TECHNISCHE UNIVERSITÄT WIEN

VIENNA UNIVERSITY OF TECHNOLOGY

DIPLOMARBEIT

MASTER'S THESIS

An integration of human transport planning criteria in the design of a light rail system with an application to Ljubljana

carried out for the achievement of the academic degree of

Diplom-Ingenieur

under the guidance of

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and
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Abstract

The thesis at issue deals with the planning and design of light rail transit networks in general and its application to the city of Ljubljana in special. An attempt has been made to an integrating planning procedure, i.e. to connect defined transport policies of certain sustainable and quantifiable measures and the planning approaches of light rail transit systems. The latter usually start from a technical point of view, however, the point of departure is here human travel behaviour and then derive the appropriate parameters for the technical transport system, i.e. the light railway system. Furthermore, such a planning procedure cannot be seen separately from a city development. This is taken into account with a description of the historic development of the city's public transport system. Ljubljana had already a tramway system from 1901 to 1958. The current bus replacement has various problems in particular with capacity and attractiveness. And therefore several concepts already exist, how light rail can be reintroduced. For the comparison and analysis of these concepts, a set of parameters has been developed, which were derived from (i) the overall transport policy objectives, i.e. the sustainable criteria, (ii) the human travel behaviour, i.e. to enable a high acceptability, (iii) technical light rail dependent parameters and (iv) an economic assessment. The comparison of these concepts showed that especially the sub-surface variants dealed in detail with technical aspects of light rail implementation, whereas human travel behaviour and sustainable development policies were only of subordinate interest.

These concepts were juxtaposed with a new development plan which incorporates some of the suggestions made by the previous concepts. But its main distinction stems from the integration of human transport planning. This means that the stop distance should converge towards 220 m; a minimum in transfer would be ensured; the sub-surface versions cannot effectively overcome the access problem; the additional lines increase the coverage of the total city area, but especially of the city centre; or no housing demolitions would be required. In regard to the economic assessment, the sub-surface version would be also economically expensive and even the network with the additional lines would be cheaper. Despite the focus in regard to the rail system it should be also mentioned, that an implementation has to be seen in connection with the other modes of transport, i.e. a pedestrian and bicycle friendly network or, most of all, a restriction of motorised transport. In particular with an effective parking management system based on the equidistance principle, where the parking place has to be at least in the same distance from home as the next public transit stop. Without those, the success of the light rail system would be limited.

Zusammenfassung (abstract in German)

Die vorliegende Diplomarbeit befasst sich mit Planung und Entwurf von Light Rail Netzwerken im allgemeinen und der Anwendung auf die Stadt Ljubljana im speziellen. Der Ansatz einer integrierenden Planung wurde gewählt, d.h. die Verbindung von vorgegebenen Grundsätzen verschiedener nachhaltiger und quantifizierbarer Massnahmen und den Planungsansätzen für Light Rail System zu schaffen. Die letzteren werden üblicherweise aus einem rein technischen Blickwinkel gesehen. Hier jedoch ist der Ansatzpunkt das menschliche Mobilitätsverhalten und die daran schließende Ableitung der zugehörigen Parameter für das technische Transportsystem, das Light Rail System. Darüber hinaus ist festzustellen, dass so eine Planung nicht separat zur Stadtentwicklung gesehen werden kann. Darauf wir Bezug genommen mit einer Beschreibung der geschichtlichen Entwicklung des städtischen Öffentlichen Verkehrs. Ljubljana hatte ja bereits eine Straßenbahn zwischen den Jahren 1901 und 1958. Das jetzige Bussystem hat unterschiedliche Probleme, insbesondere mit der Kapazität und Attraktivität. Aus diesem Grund gibt es auch schon einige Konzepte, wie Light Rail wieder eingeführt werden könnte. Für den Vergleich und die Analyse dieser Konzepte wurden Parameter entwickelt, die abgeleitet wurden von: (i) den generellen Verkehrszielsetzungen, das sind Kriterien der nachhaltigen Entwicklung; (ii) dem menschlichen Mobilitätsverhalten, d.h. eine hohe Akzeptanz ermöglichen; (iii) den technischen Parametern von Light Rail und (iv) einer wirtschaftlichen Bewertung. Der Vergleich dieser Konzepte zeigt, dass sich die Varianten mit unterirdicher Linienführung besonders mit technischen Aspekten beschäftigen, aber dem Mobilitätsverhalten und Grundsätzen nachhaltiger Entwicklung wenig Bedeutung zugemessen wird.

Diese Konzepte wurden nebeneinander gestellt mit dem neu entwickelten Plan, welcher einige Vorschläge der anderen Konzepte beinhaltet, verglichen. Aber die hauptsächliche Unterscheidung rührt von der Integration menschenbezogener Verkehrsplanung. Das bedeutet, dass sich der Haltestellenabstand an eine Entfernung von 220 m annähern sollte, was eine Umsteigeminimierung bewirken würde; die Untergrundvarianten können das Zugangsproblem nicht effektiv lösen; die zusätzlichen Linien erhöhen die Flächendeckung der Stadt und im speziellen des Stadtkerns; oder dass kein Abriss von Häusern notwendig ist. Unter Bezugnahme auf die finanzielle Beurteilung wären die unterirdischen Varianten nicht nur teuerer, sondern selbst das vergrösserte oberirdische Netzwerk wäre günstiger. Trotz des Fokuses auf das schienengebundene System sollte weiters erwähnt werden, dass eine Implementierung in Verbindung mit anderen Transportmodi gesehen werden muß. Das bedeutet eine fußgeher- und radfahrfreundliche Gestaltung der Stadt, mit besonderem Augenmerk auf Restriktionen für den motrisierten Verkehr. Das ist eine wirkungsvolle Parkraumbewirtschaftung basierend auf dem Prinzip der Äquidistanz, bei dem der Parkplatz zumindest die Entfernung von der Wohnung hat, wie die nächstgelegene Haltestelle des Öffentlichen Verkehrs. Ohne dem wäre der Erfolg des neuen Light Rail Systems nur ein beschränkter.

Preface

Already as a small kid the white and green coloured buses of my hometown left a huge impression on me. Probably because by the locals they are called “Krpan”. Named after Martin Krpan, a salt trading hero from a Slovenian tale so strong, that he could carry his own horse.

Probably my parents Marija and Rudolf in the beginning didn’t even dare to think of, what mark of long lasting impression the transport system of my town of birth is going to leave upon me. From the early days of taking the bus into town to the scientific approaches of nowadays. Besides this implicit guidance, I would like to thank them for the long lasting help and support which made my education possible and enjoyable.

Special thanks belong to Prof. Hermann Knoflacher. Firstly for his ability to provide fundamentally new ideas and insights and secondly for being so merciless – I had to repeat his exam, which in the following changed my educational and professional career for good.

Also a man who had a significant impact on me, transportation wise and personally, is Dr. Robert Kölbl, whom I would like to thank for the discussions and guidance, which led to this thesis.

The people whom I would also like to thank for providing much needed thesis-related assistance are:

- Mr. Tomaž Souvan and Mr. Marjan Cerar from the Department of Urbanism at the Municipality of Ljubljana;
- Mrs. Marjana Dermelj of Umanotera, Ljubljana;
- Mr. Jurij Primožič from the Library of the Slavs, Ljubljana;
- Mr. Heinrich Zukal from the Institute of transport planning and traffic engineering, Vienna;
- and the many more friends and colleagues, who remain unnamed, for their support and constructive criticism.

IMPORTANT NOTICES:

In difference to the Anglo-Saxon common practice, the continental European scheme of comma (,) as decimal separator and the dot (.) as thousand digit separator is used.

Regarding the map imagery: Although the circumferential highway is complete for some years now, the up-to-date issue of the topographical map, scale 1:25.000, which is the basis for all the comparative depictions of systems, has not been reviewed this far by *Geodetski zavod Slovenije* and lacks this crucial addition.

All names and expressions in Slovene (streets, towns, …) except for Ljubljana itself are written in Italic letters.

1. Introduction

1.1. The aim of the thesis

This thesis has its emphasis on the network planning and system integration of a light rail transit system (LRT) in Ljubljana.

The sustainable transport policies give a clear picture of what the objectives and general measures should be, although often expressed in rather general and vague language. But although the planning policies are clearly set, the planning implementation is not as straight forward as expected. (see also section 3.1.)

The main objective of providing healthy and high quality city life is recognised by the majority almost unanimously. But when it comes to the realisation of the second level objectives and their measures, the previous support evolves into a conflict of interests around city planning. Especially within the emotionally heavily burdened field of transport. Within these city planning procedures and institutions some of the effective forces push and pull towards solutions in contradiction to the main objective. Due to these contradictory forces (opposing pressure groups, alleged or real public opinions, misinformation, too much caution, outdated opinions, and so on ...) the view on the whole transportation system as the city's backbone for a sustainable development may get blurred.

The objectives of sustainable transport planning necessarily need to be considered within an approach of integrated planning between the city and the region. The importance is evident due to the close connections that exist between the city and its region.

Therefore, the aims set for this thesis are:

- filter out the principles of planning a sustainable LRT system;
- analysis of existing blueprints and identification of the differences and weaknesses;
- propositions of improvements and discussion thereof.

1.2. The structure of the thesis

To achieve the objective set above, the thesis is divided in two methodological parts. The first part is dealing with LRT planning and parameters to be considered therein in general. Whereas the second part then specialises on Ljubljana. The thesis' structure is as follows:

In Chapter number two a comprehensive description of the city structure and its transport situation is given. Additional data is provided in the appendix. This chapter includes in the beginning also an overview of the historic development of public transport (PT) in the city and the background behind the problems, this thesis deals with.

In Chapter three in two short subchapters the background regarding sustainable transportation and the definition of light rail is outlined. The third subchapter provides a comprehensive and classified literature review of the planning process and its parameters.

Chapter four describes the four existing plans for implementing light rail into the city and analyses them in accordance with sustainable transport aims. In the last subchapter also the differences between actual and sustainable planning principles for light rail systems are worked out.

Chapter five presents the light rail scheme, that was developed with the fulfilment of sustainable development objectives in mind, basing on one of the previously discussed plans. It also includes comparison with the previous blueprints.

Chapter six is the conclusion.

The appendix includes additional material, that was collected for further description of the wide scope of parameters of influence, but would not fit into the text.

2. The status quo of the city and its PT system

In a short historic excursion, before the problem's background and the status quo concerning transportation are dealt with, the development of public transport in the city will be portrayed. This is done for two reasons. The first reason is, that Ljubljana shares its fate with many other cities, that experienced a rise and decline of the tramway and are now in the same situation, that the once existing network is being reintroduced or is planned to be reintroduced under a great deal of accompanying efforts. The second reason is, to provide, especially by means of the network maps, a basis to compare the alignments and networks of previous times, and by this the city's extents, with nowadays.

2.1. Brief history of public transport in Ljubljana

The first electric tramway – to follow almost fifty years of horse tramway operation in cities all over Europe and the United States – was opened in 1881 in Berlin. (Taplin 1998)

Although electricity in urban use e.g. for lighting and tramways was introduced to larger European cities at the end of the 19th century, the then relatively small provincial capital had to wait 20 years to get it's own tramway. (Brate 2001)

Public transportation started in Ljubljana on September 6th 1901. The city was then the capital of the province of *Kranj* under the Austro-Hungarian regency and had reached a population of 40.000 at the turn of the century. (LPP 2001b)

The tramway service was operated by the SML ("*Splošna malo-železniška družba*" – general small railway company) which was owned by Siemens&Halske of Vienna. The first network comprised of three lines with the total length of 5,22 km (see fig. 1) and was build to a gauge of 1000 mm. Although 13 lines where planned initially, they never became reality, because SML realised, that the expensive fares didn't attract enough ridership to gain profit. Therefore, no further investments where made into the network and the rolling stock.

In 1910 the population reached the mark of 70.500 and twenty years later it was 97.500. In these 30 years the city more than doubled it's population, but didn't grow even close to the twofold size, as apart of the tramway lines, the main mode of transport still was walking. (Guzelj, et al. 1989)

This dramatic increase in population self evidently led to problems along the major in- and outbound routes due to the increasing individual transport (cars, carriages) and the lack of organisational provisions. In 1927, as the city became the 2/3 majority owner of the SML, they proposed to expand the tram network but failed due to the parliamentary opposition. Because the conditions got worse, more than five new bus lines were introduced. In 1930, since the profitability never had reached desired levels, all but one bus line where put out of service. (Guzelj, et al. 1989)

In the beginning of the 1930's the private company became a city owned corporation and changed it's name into CEŽ ("*Cestna električna železnica*"– street electric railway) first and later into ECŽ ("*Električna cestna železnica*" – electric street railway).

As Ljubljana still grew and began to include many surrounding villages into it's borders of municipality, the extension of tramway lines followed immediately. The peak was reached in 1940 as the network consisted of 21,4 km of lines, equalling 26,8 km of track. The network had a circular section between the city hall and the main railway station and 5 branches extending radially from it with 4 lines running on it. (Brate 1990, 1997)

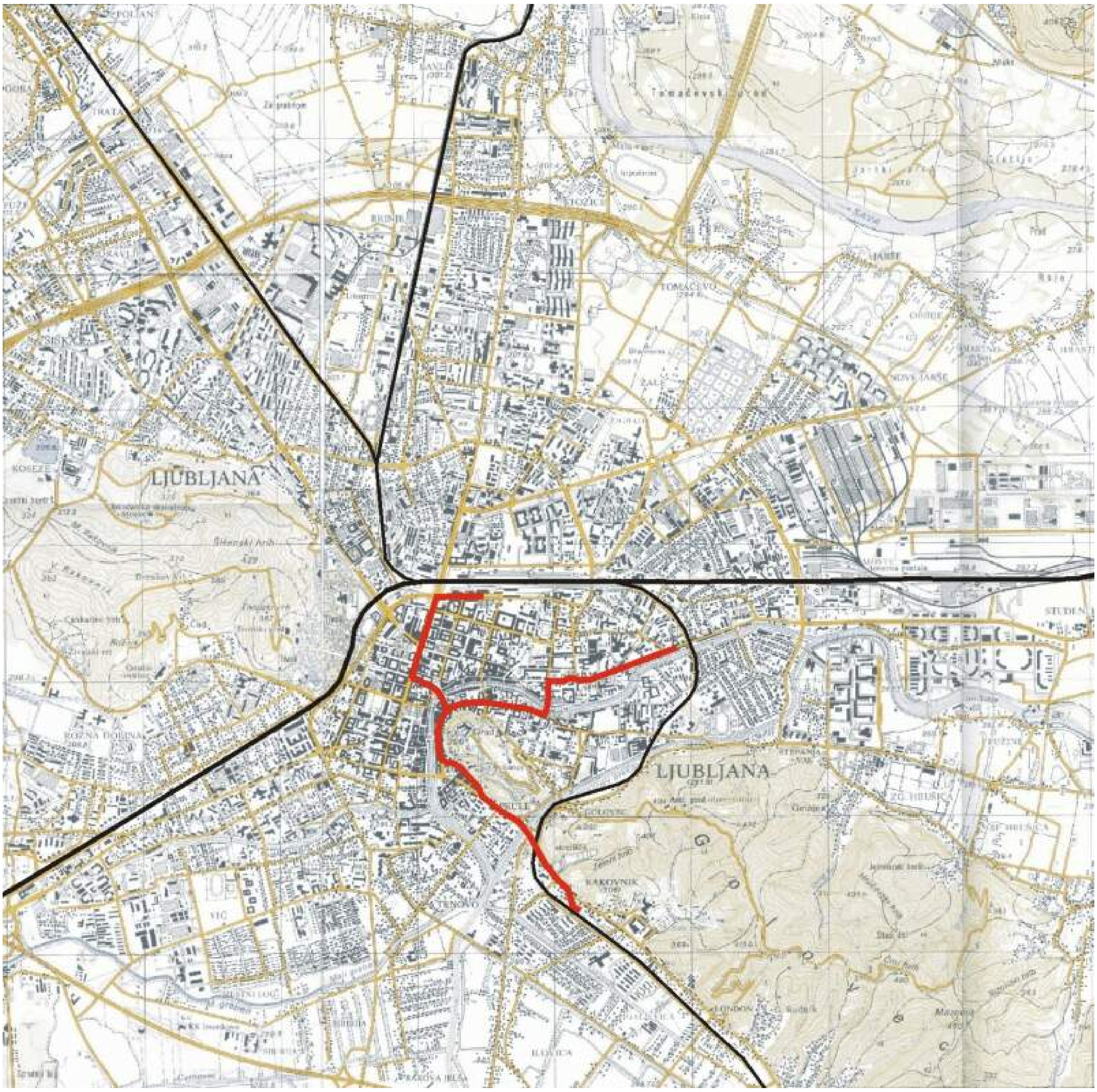


Fig. 1: The tramway network of 1901. after (Guzelj, et al. 1989)

After the war only a minor number of new cars was build, because the municipality didn't want to invest into a loud, slow and traffic handicapping means of transport. Besides, the new trolleybuses and diesel engine powered buses where already waiting to be put in service. After a few trial runs and the dictational decision, that the tramway had to be replaced, no matter what, the tram era found its end, 57 years after its inauguration.

