehicles. At the same time, standard for platforms, which is Railway Safety Principles and Guidance part.2 section.b guidance on stations requires a minimum clearance of platforms 50mm to the swept envelope. The platform level depends on all different rolling stock types. To improve accessibility, the current trend is low-floor vehicles, and this may be a problem because of platform width and height. Therefore, a second important technical requirement about accessibility. Recent new tram vehicles were designed with full or very low floor to be so close to urban street platforms. In Italy, regional rail network stops' platforms have 250mm to 600mm high, European standard EN 14752 – Bodyside Entrance Systems states that platforms can be higher than maximum 250mm. according to EN 14752, horizontal gap between vehicle and platform can exceed maximum 275mm. For this reason, the tram-train systems require retractable footboard or retractable ramps to prevent the passengers from possible hazards. [13] [37]

▪ structural resistance: the tram vehicles run on urban centre streets and they need higher acceleration and braking rates. Therefore, tram systems have lighter vehicles and lower crashworthiness if compare to regional network vehicles. According to Novales, Orro and Bugarin, active safety defines as the set of measures that can be taken in order to prevent an accident from happening (for example, the degree of collision prevention), while passive safety is oriented towards minimizing the damage that occurs in the event of an accident (for example, the protection afforded to those involved in a collision). Regarding the safety regulation which is about car-body rigidity, tram-train vehicles must fulfil the UIC standards (fiches UIC 617-5, 625-7 and 631 about passive safety) for conventional rail vehicles. [65] [67]

The standards notify that structural body resistance in railway vehicles has to be 1500 kN at least in buffer zones, for tram-train vehicles more related to passive safety and structural requirements are EN12663 – Structural requirements of railway vehicle bodies and defines car-body structure strength requirements for vehicles' categories. According to EN 12663 and category P-IV (about light metro and heavy tram), the minimum value of structural resistance in buffer zones and/or correspondence of coupling hook has to be 400 kN (for instance German tram-train vehicles have 600kN). [55]

▪ entrance prices

▪ signalisation [12][13]

5. Examples of Tram-Train Services in European Union

Karlsruhe (Germany)

The population of Karlsruhe, which is a German city, is approximately 500,000 inhabitants. The main railway station of Karlsruhe is in the suburban area of the city, about 2 km south of the urban center. This distance was negative affect for the possible users, who want to travel by train services because inhabitants had to transfer to the tram or bus services to arrive at the urban center or main railway station. This was reducing the railway transport service quality and preferability. To solve this problem, local authorities decided to eliminate the transfer processes and to offer a direct link between the main railway stations and urban centers. The idea was so simple, a tram vehicle could run on existing conventional railways. After that, the link was opened to operation with 30.2 km long and the name was Karlsruhe – Bretten – Golhausen Line on September 27, 1992. This newer line became so successful and leads the other lines around the Karlsruhe city. However, this was not so easy to operate tram vehicles on conventional railways and requires some technical and operational issues as follows: [67]

· new service vehicles had to operate both urban center tram rails and conventional regional Deutsche Bahn (DB) rails. The service vehicles' compatibility and safety requirements should be ensured concerning European and UIC standards.
· in this project, German authorities had to complete two regulations: first one about station infrastructure and trams operation, which is "Verordnung uber den Bau und Betrieb der Strassenbahnen Strassenbahn Bau und Betriebsordnung (BOStrab)", and second one about rail infrastructure and operation regulations, which is "Eisenbahn Bau und Betriebsordnung (EBO)" .
· two different rail systems had to be integrated.
· new service had to have more stops along with both existing systems without increasing travel time because of users' preferability. [37]

Table 13 illustrates the tram-train service features (such as population, vehicle features, power supply of systems) in the Karlsruhe project.

Karlsruhe (Germany)	
Population of city	290,000 inhabitants
Population of metropolitan area	500,000 inhabitants
Year of first line activation	1992
Number of lines in operation	10
Network extension	400 km
Tramway infrastructure	existing
Regional railway infrastructure	existing
Tram network supply	750 V dc electrical power
Regional railway network supply	15 kV ac electrical power
Vehicle particularity	electric dual voltage vehicle with special wheel profile
Infrastructure particularity	raising of the check rail of the railway switches

Table 13: *Tram-train service in Karlsruhe*[80]

The vehicles of Karlsruhe tram-train are implemented by Siemens with operable either under 750V dc overhead on tramway lines or 15kV ac on regional railways. To run with a dual voltage at the same time, vehicles have a transformer and related equipment. This increases vehicle weight by about 3t. At the same time, some other vehicle type opportunities work with diesel or gas engines and entrepreneurs have more interests in other opportunities to electrification for vehicles because of some reasons such as:

· dual electrification for vehicles is a complex situation.

· the electrifying processes are difficult to non-electrified rails with non-standard 750V dc equipment

· the citizens' environmental impact perception is changed, and citizens may accept vehicles that have
low-emission and don't work with overhead traction equipment.

· existing railway sections are already operated with diesel engine vehicles.

Kassel (Germany)

The Karlsruhe tram-train service became successful. The population of city, which is 550,000 inhabitants, is very close to Karlsruhe. The main aim of Kassel tram-train project was to check the possibility of tram-train services to implement other cities and its successful rate. Therefore, Kassel was chosen to implement the tram-train service because of population, tram and regional service similarities. After implementation of Kassel, tram-train project became so successful. Table 14 shows the features of city and system. [79] [80]

Kassel (Central Germany)	
Population of city	290,000 inhabitants
Population of metropolitan area	550,000 inhabitants
Year of first line activation	1995
Number of lines in operation	4
Network extension	122 km
Tramway infrastructure	existing
Regional railway infrastructure	existing
Tram network supply	750 V dc electrical power
Regional railway network supply	15 kV ac electrical - diesel power
Vehicle particularity	electric dual voltage vehicle and hybrid (electric-diesel) with special wheel profile
Infrastructure particularity	4-rail section at the stops (different width between tram and tram-train)

Table 14*: Tram-train service in Kassel*

Saarbrucken (Germany)

After the Karlsruhe and Kassel accomplishments, German authorities decided to implement a tram-train system to Saarbrucken which is a city in the German-French border and the population of the city is about 1,000,000 inhabitants. Because of the geographical position of the city, lots of passengers use train services from Germany to France. But, the public transport of Saarbrucken had no direct rail service to the French border. After implementation, users can travel to the extra-urban area of Saarbrucken and the French border city. The first line of the network was opened in 1997 with 25 km along the German-French border. Table 15 shows the features of the Saarbrucken tram-train project. [80]

Saarbrucken (German-French Border)	
Population of city	180,000 inhabitants
Population of metropolitan area	1,000,000 inhabitants
Year of first line activation	1997
Number of lines in operation	1
Network extension	25 km
Tramway infrastructure	new railway construction
Regional railway infrastructure	existing
Tram network supply	750 V dc electrical power
Regional railway network supply	15 kV ac electrical power
Vehicle particularity	electric dual voltage vehicle with special wheel profile but very similar to railway one
Infrastructure particularity	--

Table 15*: Tram-train service in Saarbrucken*

Saint Etienne-Firminy (France)

The successful of German tram-train systems, French authorities decided to try a tram-train project for Saint Etienne-Firminy corridor in 2004 Local Transport Plan (PDU). The feasibility study was completed and showed that the tram-train project taking advantages from existing regional railway network. The project had eight new stops to add existing railway network. The study area was in central France and also influenced centre of commune Fraisses. The section included the area from Saint Etienne to Firminy (L'Hostis, Soulas, Vulturescu). Table 16 and 17 shows the tram-train projects and their comparing with respect to distances (in Table 16) and time-distances (in Table 17). [52]

	Karlsruhe	Sarrebruck	Aulnay-Bondy	Mulhouse	Saint-Etienne
Line	Karlsruhe - Bretten	Riegelsberg - SudSarreguemines	Aulnay - Bondy	Mulhouse Gare - Thann	Fraisses-Firminy-S.Etienne
Length of line	35.4 km	26 km	7.7 km	22.4 km	16.9 km
Number of stops	30	23	11	18	15
Distance between stops	min: 266m max: 5280m avr: 1221m	max: 270m min: 2930m avr: 1183m	max: 550m min: 1380m avr: 772m	max: 298m min: 4690m avr: 1316m	max: 576m min: 3150m avr: 1209m

Table 16*: Comparison of inter-station distances on five different tram-train services*

	Observed time (from timetables)	Simulated-existing (TER) rolling stock-existing stops	Simulated-tram-train rolling stock-new stops	Simulated-existing (TER) rolling stock-new stops
Running time	--	17 min	18 min	22 min
Stopping time	--	6 min	7 min	13 min
Total time	26 min	23 min	25 min	35 min

Table 17*: Comparison of inter-station time-distances on five different tram-train services*

Cagliari (Italy)

The tram-train services in Germany and France proved the tram-train systems apply to different types of cities. For this reason, Italian local authorities of Cagliari decided to implement tram-train service. But, the city of Cagliari has a lower population, which is about 157,000 inhabitants, and this could be a problem for the system. In 2008, the feasibility study was completed. The features of the Italian tram-train project are shown in Table 18. [62]

Cagliari (Sardegna Island)	
Population of city	157,000 inhabitants
Population of metropolitan area	--
Year of first line activation	2008
Number of lines in operation	1
Network extension	6.3
Tramway infrastructure	--
Regional railway infrastructure	existing adapted to light rail (gauge 950 mm)
Tram network supply	--
Regional railway network supply	750 V dc electrical power
Vehicle particularity	--
Infrastructure particularity	improper tram-train, there is no mixed circulation

Table 18: *Tram-train service in Cagliari*

Sassari (Italy)

The Cagliari tram-train service showed that lower population areas may be acceptable for tram-train service. Another city, which is in Sardegna island in Italy, has about the same population and features with Cagliari and the local authorities of Sardegna decided that tram-train service can implement to Sassari. Table 19 illustrates the tram-train project features of Sassari. [62]

Sassari (Sardegna Island)	
Year of first line activation	September 11, 2009
Country	Italy
Name of line	Alghero – Sassari / Sassari – Sorso
Population of city	150.000 inhabitants
Network extension	2.45 km
Type of route	On tram and on regional railway tracks
Stations	13
Type of Network	Regional railway – single track
Vehicle dimensions	27 m length – 2.65 m width
Vehicle capacity	max 200 passengers (51 seats)
Frequency	20 min
Energy supply	750 V dc for tram and regional train
Constraint	Metric track gauge (950 mm)
Speed	Commercial 25km/h – max 70 km/h

Table 19: *Tram-train service in Sassari (Italy)*

6. Light Rail Systems

The definition of Light Rail System (LRT), according to Union Internationale des Transports Publics (UITP), as a public transport system permanently guided at least by one rail, operated in an urban center, extra-urban area and the regional environment with self-propelled vehicles and operated segregated from the general road and pedestrian traffic. This definition has all features and processes of the continuum from a tram service (non-segregated from road ad pedestrian traffic) to a conventional metro service (fully segregated). The annual passenger number of LRT service for European countries may show the importance and preferability of light rail systems for citizens. Before the annual number of passengers, some European LRT systems are classified for comparison. According to UITP data, the total number of European light rail (LR) system is 158 out of 189 LR systems.

Former European Union (EU) member states, which is called EU15, have 108 LR systems out of 126. New EU member states, which is called NMS, have 34 LR systems out of 43 and candidate states of EU (Albania, Montenegro, North Macedonia, Serbia, Turkey), which is called B-EU27, have 16 LR systems out of 20. Therefore, the European 158 LR systems carry 8.743 billion passengers per year. The average number of annual passengers is 55.3 million per LR network. This information allows an estimating number of LR passengers, which is 10.4 billion passengers, for 189 LR networks. Table 20 shows the information (such as population, passenger number, average number) about the LRT network. [35]

	Inhabitants (million)	Annual number of passengers for 158 light rail networks (million)	Estimated annual number of passengers for all 189 LR systems (million)	Average number of trips per inhabitants
EU-15	382	4278	4920	11.2
New Member States	97	3411	4190	35.2
Beyond EU-27	107	1055	1320	12.4
TOTAL	586	8743	10430	14.9

Table 20*: Number of passengers for light rail networks (UITP)*

A conventional light rail system has some features. Because of these features, an alternative public transport mode should provide three main abilities which are the following: [54]

- vehicles run on urban streets without segregation,
- vehicles operate non-discretionally guided
- vehicles have a passenger capacity between 100 and 300

Figure 3 illustrates the cost and performance relations of different types of public transport systems.

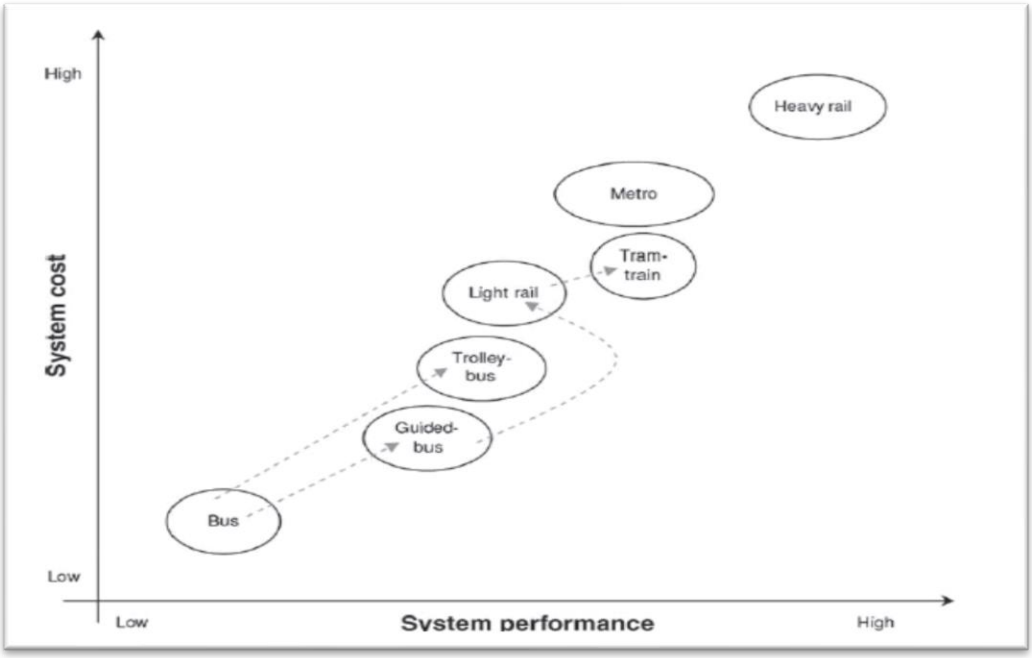


Figure 3*: Cost-Performance relationships for public transport modes*

The light rail service can be more preferable if the bus system is free of charge. Also, this may cause more competitiveness. If the system features an increase, cost increases. The system costs and economic requirements cause new developments into conventional public services. Public transport markets focus on innovative and interoperable systems such as trolley-bus, guided-bus and tram-train systems that operate with light rail vehicles (LRT). Figure 4 shows the cost-capacity-speed comparison of public transports. [85]

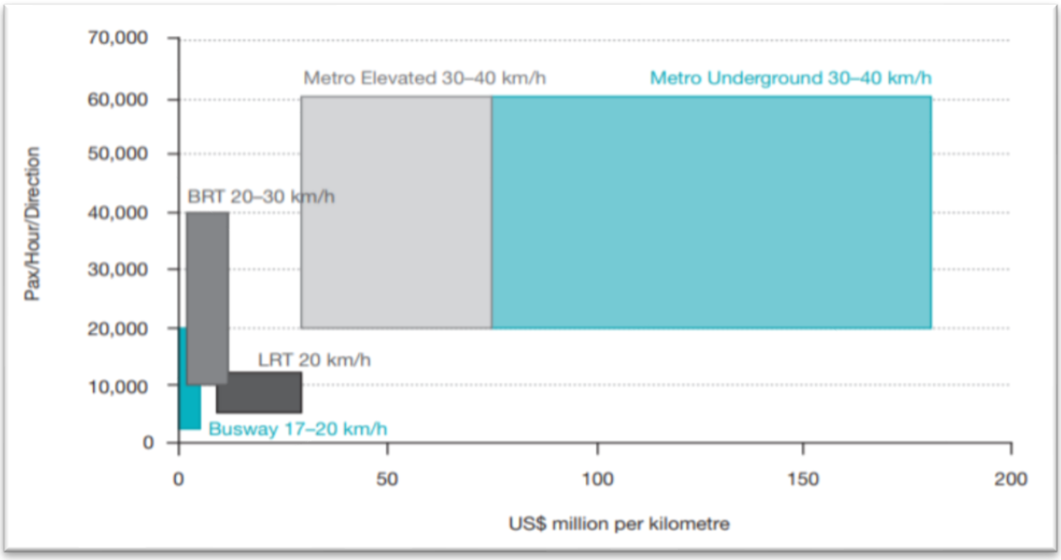


Figure 4*: Initial cost versus capacity and speed (Hidalgo 2007)*

The public services should be more sustainable and economical because European requirements settle systems should be designed for the future. Light rail systems design with less emission and high passenger volume. Table 21 illustrates the top ten light rail transit and tramway systems by ridership in the World. [35]

City	Country	Passengers per day
Hong Kong	China	617,000
Manila	Philippines	604,822
Bochum-Gelsenkirchen	Germany	392,877
Dortmund	Germany	356,164
Istanbul	Turkey	315,000
Frankfurt/Main	Germany	310,000
Essen	Germany	306,616
Kuala Lumpur	Malaysia	300,301
Calgary	Canada	276,000
Boston	United States	219,084

Table 21*: Top ten light rail and tram services by ridership (UITP)* [92]

Figure 5 shows the light rail transits around the World.