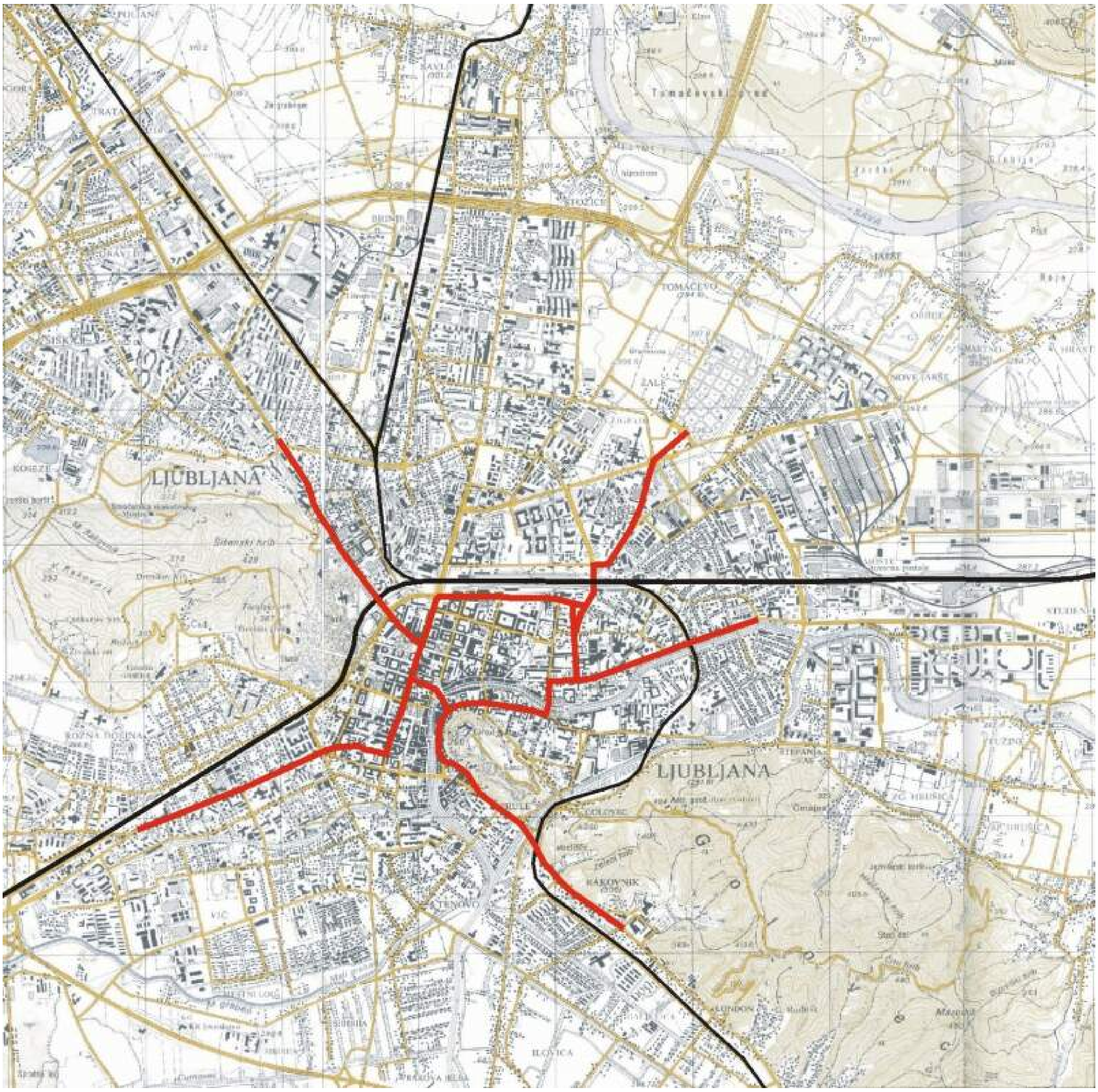


Fig. 2: The tramway network of 1940. after (Brate 1990)

event	date
start of tramway service	06.09.1901
trial runs of trolleybus	in 1951
start of regular trolleybus service	15.05.1957
last day of tramway operation	20.12.1958
last day of trolleybus operation	04.09.1971

Tab. 1: Some important dates in Ljubljana's PT operation history. (Brate 1990, 1997)

The replacing trolleybuses didn't last very long, because of increased problems during operation. E.g. the trolley often slipped off the catenary, winter conditions led to corrosion and conductivity problems and quite often, because of insulation imperfections, the shell and the chassis discharged the electricity over passengers accidentally touching some parts of the vehicle. Much faster than it's predecessor the trolleybus quit its service after 14 years and was replaced by diesel powered buses, which with according renewals and new vehicles are still the only means of public transport in the city. Similar short lasting periods of trolley bus operation within transformation of PT services could be observed in other cases too, e.g. Strasbourg (eaue.de 1996) and Mulhouse (Framenau 2002)

2.2. Description of the problem's background

For the past decades Ljubljana's development has been proceeding along major axes of development. These axes radiate from the ancient and medieval city core into all directions. (see also section 2.3.2.). Along with the increased individual motorization of the city and its inhabitants came the spatial spread away from these axes into the region. Although being physically limited due to Ljubljana's geographical position in the middle of a basin shaped landscape. Nevertheless, a lot of previously very rural settlements, mainly to the north of the city, gained in population numbers with a lot of settlements being placed somewhere in between the historically grown villages and towns.

This development gained additional momentum as the country struggled into independence from the previously semi-communist conglomerate of Yugoslavia, and the previous, centrally organised economy was transformed into a market economy. Accompanying with the general economic development also the number and distribution of automobiles increased.

In the last years the country and especially the heavily populated and therefore very important basin of Ljubljana perceived developments that can be observed in many cities in Western Europe. The generally observed problems are e.g.:

- increase of urban sprawl within the basin;
- growth of peripheral shopping centres;
- the partial degradation of the city centre;
- the decrease of the PT share of the modal split;
- decreased punctuality of road-bound PT due to congestion;
- the increased rivalry for space in the inner city, especially cars parking unpunished on pedestrian and bicycle surfaces.

In Ljubljana this development was more rapid.

Some 20 years after the extinction of tramways in Ljubljana in the beginning of the 1980's a reintroduction of a tramway network into the city re-emerged on the scene. These first, vague plans were quite ambitious as they considered the first operational sections for 1990 and the completion of the network by 2000. But nothing happened. (Brate 1990)

Somehow foreseeing the developments from above, the municipality sought for solutions to the evolving problems and commissioned a study to examine the feasibility of reintroduction of a rail-bound, partially street-running means of PT see Guzelj, et al. 1989. But the political earthquakes of the years 1990 and 1991 and the following years, full of new tasks and quests to establish and stabilise a independent state, led to different priorities and the tramway was postponed. Meanwhile the evolving problems have not disappeared, on the contrary, they grew bigger. Therefore in the late 90's the municipality started again its planning and examinations and the idea to bring a tramway back into the city was reborn.

This led to new studies with different point's of view and emphases, especially under consideration of the sensational results of the new "Karlsruhe principle". These findings of interoperability to connect cities with their hinterlands were also envisaged for Ljubljana. (see Ludwig, et al. 1995 and Perez, et al. 2002a) In the meantime, the approaches to rail-bound PT increased flexibility and the implementation of inner city right of ways (ROW) completely underground were forfeited for cost and effectiveness sake.

Besides the planning of a surface variant a separate group of engineers developed a public transportation variant with sub-surface sections. Via brochures, newspaper articles and a slot in the city's official tramway enquete they advertised different layouts. All having in common the extended, very curvaceous and spacious below surface alignments. (seeBajželj, et al. 1999a; Bajželj, et al. 1999b; Bajželj, et al. 2001; Bajželj, et al. 2002)

Meanwhile, as Slovenia's preparations are on the verge of joining the European Union, a lot of national environmental and planning policy papers have been issued under the auspices of sustainable development. They are waiting impatiently to be implemented as Slovenia faces the transportation related dangers and opportunities. (see DZ-RS 1999 and MOP 2003)

To underline it's preferences and determination, the municipality included an extended section covering the future PT plans into the new city development plan, which was published in 2002. (see Cerar, et al. 2002) From this point of view the municipal plans to partially reorganise its transportation system could be judged as Ljubljana's share of the "think global – act local" philosophy". If only the determination and stamina will be strong enough and last long enough.

2.3. The present city and its PT system

2.3.1. The region

The city is located in the middle of the Ljubljana basin, right at its narrowness, formed by the hilly landscapes to the west and east and the castle hill itself. To the north and south the basin is bordered by the towering peaks of the Alps of *Kamnik* and the *Krim* mountain. Within the basin and along its edge to the neighbouring hinterlands are located dwellings and towns of various sizes, reaching up to 52.000 in *Kranj*, the largest town within Ljubljana's reach. The strong orientation of the region towards the city is shown by the fact that about 120.000 people commute daily into the city. (Dekleva 2002) This requires the region to be included into the integrative viewpoint of planning. Due to the increasing dispersion of settlements and the resulting car dependency, an effective, competitive system is required.

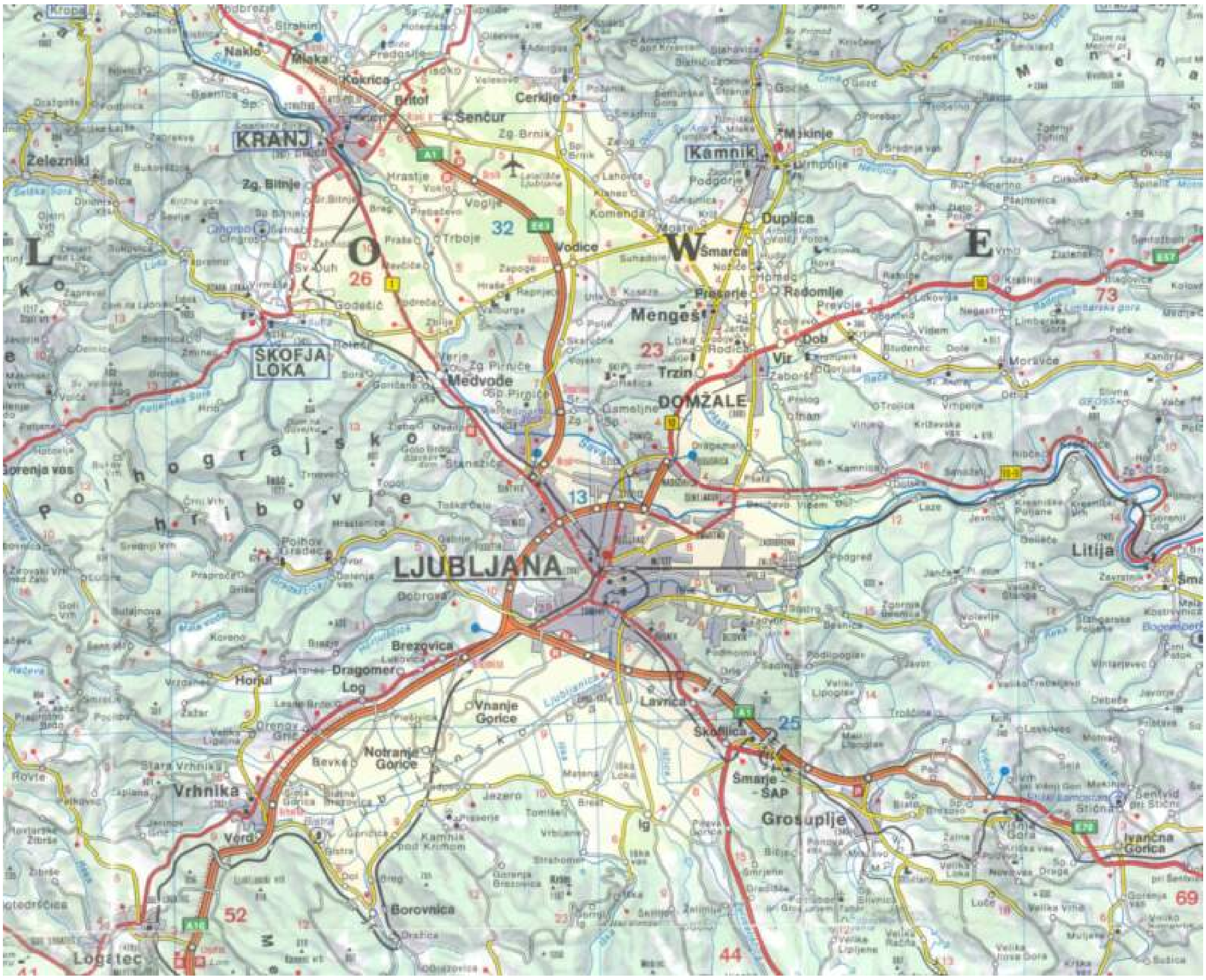


Fig. 3: Overview map of the region of Ljubljana. (Freytag & Berndt 1993)

2.3.2. The city's structure

Shape, morphology and structure

Ljubljana was already a populated place in Roman times, but only a few excavations from then remain. Therefore the still standing, oldest part of the city is from medieval times and is located in the narrowness between the castle hill and the *Ljubljanica* river. To the north and west of the *Ljubljanica* located are the 17th to 20th century houses, now forming the political, social and administrative core of the city. This CBD's limits are the railway station to the north and the park of *Tivoli* to the west. On the other side the castle hill marks the south-eastern end of the CBD. This CBD is limited by the blurred border running along the following streets: *Trg osvobodilne fronte* – *Resljeva c.* – castle hill tunnel – *Zoisova c.* – *Aškerčeva c.* – *Tivolska c.*

As already mentioned in the introduction, the historical growth of the city outside this inner district took place along five axes of development. These axes radiate into all directions of the basin. Every axis comprises of a road and a railway running in the middle or at the side of this urban "composure". (see also fig. 2)

cardinal point	street	railway
north	*Dunajska c.*	Ljubljana – *Kamnik*
east	*Zaloška c.*	Ljubljana – *Litija*
southeast	*Dolenjska c.*	Ljubljana – *Grosuplje*
southwest	*Tržaška c.*	Ljubljana – *Postojna*
northwest	*Celovška c.*	Ljubljana – *Jesenice*

Tab. 2: The axes of urban development.

Two additional axes can be identified. But they have both in common, that they evolved only along a major road and are not as strongly developed in linear shape as the previous five. This two additional axes fill the gaps between two, so to speak neighbouring "urban rays".

The first one runs directly towards the south along *Barjanska c.,* where large dwelling areas of rather low density are situated. The second one is oriented to the north-east along *Šmartinska c.,* serving industrial zones, the cemetery and further housing areas.

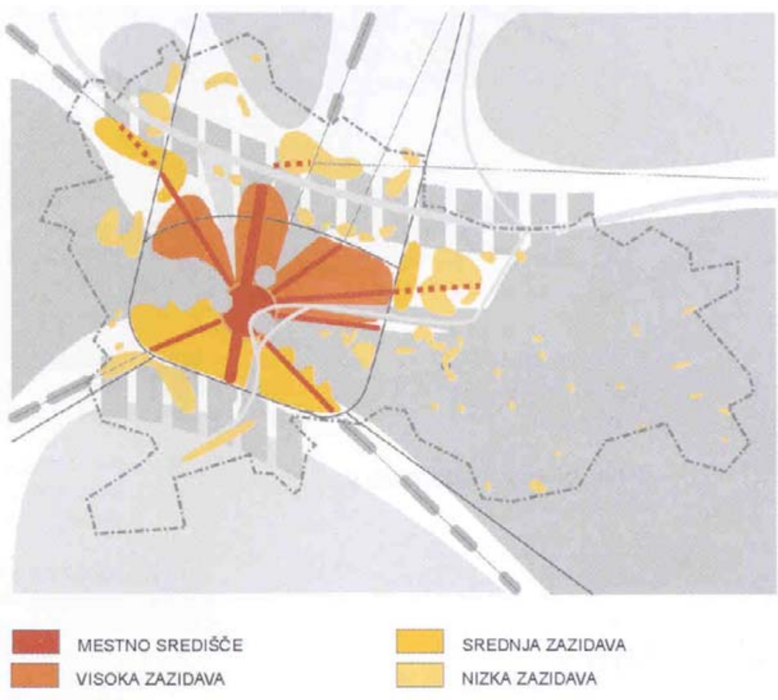


Fig. 4: The cities morphology in general respect to the surroundings. (Cerar, et al. 2002)

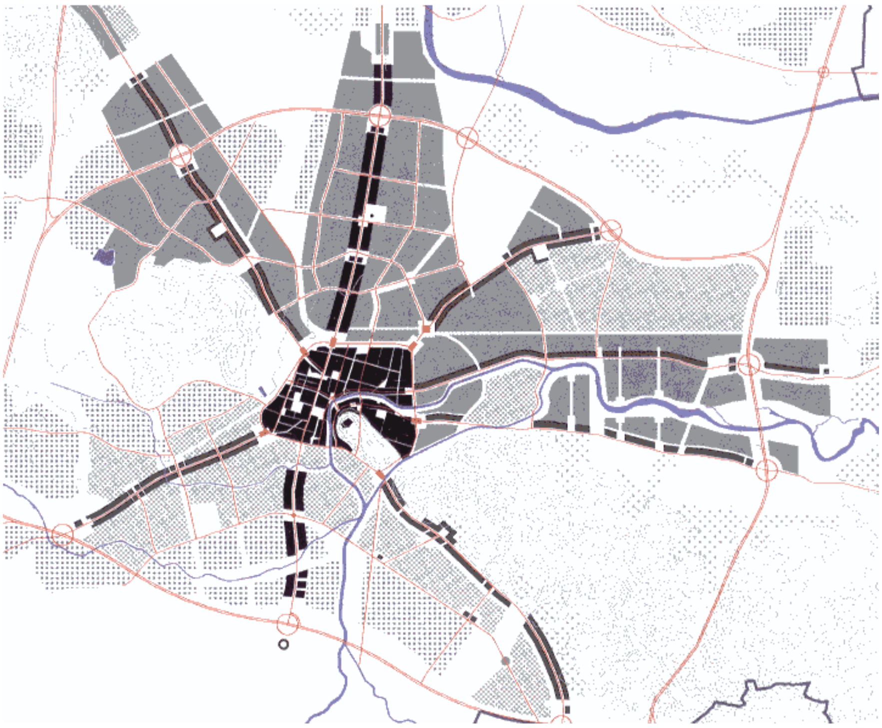


Fig. 5: The city's morphology, including future projections. (Cerar, et al. 2002)