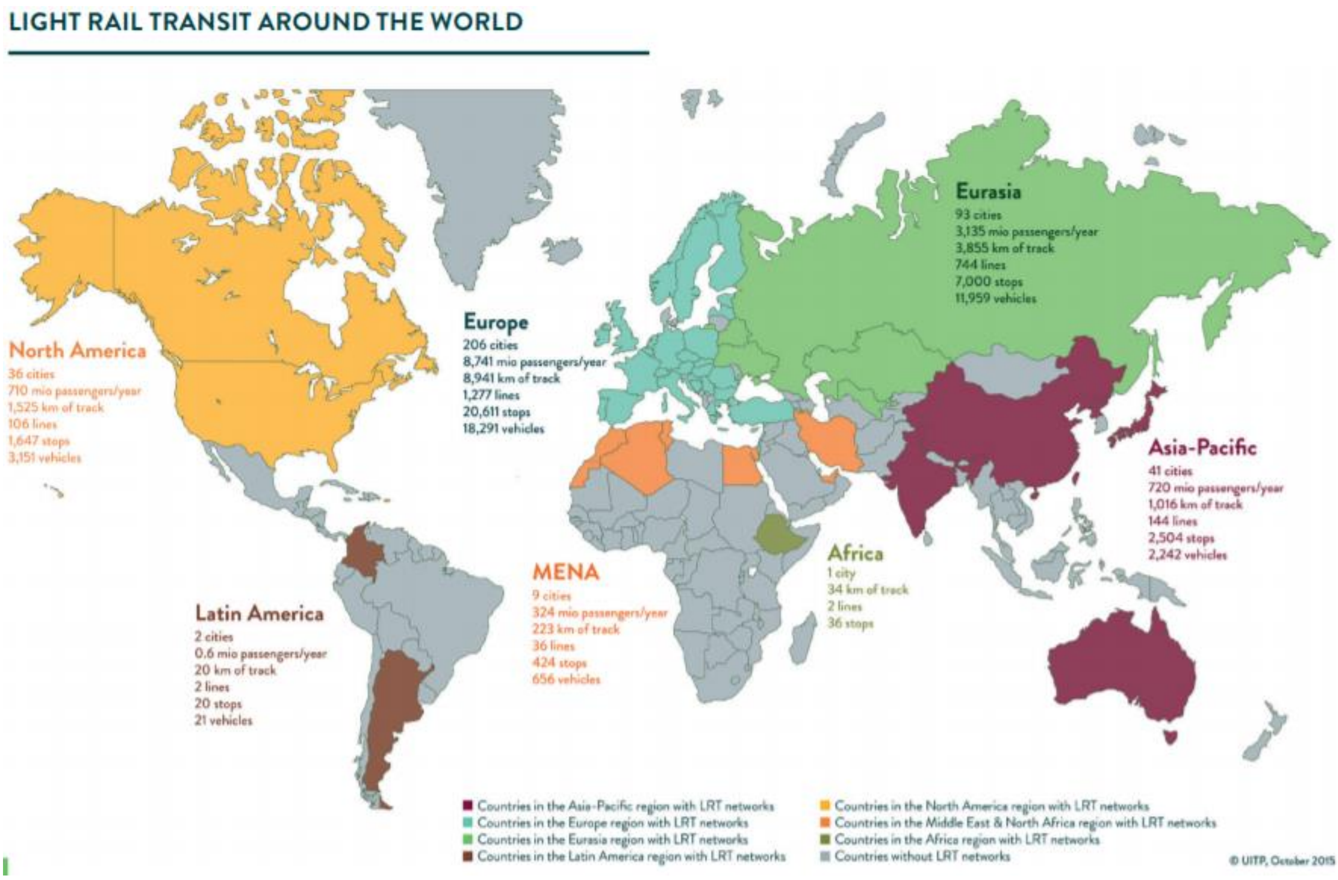


Figure 5*: Light Rail Transit (LRT) around the World*[93]

7. CargoTram Systems

The urban areas generally have traffic congestion. The distribution of urban goods may increase productivity and operational efficiency potential. At the same time, it causes higher traffic congestion, more emission (such as CO, PM, NOx), traffic accidents, noise pollution because of truck usage. Modern cities have a critical issue, which is freight transport, for their global economic situation. These cities may not exist without sustainable and efficient urban and freight transport. Urban freight transport should provide a fluent and effective flow of goods in the urban center for the future of city economies. Additively, this affects the economy positively and helps to have easier urban life for inhabitants. The fact remains that, urban freight transport also causes congestion, air pollution, emission, energy consumption and safety issues (OECD, 2003). Currently, these impacts may have become much worse because citizens prefer e-buy products, the global economy rate increases as so city economies increase, private transport may increase because of higher population and it causes more congestion, and just in time deliveries. [10]

The transport designers should find a way to reduce urban freight transport impacts without compromising economic and social activities that are happening in an urban area. Nevertheless, many European cities have no idea to solve and manage increasing urban freight transport. This requires visionary, innovative and political solutions to protect the future of urban preferability and liveability. [49]

Therefore, transport planners made a new plan to integrate urban freight transport and urban public transport. This integration generated a new service, which is called CargoTram, and this service may reduce the impacts of urban freight transport (such as emission, congestion, fossil fuel consumption, noise level, road maintenance cost). Additively, some new issues (such as new information systems, larger warehouses, standardized vehicles, flow consolidation) may help greener, sustainable and economical urban transportation and these services can manage by Urban Local Authorities. Integrated management helps more reliable, preferable, profitable and safer transportation services with more modal shifts. All of these result in improved citizens and customers satisfaction.

Some tramway infrastructures are disused, and a freight tram may exploit like a new and better opportunity. On the contrary, cargo-tram service has the same impacts and features with conventional lacking flexibility services. The cargo-tram service may compete with conventional tram services to obtain more capacity in the rail infrastructures. To recover this situation and implement door to door service, some infrastructure investments may be necessary. [5]

According to Mortimer (2008), rail in urban freight has been on the decline in favor of better-suited road transport, with regards to supply patterns, land use planning, and regulations. Rail transportation is greener, safer and at the same time, it has a lack of door to door capability, some difficult requirements to integrate with road transport, land use because of sustainability and standard regulations. Also, it has better good/volume capacity rates concerning lower energy consumption and environmental impacts and better bonding between different cities or zones inside the cities.

The current freight transport is performed by road transport vehicles (for example trucks, vans, etc.) and a little bit by intermodal services. All of these situations cause innovations and implementations. One of the new implementations for an urban freight distribution is cargo-tram, which is running on the tram railways in an urban area and at the same time passenger trams can run on the same railways, and this project may help the reduction of road freight transport. Besides, it helps a reduction of dwelling time and access time. [5]

Italian TADIRAM (Sviluppo di Tecnologie e Sistemi Avanzati per La Distribuzione e Raccolta delle Merci nella Città Sostenibile – Advanced Technologies and Innovative Tools for Freight Distribution in the Sustainable City), which was ended in 2006, is a project to research of finding operational or technological solutions and processes for the management and optimisation of freight transport processes. The cargo-tram concept is researched in this project. The TADIRAM project focused and showed a new prototype for goods assembled onto load units. After the research, the local authority of Gothenburg (Germany) has given an order new type of SIRIO Cargo-Tram (like light rail vehicles) vehicles. This vehicle has some basic features (such as a couple of capability with conventional public tram vehicle, it can run on urban streets' railways). Moreover, the tram vehicle has a part for dropping, in the middle with 350 mm from flatcar to platform. [49]

Cargo-Tram Services in Europe

The European transport business partners focus on a solution to associate economic and environmental transport services in cities. Public transport systems operate with electricity with an increasing rate of usage. After that, the transport partners focus on electricity in urban freight transport vehicles. Therefore, freight deliveries are tried to deliver by tramway services. Examples of this implementation are Dresden (Germany), Vienna (Austria) and Zurich (Switzerland). The city of Dresden operates cargo-tram service like a regular cargo service (such as Volkswagen's deliveries), cities of Vienna and Zurich operates the service for the recycling of goods. The innovations' concept is the sustainability of European transportation for the future. Table 22 shows the features of cargo-tram services in Europe.

Parameter	Cargo Tram in Europe		
	Dresden	Zurich	Vienna
Project name	CarGo Tram	Cargo Tram	GuterBim
Implementation date	2001	2003	2005
Is still functioning	Yes	Yes	No
Estimated cost of implementation	About 4.3 million €	About 32000 €	--
Routes	About 4.5 km (from warehouses to the Volkswagen's factory)	9 different routes for waste collection	Routes from 3 large logistics centers (covering the all city)
Type of composition	A five-partial, two-way	A three-partial, one-way	A two-partial, one-way
Number of cars	5	3	2
Capacity	60 t / 214 m^3	12 t / 18 m^3	13 / 40 m^3
Length	About 60 m	About 18 m	About 19 m
Width	2.2 m	2.2 m	1.5 m

Table 22*: Comparison of Cargo-Tram systems in Europe*

Dresden CarGo Tram (Germany)

The cargo-tram service in Dresden is a good implementation to be a sufficient example for freight transport by railways. The service was created by Volkswagen Company and DVB (Dresdner Verkehrsbetriebe AG). The service is a connection between Volkswagen's factory, which is called Transparent Factory and it is a Phaeton Model's production site, and the company's logistics center, which is located in Dresden-Friedrichstadt.

This "Transparent Factory" supports public participation in the production processes of Volkswagen's cars as an event. Under the condition that the "Transparent Factory" is an open working environment, the factory has to be located near the city center of Dresden (Glaserne Manufaktur, 2011, DVB, 2012). After all, this factory is not a built-in industrial zone, it is located in the urban historical center to provide a good connection for public attends. This is the reason for the factory's less stock capacity and areas. The logistic center of Volkswagen's factory has a 4 km distance to an industrial zone that has a better hinterland connection. The company decided to find a way, which is using the railway transport, for greener, easier and more economical transport its manufactory as following issues:

· because of the location of the factory, an environmental and city-friendly transport system is necessary,

· the factory and the logistics centre are in urban center and they are so close the urban tram lines, so there was no need for big investments in the transport infrastructure,

· The CarGo Tram service can operate continuous transport flow with high frequency,

· Railway transport is like a tradition in Dresden. Citizens use the tram network for transportation or the transportation of their products by railways in the last century.

The result of this is Dresden has a well-developed railway network. The CarGo Tram concept is so simple. The service has one operator, one origin, one destination, and one customer. The vehicle runs on public tram railways like a tram vehicle. At the same time, the new operation needs the only infrastructure building that is the terminus. Besides, the cargo tram vehicles and passenger tram vehicles run on same railways and this causes operational problems about timetable organization. For the solution of this confliction, the conventional (passenger) tram vehicles have priority against cargo tram vehicles. A trip from factory to logistics center takes normally fifteen minutes. The service is a loop transport because the disposal is also occurred by tram. The vehicles are loaded by curtain side trailers and this helps the whole vehicle is loaded. Before the CarGo Tram, this transport is done by three trucks. After the new service, the city has less CO_2 emission and road freight traffic in city center (data from DVB, 2012). [56]

Vienna – GuterBim Project (Austria)

The transport authorities decided to check the possibility, requirements, infrastructure improvements and possible results of freight transport by urban center's existing railways, GuterBim, in Vienna. The purpose of this project is freight transport by existing urban railway network, called Cargo-Tram service, and to switch freight transport from the road to railways. The project was started with a selected smaller route and step by step the project was implemented in tram railways of Vienna' street in August 2005. In the same year, the planners checked the possibility of operation together tram service and freight transport by railways. This project is applicable for especially high-density populated cities. The public transport operator of Vienna uses the freight transport for its own internal needs. The first applications of GuterBim project proved that the service need a feasible telematics system for further traffic applications because of ordering, logistics planning and operation management. [5]

At the beginning of project, the Austrian Ministry of Transportation, Innovation and Technology published an announcement to research and improve the project features such as low-cost solutions, sales points and stores location in Vienna, techniques for fast handling. This research is done by the Wiener Linien, Wiener Lokalbahnen (WLB), TINA Vienna Transport Strategies and Vienna Consult.

Zurich – Reverse Logistics (Switzerland)

The public tram service of Zurich had been used to deliver mail, milk, beer and other suitable type of products until 1966. After that, public tram service carries only inhabitants and remains a preferable public transport system. In 2003, local transport authorities decided to regenerate the freight transport by tram service. Zurich has a problem because of illegally bulky refuses thrown (about 300 tons in a year). The municipality had to find a way for providing a cheaper and efficient bulky refuse service. The Zurich's tramway service is quite extensive, it covers most of streets of the city. This existing and large network gave an opinion to city recycling planners (ERZ – Entsorgung und Recycling Zurich). The plan, which declares existing tram service transport the bulky refuse, was created and presented from ERZ to tram company of Zurich, which is called VBZ, and approved to put into implementation. The project purpose is switching the garbage collection from road transport to railways, cheaper service and more accessible system. The project was implemented step by step, after the pilot application, and answered the customers' expectations. After January 2005, the cargo-tram service has started to collect undesirable electrical-electronical devices. The service was saved money, about 20000€, if compare the garbage collection by road transport. [56]

The reason of this low cost is usage of existing rail network and vehicles that is produced in 1929 but they were renewed. In the beginning of the project, the frequency was four times in a month. At present, the service operates every day because of increasing usage. Citizens can throw their garbage to cargo tram from 3 pm to 7 pm every day and free of charge. The service lefts the garbage to Werdholzli terminus that is so close to ERZ location. According to VBZ and ERZ data, the service collected 785 tons of garbage in 2004 and reduced 5020 km road transport, decrease 4911.3 kg CO_2, 1.4 kg SO_2, 80.6 kg NO_x, 2.3 kg PM10, 4.2 kg VOC, 14.6 kg CO, 37500 l diesel fuel and 960 hours truck running. The cargo-tram gives a better urban life quality to citizens. So, they have a sympathy and desirousness to the service. [49]

8. Environmental Effects of Transportation Services

The transportation modes need to consume energy (such as fossil fuel, LPG, electricity, etc.) for the movements. Fossil fuels produce energy with the combustion. The combustion causes CO_2 production and many other environmental impacts (such as Nitrogen Oxides-NO, Sulphur Oxides-SO, Volatile Organic Compounds-VOC, Particulate Matters-PM, Carbon Monoxide-CO) because engines cannot do perfect combustion. These pollutants negatively affect physical and biological features of the air (mainly troposphere layer) with badly changing of health, climate and weather precipitations. The increasing private transport usage generate the greenhouse gases that are environmental impacts. These environmental impacts are limited by EU Commission by standards. EU standards state to reduce emission with different engine types from Euro 0 to Euro 6, more restrictive emissions limits. These limitations step by step reduce the amount of greenhouse gases in Europe and this obtained success proves EU standards and new innovations about engine technology (such as reduction SO_2 level in fuel, NO_x catching with catalyst engines) can protect the air quality for better urban life. New technologies in engines (such as hybrid electric vehicles with dual mode, fuel-cell powered vehicles) may provide zero-emission vehicles, with no disadvantages about performance, in the future. In Europe, member states should reduce the emission levels because of EU standards. However, other countries have big differences about greenhouse gases that are producing by transportation systems. Table 23 look to greenhouse gases that are produced by Italian transportation systems. [11]

For the providing more environmental efficiency and better energy of the railway transportation:

· more efficient steel wheels movements on steel railways,
· increase the motion regularity with separation from other transport vehicles,
· less friction losses and incidence of mass.