Fig. 6: The old part of town. (photo: T. Brezina)

Fig. 7: The main urban artery *Slovenska c.*. (photo: T. Brezina)

Population

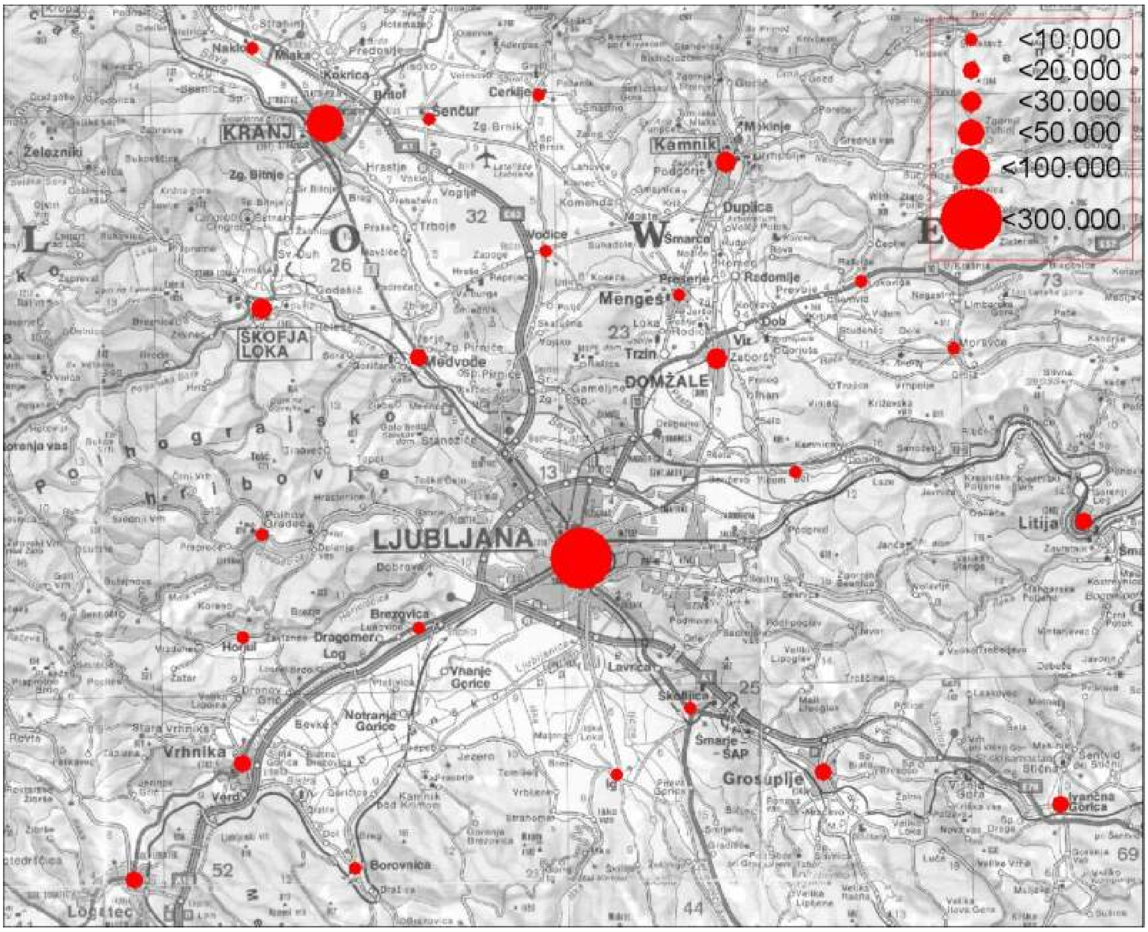


Fig. 8: The municipalities within the region and their population.

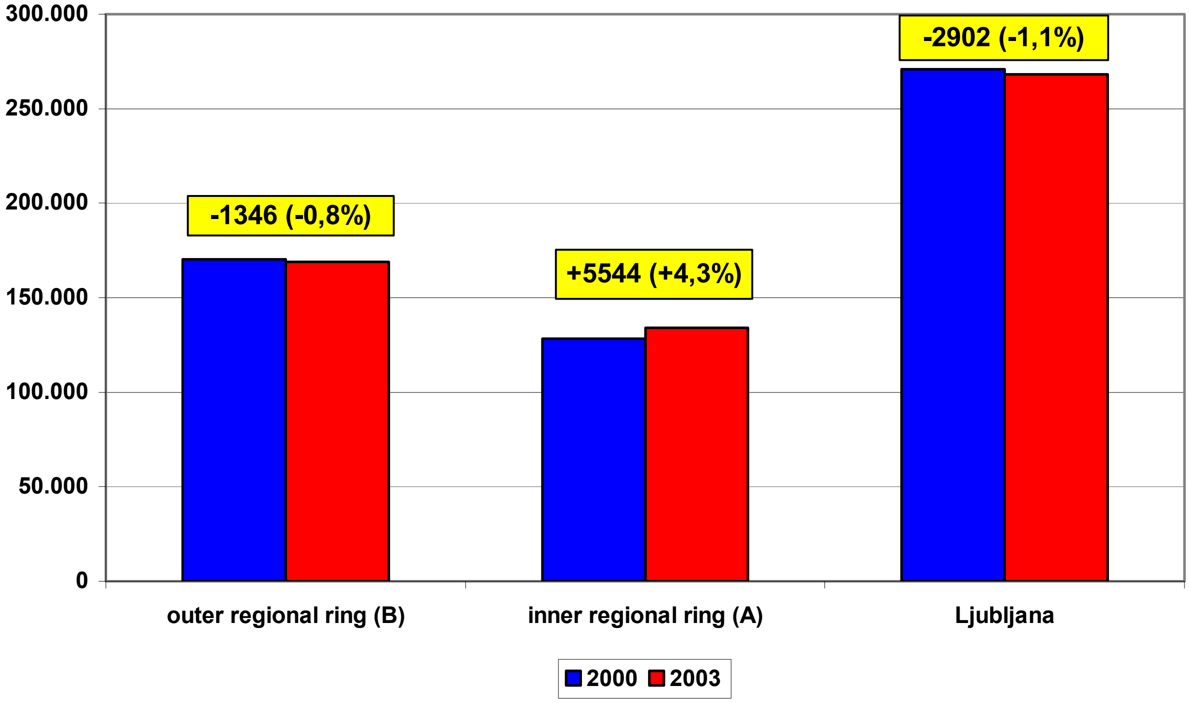


Fig. 9: The changes in population within the region, 2000 - 2003. (SURS 2001b, 2003b)

The region of Ljubljana is to be seen in two parts. One inner and one outer ring, although the arrangement does not look like strictly circular. As the region's topography is determined by the primary basin and it's hilly hinterland, the logical separation into primary and secondary region was carried out accordingly. The municipalities, respectively their name-giving main town, located in the basin were assigned to the inner regional ring. The municipalities/main town located outside of the basin, but still in the immediate influence of the nation's capital, were assigned to the outer regional ring. Fig. 8 shows the spatial distribution of these municipalities within the region. The population in Ljubljana and the outer regional ring is decreasing, whilst the inner regional ring's population is increasing. (see appendix A for details)

The effect of urban sprawl can be observed optically at Ljubljana's outskirts, especially in the northern and north-eastern parts, reaching from the town of *Medvode* to *Zalog* and in the south towards the border to the *Barje* moor.

One of the categories, where the overwhelmingly fast development of the city took place in the last decade, is definitely shopping centres. As of the late eighties there were virtually no shopping centres to be found within the municipality's borders or in the region. Let alone in other, smaller cities or rural areas. Trading and retail were mainly focused on the inner city area or along the major routes, being integrated into the existing buildings. These were almost solely small to medium sized retail stores and department stores which were to be found in the city centre.

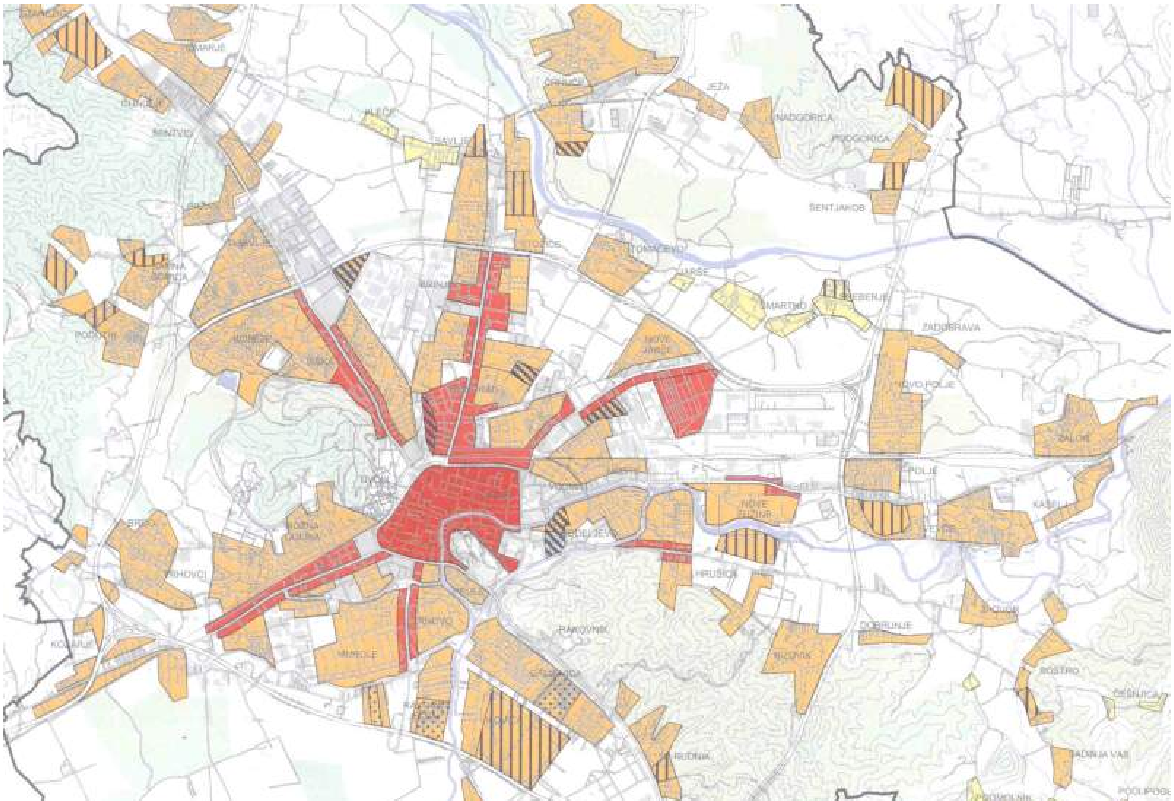


Fig. 10: Dwellings (light orange) and additional housing areas (hatched). (Cerar, et al. 2002)

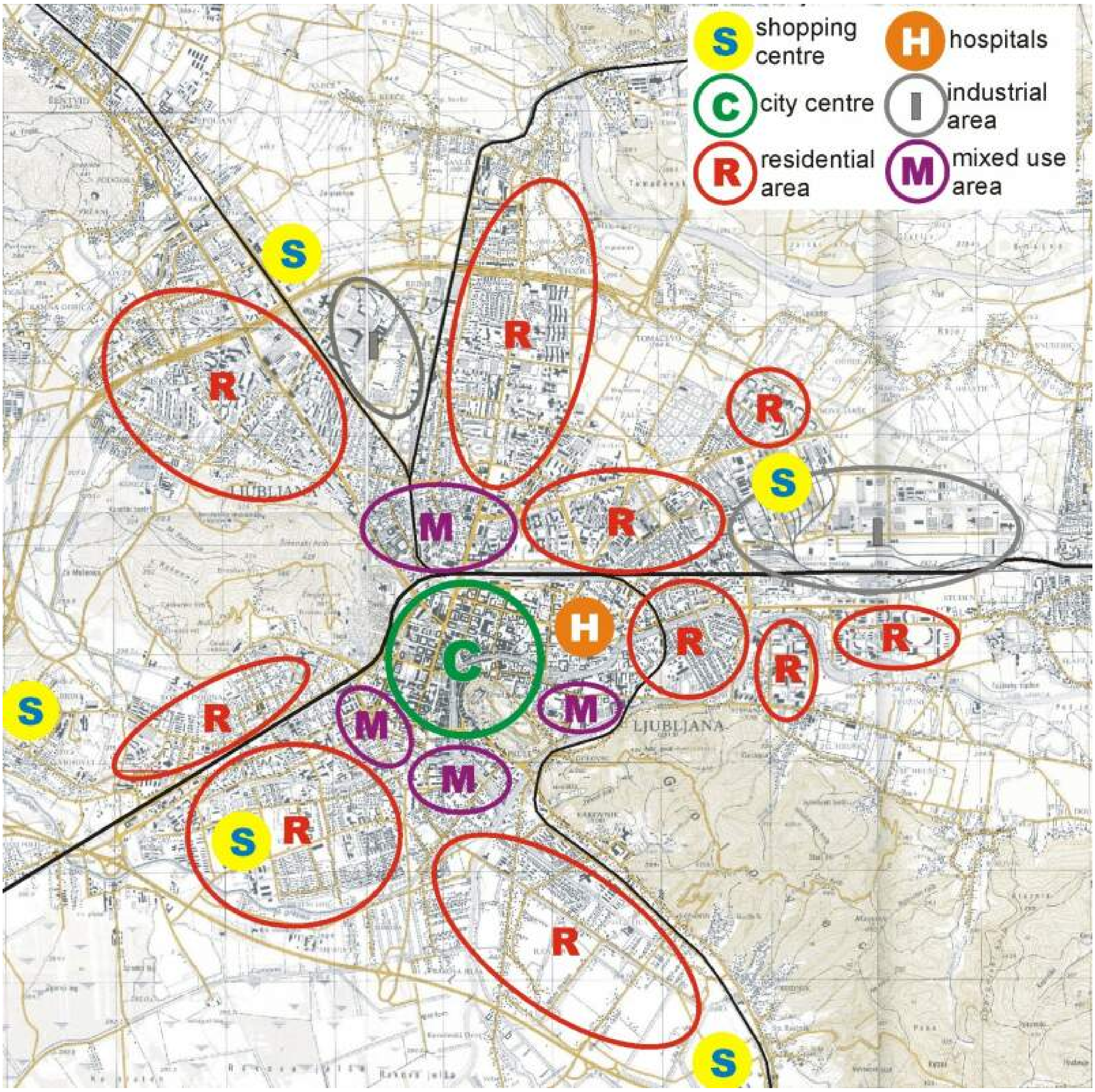


Fig. 11: Map showing a coarse arrangement of different uses within the city.

During the nineties the shopping situation changed dramatically as almost out of nothing large to very large shopping centres located outside of the homogenous city core were created. Some of them were literally build on the previously green lawns. But not all. In the north-eastern part, outside of the “secondary dwelling sector”, bordered by the railway to the south and Ljubljana’s circumferential highway to the north and east, is an large area with large warehouses. The western part is still in it’s original use. The eastern part, the so-called “public warehouses”, which were warehouses for wholesalers and have therefore a lot of street running rail tracks and customs facilities. These “public warehouses” lost their primal importance and were one by one converted to a large accumulation of shopping facilities throughout the years. Even almost all of Ljubljana’s many city located cinemas were moved to one single spot at right that “public warehouses” area. (see fig. 11)

The city's other transport modes

Along with the public transport system, which will be introduced later on (see section 2.2.2.), there are of course also other modes of transport present.