	SO_2		**NO_x**		**PM10**		**CO**		**VOC**		**Energy [gep/pkm]**	
	Total	Urban	Total	Urban	Total	Urban	Total	Urban	Total	Urban	Total	Urban
Private Vehicles	0.027	0.045	0.587	0.668	0.027	0.034	5.646	16.507	1.068	3.268	34.9	60.1
Buses& Coaches	0.010	0.018	0.393	0.768	0.019	0.038	0.102	0.235	0.046	0.094	10.6	18.5
Tram& Metro	0.097	0.097	0.034	0.034	0.004	0.004	0.003	0.003	0.001	0.001	11*	11*

Source: Amici della terra – ENEA (*TrenItalia)

Table 23*: Specific consumption and emissions in Italy [g/pkm]*

The public transport vehicles need the energy consumption. Therefore, these vehicles produce greenhouse gases, negatively affects to the air quality, with respect to vehicle type and long because of fuel consumption. Starting to the point of view, fuel consumption of public transport vehicle is important to cause the greenhouse gases. Table 24 illustrates the vehicle types and its passenger capacity with estimated fuel consumption per km and also new public transport vehicles that have innovative hybrid engines. [69]

Type of vehicle	Passengers transported / h per direction	Estimated consumption / km (goe/km*)	Estimated specific consumption (goe/pkm**)	Cost of vehicle €k	Cost of infrastructure €k / km
12 m bus	1500	368	24.2	310	0 – 100
18 m bus	2500	423	20.4	380	0 – 100
24 m bus	3500 – 4000	478	17.3	500	0 – 100
12 m hybrid bus	1500	294	19.3	460	0 – 100
18 m hybrid bus	2055	338	16.3	570	0 – 100
24 m hybrid bus	3500 – 4000	382	13.8	900	0 – 100
12 m trolley bus	1500	276	18.2	500	400 – 600
18 m trolley bus	2500	317	15.3	800	400 – 600
24 m trolley bus	3500 – 4000	359	13	1000	400 – 600
Tram	4000 – 6000	488	15	2000 – 3000	7000 – 10000
Underground	15000 – 30000	538	10	9000	12000 – 50000

*goe/km: grams of oil equivalent per km

**goe/pkm: grams of oil equivalent per passenger km

Table 24*: Comparison between public transport systems – passengers transported consumption and costs*

Another pollution, which results of public transport services, is noise pollution. EU standards state limitations about noise level that is the result of public services. The noise, which produces by road transportation, negatively effects the health of EU citizens. About 210 million EU citizens, over 44% of the EU population, are regularly exposed to noise produced by road transportation over 55 decibels. The World Health Organisation (WHO) declares this level recognized to pose a serious risk to health. [38]

Table 25 illustrates the comparison of the different types of vehicle comparisons according to noise and Figure 6 shows the noise pollution reduction according to EU Standards for the future. Due to the figures, abbreviates are following; [32]

EC: European Comission
ACEA: The European Automobile Manufacturers' Association
JASIC: Japan Automobile Standards Internationalization Center
German Ministry of Transport

	Step 1			Step 2		
Vehicle category	German vs. EC	ACEA vs. EC	JASIC vs. EC	German vs. EC	ACEA vs. EC	JASIC vs. EC
Cars (M1)	+2 / +4	+2 / +4	+2 / +4	+2 / +5	+2 / +5	+2 / +4
Medium Buses (M2)	-1 / +1	0 / +2	-1 / +2	-1 / +1	0 / +3	-1 / +2
Heavy Buses (M3)	+1 / +3	+1 / +3	+1 / +3	+1 / +3	+2 / +4	+1 / +3
Vans (N1)	+1 / +2	+1 / +2	+1 / +3	+1 / +2	+1 / +2	+1 / +3
Light Trucks (N2)	+1 / +3	+1 / +3	+2 / +4	+2 / +3	+2 / +4	+2 / +4
Heavy Trucks (N3)	+1 / +4	+1 / +2	0 / +3	+1 / +4	+2 / +3	0 / +3
Average	**+1.7**	**+1.8**	**+1.9**	**+2.0**	**+2.5**	**+2.0**

Table 25*: Comparison of the stringency of alternative proposals for vehicle classification*

Vehicle category	Vehicle sub-category	Limit values expressed in dB(A) [decibels(A)]					
		Step 1		Step 2		Step 3	
		Valid 1 years after publication for new type approvals (2013)		Valid 3 years after publication for new type approvals; 5 years for all vehicle sales*) (2015-2017)		Valid 8 years after publication for new type approvals; 10 years for all vehicle sales*) (2020-2022)	
		General	Off-road **)	General	Off-road **)	General	Off-road **)
M	**Vehicles used for the carriage of passengers**						
M1	no of seats ≤ 9; power-to-mass ratio ≤ 150 kW/ton	70	71***)	68	69***)	66	67***)
M1	no of seats ≤ 9; power-to-mass ratio > 150 kW/ton	71	71	69	69	67	67
M2	no of seats > 9; maximum mass ≤ 2,5 tons	72	73	70	71	68	69
M2	no of seats > 9; 2,5 tons < max. mass ≤ 3,5 tons	73	74	71	72	69	70
M2	no of seats > 9; 3,5 tons < max. mass ≤ 5 tons;	74	75	72	73	70	71
M3	no of seats > 9; maximum mass > 5 tons; rated engine power ≤ 250 kW	75	76	73	74	71	72
M3	no of seats > 9; maximum mass > 5 tons; rated engine power > 250 kW	77	79	75	77	73	75
N	**Vehicles used for the carriage of goods**						
N1	Maximum mass ≤ 2,5 tons	71	72***)	69	70***)	67	68***)
N1	2,5 tons < max. mass ≤ 3,5 tons	72	73	70	71	68	69
N2	3,5 tons < max. mass ≤ 12 tons; rated engine power ≤ 150 kW	75	76	73	74	71	72
N2	3,5 tons < max. mass ≤ 12 tons; rated engine power > 150 kW	77	79	75	77	73	75
N3****)	maximum mass > 12 tons; rated engine power ≤ 250 kW	77	78	75	76	73	74
N3****)	maximum mass > 12 tons; rated engine power > 250 kW	79	81	77	79	75	77

*Source: European Environmental Bureau and Transport & Environment [93]

Figure 6*: Proposed noise emission limit values and vehicle classification*

STUDY CASE: LANCIANO TRAM-TRAIN PROJECT

9. Information about Abruzzo Region (Italy)

Abruzzo, which is a region located in Southern Italy (showed in Figure 7), has a population of about 1.2 million citizens and area about 10,763 square km. The region has four provinces that are L'Aquila, Teramo, Pescara, and Chieti (it is showed on Figure 8). The distance between Rome and the western border of Abruzzo is about 80 km. Abruzzo has three neighborhood regions (which are the Marche region in the north, Molise region in the south-east, and Lazio region in the west and south-west) and one sea, which is the Adriatic Sea, to the east. Abruzzo has great mountain areas in the west, which includes the Gran Sasso d'Italia, and beautiful beaches (on the Adriatic Sea) in the east part of the region. According to the map of the Italian regions, the Abruzzo region may also be in central Italy concerning culture, language, economy, and history. According to ISTAT (Istituto Nazionale di Statistica), which is the Italian Statistical Authority, Abruzzo belongs to Southern Italy because of the Kingdom of Two Sicilies' history. The greenest region in Europe is the Abruzzo region since. Most of its surface are the national parks (three national and one regional parks) and protected natural zones (about 38 zones). The parks and natural zones hold lots of living species, about 75% survival in Europe, and the southernmost glacier that is called Calderone. [1][2]

Figure 7: Italian regions map

Figure 8: Provinces of Abruzzo Region

10. The Geography of the Region

The Abruzzo region has three National Parks, one Regional Park and thirty-eight natural zone and these areas under-protection because of nature. This nature reserves supports the green tourism of Abruzzo region and these number of parks and protected zones was not a simple decision because of increasing tourism, population and economic developments related to industry. Overall most of this legacy – but not all – is to be found in the mountains, where the landscapes and ecosystems change according to altitude, shifting from typically Mediterranean milieus to outright alpine scenarios, with mugo pine groves and high-altitude steppe. The lands of Abruzzo region belong to prevalently mountains nature that have over 750 meters altitude. The Apennine mountains are unique and complex systems and the tallest peaks of these mountains, which are Corno Grande (2912 m) on the Gran Sasso range; Mount Amaro (2794 m) on the Majella range; Mount Velino (2486 m), are in the Abruzzo region. [1] [2]

According to the Abruzzo Promozione Turismo, the important vast system of interior basins and highlands are the Fucino plateau, in Marsica, derived from the draining of what was the second biggest lake of Italy in 1877 and it is now one of the most special market gardening areas in Central Italy; two extensive intramountain basins – L'Aquila and Peligna, much the same many others that are smaller; a complex system of highlands, including the boundless karstic plain of Campo Imperatore, a pseudo "Tibet" in the middle of the Mediterranean, the Rocche plateau, the northern slopes of Velino and Sirente, not to mention the enormous and articulated great plateaux system known as the Altipiani Maggiori, southwest of Majella. This mighty mountain bed reaches down to just a few kilometres from the coast, with the taller peaks ranged behind like a spectacular balcony; the rest of the territory is occupied by the stalwart hills, sloping gently down to the sea. The narrow coastal strip, with the terminals of the river valleys, are the only low altitude plains in the region. This tormented territory and forceful nature, with whom it is necessary to coexist, has allowed the survival – in its multiple habitats – of a huge number of flora and fauna, configuring Abruzzo as a "green" region, the Italian treasure chest of Italian biodiversity. [1] [72]

The Apennine protects several animal and plant species from extinction, and this means Abruzzo is also a reserve of animal and plant species (such as the wolf, the Marisca brown bear). In addition to this, three animal species depend on the mountains and these species cannot survive without these mountains. Besides, the eagle, which is the lynx, the otter, which lives in the Orfento waters, the griffon that is a vulture brought to the Sirente – Velino Regional Nature Park. [1] [73]

11. The Study Area

In this study, the project is studied for Sangritana Railways which is located in the Abruzzo region. Therefore, the Ferrovia Sangritana serves the more densely inhabited coastal areas of the region. Besides, some existing lines are dismissed, and bus services serve. To the improvement of environmental situation, Sangritana aims at relaunching the existing dismissed railways in form of tram-train service. The project area covers four municipalities which are Castelfrentano, Treglio, San Vito, and Lanciano for a population of 50.000 citizens. The main attractor of this project is Lanciano because of public services. [18] [40]

The study focuses on the analysis of the tram-train project's feasibility by the comparison of tram-train service with other two transport modes which are light rail train and bike services. Figure 9 shows the study area of the project.

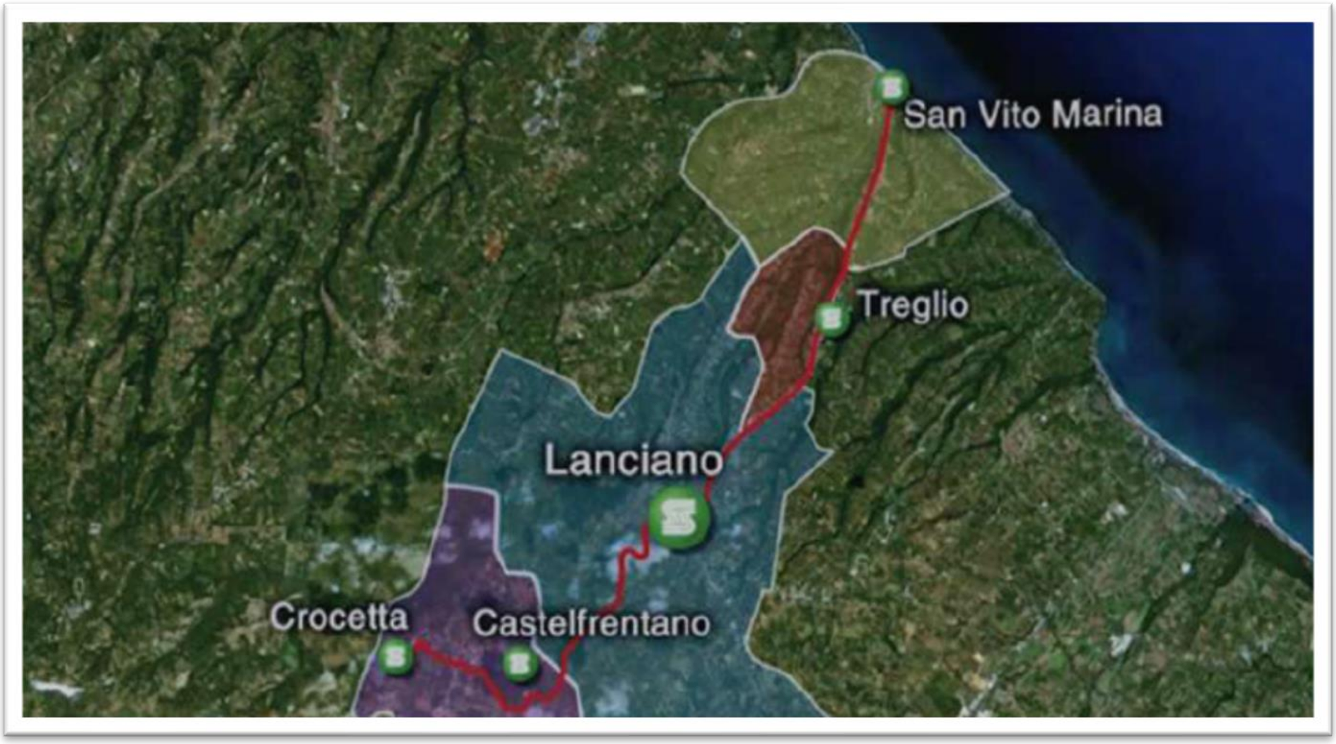


Figure 9: The study area of project

12. Railway Network of Abruzzo Region

The Abruzzo region has national railway services. However, the modernization of the railway infrastructures is necessary because of obtaining better service quality (especially Rome – Pescara line). Figure 10 illustrates the railway network of Abruzzo region on the map. The existing lines that operate in Abruzzo are following: [77]

· Adriatic railway runs through the whole of Italy from the north to the south, along the Adriatic Sea

· Train Rome – Sulmona – Pescara

· Sulmona – Carpinone

· Sulmona – Terni Railway

· Avezzano Rail-road – Roccasecca

· Giukianova – Teramo

· Sangritana (Lanciano – Castel di Sangro)

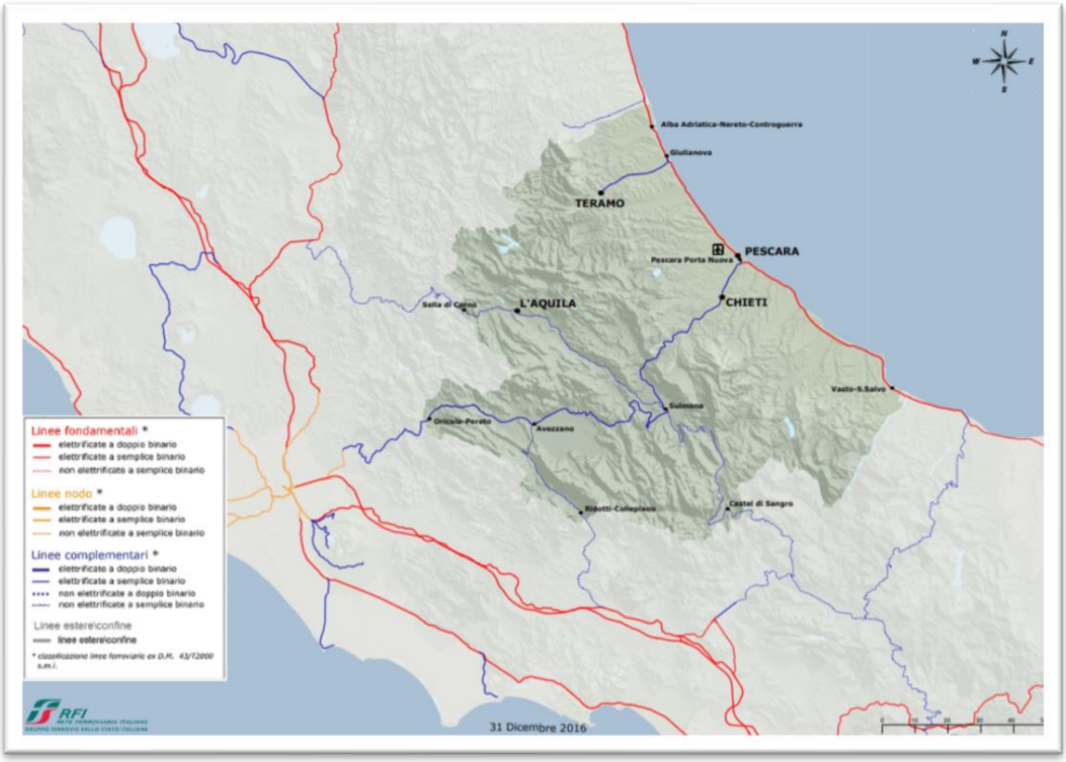


Figure 10: *Abruzzo region railway network (Rete Ferroviaria Italiana)*

According to the data of RFI (Rete Ferroviaria Italiana), which means Italian Railways, Table 26 shows the long of the existing railway infrastructures. The data shows the information of railways until 31/12/2018.

Operational Railway Lines	524 km
Classification	
Fundamental lines	123 km
Complementary lines	401 km
Typology	
Double track lines	123 km
Simple track line	401 km
Power supply	
Electrified lines – Double track lines	123 km
Electrified lines – Simple track line	195 km
Non-Electrified (diesel)	206 km
Overall length of the tracks	648 km
Conventional line	648 km
Innovative train gear protection technologies	
Traffic remote control systems	336 km
SCMT, for controlling train travel	318 km
SSC, for driving support	206 km

Table 26*: Railway lines – RFI*

13. Supply Services of the Abruzzo Region

According to the current public transport service, extra-urban road transport services operate, manage and plan by together local authorities of the region and transport operators. The public transport service lines are assigned by regional authorities to the provincial authorities based on routes, frequency and capacity. Table 27 illustrates the public transport services of provinces of Abruzzo region with respect to service distances.

Province	Service distances – suburban and extra-urban contributions [bus*km]	Service distances extra-urban non contributions [bus*km]	Subtotal service distances – suburban and extra-urban [bus*km]	Replacement service distance for rail services [bus*km]	Total distances [bus*km]
L'Aquila	10.635.815	975.740	11.611.556	8.526	11.620.082
Teramo	7.880.668	517.114	8.397.782	--	8.397.782
Pescara	5.023.028	533.715	5.556.744	--	5.556.744
Chieti	14.133.622	856.478	14.990.100	436.789	15.426.889
Region	**37.673.133**	**2.883.048**	**40.556.182**	**445.314**	**41.001.496**

Table 27: Current annual distances by public transport services (suburban, extra-urban and replacement of railway services – contract of 2005-2006)

The public transport services of Chieti province supply 14.990.100 buses*km per year (contract 2005-5006), which the part of 856.478 bus*km per year is intercity lines, currently not contributed. Addition to this, the total public transport service of Chieti province run 15.426.889 buses*km that include the part of 143.789 bus*km per year that runs by regional railway services. [40] [41]

14. Demand of in the Study Area

According to the ISTAT (Istituto Nazionale di Statistica – Italian National Statistical Institute) data, the population of the municipalities in the case study area, further described, is reported in Table 28, which shows the situation in 2011, and Table 29, which shows the population in 2018, with respect to age ranges. [44] [45] [46]

Province code	Municipality code	Municipality name	**Total population**	Population 0-13 ages	Population 14-25 ages	Population 26-65 ages	Population greater 65
26	25	Crocetta del Montenello	**6090**	786	706	3433	1165
69	18	Castel Frentano	**4305**	554	460	2345	946
69	46	Lanciano	**36304**	4343	4387	20122	7452
69	86	San Vito Marina (Chietino)	**5321**	648	635	2874	1164
69	96	Treglio	**1610**	239	203	914	254
Total			**53630**	6570	6391	29688	10981

Table 28*: The population of the study area in 2011* [44]

Province code	Municipality code	Municipality name	**Total population**	Population 0-13 ages	Population 14-25 ages	Population 26-65 ages	Population greater 65
26	25	Crocetta del Montenello	**6106**	826	688	3259	1333
69	18	Castel Frentano	**4385**	586	450	2403	946
69	46	Lanciano	**35002**	4033	3941	18868	8160
69	86	San Vito Marina (Chietino)	**5270**	611	593	2901	1165
69	96	Treglio	**1669**	234	218	918	299
Total			**52432**	6290	5890	28349	11903

Table 29*: The population of the study area in 2018* [46]

After the population of region's provinces, the demand of provinces was estimated by the data, which is obtained from the Pendolorismo 2011 survey by ISTAT. According to the data, following tables show the local demands with respect to purposes which are studying or working. For the study purpose, more chosen school centers are Chieti, Lanciano and Vasto provinces. The journeys of studying purpose are shown on Table 30 (journeys to Chieti province), Table 31 (journeys to Lanciano province), and Table 32 (which journeys to Vasto province) according to the project's municipalities which are Crocetta del Montenello, Castel Frentano, Lanciano, San Vito Marina (Chietino) and Treglio. [47]

Start from			**To**			
Province code	Municipality code	Municipality name	Province code	Municipality code	Municipality name	Number of users
026	025	Crocetta del Montenello	069	022	Chieti	271
069	018	Castel Frentano	069	022	Chieti	62
069	046	Lanciano	069	022	Chieti	327
069	086	San Vito Marina (Chietino)	069	022	Chieti	61
069	096	Treglio	069	022	Chieti	14
Total number of users						735

Table 30: Number of users who travel to Chieti area for studying (daily)

Start from			**To**			
Province code	Municipality code	Municipality name	Province code	Municipality code	Municipality name	Number of users
026	025	Crocetta del Montenello	069	046	Lanciano	86
069	018	Castel Frentano	069	046	Lanciano	205
069	046	Lanciano	069	046	Lanciano	3665
069	086	San Vito Marina (Chietino)	069	046	Lanciano	462
069	096	Treglio	069	046	Lanciano	375
Total number of users						4793

Table 31: Number of users who travel to Lanciano area for studying (daily)

Start from			To			
Province code	Municipality code	Municipality name	Province code	Municipality code	Municipality name	Number of users
026	025	Crocetta del Montenello	069	099	Vasto	11
069	018	Castel Frentano	069	099	Vasto	7
069	046	Lanciano	069	099	Vasto	72
069	086	San Vito Marina (Chietino)	069	099	Vasto	6
069	096	Treglio	069	099	Vasto	2
Total number of users						98

Table 32: Number of users who travel to Vasto area for studying (daily)

After these tables, another main purpose to create a journey is working. The main working places are industrial zones which are called Atessa and San Salvo industrial areas. The following tables, which are Table 33 (journeys to Atessa) and Table 34 (journeys to San Salvo), show the journeys of working purposes according to the project's municipalities which are Crocetta del Montenello, Castel Frentano, Lanciano, San Vito Marina (Chietino) and Treglio.

Start from			To			
Province code	Municipality code	Municipality name	Province code	Municipality code	Municipality name	Number of users
026	025	Crocetta del Montenello	069	005	Atessa	3
069	018	Castel Frentano	069	005	Atessa	353
069	046	Lanciano	069	005	Atessa	1647
069	086	San Vito Marina (Chietino)	069	005	Atessa	259
069	096	Treglio	069	005	Atessa	83
Total number of users						2345

Table 33: Number of users who have journeys to Atessa industrial zone for working (daily)

Start from			To			
Province code	Municipality code	Municipality name	Province code	Municipality code	Municipality name	Number of users
026	025	Crocetta del Montenello	069	083	San Salvo	5
069	018	Castel Frentano	069	083	San Salvo	9
069	046	Lanciano	069	083	San Salvo	38
069	086	San Vito Marina (Chietino)	069	083	San Salvo	11
069	096	Treglio	069	083	San Salvo	2
Total number of users						65

Table 34: Number of users who have journeys to San Salvo industrial zone for working (daily)

15. Public Transport Patterns in the Study Area [75]

The Overall Applications and Potential Directives

To better understanding the which routes need more potential demand of integrated rubber-rail transport mode section, both in terms of integration between different TPL (Trasporto Pubblico Locale – Local Public Transport) modes and service frequency, were described by two OD (origin-destination) matrixes depend on public transport service (TPL_Esp) and private transport service (TPR_Esp) that these two services currently run on existing transport network by transport operators. These two matrixes related only to inter-municipal, systematic and non-systematic journeys, time period from 7:00 am to 11:00 am of an ordinary weekday. Figure 11 shows the results of these two assignments to remark the inter-municipal mobility needs that characterize the province of Chieti. [18] [40] [41]

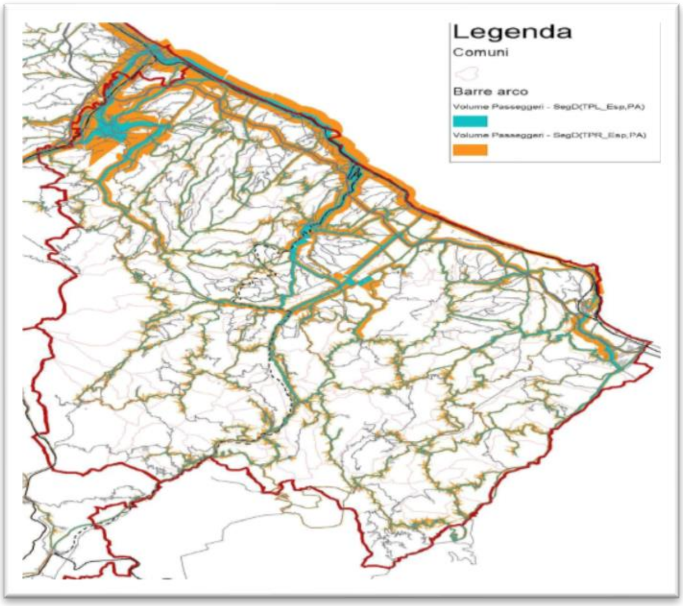


Figure 11: *Assignment flow chart for transport network*

According to Figure 11, supra-communal movements or inter-municipal journeys in the province of Chieti, the possible highest traffic volume of public transport service is distributed concerning decreasing order; [40] [41]

· On the Chieti-Pescara road report

· On the Adriatic railway service, in this part, traffic volumes decrease from Pescara province with two sharp parts at the intersections of the Lanciano-San Vito Chetino line and the Fossacesia-Torino line

· The Lanciano-San Vito Chetino railway service and subsequently to the Adriatic line

· The A14 highway, traffic volume decreases from Chieti province to the Casalbordino tollbooth, however, the rail service traffic present variations more than A14 highway traffic

· On the road service leading to the Val di Sangro industrial zone from Lanciano, Casoli, Attesa provinces and Val di Sangro's exit on the A14 highway

· Along with the state road service of Fondo Valle Alento between Guardiagrele and Via Ripa Teatina (a street in Chieti province) with progressive approaching to the provincial center

· The report of S. Salvo-Vasto and its continuation from SS16 to the Casalbordino tollbooth

· The state road service between Lanciano province and Fossacesia with progressive increase traffic flow on Lanciano province

· Along the Sangro sea-level

· Between Gissi and the bipole Vasto-S.Salvo, passing through Monteodorisio and Capello zones

· Along with the provincial road service between Chieti and Tollo

· Between Francavilla and Chieti province with along the SS152 dei Frentani section

· The state road service of Val di Foro and Bocca di Valle section, between Miglianico and the coast

Figure 12 illustrates the Chieti transport network concerning the results of the assignments by the transport system.

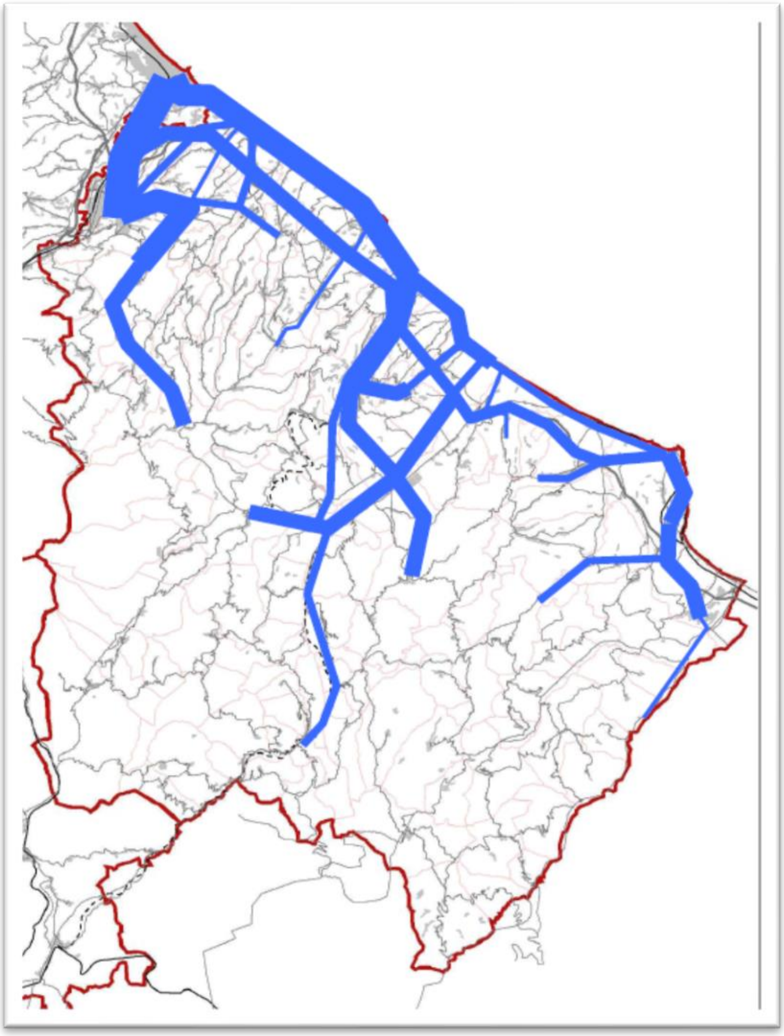


Figure 12*: The transport network of Chieti starting from the results of the assignments*

The Pubic Transport Types

a. School Service

The experimental works, which were done by students of higher educational institutions, for replacement the school service systems, which have been designed to analyse possible new and efficient routes, and improve the current offering of public transport service times of accessibility with respect to frequency, on the other hand the more efficiency for public network lines, is done by Osservatorio delle Istituzioni Scolastiche della Provincia (especially school service network in this part). The results of this study are shown in Figure 13. [40] [41]