Pedestrians

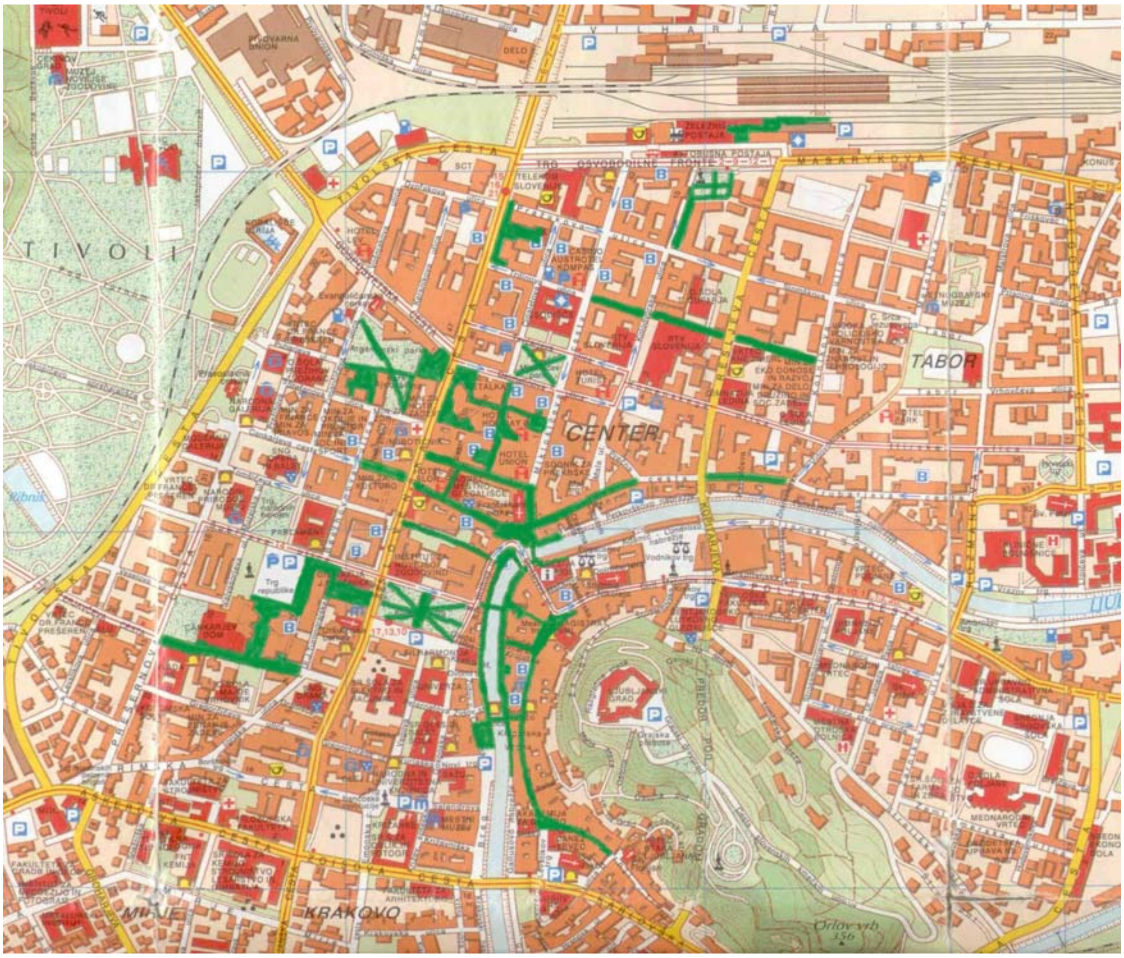


Fig. 12: Detail of city centre - pedestrian areas in green. (Inštitut za geodezijo in fotogrametrijo FGG 1999)

Ljubljana's city centre is basically very suitable for pedestrian transport as it has an medieval core, a rather large pedestrian precinct and the 18^{th} - 19^{th} century part with still rather small sized dimensions of blocks and a lot of passages. Nevertheless there are a lot barriers for pedestrians remaining:

- the wide, north-to-south running axis of *Slovenska c.* dividing the newer parts of the city centre, and in the northern outskirts, into halves; this is also valid for the other major axes;
- the river *Ljubljanica*, bordering the medieval part;
- the heavy car traffic on major roads like *Tivolska c.*, *Aškerčeva c.*, *Zoisova c.;*

- the uncontrolled illegal parking on walkways, pedestrian crossings and other pedestrian facilities like the pedestrian precincts and squares

As from the summer of 2001 on, the municipality started to approach the solution of the latter problem by introducing an inner city parking scheme based on fees, time limits and control (see Ed. Ljubljana 2001). Until then, cars parked anywhere and everywhere due to missing conceptions and lack of control, where the worst nuisance from the pedestrians point of view.

Fig. 13: Parked cars conflicting the other transport modes. (Photo: T.Brezina; Dnevnik 05.02.2002)

Cycling

In the latter half of the 1990’s and in the first three years of this decade, bicycling received some transport planning attention. From earlier years on the large streets running along the urban developmental axes included cycle paths due to the vast available widths. But they remained linear islands in a sea without any network. In the period described above, a lot of additional cycle lanes were installed/marked in various parts of the city. Due to the prevailing red colour of markings, the new cycling lanes catch attention, at least visually. They only have two, but rather annoying weaknesses.

Fig. 14: Typical cycling lanes on sidewalks in Ljubljana. (Photo: T.Brezina)

Firstly, the sometimes already not sufficiently wide enough sidewalks were often narrowed even more by the added cycle lanes. And secondly, as these cycle lanes seem to be only provisional arrangements, a lot of non satisfying sections remain. Even with missing links in the network at locations where short term solutions could not be adapted without alteration of the street layout.

Motorised individual transport

Not only in railways, but also in road transportation, Ljubljana is in the middle of the so called "Slovenian transport cross" as the national highway system's four main routes meet in the circular bypass highway in the basin of Ljubljana. These main routes are:

direction	route
north-west	A1/E63 (Ljubljana – Villach)
north-east	A10/E57 (Ljubljana – *Maribor* – Graz)
south-east	A1/E70 (Ljubljana – Zagreb)
south-west	A10 (Ljubljana – Trieste)

Tab. 3: The four highways meeting at Ljubljana.

Fig. 15: "Cross-section" of *Celovška c.*. (photo: T.Brezina)

Since the independence the focus in transportation and the accompanying construction was and still is on the national highway system (see appendix A). The circular bypass highway remained for many years an open circle with about 90-120° missing (see overview map in fig. 8), but was closed in the mid nineties. The only missing link remains the connection of the A1/E63 at it's present terminus in Šentvid and the north-western section of the circumferential highway. As already mentioned in the section on general city morphology, the major axes of urban development also represent the major in- and outbound routes for the city for individual traffic. These streets are partially of remarkable width, as can be seen in the schematic regular cross-section, fig. 17 (brackets indicate optional entity). These cross-sections are subject to some alterations, according to availability of additional space or the limitation of space. In some lengthy sections these major routes provide tree alignments. In other sections – under relatively limited width conditions – the cross-section alters too, but only the grass strips or bike paths are narrowed. No restrain is executed on the number of car lanes, which remain two in every direction.

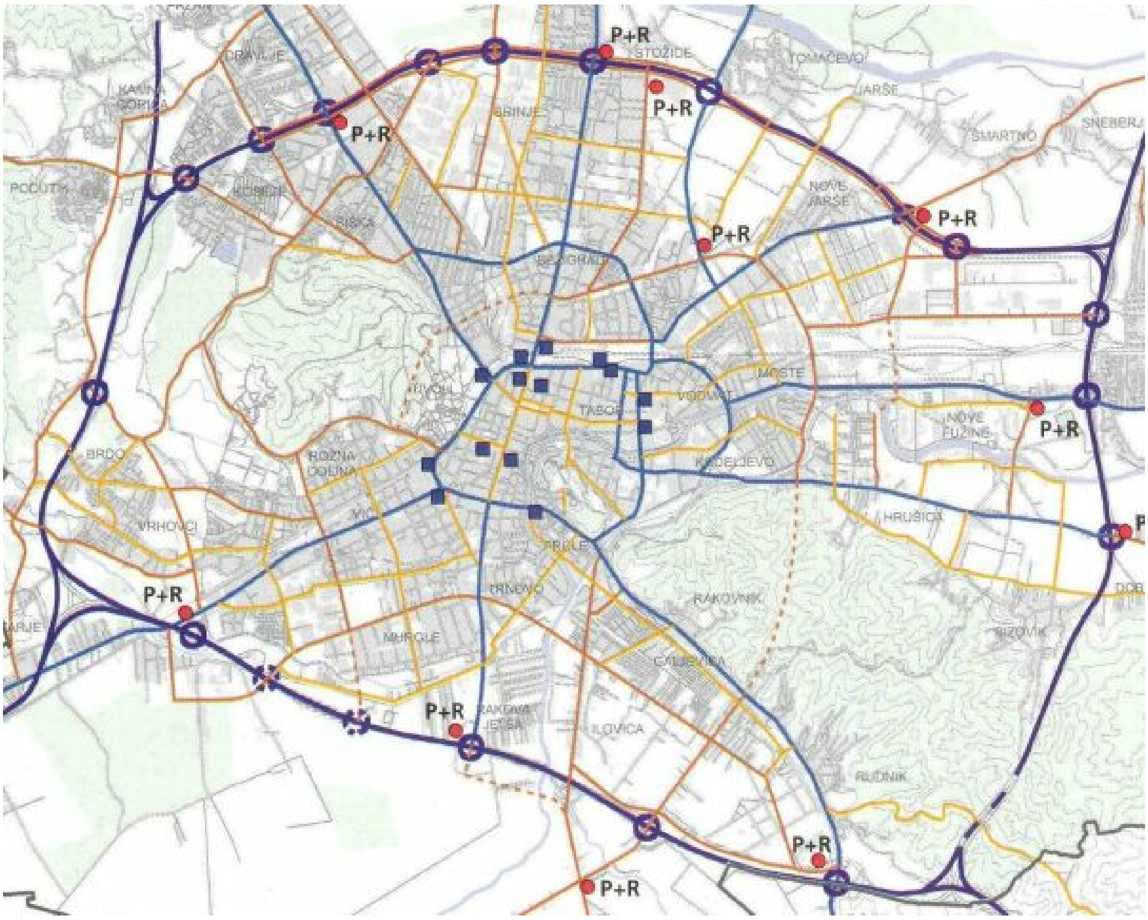


Fig. 16: The layout of the street network in Ljubljana. (Cerar, et al. 2002)

sidewalk	bike path	(grass strip)	car lane	car lane	grass strip	car lane	car lane	(grass strip)	bike path	sidewalk

Fig. 17: Schematic cross-section of in-/outbound avenues.

2.3.2. The PT system

The railway system

In Ljubljana five railway lines meet (see fig. 18). The lines to the north-west, south-west and east are mainlines and are being used by local, regional and long distance trains. Whereas on the south-eastern and northern railway only local and regional trains run.

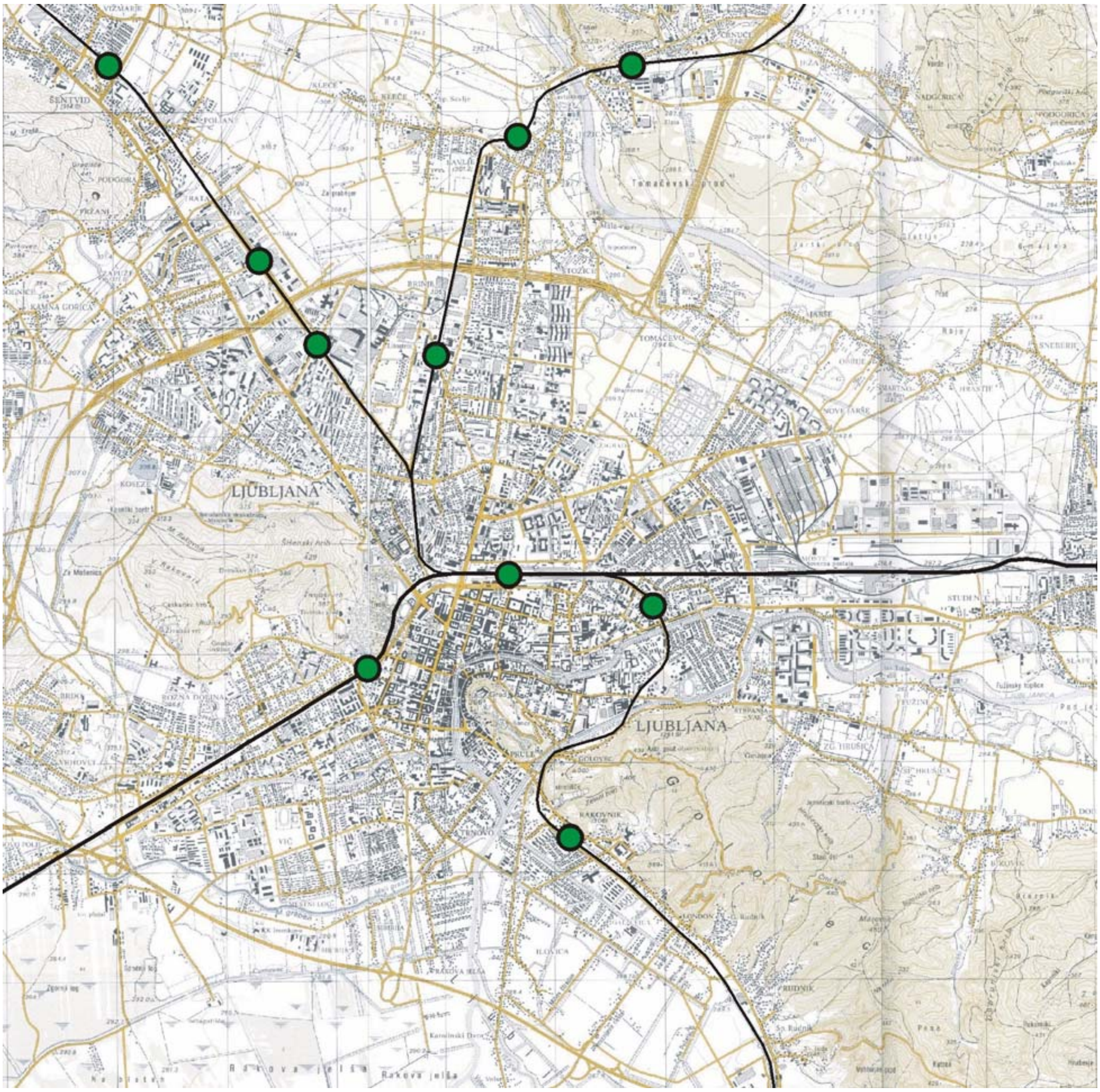


Fig. 18: Status quo of railway stations within Ljubljana's municipal borders.

As the northern branch to *Kamnik* is only 25 km long, there are only local trains running on it, with stops at all stations. This line is being serviced only on workdays. The south-eastern line towards *Grosuplje*, which extends to the towns of *Novo Mesto* (75 km from Ljubljana) and *Metlika* (122 km from Ljubljana) in the south-eastern part of Slovenia, is also serviced by regional trains. It is not a strict workdays-only line but has very limited services on weekends and holidays. As can be seen in fig. 18, the number of railway stops besides the main railway station is quite small and the distance between individual stops rather large. In addition to the low physical density of the railway stops supply, also the frequency of services in some cases does not provide sufficient service quality.

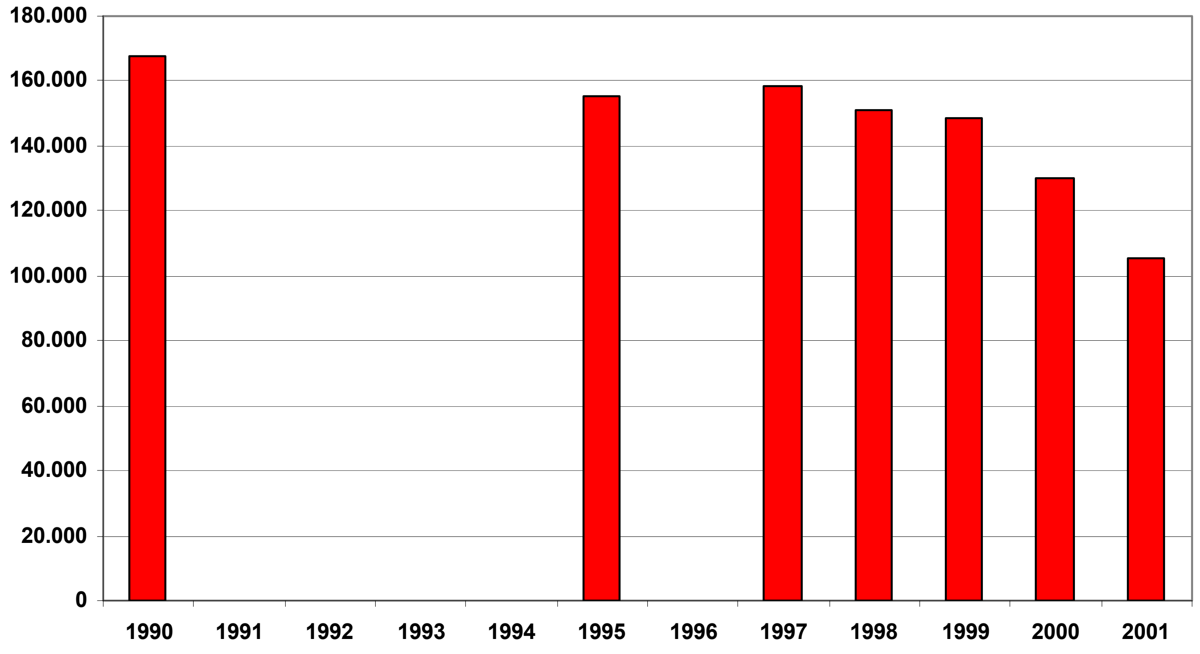


Fig. 19: Development of PT passenger numbers in Ljubljana and *Maribor* city PT. (SURS 1996, 1997, 1998, 1999, 2001a, 2001b, 2002, 2003b, 2003a)

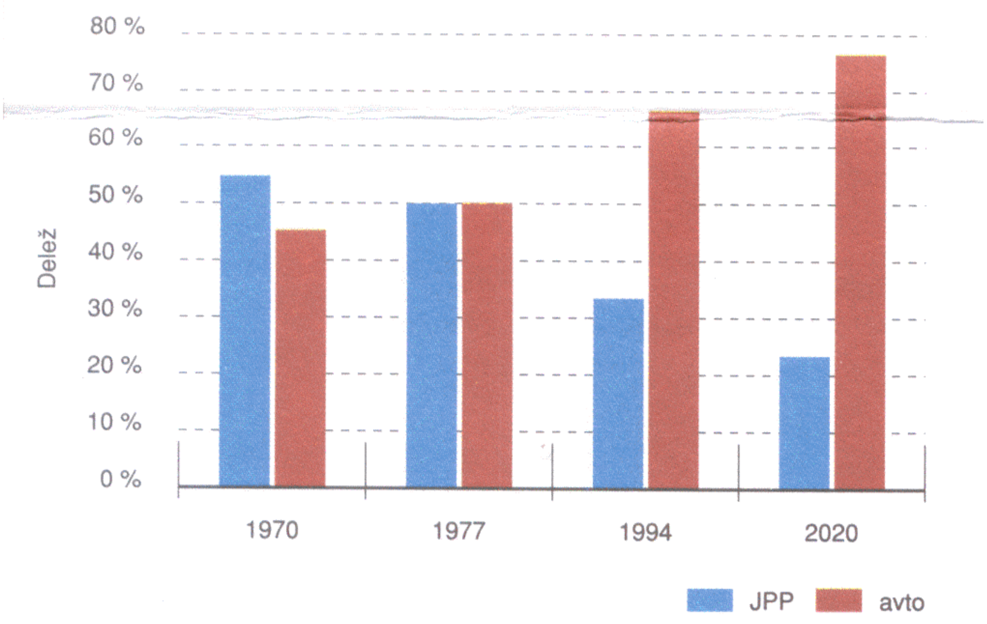


Fig. 20: Development and prognosis of shares of PT (blue) and MIT (red) for Ljubljana. (Dekleva 2002)

The regional bus system

Due to the relative lack of an efficient local and regional rail transport system, the regional bus system is developed complementarily to serve the railway free settlements of the basin and the settlements along railroads with sparse and insufficient service. These regional services start/terminate from the Ljubljana bus station which is located directly in front of the main railway station. Although the major service provider is LPP, other providers run regional bus services too. In fig. 21 the network of LPP regional services originating from Ljubljana is depicted.