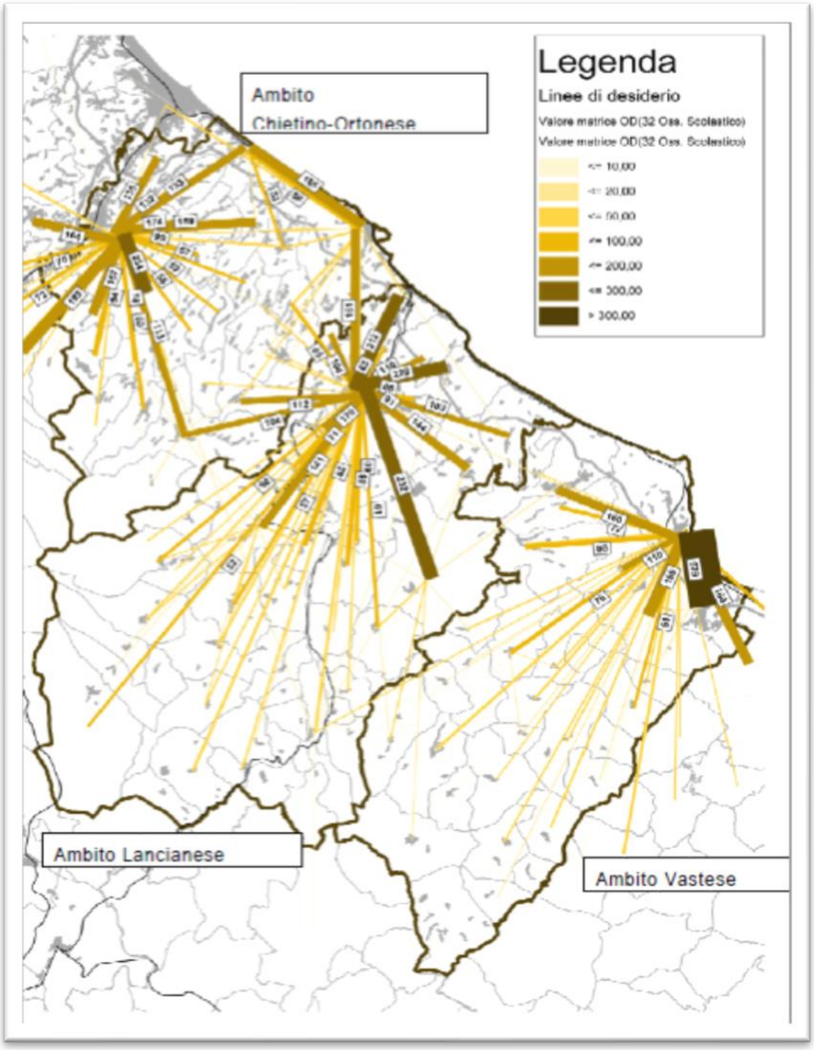


Figure 13*: The lines of inter-municipal journeys to purpose of study in 2004-2005*

According to the data of Figure 13, the journey cones have been designed by taking into consideration of the following criteria:

▪ from each part of provincial zones, a pair of school types were described that related with the reference educational pole within the zone to which the fraction belongs (Chieti province for the circumambient of Area A / B Lanciano province for the fractions of Area C, and Vasto province for the fractions of Area D). However, some municipalities were not included; [47]

· Some places, which are Guardiagrele – Orsogna – Arielli – Poggiofiorito and Crecchio, belong to both Chieti Area A / B and Lanciano province or only belong to only Lanciano province (source is School Institutions Observatory of the Province of Chieti – 2004/2005).

· Castiglion Messer Marino belongs to Area D of Vasto province and Agnone in the Molise at the same time (source is ISTAT – 2001).

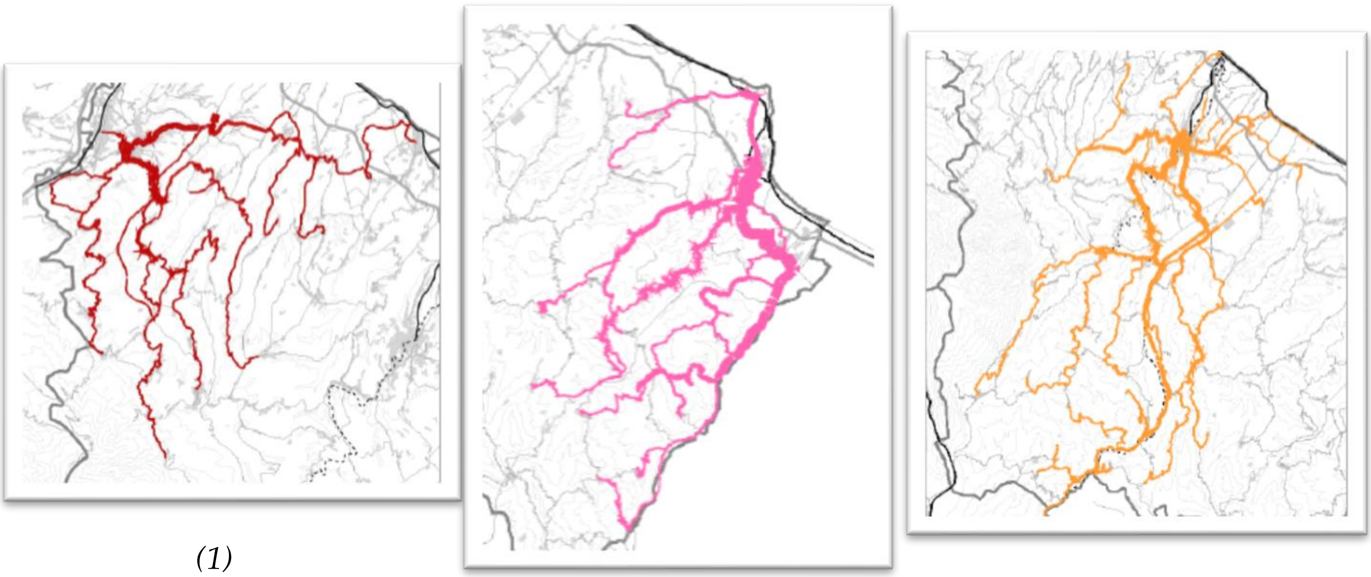
▪ other school centers, which are Francavilla – Ortono – Guardiagrele – Casoli – Atessa – Villa Santa Maria – Casalbordino – Scerni – Gissi and San Salvo, were described pairs of school types by the fractions that investigate the given conditions:

· According to the School Institutions Observatory of the Province of Chieti, data collected in 2004-2005 the study represents the students who greater than 10

· Provide less access time to school centers if compared the any of the other main school centers

▪ for all cases, school services are designed to arrive at the institutes at 7:55 am and departure from the institute at 14:05.

Figure 14 illustrates the possible school service routes with respect to the main or secondary school poles.



(1)

(3)

(2)

Figure 14: School lines toward the Chieti (1), Lanciano (2), and Vasto (3) provinces

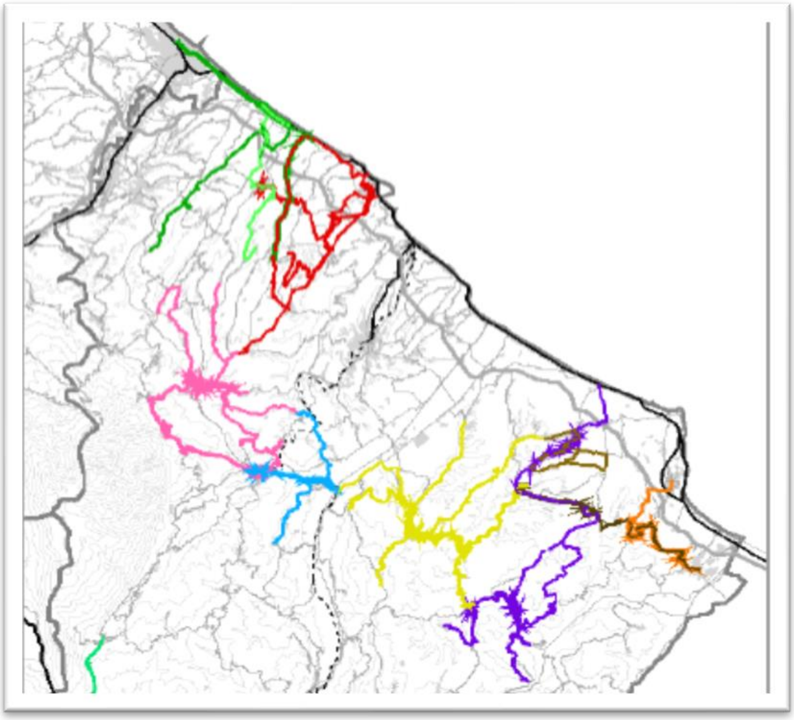


Figure 15*: School lines of the smaller poles*

b. Work Services

After the experimental studies, for improvements of public transport services, the workers' journeys (to the industrial poles of Atessa and S. Salvo) have been designed related to given criteria:

· the worker public transport lines run to industrial poles by local authorities (municipalities) with several journeys is greater than 30 (source is ISTAT in 2001)

· other municipalities of the province, the connection between central zones and industrial poles supply with interchanging with other network lines of the provincial public transport service

· for both industrial centers, the travel times are designed such as arrivals and departure times of beginning and end of the working hours that are 06:00-14:00, 14:00-20:00 and 20:00-06:00.

Figure 16 shows the transport network for working purposes related to Atessa industrial zone. Also, it illustrates the relations of industrial zones and central housing areas with a number of trips greater than 30 trips. [40] [41]

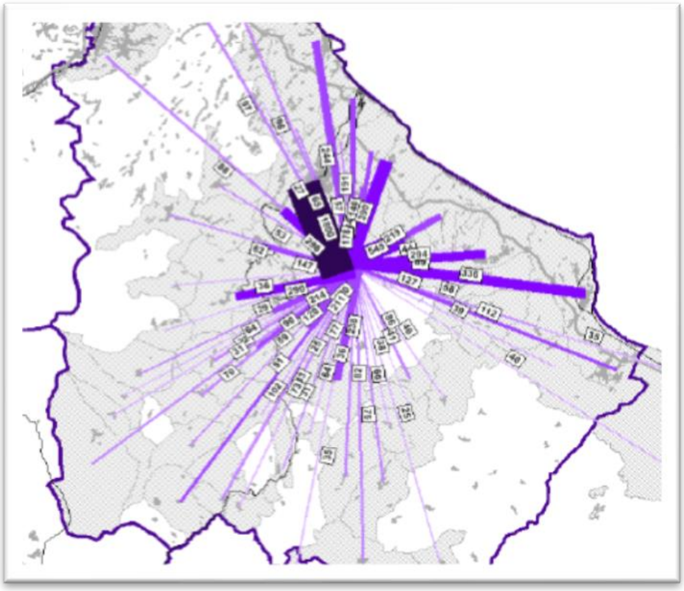


Figure 16*: Travels to the industrial zone of Atessa in 2001 (ISTAT)*

The possible public transport service lines for working purposes to the Atessa industrial zone are shown on the following figure that is Figure 17.

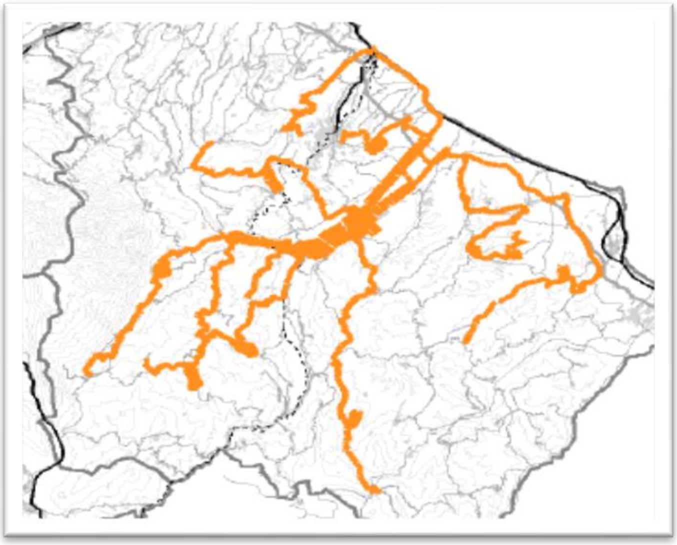
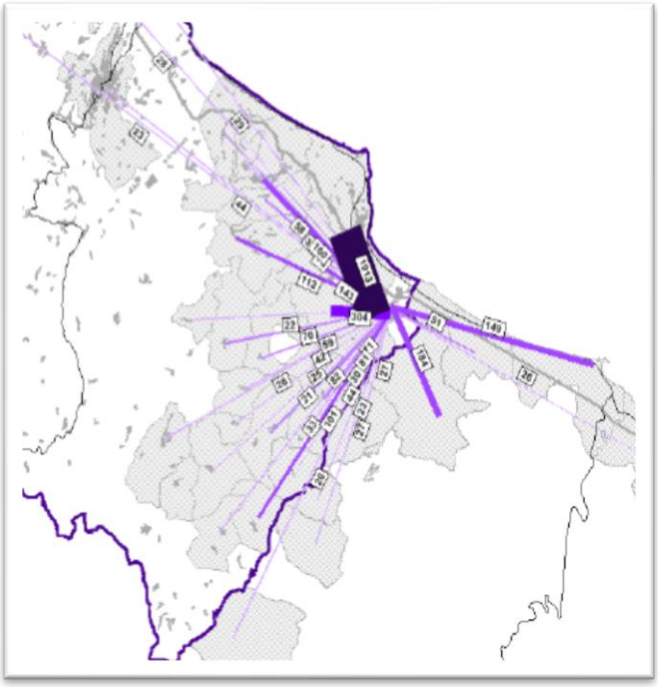


Figure 17*: Public transport supply lines to Atessa industrial zone*

After the public transport service to the Atessa industrial zone, San Salvo industrial zone is the second main center in the Chieti province in the Abruzzo region. The following figure, which is Figure 18, illustrates the public transport service travel directions, which have several trips greater than 30, arrivals and departures to San Salvo industrial zone (data from ISTAT in 2001). After Figure 18, another one, which is Figure 19 shows the public transport network lines to the San Salvo industrial zone. [47]



(Figure 18) (Figure19)

Figure 18: Travels to the industrial zone of San Salvo in 2001 (ISTAT)

Figure 19: Public transport supply lines to Atessa industrial zone (TUA)

16. The Environmental Situation of Abruzzo Region

As said, Abruzzo is the greenest region in the European Union. Therefore, the environment and sustainability of the region's transport services are so meaningful and important. The environmental issue about transport networks related to emission and noise level. The main problem of is that emissions affect the air quality. The highest pollutants, which are PM10, CO, C6H6, SO2, and NO2 are chosen to represent air pollution or quality level. The following Table 35 shows the limitation of air pollutant materials according to the EU Standards. [4] [31]

	Limit values	Allowable number of days to exceed the limitations
SO_2 (average of 24h)	125 µg / m^3	3 days per year
PM10 (average of 24h)	50 µg / m^3	35 days per year
PM2.5 (average of a year)	25 µg / m^3	--
CO (average of 8h)	10.000 µg / m^3	--
NO_2 (hourly average)	200 µg / m^3	18 days per year

Table 35*: The limitations of impact materials for environment with respect to EU Standards*

After the limit values of air pollutant materials, the following Table 36 illustrates the relationship between pollutant material, its possible effects on public health and the sources of pollutant materials.

Pollutant	**The source**	**Affects**
SO_2 (Sulfur dioxide)	Fossil fuel combustion, vehicle emissions	Respiratory tract infection, acid rains
NO_x (Nitrogen oxides)	Vehicle emissions, high temperature combustion processes	Eyes and respiratory diseases, acid rains
PM (Particulate Matter)	Industrial and vehicle emissions, fossil fuel combustion, agrucultural and secondary chemical reactions	Cancer, hearth diseases, respiratory diseases, increasing of baby deaths
CO (Carbon monoxide)	Incomplete combustion products, vehicle emissions	Decreasing the oxygen carrying capacity by combining with hemoglobin in blood, deaths
O_3 (ozone)	Combination of nitrogen oxides and volatile organic compounds (VOC) with traffic	Respiratory system diseases, eye and nose irritation, asthma, decreasing of body resistance

Table 36*: Pollutant materials and their effects*

The following Figure 20 shows the distribution of deaths due to outdoor air pollution according to the diseases in 2012 (source is WHO – World Health Organization). The diseases and number of deaths are given:

Ischemic hearth disease: 1.505.000

Acute lower respiratory diseases: 127.000

Chronic obstructive pulmonary disease: 339.000

Lung Cancer: 227.000

Stroke: 1.485.000

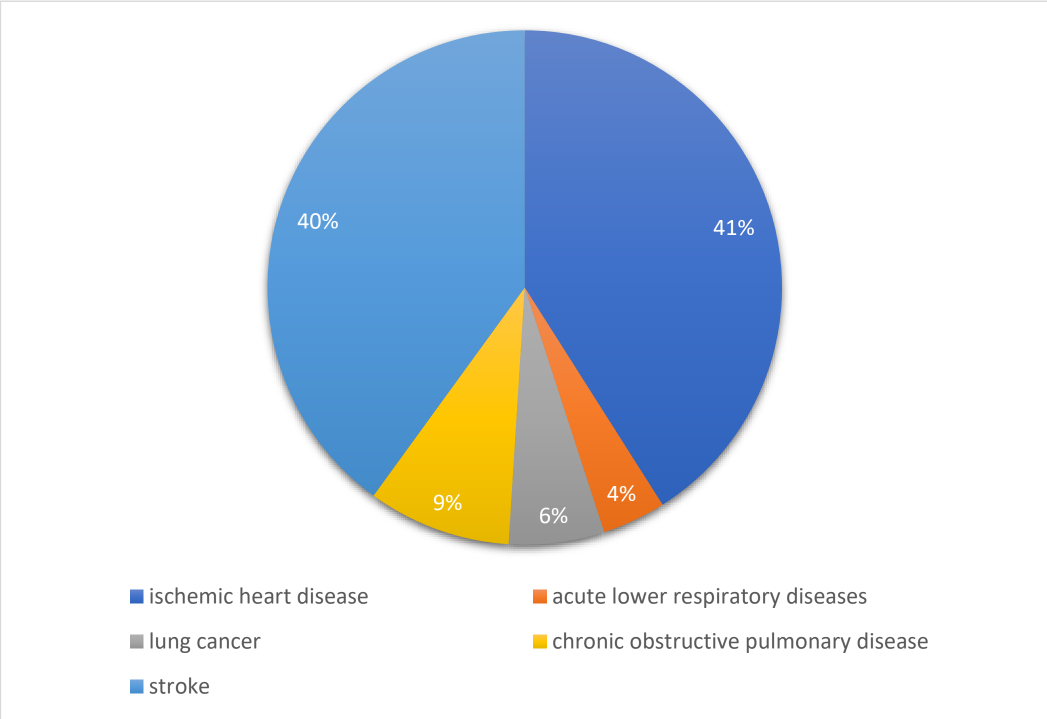


Figure 20: *The distribution of deaths due to air pollution*

After the general information about pollutant materials' limit, pollutant materials, which are PM10 – CO and C_6H_6, of the Abruzzo region are given on following figures: [4][14]

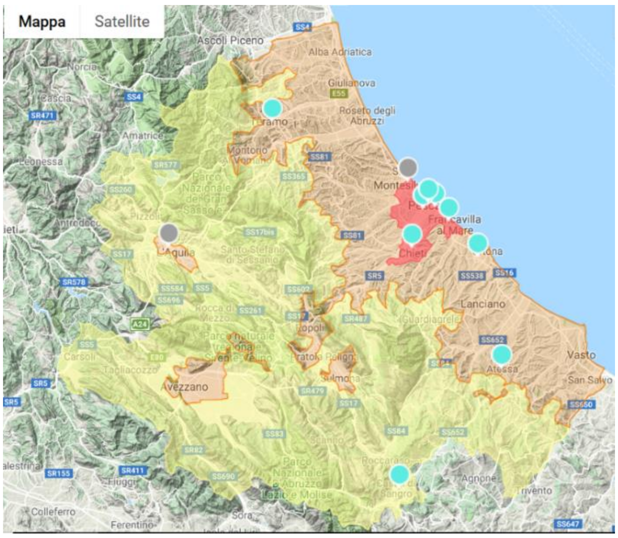


Figure 21: *average PM10 value in Abruzzo region*

Not available	n.d.	µg / m³
Good	0 – 20	µg / m³
Acceptable	31 – 35	µg / m³
Moderate	36 – 50	µg / m³
Poor	51 – 100	µg / m³
Very Poor	>100	µg / m³

24h limit for the protection of human health (average): 50 µg / m³

Annual limit for the protection of human health (average): 40µg/m³

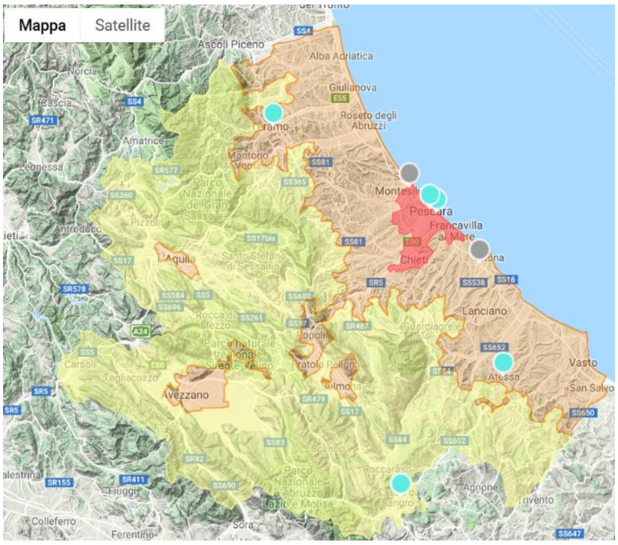


Figure 22: *average CO value in Abruzzo region*

Not available	n.d.	mg / m³
Good	0 – 4	mg / m³
Acceptable	5 – 7	mg / m³
Moderate	8 – 10	mg / m³
Poor	11 – 20	mg / m³
Very Poor	>20	mg / m³

Limit for the protection of human health (daily maximum of the mobile average): 10 mg / m³

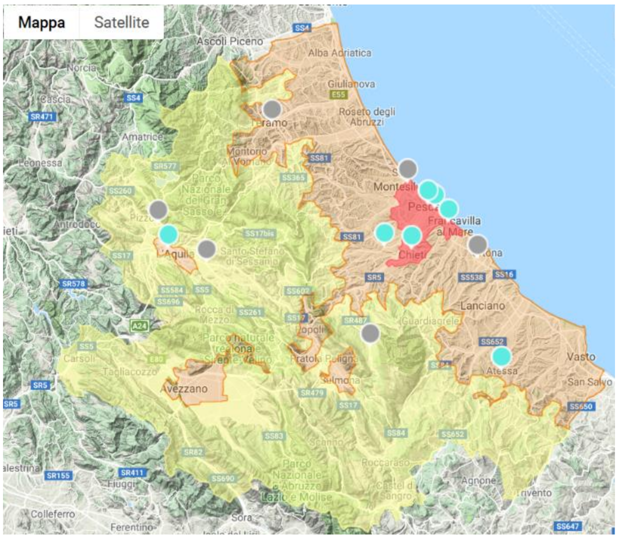


Figure 23: *average C6H6 value in Abruzzo region*

Not available	n.d.	µg / m³
Good	0 – 0.5	µg / m³
Acceptable	0.6 – 1.0	µg / m³
Moderate	1.1 – 2.0	µg / m³
Poor	2.1 – 5.0	µg / m³
Very Poor	>5.0	µg / m³

Annual limit for the protection of human health (average): 5.0 mg / m³

Table 37 shows the average values of pollutant materials in project zone. The observation stations are called Atessa and Villa Calvari stations because they are the nearest stations to the project zone.

Name of observation station	PM10 [µg / m³]	CO [mg / m³]	C6H6 [µg / m³]
Atessa	15.85	20.918	1.13985
Villa Caldari	21.13*	19.494	0.45053
Average	**18.49**	**20.206**	**0.79519**

Table 37: The average pollutant materials of project zone in 2017 (data from RSA – Regione Statistica Abruzzo and ArtaAbruzzo) (* data from Scuola Antonelli station)

THE ASSESSMENT APPROACH

The study focusses on the evaluation of the feasibility of the tram-train transport mode, by comparing the other transport modes which are light rail train and bike services. Ferrovia Sangritana is the local operator of the Abruzzo region's railway network. Abruzzo region has less densely populated areas and railways serve along the coastal part of the region. The operator, Sangritana, aims to re-operate the dismissed existing railway networks via tram-train systems in four municipalities, which are are Castelfrentano, Treglio, San Vito, and Lanciano, of the region.

Besides, the study will provide a comprehensive assessment for the tram-train project with it is going to perform a multi-criteria analysis of transport modes (that are tram-train, light rail train, and bike service), since this enables to include a number of parameters (that are environmental situation, social reactions, operational issue, and economic situation) fit to describe the prospective implementation of the tram-train service.

17. Multicriteria Analysis Techniques

Information about Multicriteria Analysis (MCA)

The techniques are extensively acknowledged as multicriteria analysis methods, they include significant approaches (on the contrary to Cost-Benefit Analysis – CBA, which has more united techniques). The MCA (Multicriteria Analysis) methods cannot provide enough decision, however, some of them provide considerable solutions. The MCA methods require the comparison of opportunities and show the options contributions related to different criteria. At the same time, methods may vary each other because of their combination type of data. The MCA methods procure a relative weighting concerning different criteria for all options. The main purpose of the MCA methods is helping to the decision-makers to find better options and comparisons of different options with consistency. [60]

The multi-criteria analysis' methods describe the most preferable option and to rank all options to obtain the better one, to make a list with a limited number of options for detailed evaluation, and to discriminate the acceptable options from unacceptable opportunities. After the controlling of the literature about MCA methods, easy to understand that there are many methods and the number of methods is still increasing because of some reasons that are the following: [95]

· there are many different types of decision which proper the conditions of MCA
· the time is convenient to assume the multicriteria analysis may change
· the number or feature of data is convenient to assist the variety of analysis
· the analytical features of methods assist the decision may change
· the requirements of local authorities and organizations may change

However, all methods of MCA cannot be controlled or checked in deeply, and it is not necessary. Some of them for the unsolved problems or situations of local authorities, some of them are so complex and others have a lack of theoretical foundations.

The MCA has some types of methods for comparison of options. The selection of method depends on the following criteria: [59]

- · internal consistency and logical soundness
- · transparency
- · ease of use
- · data requirements not inconsistent with the importance of the issue being considered
- · realistic time and manpower resource requirements for the analysis process
- · ability to provide an audit trail, and
- · software availability, where needed.

Key features of Multicriteria Analysis (MCA)

The MCA defines acceptable preferences to specify how much the results of the analysis close to the target, which is defined by decision-makers, related to measurable criteria. In ordinary circumstances, the process of a description of analysis' objectives and criteria may give enough results to the decision-makers. However, where the decision-makers require more detail like cost-benefit analysis (CBA) is needed, MCA supplies several numbers of ways to collect the data of options' performances with indicators. A key feature of the multicriteria analysis is that providing the data for decision-makers to help for a decision, specifying of criteria and targets, evaluation of relative importance weights, and description of the addition of each option to each performance criterion. This is more widespread because of subjectivity worries.

In principle, the decision-makers have an idea about targets, criteria, weights, choices of objectives, and evaluation of success the objectives, in the meantime, they may also count in the objective data. At the same time, MCA may describe or clarify the analysis, level of structure, and openness to the practical reach of the CBA.

The one restriction of MCA is that the analysis doesn't describe an action has more features or contributions. According to MCA methods, variously CBA methods, evaluates the best option without improving the economic situation. Therefore, doing nothing may be preferable. [95]

Advantages of MCA related to informal knowledge

The MCA has many benefits, which over informal knowledge and they are not evaluated by analysis, and they are given the following: [59]

· open and explicit

· decision-makers may change or analyse the choice of objectives and criteria if changing or analysing are necessary

· according to the methods, scores and weights are explicit and developed. Therefore, they may also give the cross-references to other data sources related to relative values, and it may be fixed if it is necessary.

· decision-makers don't have to measure the performances. The sub-contractors may evaluate them. Performance measurement doesn't depend on decision-makers' evaluations.

· MCA may help for creation of an important relationship between decision-makers and the community

· scores and weights are required to use, and they provide an audit trail

The Performance Matrix

The main feature of the multicriteria analysis is that having a performance matrix in which each row determines an option and each column determines the performance of the options against each criterion. Generally, the performance evaluations are mostly numerical, however, may be denoted as "bullet point" scores, or colour codes. Table 38 shows an example of a simple performance matrix. [95]

Options	Product price	Re-heating feature	Warming rack	Configurable slot gauge	Equality of toasting	Number of handicaps
Company A	21 €				☺	4
Company B	30 €	++	++	++	☺	3
Company C	28 €	++	++		☻	4
Company D	25 €				☺	3
Company E	24 €	++			☻	2
Company F	33 €				☺	3
Company G	23 €	++		++	☻	5

"++" represents the presence of feature. Equality of toasting is evaluated with smiling face, which solid-face (☻) represents the best toaster and an open-face (☺) represents the next best. The family didn't choose the toasters which are scored less than the best or the next best

Table 38*: An example of MCA performance matrix*

The table describes several various of example's performance concerning some criteria related to decisions of households' choices between different toaster types. The chosen indicators of performance evaluation criteria per option are product price, the existence of the re-heating feature, warming rack, configurable slot gauge, equality of toasting, and several possible handicaps. Furthermore, some of the evaluated criteria have values in cardinal numbers (which are product price and several handicaps), some of them in binary terms, which means a determination of certain features, and one of them, which is equality of toasting, is in qualitative form.

The performance matrix may be the last output of the multicriteria analysis when a basic MCA method is used. Besides, the decision-makers don't have to control which objectives are met under targets by the inputs of the performance matrix. Sometimes, this type of non-rational data processing may be faster and effective, however, it is possible to be a reason for undeserved assumptions with causing incorrect ranking of options. The data of basic matrix is transformed into compatible numerical values when more complicated analytical MCA methods are implemented.

Scoring and Weighting

The MCA methods supply a numerical analysis to the performance matrix with two steps which are: [95]

- Scoring, the expected results of each option are determined a numerical value, which is also called the score, on a preference scale for each option related to criteria. If the option is more preferred, it takes a higher score value. On the other hand, less preferred options have lower score values. Mostly, the preference scales have values between the range from 0 to 100, where 0 (zero) shows the least preferred option and 100 shows hypothetical the most preferred one, in implementations.
- Weighting, numerical weights' values are determined to represent the relative assessments of a slide between the top and bottom of the preferred scale.

Mathematical equations/processes, which are running by computer programs, provide a combination of these two steps, which are scoring and weighting, to obtain the general evaluation of each option. Therefore, these programs need to take the best proper input data, which may provide by individuals, and computers are handling consistent detailed information that using inputs that have been obtained by human sources. These types of approaches are described as compensative MCA methods because a lower score on one criterion may recuperate by a higher score on another. The main way to obtain the combination between criteria scores and relevant criteria weights is the calculation of a simple weighted average of scores. Besides, weighted averages using depends on the assumption of mutual independence of preferences. In other words, the evaluation of preference for an option concerning one criterion is independent of the evaluation of preference on another. [95]

The Weighted Summation Approach

Assuming that a set of n criteria (c_1, .., c_n) is given, an evaluation matrix with the results (e_{11}, e_{12}, ..., e_{1m}) for each scenario (S_1, …., Sm) against these criteria has to be assembled. In the weighted summation method, these performance results are then transformed into commensurate units reflecting the aggregated value (or utility) for each scenario. A requirement for the application of the weighted summation method is the mutual independence of decision-maker's preferences for the evaluation criteria (DETR, 2000). This means that the preference for one criterion is not influenced by preferences and values for others. In the weighted summation method, the results of the evaluation matrix are aggregated in two steps which are illustrated in Figure 24.