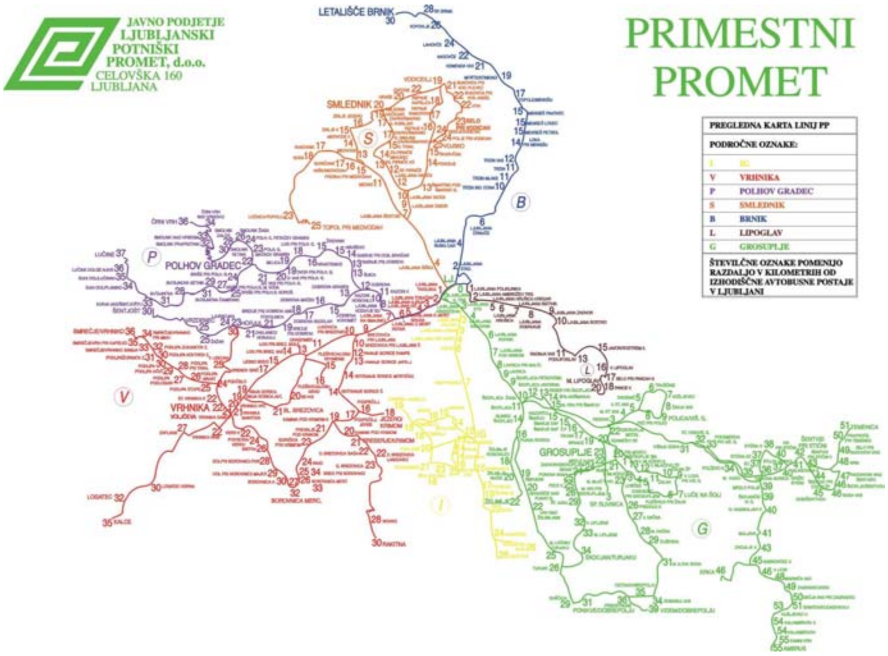


Fig. 21: The regional bus system around Ljubljana run by LPP. (LPP 2001a)

The bus system in the city

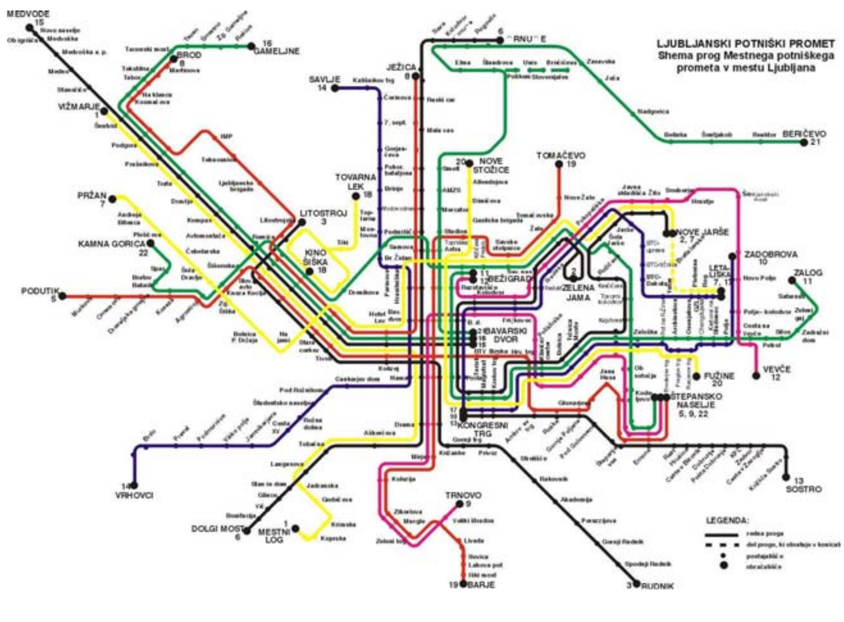


Fig. 22: Schematic map of Ljubljana city bus system. (LPP 2001a)

The extent of separated bus priority lanes, either of legal or physical nature is still rather low. Only the 4-lane main street of *Slovenska c*. running north to south has one bus lane in both directions. This legal separation is marked in the section with the strongest bus load, which is between the intersections with *Gosposvetska c*. and *Aškerčeva c.*

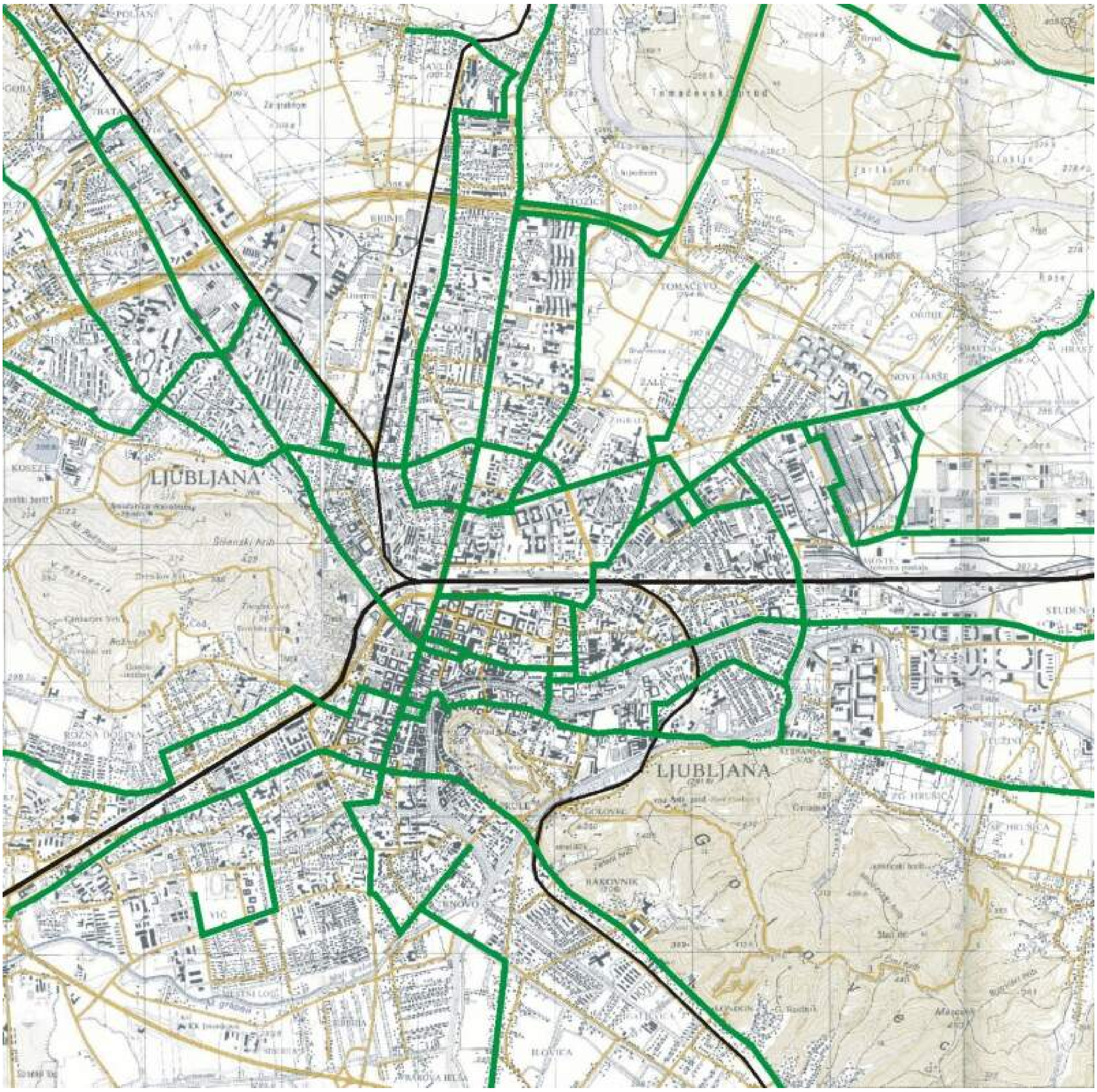


Fig. 23: Map of bus system in Ljubljana.

The bus system, serving the settlements within the municipality's borders, consists of twenty two lines. These lines are, according to the previous description of the city's morphology, predominantly radially oriented and run along these major urban axes. In the outskirts the bus lines divide and serve the settlements, which are situated off the axes. Only in the eastern parts of town this strictly radial arrangement is lightened up by some "inter-axial" connections like the bus lines 9, 10, 17 and 22. Line 22 is an exemption of the radially oriented layout from another point of view, as it is the only tangential line, running along the dense inner city's north border from east to west.

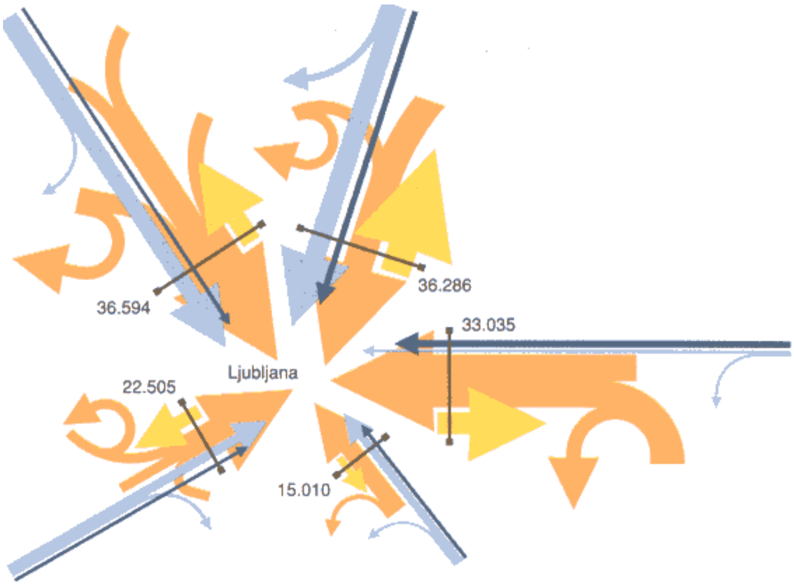


Fig. 24: Daily commuters using PT. (Dekleva 2002)

3. The planning process and methodology

This chapter gives an overview of the status quo in three fields necessary to tackle the task of planning a new tramway system for the city.

In the first section the terms of “sustainable development” and “sustainable transport” are briefly reviewed, to keep them at hand’s reach for further reference during the thesis.

The second section reviews the actual definitions of terms for rail-bound modes of city transport. This makes sense, as within this specific sector a lot of names and definitions for systems, often interlacing each other, exist.

The parameters needing consideration for the planning and design of LRT networks used in the specific literature are reviewed in section number three.

3.1. Sustainable transport planning

As this thesis sets the aim to connect the planning and design of a tramway’s network to sustainable development (for general definitions see appendix B), the terminus technicus for itself needs to be looked upon beforehand. Sustainable development has been put on the political and planning agenda with priority since the last few years. Due to the high interconnectivity between transport, land-use and city shape, the establishment of sustainable development calls for a change of urban and transport structures.

The attempt of defining the concept also shows one remarkable weakness: As a definition it is not stringent. It is a rather loosely formulated description, which can be seen positively or negatively. The positive point of view is, that the wide spanning formulation leaves enough space to adapt or engross the concept in the future according to the increase in knowledge and the ongoing evaluation, as mankind’s activity will proceed on the path towards sustainability. The negative part is, that due to the very widely interpretable nature of the issue a lot of sub-issues, which are not necessarily closely related, can be and actually are put under the auspices of the sustainability concept. Hence a lot of other descriptions of the technical term exist there, according to it’s field of application. For the field of transportation a definition is given by Tuuli 2003 (see appendix B).

This widespread nature of the sustainability definitions gives room for the actual planning approaches, where the principle conclusions of sustainable transport are acknowledged almost unanimously, but the proposed measures, like further road construction and MIT promoting measures, do not comply with the objectives set before. For objectives and envisioned, general measures set for Slovenia (DZ-RS 1999, MOP 2002, MPZ 2003) see appendix B.

3.2. The tramway system and its variations

3.2.1. The tramway renaissance

Since its invention in Berlin in 1881 (Taplin 1998) and the following rapid expansion of lines and services in many cities around the world, the classic, electrically powered tramway, had a rather stormy history. This history included, after the highflying years until the 1920's, a decrease in systems, lines and services – with some delays like during WWII – of the street-running rail city transportation in many cities and almost led to its extinction. (Yago 1987, Bratzel 1997, Dienel, et al. 1997, Schott 1998, Taplin 1998) and other authors describe in detail this dramatic development from different points of view and with different focuses. Some countries were affected more severely than others. Mostly those countries with planned economies like Russia, East Germany and Czechoslovakia were able to keep their networks.

Year	City
1978	Edmonton
1980	Newcastle upon Tyne
1981	San Diego, Calgary
1983	Utrecht
1984	Buffalo, Genf (low floor)
1985	Nantes, Tunis, Manila
1986	Portland
1987	London/DLR, Sacramento, Buenos Aires, Grenoble
1988	Hong Kong
1989	Guadalajara
1990	Los Angeles
1991	Lausanne, Pyongyang, Silicon Valley
1992	Manchester, Paris/St. Denis, Baltimore
1993	St. Louis
1994	Sheffield, Strasbourg, Rouen, Valencia, Denver
1996	Dallas
1997	Saarbrücken, Sydney, Paris/Issy
1999	Salt Lake City, Birmingham, Stockholm
2000	London/Croydon, Orleans

Tab. 4: New LRT-systems (LRTA 1997, Scheurer, et al. 2002, Thomas 2002; Topp 2004)

According to (Scheurer, et al. 2002) about two thirds of tramway and light rail systems nowadays in operation world-wide can be found in communist and ex-communist countries. One remarkable exemption within the market economies is the previously western part of Germany, which despite of all the massive closures still managed to keep numerous systems alive and active. But technology oriented transport planning of the 60-80ies removed the tram from the inner city streets into the underground and in the suburbs LRT lines often became real heavy rail lines. The German variant "Stadtbahn" was born.

Although the tramway was almost written off, the renaissance of it started and rail-bound, street-running PT began to reconquer the cities. The year 1978 is by many authors (Taplin 1998, LRTA 1997, Scheurer, et al. 2002) considered as some kind of turning point in tramway evolution. Although the majority of systems was closed down or trimmed down by the late 1960's, the closures did not stop before 1978, when the last system of a major city was removed from Hamburg's streets. In exactly the same year also the first all-new system was introduced to a city, namely Edmonton in Canada. Shortly afterwards a new period of promotion for tramways started. This rediscovery has been implied by the beginning realisation within the responsible circles, that the cities' transportation problems could not be solved by reshaping the cities for exclusive car use. Tab. 4 shows an overview of the most important systems introduced since 1978.

Currently in 35 cities of the EU-15 new lines are being built or existing lines extended. Further 74 cities are planning new lines or extensions. 59 completely new systems in cities without LRT are either being planned (41) or built (18). (Dauby 2004) Tab. 5 gives an overview of the situation in Europe, organised according to the European Unions' actual and near future size.

countries	systems		lines		route length	
	[nr.]	[%]	[nr.]	[%]	[km]	[%]
EU-15	107	63	448	48	4793	59
joining EU	30	18	349	37	2240	28
outside EU-25	33	19	144	15	1027	13
total	***170***	***100***	***941***	***100***	***8060***	***100***

Tab. 5: European LRT systems. (Dauby 2004)

3.2.2. Rail-bound public transit modes in the city

As an LRT oriented introduction it can be said, that basically four different subvariants within the range of LRT systems exist (Besier 2002):

- classic tramway with extensive networks, partially modernised (e.g. Wien, Zürich, München, Toronto, Amsterdam, Praha, Budapest, St. Petersburg, …)
- new built, surface running LRT on few urban axes (e.g. Strasbourg, Montpellier, Nantes Grenoble, Houston, Los Angeles, Salt Lake City, …)
- new built LRT with sub-surface sections on few urban axes (e.g. Stuttgart, Hannover, Ruhrgebiet, Frankfurt/M, …)
- tram trains or regional LRTs, running as tramway within the city and on heavy rail tracks in the region (e.g. Karlsruhe, Saarbrücken, Portland, San Diego, Denver, Manchester, …)

The tramway's boundary conditions of operation within other means of transport are depicted in fig. 25.