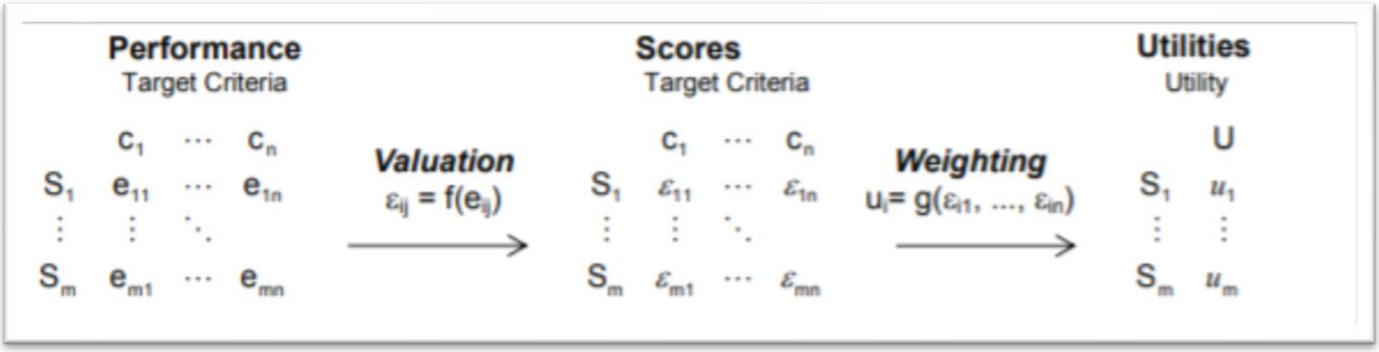


Figure 24: Valuation and weighting procedure in the linear MCA approach

In the first step, the performance result e_{ij} for each criterion c_j is assigned a score ε_{ij} (or partial utility value) on a harmonized scale using a value function. In this study, linear value functions with scores ranging between 0 (lowest performance = least preferred) and 100 (highest performance = most preferred) will be applied. A linear value function represents a risk neutral attitude. This is a common approach used due to its robustness. It requires the definition of a maximum range for the possible outcome for each indicator. The value ranges for the selected criteria have been determined based on previous model results and values from literature in order to establish the same decision basis for all respondents.[38]

The second step of the weighted summation method is the aggregation of the scores to a commensurate utility value (u_1, ..., u_m) for each scenario. In the linear additive model, the utility value for scenario S_i is calculated according to the following formula:

$$u_i = \sum w_j \,.\, \varepsilon_{ij}$$

This requires the definition of weights (w_1, ...w_n) for each of the criteria that reflect the relative importance of the criteria according to decision-makers' preferences for achieving the sustainability objectives.

The procedure is repeated with all remaining criteria in the order of their ranking assigning points in relation to the higher ranked criterion. Finally, the scores are normalised to sum up to 100% in order to derive weights for the criteria. After the n criteria have been assigned the point scores s_1, ... s_n, the corresponding weights w_j are calculated as Figure 25: [38]

$$w_j = \frac{s_j}{\sum_{k=1}^{n} s_k}$$

Figure 25: The formula of weights

Multi-Criteria Analysis (MCA) Summary

The multicriteria (or multi-criterion) analysis methods consist of the following parts:

· a set of quantitative tools
· evaluation of options
· determined by multiple and incompatible criteria

Multicriteria analysis methods have some approaches and basic ingredients which are: a finite set of actions (such as alternatives, solutions, etc.), at least two criteria per comparison, and at least one decision-maker for decision. According to this main information, multicriteria analysis provides a helping of the best alternative choosing, evaluation of scoring and weighting to rank alternatives. [95]

The main objectives of MCA are the following:

· the targets and set of purposes
· the decision-makers: evaluation of alternatives and choosing of the best one
· the alternatives: objects of evaluation and choice
· the criteria: the main indicators of comparison of alternatives
· the preferences: the weight system which determined the importance of the all criteria

18. Processes of Analysis

To the multicriteria analysis, this part is focused on comparison of three different transport modes (options of MCA), which are light rail transport (LRT) – bike service and tram-train service, with respect to four different criteria which are economic, social, environmental and operational issues. The study area is shown on Figure 26. According to the figure, the points show the stations of tram-train project and the distance between the beginning and the end of the line is 5.65 km.

Figure 26*: The study area of multicriteria analysis*

Economic Situation

To the comparison of different types of transport services, this part is assuming there are three types of service costs which are operational, maintenance and implementation. The following tables show the evaluated costs of each transport modes. First transport mode is tram-train service which is projected. According to the Lanciano project data, estimated demand is 6.400 citizens per day (one-way ticket is 1.2 € from TUA), cost of a vehicle is 3.000.000 €, management activities is 1.500.000 €, and total infrastructure cost (12 stations) is about 2.000.000 €. Table 39 shows the all costs of Lanciano tram-train service. [75] [87]

Furthermore, tram-train service has driving and managing cost, which is about 300.000 € per year, and energy consumption which is about 102.000 € per year. However, only full life-cycle estimated expenditure is assumed to comparison. [88]

Item	Cost [euro]
Quantity analysis and surveys	2.200.000 €
Infrastructure and equipment	2.000.000 €
Electrification	750.000 €
Rolling stock (3 vehicles)	9.000.000 €
Depot refurbishment and adaptation	900.000 €
Risks and other technical management activities and maintenance	1.500.000 €
Total of estimated expenditure	16.350.000 €
Revenue (yearly)	5.606.400 €
Driving and managing	300.000 €
Energy consumption	102.000 €

Table 39*: Life-cycle estimated costs of Lanciano tram-train service*

After Lanciano tram-train service, the second transport mode is light rail transit (LRT) service. According to the UK Low Cost Electrification of Branch Lines document, LRT service electrification price is about 160.000 € per kilometre. Besides, Siemens Avenio light rail products have 2.600.000 € cost per each vehicle. Quantity analysis and surveys parameter is assumed that LRT has same value with tram-train service. Driving and management cost is same with tram-train because they are same number of vehicles. However, energy consumption is different because LRT service use only 750V DC. Therefore, LRT consume 13% less energy according to US Department of Transportation. Potential demand is same and 6.400 citizens per day (one way ticket is 1.2 € from TUA). The costs of LRT service are shown on Table 40. [81] [94] [96]

Item	Cost [euro]
Quantity analysis and surveys	2.200.000 €
Infrastructure and equipment	2.000.000 €
Electrification	900.000 €
Rolling stock (3 vehicles)	7.800.000 €
Depot refurbishment and adaptation	780.000 €
Risks and other technical management activities and maintenance	1.370.000 €
Total of estimated expenditure	15.050.000 € per life-cycle
Revenue (yearly)	5.606.400 €
Driving and managing	300.000 €/year
Energy consumption	89.000 €/year

Table 40*: Life-cycle estimated costs of LRT service*

The third transport mode is bike service. For the bike service cost evaluation, cost of a bicycle for city is about 1.500 € (data from ITDP – the bikeshare planning guide), cost of stations construction is 315.000 €, cost of 1 km bike way (signs and equipment's included) is about 1.015.000 € (data from UK Typical costs of cycling interventions), and cost of management is 216.000 € per year (data from CIVITAS – Cycle friendly cities project). Also, Quantity analysis and surveys parameter is assumed that bike service has same value with tram-train service. Table 41 shows the evaluated costs bike service. Bike service requires 350 bikes because of the capacity regulations with respect to examples of CIVITAS – Cycle friendly cities project. The daily rental ticket is 4 € (per Milano) in Europe (data from ITDP – the bikeshare planning guide). Potential demand is same and 6.400 citizens per day (data from Lanciano project). [16] [48] [68] [97]

Item	Cost [euro]
Quantity analysis and surveys	2.200.000 €
Infrastructure and equipment	5.735.000 €
Electrification	Not needed
Bicycle cost (350 bikes)	525.000 €
Depot refurbishment and adaptation	52.500 €
Risks, other technical management activities and maintenance	852.000 €
Total of estimated expenditure	9.365.000 €
Management (operational cost)	216.000 €/year
Revenue (yearly)	9.344.000 €/year
Energy consumption	Not needed

Table 41*: Life-cycle estimated costs of bike service*

After the scoring of criteria, the second part of the analysis is weighting of all criteria. Table 42 shows the weighing of criteria.

criterion	Infrastructure and equipment	Electrification	Vehicle cost	Depot refurbishment	Maintenance and risks	Management (operational cost)	Revenue
weight of criterion	30	5	15	10	15	10	15

Table 42*: weighting of criteria for economic situation* [38][95]

After the evaluations of scores and weights for each criterion and according to the 0-100 ranking method of multicriteria analysis, Table 43 illustrates the MCA results of options, which are tram-train; LRT; and bike service, with respect to chosen criteria which are infrastructure and equipment, electrification, vehicle cost, depot refurbishment and adaptation, and risks and other technical management activities. The MCA is run according to total of estimated expenditure.

	Infrastructure and equipment	Electrification	Vehicle cost	Depot refurbishment	Maintenance and risks	Management (operational cost)	Revenue	**Total MCA**
Tram-Train Service	100	0	6	6	57	72	60	**49**
LRT Service	100	0	7	7	62	72	60	**51**
Bike Service	35	100	100	100	100	100	100	**80**
average	78	33	38	38	73	81	73	**60**
weights	30	5	15	10	15	10	15	**100%**

Table 43*: MCA 0-100 ranking method results for economic situation*

Social Reactions

According to the Abruzzo region's local authorities, the environmental future for public transport service is important to protect the greenest region, which is the Abruzzo region, of the European Union. Concerning this idea, they projected Lanciano tram-train service to cancel some lines of the existing bus service and reduce the emission of public transport service. However, the bus has a greater number of stations than rail service. Furthermore, railways pass into the city center and it may cause some confusion and some restricted lands from public usage.

To understand the citizens' opinions about the project and acceptance level, there should be some surveys that show the citizens' opinions and needs. The main purpose of the project is reducing the private transport and bus lines usage of workers and students from suburban zones to urban centers. To better understanding of citizens' opinions, some criteria, which are project acceptance of students and workers; satisfaction of suburban citizens; satisfaction of users according to connection; satisfaction of users according to cost; and satisfaction of users according to convention, are described for easier comparison and running of multicriteria analysis. Table 44 shows the weights of the chosen criteria. [22] [2]

Criterion	Acceptance of students	Acceptance of workers	Satisfaction of suburban citizens	Satisfaction of users according to connection	Satisfaction of users according to cost	Satisfaction of users according to convention
weight of criterion	25	25	15	15	10	10

Table 44: *weighting of criteria for social reaction* [22] [38] [95]

After the weights of criteria, the performance matrix of multicriteria analysis of social issue are shown on Table 45 with respect to three different transport modes, which are tram-train, LRT and bike services, and the assumption is this analysis as similar to the data of "Measuring the satisfaction of multimodal travellers for local transit services in different urban contexts by Marco Diana".[22]

	Acceptance of students	Acceptance of workers	Satisfaction of suburban citizens	Satisfaction of users according to connection	Satisfaction of users according to cost	Satisfaction of users according to convention	**Total MCA**
Tram-Train service	100	95	100	100	87	87	**96**
LRT service	87	93	84	93	76	100	**89**
Bike service	78	81	33	70	100	67	**68**
Average	88	90	72	88	88	85	**84**
Weights	25	25	15	15	10	10	**100%**

Table 45: *MCA 0-100 ranking method results for social reaction*

Environmental Situation

Environment is the future of the Earth. Every city, region, country should protect the environment and provide it to new generations. According to this idea, local regional authorities of Abruzzo created a project, which is ELIPTIC Lanciano tram-train service, with European Commission to obtain more sustainable transport service. The project converts the transport mode from bus service lines, which have diesel fuel vehicles, to railway service which have electric motorized vehicles. Bus service produces air pollutant materials such as CO_2, NO_x, PM10, etc.

More sustainable transport modes are better than the environmental protection because they need less land use and produce less air pollutant materials. Therefore, this may have lower noise level if compared the diesel engine vehicles. Table 46 shows the weights of air pollutant materials (such as CO_2, NO_X, PM10), noise level and land use into the multicriteria analysis with respect to environmental situation related to three different transport modes which are tram-train. LRT and bike services. [75] [100]

Criterion	CO_2	NO_X	PM10	Noise level	Land use
weight of criterion	35	10	10	20	25

Table 46: *weighting of criteria for environmental situation* [38][95]

According to the ELIPTIC – Lanciano tram-train project data, tram-train service may reduce the air pollutant materials and they have the following expected reduction values:[24]

CO_2 reduction;

5.4 kg less per hour

64.8 kg less per day

22 ton less per year

NO_X reduction;

180 g less per hour

2.1 kg less per day

720 kg less per day

PM10 reduction;

9.5 g less per hour

115 g less per day

40 kg less per year

The LRT service reduces the air pollutant amounts of CO2, NOX, and PM10 as like tram-train service. However, the other system, which is called bike service, provides about zero air pollutants', which are CO2; NOX; and PM10, amounts. Besides, the scores of tram-train and LRT service should be 0 (zero), and bike service should be 100 (a hundred).

Another data for environmental protection is noise level. EPA (Environment Protection Authority)'s Rail Infrastructure Noise Guideline states tram-train vehicles should have less 76 dB(A) (such as Siemens Avenio vehicle) and LRT service vehicles should have less than 80 dB(A). for the bike service, there is no noise level, however, the Australian Acoustical Society states bike service should have less 30 dB(A) noise level. [6] [25] [26]

The third environmental impact of transport service is land use for infrastructures. Because of these infrastructures, housing, agriculture, park zones and animals directly affected.

For the tram-train lines and stations, the project says 5.65 km railway and 12 stops/stations are required. A one-way tram-train railway requires 3370 mm width (data from Kassel tram-train service) and stops will be as same as tram stops or regional train stations. To the tunnel passing, the service requires 3560 mm without pantograph. Figure 27 shows the dimensions of a typical tram-train service line. According to European Standards (PRM TSI 4.2.1.12), the width of the platforms should have the width of the danger area plus the width of two opposing freeways of 800 mm (1600 mm). The permitted to have obstacles inside this freeway of 1600 mm and free space (no obstacles) of 1500 mm from the edge of the facility towards the direction. In a word, the lift platforms should have a minimum clear width of 800 mm and a length of 1200 mm for one direction (data from EU Standard which is PRM TSI 5.3.1.3).

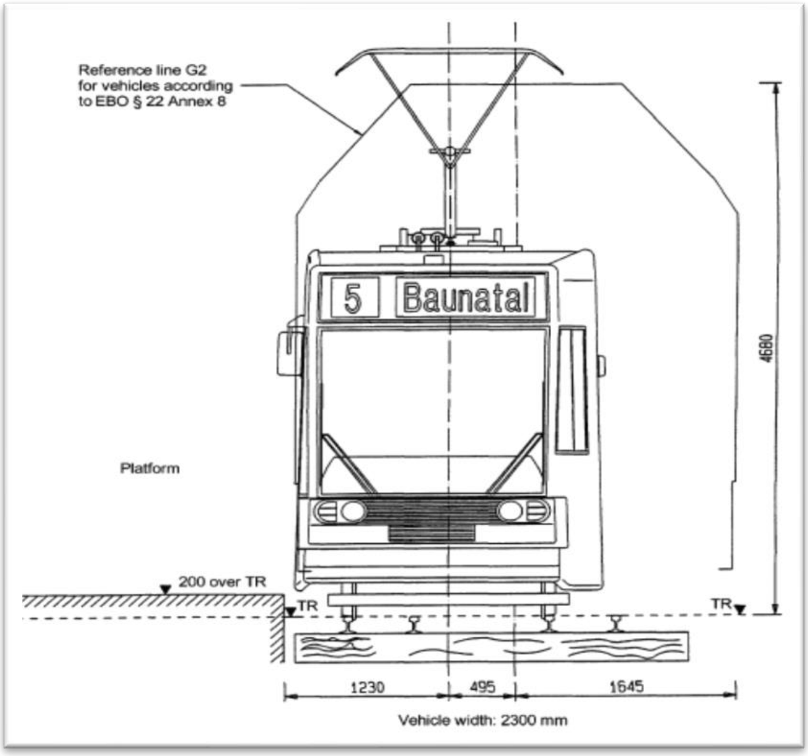


Figure 27: A tram-train railway dimensions

According to the UK City of Edmonton LRT Design Guidelines, LRT station platforms have about 9 m width and 123 m length, and other supply services (such as power substations, platform electrical services, signals) have 260 m^2 area. Figure 28 shows the LRT station dimensions. Furthermore, the LRT service railways have 5.65 km long and width of 3460 mm (data from UK LRT Design Guidelines) [94] [96]

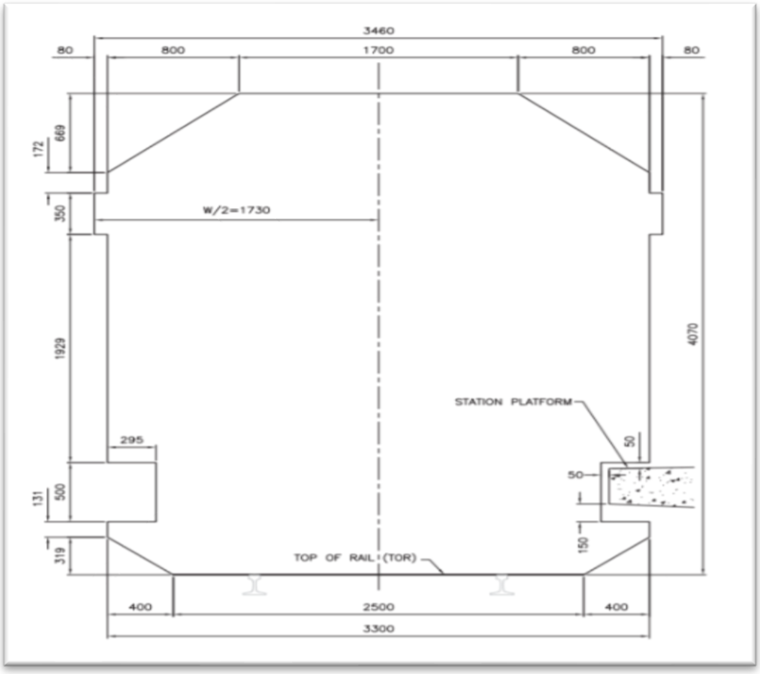


Figure 28: Dimensions of a typical LRT station

Another transport mode is a bike service. A bicyclist should feel safe from danger or harmful situations to service quality. According to the European Commission (EC) Cycling Policy regulations, for the cyclists' fear distances from obstacles, the obstacle distance is 0.25 m; higher kerbstones 0.5 m and for closed walls 0.625 m. Besides, for the section of free space for one cyclist, the width required by the bicycle and its rider (0.75 m) and add to that zigzagging margin. So, the most common situation is that a cyclist riding along a high kerb on one side: an absolute minimum pavement width of 0.9 m is stated.