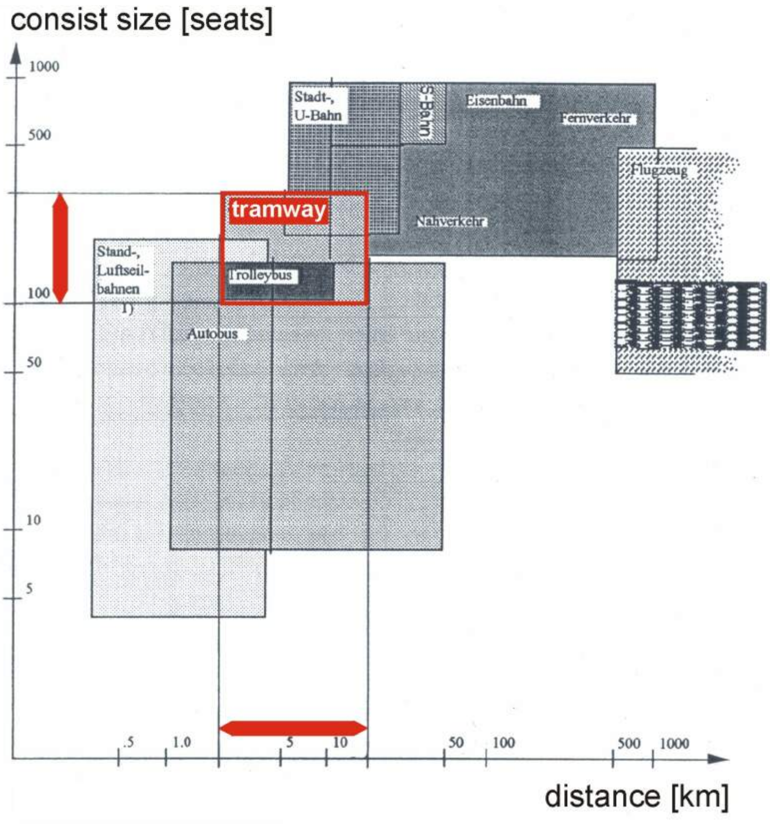


Fig. 25: The tramway's/LRT's range of use. (Brändli 1995)

The original streetcar systems had predominantly single cars running on tracks completely included into the street pavement without any separation from other modes. When the tramway had it's blossoming era, it logically had no competitor to fight for space, so it was without any problems running in the streets. As motorised individual traffic on a larger scale emerged, and therefore transportation planning's focus shifted on automotive traffic, the old tramways, which in many places had not received any modernisation at all, were only seen as an street blocking obstacle to the all new, all fancy and soon to be affordable for everyone car. In some cases the tramways were removed from the cities completely, starting line-wise, in other cases the trams were banned below the surface, at least within denser city sections, to be no hindrance for the individual surface transport anymore. These displacements started in the USA as early as in the thirties, in Europe after WWII.

Due to the above mentioned renaissance, which is the result of the slowly, but steadily spreading realisation that LRT is better compatible with the city than increased, further MIT promotion, a lot of improvements to the old systems were made from the year 1978 on. These improvements were regarding systems, ROW's, stations, vehicles, operations, etc. and quite often lead to almost new PT modes. Some examples are:

- at grade separation of ROWs for car and streetcar;
- new vertically separated ROW's for streetcars, passing over (bridge, dam) or under (tunnel, trench) some alleged or real obstacle;

- increase of mode separation to almost 100 % in some systems or along designated lines or line sections;
- lowering of vehicle entrance heights and rising of curb-side stations;
- increase in vehicle size due to articulated cars or multiple car consists.

These and many other changes, improvements and inventions also lead to numerous technical terms for rail-bound transportation derived from the original streetcar concept. These technical terms may vary according to region, continent or language (e.g. Anglo-Saxon vs. German). Fig. 26 shows an organisational scheme of different means of PT with the light rail path highlighted.

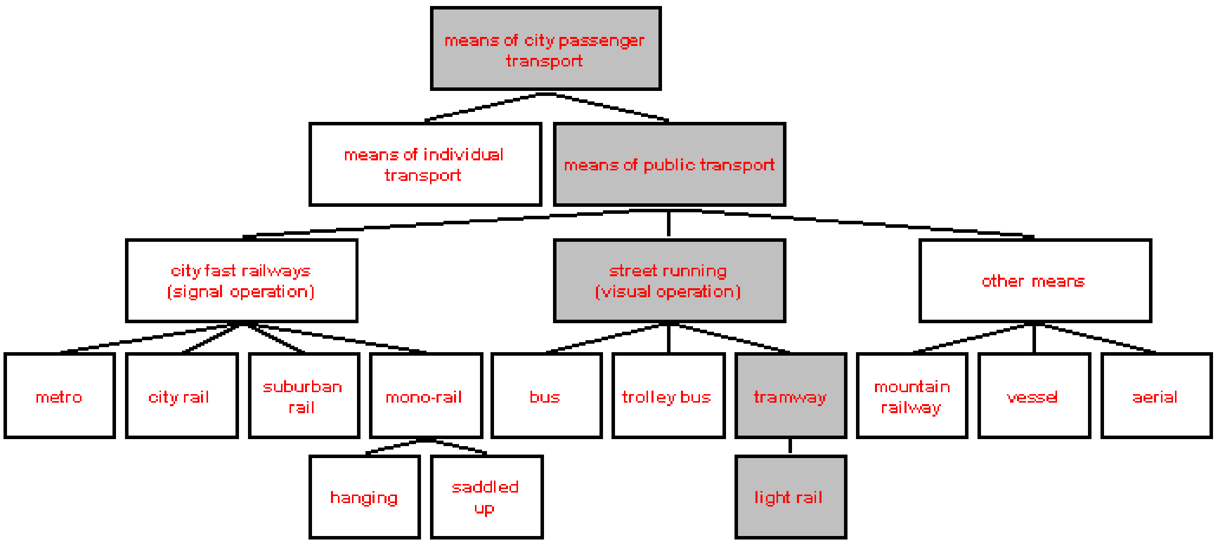


Fig. 26: Scheme of public transit. According to (Rüger 1986)

Tramway

Its other names in use are also "streetcar" and "trolley car" and it refers mainly to the "age-old" concept of single cars running almost entirely in the street area on road-dependent track embedded in the road itself. There is no physical separation of ROWs for trams and car lanes. (VDV, et al. 2000)

> *"The predecessor to the LRV. Used to describe a steel tired vehicle that operates in mixed traffic only. ..."* (lightrail.com 2003a)

According to (VDV, et al. 2000) other typical features of tramways are:

- visual operation in a manual mode;
- stops are at ground level or with low level stopping islands, capes or platforms;
- short tunnel sections may be in use to "avoid" infrastructure bottlenecks.

Light rail

According to (Fox 1978, VDV, et al. 2000, lightrail.com 2003b) (for definitions see appendix section B) light rail transit is the evolution of the old tramway in terms of alignment, ROW, capacity, vehicle, ride comfort and others.

As (Topp 2004) states, the key feature of light rail is not the supposed very low weight of cars and train consists, but the incredible flexibility of network layout due to the increased ROW possibilities. Tab. 6 shows the LRT's specific weights within the range of different styles of urban transport.

vehicle	specific weight [t/m²]	specific weight [t/PAX]
bus-tram	0,41	0,12
LRT	**0,50**	**0,20**
metro	0,50-0,52	0,19
suburban rail	0,55	0,20

Tab. 6: Specific weight of different PT types. (Topp 2004)

Tram-train

To provide public transportation without the need to transfer from one rail-bound mode to the other, tram-trains were invented lately. They are the combination of the best of both worlds. A tramway or light rail system of a city is linked with the heavy rail system within the city or only branches of it. This makes it possible to provide services from towns or villages situated along a heavy rail track in larger distances from the city to be directly and attractively connected with points of interests in the city, without the de-attracting procedure of transfers by passengers.

It has to be pointed out repeatedly, that tramway, LRV and tram-train are systems and modes of operation with very common similarities and soft transitions in between. Karlsruhe, Saarbrücken and Chemnitz are three examples of already implemented or soon to be implemented systems in Germany, where this tram-train philosophy is being used very successfully. Karlsruhe has been the focus of development, therefore the tram-train concept is also being called "Karlsruhe principle".

For further city rail definitions see appendix B.

3.3. Parameters and principles connected with LRT planning

Due to the strong technology orientation of classic transport planning up to now, the human needs and the travel behaviour have been put aside. But urban sustainable transport planning requires the human being and its liveable environment to be put into first place again. The city primarily serves as the place where people live and work. Therefore, to achieve the maximum possible quality of life for all citizens, the transport system needs to be compatible with the inhabitant's and the city's needs. These needs are fresh air, safe living space streets, quietness and visually pleasing cityscape on the one hand and certain possibilities for travel on the other. These demands can be achieved by an quality public transit system, that includes the according structural changes of the built environment as well, and other forms of soft mobility. Due to the fact, that human travel behaviour is determined by the urge to minimise human energy expenditure (see Knoflacher 1996), the PT system needs to be designed accordingly. This means that the access to stops needs to be short - which means a high density of stops in areas of high density uses - and invitingly designed.

The implications of a transport system covering the city are very complex, as it has to cater for different needs. There is firstly the supply of transport services for city inhabitants, but then there are others like the interaction between the integration into and the shaping of the city structure and form, then the impact on the environment including the residents and other fields, which are being influenced by the transport system. So the implementation of LRT into a city means a drastic change to the covered area and also its neighbouring areas. Whenever and wherever the intention to plan, design and implement LRT arises, an extensive number of questions, considerations and problems needs to be viewed at carefully.

Aims

LRT implementation example objectives (Fox 1978):	Twin Cities LRT regional goals (Dallam, et al. 1982):	LRT Strasbourg objectives (eaue.de 1996):
• capture a larger share of total transportation market • establish an infrastructure to guide future planning and land-use decisions • develop transport infrastructure that can function effectively in a range of future energy and transport situations • support national environmental goals • reduce the need for automobile travel	• good accessibility to regional and subregional opportunities • efficient, convenient and attractive choices of transportation • utilise transportation to strengthen the two downtowns … • provide transportation facilities and services that produce positive impacts on the social, economic and physical environment	• increase green areas • increase non-motorised mobility • reduce car dependent mobility • reduce car parks • reduce energy consumption

Tab. 7: LRT objectives chart.

The implementation of a LRT system is seldom seen as a stand-alone measure. It is almost always one part, although always one of the biggest, of a general transport plan covering the city, the whole conurbation or even the surrounding region. Within these conceptual blueprints, objectives, that are desired to be achieved by implementing the plans, are usually named. The chart in tab. 7 provides three different examples, wherein the first entity is not project related, but stems from a general paper dealing with LRT implementation. The remaining two give "real life" objectives used in projects.

Benefits of LRT in general

The benefits of LRT are by many authors outlined in general, before specific properties are dealt with. This is often done in the quite frequent debates, if the LRTs abilities could not be achieved with buses at presumably lower operation costs. (Felz 1989, Schmidt, et al. 2001; Schmidt 2003, Besier 2002, Heinemann 2003) for example name (see also appendix B):

- Ability to become the future mode of city PT;
- Integration of tracks under different widely varying conditions;
- Higher capacity than buses;
- Implementation is mostly gain for environment and the town's living quality;
- Improvement of PT Network in the city with all its side effects leads to a rise in city image;
- Ability to connect the city and the towns within the region on, e.g. previously unused track;
- Increase of service value of route by rehabilitation and installation of stops serving new developments.

Classifications

Although every passenger within a complex PT system experiences all the modes used by him as important and therefore all system parts are to be considered important, a classification regarding importance exists in classic transport planning. This classification is strongly technology oriented, as the speed of travel and separation are the determinants for superiority or not, and therefore must not comply with sustainable development points of view.

- superior to LRT: metro, S-Bahn/commuter- or suburban rail
- subordinate to LRT: walking, BUS, B&R, P&R, … as feeder systems

When considering network construction, at first and foremost stands the classification of the project relating to the existing PT structure. There three basic cases of LRT network works and improvements can be distinguished:

1.) The **elongation of one or more lines** in a city that already has an existing tram/LRT network of larger or smaller extent.

2.) The **construction of one or more new lines** also in a city with existing network.

3.) The **creation of a brand new tram/LRT network**. These cities already have as a rule other different means of PT, like bus networks, commuter rail or metro according to the size. E.g. the LRT is supposed to replace major bus corridors or to operate jointly with existing rail modes. As mentioned later on (see modularity section in appendix B) this network construction normally starts with individual lines. (Other method: in Bordeaux, 3 lines in the CBD with radial extension in stages.)

The classification of planning parameters in this thesis will be as follows:

1. customer relations	2. spatial entities – network
• transport supply • handicaps and barriers • “rail-bound bonus” in comparison to bus • ride comfort • safety	• size and morphology of the city • catchment area • passenger potential • spatial ROW alignment in comparison to the city structure • stop spacing and distribution • system breakdown safety
3. integration into the city	**4. economic aspects**
• surface design • city structure redesign • attractiveness of stop access and egress • preferential treatment within the transport system • environmental impact • use of space • transport capacity • influence on the modal split • right of way	• costs • economic effectiveness

Tab. 8: Classification of parameters within this thesis.

3.3.1. Customer relations

By customer relations all factors influencing the direct relation LRT and riders are meant. This includes: transport supply, handicaps and barriers that are maybe to be found, the “rail bound bonus”, the ride comfort and safety concerns.

But it’s not only the relation of riders already using PT, it’s also the public awareness of the system, besides the physical and layout issues (see 3.3.2. and 3.3.3.) for potential users. The better formed the public image of the LRT is, the more respected it is and the more likely it will become a means of transport used not only by captive but also by choice riders.

How important a public information campaign, freeing the people of anxieties of something new and clearing up misunderstandings regarding safety or noise concerns, is, shows the example of Nottingham. There during the construction period a information campaign was run so relentlessly, that “…there was no citizen in Nottingham who is unaware of what’s happening.” (Debell 2004)

If the city approaches it's citizens the right way, the effort shows off in public support, as the two following examples may show. In both cities of Grenoble and Nantes about 50 % of the population was "pro construction" of a new LRT system. Then after construction, a few years that the transport systems got into practice and the LRT started to expand its influence on the inhabitants lives, the "pro" share soared to almost full approval. (see tab. 9) That environmentally sound transport is a topic touching the people, especially the young ones, shows the example of Luxembourg, where 7 5% of young citizens (18 – 24 years old) said "yes" to a LRT system for Luxembourg. (Mouvement Ecologique 1999)

city	pro LRT before introduction	pro LRT after introduction
Nantes	< 50% (1983)	93% (1993)
Grenoble	~ 50% (1985)	91% (1992)

Tab. 9: Change of public approval. (Mouvement Ecologique 1999)

3.3.1.1. Transport supply

Besides other factors, LRT has one incredible advantage. It is the faster availability of LRT in comparison to metro or other sub-surface systems, the time from planning decision to start of operation takes for LRT from **1 year** up, for the metro about **10 years**. (Jahn 2003, LRTA 2003)

By means of LRT the transport supply of a city, for example with an attractive alignment within the settlement's structure, can be extended over the city's primary borders using different innovative concepts of mixed operations. This enables to provide attractive connections within the dense city itself and from the city into the agglomeration and vice versa. By this in an agglomeration a first, competitive option to car usage can be provided. (see also catchment area section 3.3.2.2.)

Besides all that, there is the option to provide possibilities for "special operations lines" to outstanding locations with high part time passenger (PAX) potential. (Käfer, et al. 1994) E.g. to recreation areas, fairgrounds, large or central cemeteries (Nov. 1st and 2nd), sports arenas, large concert facilities, etc. "Special operations" lines are lines, that do not run in everyday service, but only at special occasions. They interconnect different branches, previously not serviced together, as "widespread" feeder or distributor services without the need of transfer between lines.

These options therefore need to be considered in the primary stages of network design to be implemented. For instance at ROW crossings of different lines switches and/or "loops" need to be provided, which are used only by these "special operations lines" or in emergency or maintenance cases. (see alignment section 3.3.2.4.)

Details for the decisive considerations of providing

- a competitive travel time and sufficient punctuality;

- an attractive timetable

can be found in appendix B.

3.3.1.2. Handicaps and barriers

Handicaps and barriers can be found in a wide variety of appearances and should be treated with due importance as they often decide, if a LRT supply is being accepted or not:

- physical barriers
- organisational barriers

These barriers can be either of qualifying or non-qualifying nature. Qualifying barriers are barriers that exclude one or more groups of actual or potential users. Non-qualifying barriers do not exclude someone from participation, they are handicaps that make using the LRT annoying and troublesome. Usually qualifying barriers tend to be physical ones. (see appendix B)

3.3.1.3. "rail-bound bonus" in comparison to bus

In Würzburg one examination's findings were, that the LRT system was used by 24,5 % choice riders in comparison to 17,5 % in buses.

In Nantes 16 % of tram users never used PT before the tram was introduced. Regarding the choice riders it was found, that 39 % of riders would have a private car at their disposal. (LRTA 2003)

As some of the examples in the passenger potential section (3.3.2.3.) and the two examples above show, the introduction of LRT increased the patronage numbers of previous bus services. In comparison to bus services a higher potential of PAX, especially of choice riders, can be activated due to rail-bound transport (Käfer, et al. 1994) - some kind of "rail-bound bonus" (German: Schienenfaktor, Schienenbonus) exists.

As (Schmidt, et al. 2001; Schmidt 2003) reports, the experience from cities with already re-introduced LRT – mostly instead of one or more bus lines – shows that even the prognoses of LRT ridership, usually higher than the buses' ridership, are almost always being topped by at least 20 percent. This increase can be expanded by running time decreases, upgrading of the townscape, limitation of motorised individual transport (MIT) and the decrease of interchange constraints. Why is that?

Most authors explain it by a continuous optical presence of the PT through the ROW in the cityscape, calling the other transport participants' attention. (Käfer, et al. 1994) The cityscape at the stop and its immediate surroundings is impacted by the existing ROW - the tracks vanishing to both directions into the city - the presence of the PT is secured, without a vehicle being at sight. (Schmidt 2003) Where tracks are lying, there usually a regular service is provided. This physical presence of LRT tracks, gives the opportunity for orientation coupled with security and overview for pedestrians. Furthermore it raises the area or street in importance, because tracks are not to be found in other subordinate areas and tracks are usually running as a backbone through the city and lead inevitably to focal points of urban life. (Besier 2002) In comparison to buses sharing their ROW with private cars on lanes, a LRT alignment is also the manifestation of transport policy priorities, emphasis and political will visible for everyone.

3.3.1.4. Ride comfort

A passenger expects to experience very high ride comfort. This means:

- a quietly running vehicle;
- comfortable seats and sense pleasing interiors;
- a smoothly running vehicle on a continuous and harmonic ride.

With better sound insulation of vehicle, self greasing rails, radially adjusting wheels - abolishing or minimising the small radius squeaking (Käfer, et al. 1994) – all this has been achieved recently by new technology vehicle side. But ride comfort and running-calmness of an improved vehicle can only work in union with a state of the art infrastructure. A harmonic and speedy alignment without irregularities, with exact and long lasting rail positioning and regular rail maintenance are required to take advantage of new and improved types of ROW.

3.3.1.5. Safety

As LRTs improve public life at their stops and by pedestrianised areas, also the subjective security feeling of passer-bys and pedestrians during off peak times, especially in the evening and at night, resulting from interplay of social security/control of different street life participants, is improved.

Two basic cases have to be distinguished:

- **the safety of pedestrians moving next to the ROW**

In the comparison LRT ROW vs. car lane the LRT proves to be less dangerous for pedestrians. Simply from the fact, that the number of vehicles is lower and by this the density of potential incidents and the likelihood to hit into a tram.

- **the safety of passengers using the means of transport**

The most important task regarding safety is to keep ROW free of third party users when LRV passes through. For completeness sake, it is only then strictly needed. It need not be free in between LRVs. (Brändli 1995) (for examples see appendix B)

3.3.2. Spatial entities – network

The network of a properly designed public transport (PT) system should be the physical reflection of the major relations and travel demands. But as the provision of transport services and settlement structure, and with it the lack or existence of trip origins and destinations, influence each other reciprocally (Knoflacher 1996), network design cannot be seen only as a means of feeding demands, but also a means of steering and shaping them.

According to (VDV, et al. 2000) there are three basic requirements for LRT network planning, that need to be considered.

1. The sum of trip times for all journeys within the network should be kept at a minimum.	$\sum t_{TRIP} \rightarrow \min$
2. The proportion of journeys requiring transfers between different lines and modes should be kept at a minimum.	$\sum T \rightarrow \min$
3. The sum of vehicle-kilometres, as a measure of the system's required performance, should be kept at a minimum.	$\sum vkm \rightarrow \min$

Tab. 10: Basic requirements for LRT networks. (VDV, et al. 2000)

The first and the second of this three requirements are also the most important regarding interaction with and attraction of passengers. Because human travel behaviour is determined by the differing, but mostly negative perception of access times, transfer times and walks, these need to be minimised. The PT planning credo of the 1960-80ies was to increase running speed of rail bound PT – and to clear the surface of PT obstacles – by any means. And this very often meant the transfer of surface running services below ground. But in the last decade the realisation, that neither the vehicle's maximum speed, nor it's commercial speed are relevant for the transport market, "starts to take place". (Brändli 1995)

For details see section 3.3.2.5.

3.3.2.1. Size and morphology of city

Although the shape, size, topography, spatial distribution of uses and other descriptive qualities may differ from case to case, some index values for a rough estimate of application and applicability exist. The chart in tab. 11 from (VDV, et al. 2000) gives an overview in extracts of selected urban properties for different categories of rail bound PT. Special attention needs to be paid to population circumstances, i.e. densities and absolute numbers.

The morphologic characteristics of a city are mainly resulting from the topographic boundary conditions to be found in and around the location, like: shores, mountains, ground inclination, waterways and other existing or missing constraints to city development. In many cities this morphology has been significantly shaped by motorised transport. Line oriented transport, i.e. railways stimulated axial orientation while automotive transport pressed ahead the spatial development. This results in one significant statement (Fox 1978), that by contrast to major route networks, a PT network tends to have a strongly radial form with weaker circumferentials.

		similar to tramway ◄──►			similar to metro
		category 1	category 2	category 3	category 4
city and travel demand classification	size	small city	medium city	large city / conurbation	metropolis / conurbation
	population [million]	**0,2 – 0,5**	**0,5 – 1,0**	**1,0 – 2,0**	**2,0 – 5,0**
	population density in corridor [inhabitants/km²]	2.000	3.000	5.000	8.000
	15km corridor PT demand [patronage/weekday]	30.000	60.000	100.000	>160.000
	feeder traffic demand [patronage/weekday]	5.000	15.000	25.000	>40.000
criterion for category choice	min. specific weekd. transport performance [pkm/line-km]	2.000	5.000	10.000	>15.000
guideway	ROW alignment: [%] vert. separated/shared/separated	0/20/80	5/10/85	20/0/80	>50/0/<50
stations	avg. spacing [m]	500	600	750	1.000
operation	max. capacity [PAX/h/direction]	13.000	18.000	31.000	48.000

Tab. 11: City size and type of rail bound transport. Excerpt from (VDV, et al. 2000)

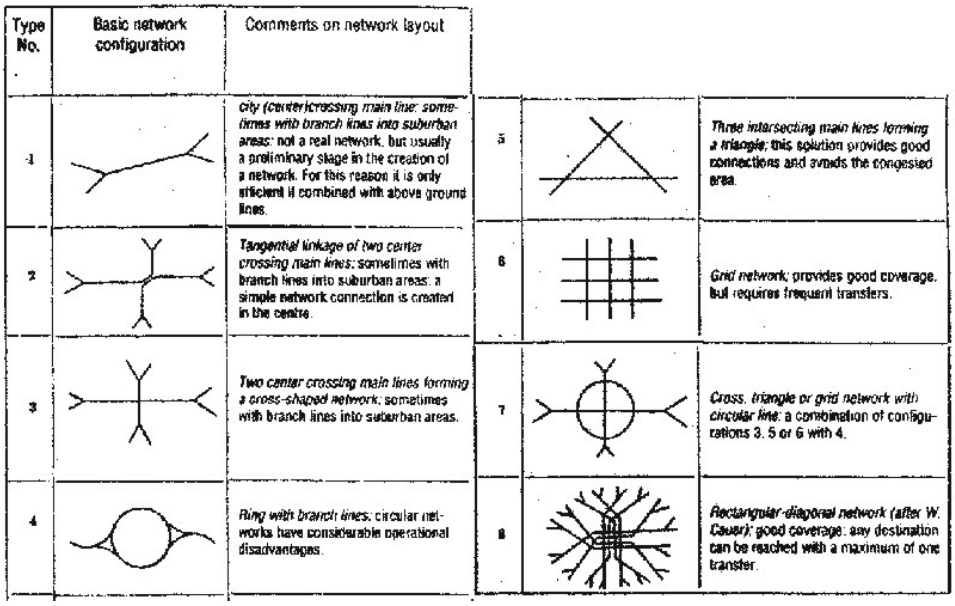


Fig. 27: Typical schematic network layouts. (VDV, et al. 2000)

As the chart above shows, metro like transport means should be used exclusively in areas with sufficient population densities and absolute numbers, to provide satisfactory patronages. Following this, (Groneck C. 2004) states, that LRT instead of metro makes by all means sense in a flat and spacious urban structure of the agglomeration without distinct urban axes. Provided that there are sufficient indexes of population for LRT available.

As will be discussed later on in this thesis in detail, is the alignment of the LRT line within the city's structure one very important aspect within LRT planning. As described by (Fox 1978) cases occur, where the intention to position a LRT line into the city is focused too much on a possible itself presenting strip of alignment. This strips are often existing freeway corridors, existing but underused railroads or brownfield sites. There the focus is on mostly vast available space for implementation, but less on the first and most important prerequisite: dense population around the line. Therefore should no network decision be made prior to selection of mode, because it would leave little opportunities left for the designer to optimise the network according to the mode's flexibility.

Another thing closely connected to the city morphology is the location of railway stations within the urban texture. Due to the relatively late invention, compared to the age of the inner city parts, of railroads, the stations are often outside the immediate city centre. In organically grown cities, they are somewhere at the edge of the city's limits at the age of promoterism. The actual locations may vary, dependant upon the city itself. From this point of view, to provide sufficient and convenient connections, (Heinemann 2003) states, that therefore

- LRT should connect the CBD with its main railway station or
- the CBD should be serviced via direct tram/train connections.

This aspect gains additional momentum and importance, as the horizon of LRT planning is broadened over the city's legislative borders and towns, villages and settlements within the zone of physical influence are included. The strong dependence in travel between the city and its immediate surroundings, combined with the ever increasing spatial separation and specialisation of different uses and needs – strongly affected by motorised transport – implies high expectations on PT to relieve the situation's negative impacts. The more the city's and its conurbation's structure is oriented along linear elements, the easier can this purpose be fulfilled by PT.

3.3.2.2. Catchment area

The catchment area of a LRT stop is the circular shaped area around a stop, wherein potential riders – inhabitants and workers – are attracted to use this LRT line. According to tab. 11, the higher the "rank" of a PT means is, the longer walks or rides to a stop are accepted, i.e. lower stop densities and longer stop distances are acceptable. The demanding task, especially when operating in the outskirts or other areas with decreasing densities, is the positioning of stops to cover the highest potential of riders. It's important, that pedestrian destinations need to be served. So LRT has to penetrate urban mesh within walking distance of major trip generators. (Fox 1978) The radii of these areas around stops, that are influenced by it, range from 220m to 800m.

(Peperna 1982) analysed this problem and came to the conclusion that the pedestrian accessability of stops – with a 100% attractiveness in pedestrian friendly surroundings – reaches as far as 220m into the PT stop's hinterlands. After that the acceptance decreases rapidly. (see fig. 28)

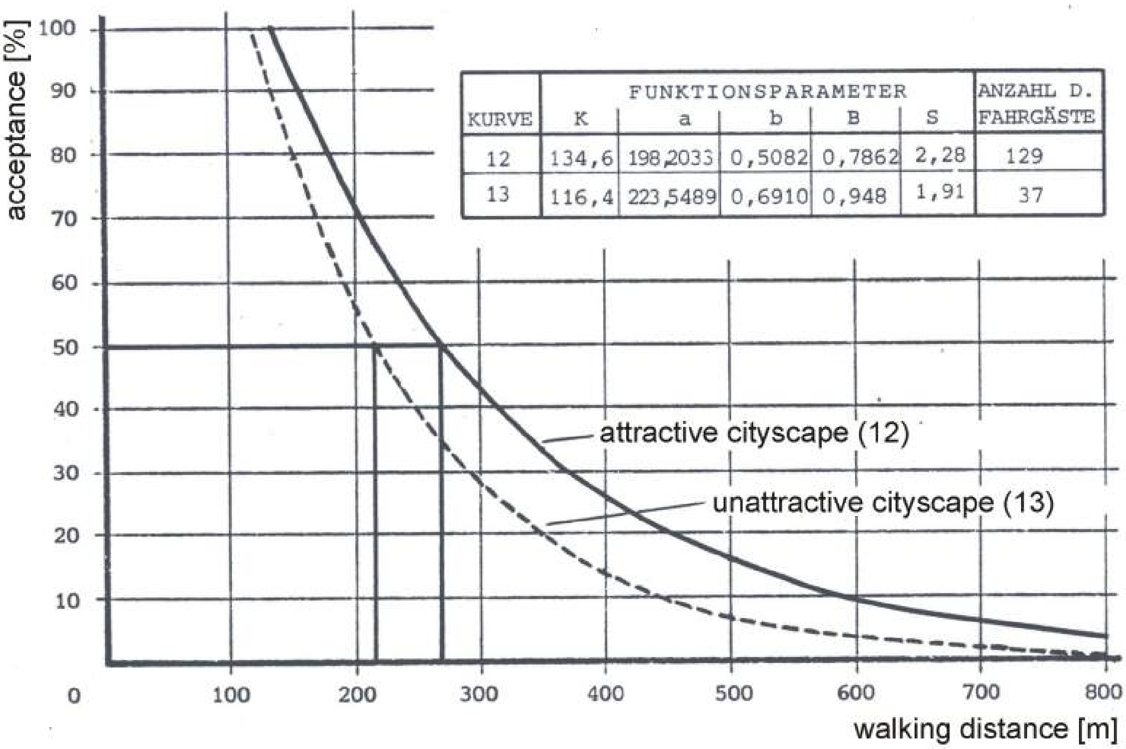


Fig. 28: Curve of pedestrian stop access attractiveness. (Peperna 1982)

When including the bicycle as a very potent means of LRT feeder service, given that the ability to unfold its potential is not hampered by any possible obstacles, this radius of attractive accessability can be increased. The guidebook "LRT – theses and topics" (UITP 1989) states, that the radius of LRT stops' influence is no bigger than 600m. (VDV, et al. 2000)'s values (see fig. below, left column) for LRT are placed somewhere in between those two extremal values.

urban area	tramway / bus [m]	metro / suburban rail [m]
centre	– 300	350 – 500
outer urban area	– 350	400 – 700
suburbs	– 450	500 – 800

Tab. 12: Expected accessability of stops. (VDV, et al. 2000)

Regional perspective

As already touched in the size and morphology section, the inclusion of regional destinations/origins, which are towns, villages and dwelling areas in the primary city's hinterlands, has become a more and more important task. Two basically different cases need to be distinguished:

1.) As long as these destinations are villages with a compact structure, that is separated from the major city or other external, fellow villages, the stops catchment area is quite easily to be determined by the settlement's borders.

2.) If this secondary settlement's structure is not separated, as it is often the case at the immediate border region to the outskirts, then the task to determine and optimise the stops best position becomes demanding.

3.3.2.3. Passenger potential

Densities of inhabitants and workplaces along the corridor of a LRT line in general and around stops in special are absolutely crucial for potential ridership. When talking about passengers, two basic groups have to be distinguished. These are captive riders and choice riders. Captive riders are riders, that depend fully on PT as they have no other option to master their travel needs. This could be out of financial, health, age, courage (bike) or other restrictive reasons. Choice riders choose to use LRT, although they would on principle have at least one other option to carry out their trip. This is mainly car and/or bicycle.

The best exploitation of passenger potential and therefore largest increases in passenger numbers are gained by improvements in the PT system and the realisation of additional measures regarding MIT. This are e.g. traffic calming, parking restrictions, reduction of permanent-parking space, at the same time of improvement. (Felz 1989) Details on that will be given in the surface design section (3.3.3.1.).

Karlsruhe: The PAX volumes on the first tram-train line increased from 1992 – before system implementation – to 1997 sixfold: from **2.200** to **12.000 PAX/d** on that specific line.
58 % of these journeys represent real new passengers for the LRT (**40 %** instead of car trip, **12 %** newly induced travel, **6 %** instead of walking or cycling) (VDV, et al. 2000, Käfer, et al. 1994)

Further random examples of LRT implementation success stories, depicted in passenger figures, are to be found in appendix B.

Regional perspective

(Hoffmann, et al. 2002) gives a kind of lower boundary for viable connections into the region. For implementation of LRT/tram-trains reaching into smaller (**50.000+** inhabitants) cities' regions, the existence of growing municipalities with **20.000+** residents within the suburban region and distinct transport relations are required.

Examples of LRT lines running into the region on previously under-utilised railroads show, that the passenger potential exploitation can be increased by attractive PT supply. For figures see appendix B.

3.3.2.4. Spatial ROW alignment in comparison to city structure

As already described in one previous section, the catchment area of the LRT, or to put it accurately, its stops, is one decisive parameter of planning. To attract sufficient ridership, the alignment of the LRT line should be oriented according to the coverage of areas with likely highest densities of human induced activities. This are areas with high densities of population and absolute numbers thereof, places of work, shopping opportunities, areas for recreation and so on.

What really makes a LRT light, is the ease and flexibility, with which it can be implemented under differing circumstances. (Topp 2004) Although LRT is less costly to construct than other rail modes "superior" to LRT, it is by no means easier to plan. Planning should be thorough and appropriate, as there exists a sometimes emerging desire to build big. (Fox 1978) Such plans "focus on building the largest fundable project" rather than designing lean and matching the technical solution to the scale of a problem. Such planning is often to be found with financial and legal frameworks that prioritise "earthy" solutions. A classic example, in combination with the now antiquated planning dogma, was the German "Gemeinde-Verkehrs-Finanzierungs-Gesetz" GVFG (municipality transportation funding bill) under which many of German LRT lines were buried into the ground from the 1960ies to the 1980ies. (see e.g. Dienel, et al. 1997)

The in depth discussion of the following six sub categories is included in appendix B.