Furthermore, for the design of a bikeway, the recommended minimum width of 1.5 m. Therefore, for the comfortable driving in tunnels, the design provides 0.75 m headroom. All these dimensions and requirements are shown in Figure 29. According to EC – Presto Bicycle Parking and Storage Solutions, one bicycle requires a length of 1.8 m, a width of 0.7 m parking area and a width of 1.75 m for walking to the entrance or exit to a bike station. All bike stations' dimensions are shown in Figure 30. [16] [17]

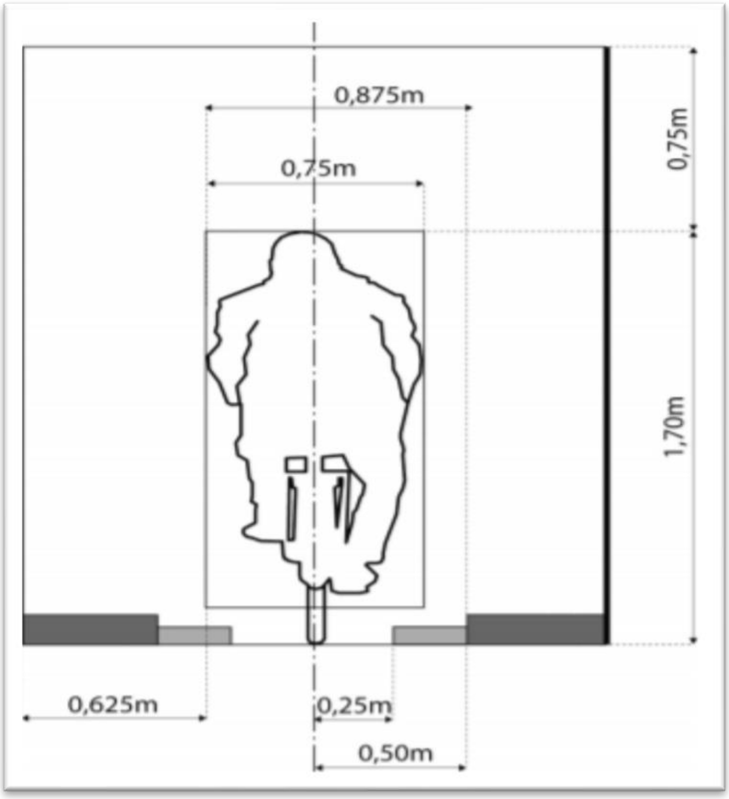


Figure 29: Design manual for bicycle traffic (from EC – CROW - 2016)

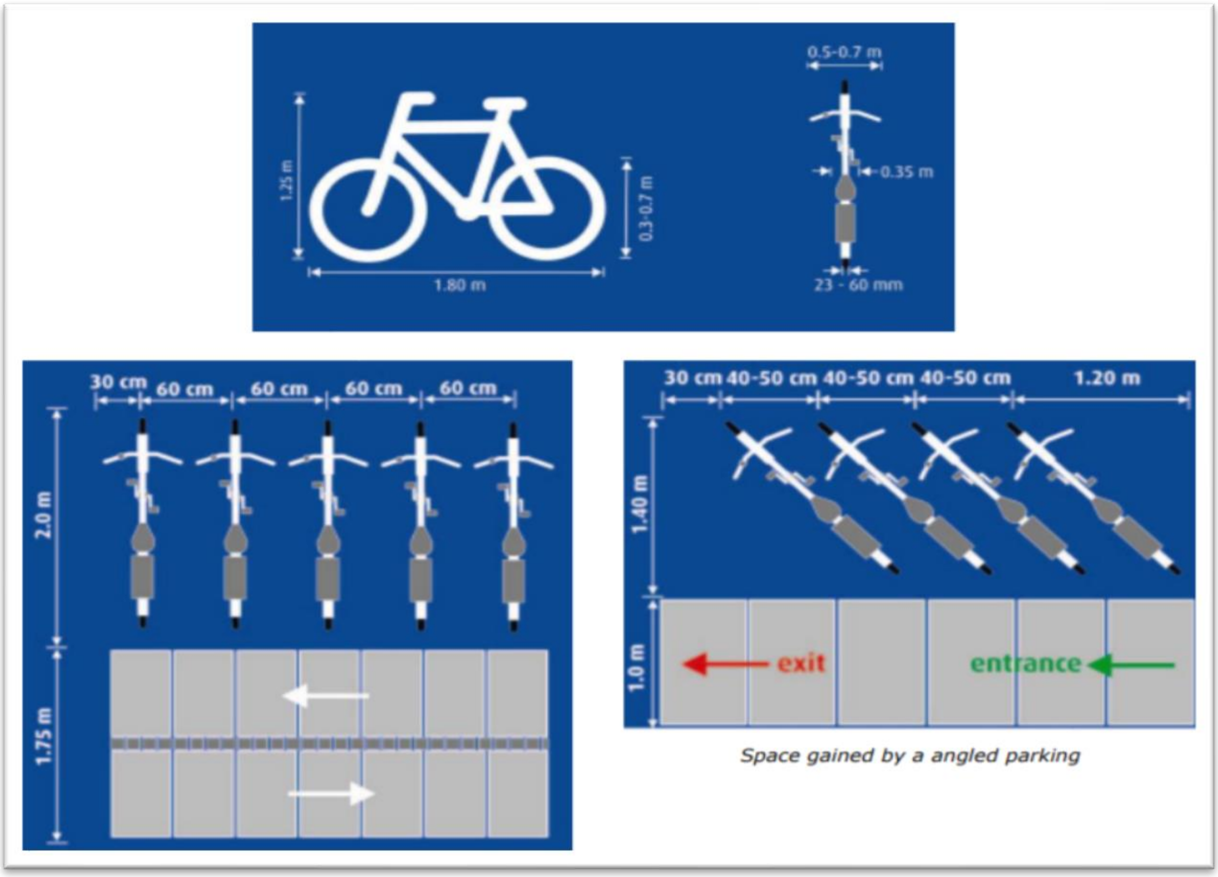


Figure 30: An example of a bike parking area

After the information about services Table 47 shows the land use of transport modes' infrastructures because of ways and stations.

	Land use by way infrastructure	Land use by a station infrastructure	Total land use
Tram-Train Service	19.040,50 m^2 (one way)	446,40 m^2 (12 stations)	24.397,30 m^2
LRT Service	19.549,00 m^2 (one way)	1.107 m^2 (12 stations)	32.899,00 m^2
Bike Service	11.300 m^2 (one way)	5.25 m^2 (350 bikes)	11.324,00 m^2

Table 47: Land use of chosen transport modes which are tram-train, LRT, and bike services

According to the evaluations and the calculations, Table 48 illustrates the multicriteria analysis scores with respect to environmental situation.

	CO_2	NO_x	PM10	Noise level	Land use	**Total MCA**
Tram-Train service	0	0	0	40	46	**20**
LRT service	0	0	0	37	34	**16**
Bike service	100	100	100	100	100	**100**
average	33	33	33	59	60	**45**
weights	35	10	10	15	30	**100%**

Table 48: *MCA 0-100 ranking method results for environmental situation*

Operational Issue

The data of Lanciano tram-train project states the vehicle capacity of a vehicle is 160 passengers, the hourly capacity is 480 passengers in non-peak hour, average travel time is 15 minutes, frequency is 3 services per hour, and for the station capacity; 0.25 m^2 per passenger required with respect to directive 2012/34/EU. The LRT service is offers, the vehicle capacity of 216 passengers (Siemens Avenio), the hourly capacity of 648 passengers, the frequency of 3 services per hour (assumption with respect to the Lanciano tram-train project), the travel time is about 13 minutes (evaluated with respect to the vehicle feature of Siemens Avenio and long of Lanciano project, 5.65 km), and for the station capacity; 0.25 m^2 per passenger required with respect to directive 2012/34/EU. The other transport mode is bike service and it has 1 rider capacity per one bike, the travel time is 11 minutes (30 km/h speed according to EC Bike guidelines), frequency is 1 service per hour, maximum station capacity is 20 bikes, and hourly service capacity is 350 passengers. All information is shown in Table 49. [16] [23] [30] [75] [81]

	Vehicle capacity	Hourly service capacity	Frequency	Station capacity	Travel time
Tram-Train Service	160 passengers	480 passengers	3	1.785 passengers	16 min
LRT Service	216 passengers	648 passengers	3	4.428 passengers	13 min
Bike Service	1 user	350 passengers	1	20 users	11 min

Table 49: Information about transport modes which are tram-train, LRT, and bike service

After that, Table 50 illustrates the expected weights of each multicriteria analysis criterion for operational issue.

Criterion	Vehicle capacity	Hourly service capacity	Frequency	Station capacity	Travel time
weight of criterion	15	35	20	10	20

Table 50: *weighting of criteria for operational issue* [38][95]

The Table 51 shows the multicriteria scores of each transport modes, which are tram-train; LRT; and bike service, with respect to weights of criteria which are vehicle capacity, hourly service capacity, service frequency, station capacity, and travel time.

	Vehicle capacity	Hourly service capacity	Frequency	Station capacity	Travel time	**Total MCA**
Tram-Train service	74	74	100	40	69	**75**
LRT service	100	100	100	100	85	**97**
Bike service	1	54	33	1	100	**46**
Average	58	76	78	47	85	**73**
Weights	15	35	20	10	20	**100%**

Table 51: *MCA 0-100 ranking method results for operational issue*

RESULTS

After all evaluations and expected weights, Table 52 shows each criterion and its expected weight. According to evaluated final multicriteria analysis criteria and their weights, Table 53 illustrates the multicriteria analysis results of chosen transport modes, which are tram-train, LRT, and bike services, depend on criteria which are economic, environmental, social, and operational issues.

Criterion	Economic S.	Social R.	Environmental S.	Operational I.
Weight	35	15	25	25

Table 52: *weightings of each criteria* [38][95]

	Economic S.	Social R.	Environmental S.	Operational I.	**Total MCA**
Tram-Train Service	49	96	20	75	**59**
LRT Service	51	89	16	97	**64**
Bike Service	80	68	100	46	**73**
average	60	84	45	73	**65**
weight	35	20	20	25	**100%**

Table 53: *MCA 0-100 ranking method results for each transport modes with respect to criteria*

According to the evaluated values, the best option for the study area is bike service with the best results of the criteria of “economy” and “environment”. The second option is the light rail train service and the third one is the tram-train service. The bike service is the best option because the environmental impacts of it are almost nothing. The bike service does not require a motorized vehicle.

The assumed bike service is separated from urban road traffic because of safety. However, the bikeways require new infrastructures (it means more land-use) and dismantling of rail tracks, aerials, and some road signs or protection objects (such as barriers, concrete blocks, etc.). These changings require more money, and this means higher infrastructure costs if compares to the tram-train service. Therefore, bike service is not so efficient for suburban citizens because of long-distance to central zone and this causes less preferability. Furthermore, integration of bike service operation and local public service operations is not so easy because of payment requirements and traditional service acceptance.

The light rail service is the second option and it has the best value of the criterion of operational issues because light rail service is separated system and integration with Sangritana SpA is easier. However, separated tracks cause more land-use and division in the central area.

However, the tram-train service doesn't require the separation in the central area because it runs like a tram service in central zones and like a regional service in suburban zones. Furthermore, tram-train service has fewer emissions because of electricity and no need for new infrastructures because of the relaunching of existing dismissed railways.

CONCLUSION

According to the multi-criteria analysis scoring-weighting technique results, the performance matrixes shows the following (Tram-Train: TT, Light Rail Train: LRT, and Bike Service: BS):

For the economic situation, the performance matrix determines the criteria and their scores. The criterion of infrastructure and equipment has the lowest score for bike service because TT and LRT use the existing railways, however, BS requires new infrastructure. The electrification, vehicle cost, depot refurbishment, maintenance and risks, management and revenue criteria have the highest scores, which is 100, for the BS because the service has lowest emission level, lower product prices, and almost no need for energy consumption. In the end of economic situation, the best transport mode is BS and it has 80 out of 100 points. The other services have score of 51 for LRT and score of 49 for TT.

For the social issue, the performance matrix describes the criteria and scores of service acceptance level of students (the best score is 100 of TT) and workers (the best score is 95 of TT), and satisfactions of suburban citizens (the best score is 100 of TT), according to connection (the best score is 100 of TT), according to cost (the best score is 100 of BS) and according to convention (the best score is 100 of LRT). Tram-Train service has better connection between suburban and urban zones. Besides, satisfaction of suburban citizens has higher score.

For the environmental situation, the environmental situation performance matrix has the best scores for BS (100 out of 100) because the bike service has no fuel consumption (at the same time no emission), no noise production (without horns). However, bike service requires land use. The land use by bike service is the lowest value if compares the TT and LRT because the BS needs bike ways for one bicycle (it has width of 0.5-0.7 m) and stations' aim both for parking and renting.

For the operational issue, the best transport mode is LRT comparison of TT and BS. The LRT has score of 97 out of 100 because the one vehicle capacity and stations' capacity is higher, and frequency almost same with TT but higher than BS, and hourly service capacity is the highest.

In the end, final performance matrix, which is evaluated with main criteria, illustrates the best transport mode is bike service because the environmental situation and economic perspective is the best for bike service. Therefore, the criterion of social effects is the best for tram-train because of suburban citizens, and the criterion of operational issues is the best for light rail train because of vehicle and station capacity.

COMMENTS

For the future's possible studies, some suggestions, which are for obtaining better and more effective results, are given the following:

▪ the surveys may be done to understand the idea of citizens who live in urban area and suburban zones of Lanciano province.

▪ the existing road infrastructure checks for calculation of bike service (possibly the infrastructure cost of bike service will reduce)

▪ the environmental criteria of air pollution and noise level need the local measurements. This may be done in city center of Lanciano province and around the most crowded rail lines which pass the urban zone.

▪ the revenue values may change with some additional advertisements and promotions with each other.

▪ for the comparison of vehicle and station capacities of tram-train and light rail train services, the vehicle types may be chosen for them and the station dimensions can measure in urban and suburban project area.

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END OF THE STUDY

FINE DELLO STUDIO