- **Typology of network**
- **Network design**
- **LRT/tram alignments**
- **The secondary network**
- **Modularity of network design**
- **Local and regional networks**

3.3.2.5. Stop spacing and distribution

Conflict trip time vs. commercial speed

A LRT's character – actually the character of all line haulage operation systems - includes one major contradiction: The operational demand for as undisturbed as possible rides stands against the access demand of inhabitants wanting to have the shortest possible trips to and from the stops to keep the total trip time to a minimum.

Operating speed is the speed that is being reached by the consist in between stops, it needn't be identical to the vehicle's maximum possible speed. Commercial speed is the average speed of the consist along the line. Both speeds' mathematical definitions are given in figures 29 and 30.

$$\boxed{operating\ speed = f\left(stop\ spacing, dwell\ time, vehicle\ performance\right)}$$

Fig. 29: Operating speed for guideway systems with on-line stations. (Fox 1978)

$$\boxed{v_C = \frac{\sum stop\ distances}{\sum\left(travel\ time + dwell\ time\right)}}$$

Fig. 30: Commercial speed. (UITP 1989)

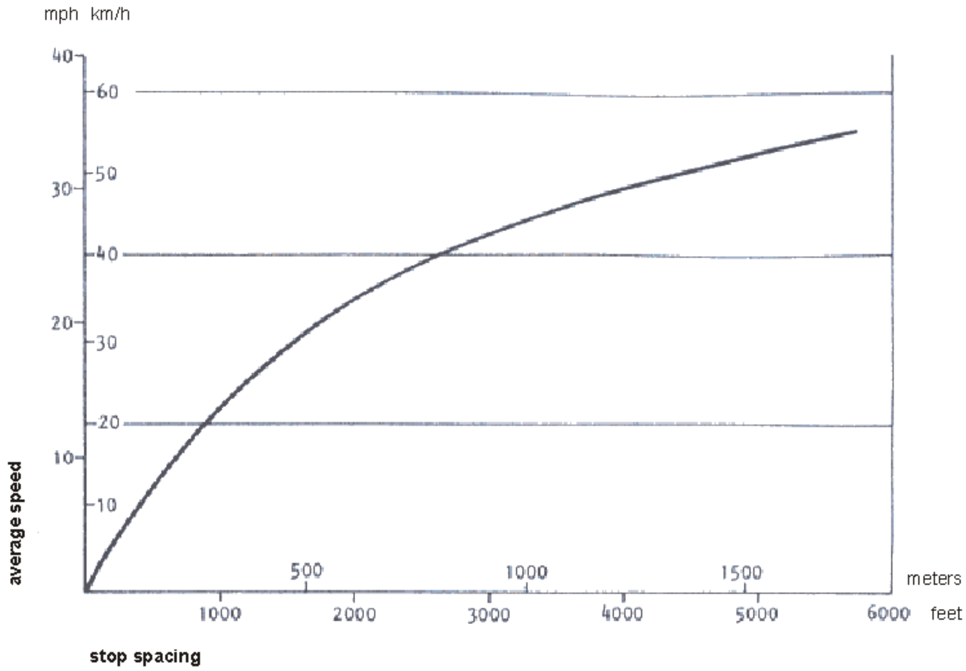


Fig. 31: Relationship stop spacing and operating speed for given parameters. (Fox 1978)

As the calculation of precise travel and speed behaviour needs for detailed specifications for both the system's and the vehicle's properties, this is not elaborated in detail here. Nevertheless, to give an overview, how the different parameters included work, the resulting diagrams from a detailed example calculation in (UITP 1989, Fox 1978) are depicted here and later in the context. (see fig. 31 and 32)

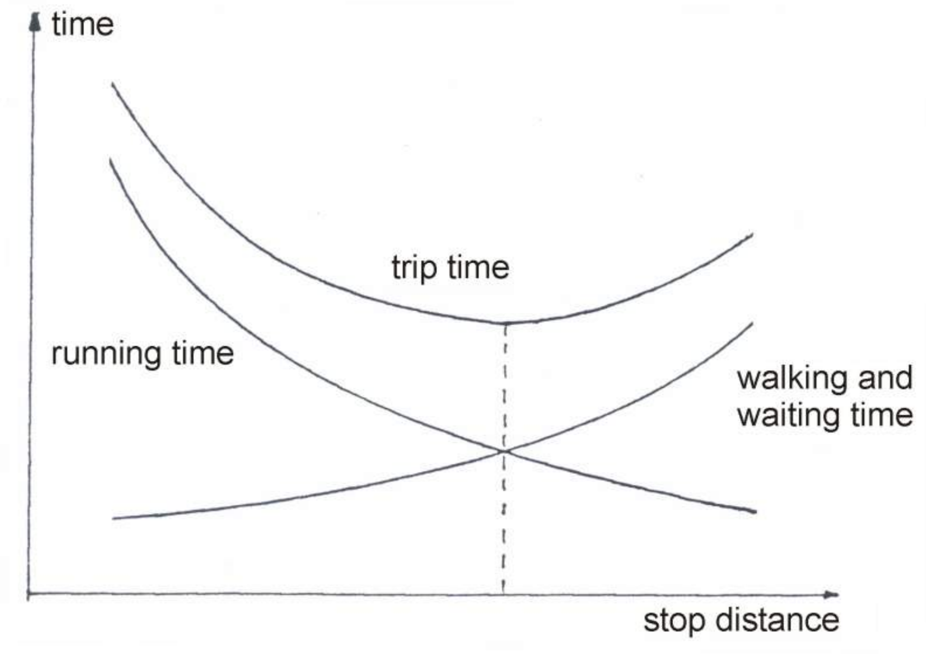


Fig. 32: Schematic coherence of running- , walking- and trip time. (UITP 1989)

Also an overview of impact of changing parameters dwell time and stop distance on the commercial speed under two basic scenarios of maximum reachable speed is given in tab.13.

	dwell time [sec]	stop distance [m]	com. speed [km/h]
carriageway dependent systems with state of the art acceleration measures **v_{MAX}=30km/h**	20 20 25	300 500 700	17 20 22
carriageway independent systems **v_{MAX}=60km/h**	20 25 25	500 700 900	27 30 34

Tab. 13: Schematic comparison max. speed to commercial speed. (Brändli 1995)

The higher operating speeds are, that are reached in systems with complete separation of ROW, either sub-surface or on aerial structures, are reached due to longer stop distances. The longer stop distances imply a worse coverage of the area with stops and therefore requires for longer access and egress trips. In addition the vertical separation above or below surface level increases access/egress distances.

The point of equality is given by (Brändli 1995) as LRT is superior to metro for trips of up to **3,5 km** length regarding the trip-time.

One practical survey in Toronto lead to this example. There a tramway was replaced by a newly built metro line serving the same corridor. The findings of analyses before and after the change (Fox 1978) corresponded in the second category very well with Brändli's general rule. The two basic categories of investigation were:

- People with origin/destination approximately in the middle between stations experienced an **increase** in average trip time for trips of up to **8 km** due to the metro.

- For people with origin/destination at stops or in their immediate vicinity the **LRT was faster** for trips of up to **3,2 km** of length.

As described in (Fox 1978), surface LRT facilities in the CBD offer greater accessibility for users by providing simpler and more frequent stations. Therefore, to improve the service quality, LRT planners try to increase the commercial speed without giving up the advantage of as close together as possibly located stops. For example, in Bordeaux with a rather recently planned and built LRT system without vertical separation the envisioned commercial speed was 21 km/h. (Groneck C. 2004)

The alignment and the choice of stop distances should take place under three basic considerations (UITP 1989, Etzold 1999a, 1999b):

- The stop positioning should primarily be according to major areas of origin/destination and according to traffic needs in the vicinity of neighbouring uses producing high numbers of potential riders for short access trips for as much PAX as possible.
- In favour of PAX comfort. This means to keep walking distances as short as possible, without unnecessary elongation of overall trip time to minimise door to door trip times.
- Under consideration of minimising energy consumption for traction.

In addition to the above, (UITP 1989) states that, the alignment should be so, that in between the stops the maximal, intended velocity can be reached and the max. stop distance within built-up area of 800 m is not exceeded.

The further sub characterisation of:

- **stop location** and
- **stop importance**

can be found in more detail in appendix B.

3.3.2.6. System breakdown safety

If LRT is supposed to provide backbone quality services for the city, very demanding claims for service stability need to be fulfilled. Of course there will be, also calculated, possible incidents that will afflict the operation heavily. And from this point of view not the utopian claim to provide full service can be issued, but a basic ability of the system to not completely collapse under very adverse circumstances needs to be provided. All aspects that concern a regular, constant and responsible service under a number of possible, predictable or unpredictable incidents are united under the term "system breakdown safety".

System "redundancy"

The first and most basic aspect concerned is the networks typology itself, which needs to provide redundant system components that can be used in emergency cases. This means that multiple (2+) network options, including all required switches, crossovers and devices, for temporary changes in line courses due to breakdown of network parts should be provided. In systems with "low network characteristics", this means a low number of tracks/lines and connections thereof, the segments in the CBD should have duplicate sections (Fox 1978) to provide the ability for reliable operation of the system on independent route options in an event of accident or other service interruptions. But it may not always be negative occurrences, also possible roadblocks due to e.g. festivities should not lead to a complete cut-off of the system. (compare with Schmidt 2003, p.78)

For example: A system with multiple branches both sides of the CBD, but only one single line in it, will be strongly dependent upon it. Not only from the "service safety reason" point of view one single line is questionable, but also from the "better distribution and coverage of the CBD" perspective a second alignment would prove useful. In general, multi-line systems are superior over single-line systems regarding failure proneness. (Fox 1978)

Turnarounds

The next step is the provision of additional turnaround facilities along lines that allow for alternative routings. So if the CBD passage or one intermediate section is interrupted, these turnaround facilities enable operations on the cut-off outer sections. (Fox 1978, Hoffmann, et al. 2002) The type of turnaround facilities is dependant on type of vehicle used, bi- or mono-directional.

bi-directional vehicles:

Temporarily shortened courses are quite easily manageable with bi-directional switch groupings and crossings at strategically important spots or sections within the network.

mono-directional vehicles:

They require for turnaround loops instead of simple crossovers in between both tracks for temporarily shortened courses. Due to their nature the positioning is strongly limited by available place, either on available open plots of land off the route or around street blocks in built-up areas. In both cases the provisons enable for:

1.) "emergency shortened courses" or

2.) scheduled short running courses in "weak load hours".

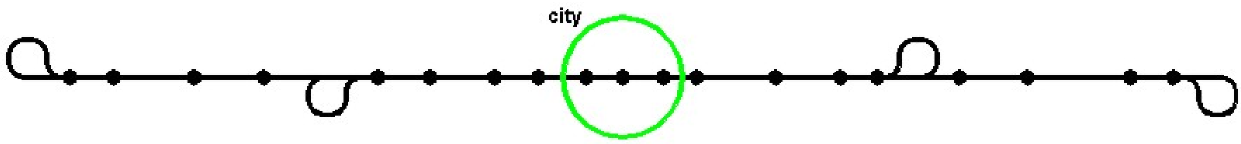


Fig. 33: Scheme of possible "mid-term turnaround loops" locations.

Undisturbed ROW

Contrary to other rail bound transport modes, LRT does not have a ROW fully separated from all other kinds of transport. Therefore, to provide punctual, reliable and smooth services, the task is to keep the ROW as clear as possible of any potential sources of delay and interruption. As line operations are prone to accumulation of disorders, therefore potential primary disorders need to be minimised. According to (Brändli 1995) three prioritised approaches need to be enforced to ensure a true to type LRT operation:

Priority one is to minimise the variation of time losses per source of disorder. This leads to reliability and predictability

Priority two is to minimise the mean of time losses per line, consist or "course". This leads to a increased commercial speed which can be relied upon. Basing on this, the operators productivity can be raised.

Priority three is to make the occurrence of disorders as rare as possible, which has impacts on capacity in consists per time.

The increased reliability of grade separated ROW is caused due to freedom from interference from other traffic, which is very important in networks with no or limited emergency detour routes. (Fox 1978) To achieve the reduction of delays requested above, different measures need be taken (will be discussed in detail in the preferential treatment section 3.3.3.4.).

(Felz 1989) for instance gives examples for PT in general: replacement of carriageway bound ROW by separated ROW, bus lanes and consequent preference of PT at traffic signals. Tab. 14 shows how some measures implemented on different networks lead to remarkable increases in commercial speed.

city	before [km/h]	after [km/h]	change [%]
Köln (network)	19,6	23,7	+22
Stuttgart (centre)	12,0	20,2	+68
Dortmund	15,0	24,0	+60
Essen	19,0	34,0	+79
Hannover	18,7	27,2	+45
Karlsruhe (tram)	27,6	33,6	+22
Krefeld (tram)	15,2	19,0	+25

Tab. 14: Increase of LRT commercial speeds due to improvements. (Felz 1989)

On highly frequented spots within the network, e.g. major stop with several lines and junctions closely to this stop, measures like LRT sorting infrastructures or interlaced presorting tracks, with point blades positioned in advance of the junction or branch-off, increase the system's capacity.

3.3.3. Integration into the city

The Implementation of a LRT system into the city texture (Besier 2002) is a twofold task. It comprises of the strategic integration of the line network – where to place the alignment in the city – on one hand and the construction wise integration on location on the other hand. The second issue is of immense importance as there exists a remarkable difference to rail and road systems with higher velocities: full integration – viewed in length and width – into the townscape. Considering the high grade of complexity of relationships in cityscapes and its influence on every day life, this issue needs intensified attention.

> *"LRTs go directly through public urban life of street- and city space. Underground systems are like city freeways decoupled from this urban publicity, without participating with it." (Besier 2002)*

Some of the latest real life LRT projects already included highly sophisticated approaches towards a comprehensive design quality – to be identified as an integral part of the city and by thus attract riders. In Nizza like in almost all of France the LRT is supposed to become an "aesthetics pleasing designer tram". (Wansbeek 2002) Besier's findings identify four major guidelines for designing and handling the ROW and its surroundings:

- public space is primarily space for pedestrians;
- high quality of living – improved surroundings quality within the townscape;
- esteem for historical basis;
- durable design due to quality over time.

In the following sub sections, eight different planning parameters and design categories are reviewed in detail.

3.3.3.1. Surface design

Integration into urban scape

As transport is part of city life and by thus is subordinate to it and not vice versa, the implementation of the new backbone of transportation into the city requires for a interdisciplinary approach, with a comprehensive view from façade to façade (Besier 2002). All the single elements which are part of the cityscape (UITP 1989) like ROW, stops, other mode's surface design, green surfaces, catenary, lighting, street furniture, … need to be considered and properly designed, so that the tramway won't be seen as an alien element.

The positive example of Strasbourg (Besier 2002), where the construction expenditure was used to reconstruct the whole public space between opposing façades shows, that a courageous and determined approach towards this issues pays off in terms of public support.

The physical and visual integration into the cityscape is closely connected to the systems direct properties. For example (VDV, et al. 2000) low-floor platforms are easier to be integrated into existing street layouts compared to high-floor platforms. This is due to their lack of bulkyness and by this they are not as "noticeable" within the urban landscape as high-floor platforms. So to fit a LRT system into existing urban environment calls for great design versatility, as for example the planning of the LRT for Miami Beach has shown. There in a survey the residents demanded a system "that fits into the character of the community to comply with its dense urban pattern and architectural character" (Fox 1978, Walker 1995)

Interface to different transport modes

One of the main implications of LRT is the co-habitation with all other city transport modes and the often resulting conflict situations. As (Dallam, et al. 1982) writes, in a very cautious, almost excusing way, LRT should be planned and designed to be compatible with these activities. These are pedestrians, cyclists, car, bus, taxi, goods movement, emergency services, … Due to the evolutionary development in transport, different needs in place and speed within the streets space lead to de-mingling of transport types along the street. (Besier 2002) The zone with the most intensive usage remains closely along the façade. As can be easily seen in fig. 34, the adverse requirements of usage of public space lead to inherent conflict situations.

But there is a difference for pedestrians within the uses of higher velocities. As (Besier 2002) clearly explains: On a car lane the crossing opportunity arises only as a short period in between traffic flow, on the LRT ROW the permanent crossing opportunity is only briefly interrupted by LRT consist. This is underlined by the multifunctional use of urban space/ROW. The ROW is used by PT rather seldom in comparison to "free periods". The passing by of PT is in comparison to MIT a rare event. For very dense frequencies (1 to 2 min headway) and different speed ranges (36 km/h on streets and 18 km/h in ped. precincts) only 2,5 to 10 % of people are hindered in their initial crossing desire. Much lower headways call for multiple usability of the ROW surface. (Schmidt 2003): Short LRT headways do not necessarily decrease the amount of prospective "track crossers".

So the compatibility with cityscape and city life asks for a inclusion into the street space, not completely protected, heavy rail like ROW. This is the overdue attempt to give back the transport space the character of a living space. And it requires for promotion of slow speed modes and the end of the monopoly of use by MIT (Brändli 1995) which leads to the increase of pedestrian amenity value in the lateral areas. (Besier 2002) The opportunity for unhampered crossing of ROW, like LRT operation in pedestrian malls (Fox 1978), proves crucial for undisturbed and natural pedestrian traffic, part thereof is the highly desirable allowance of accessability and convenience to passengers. (LRTA 2003) The ROW is priority zone for PT, but nonetheless is open to intermediate use by others.

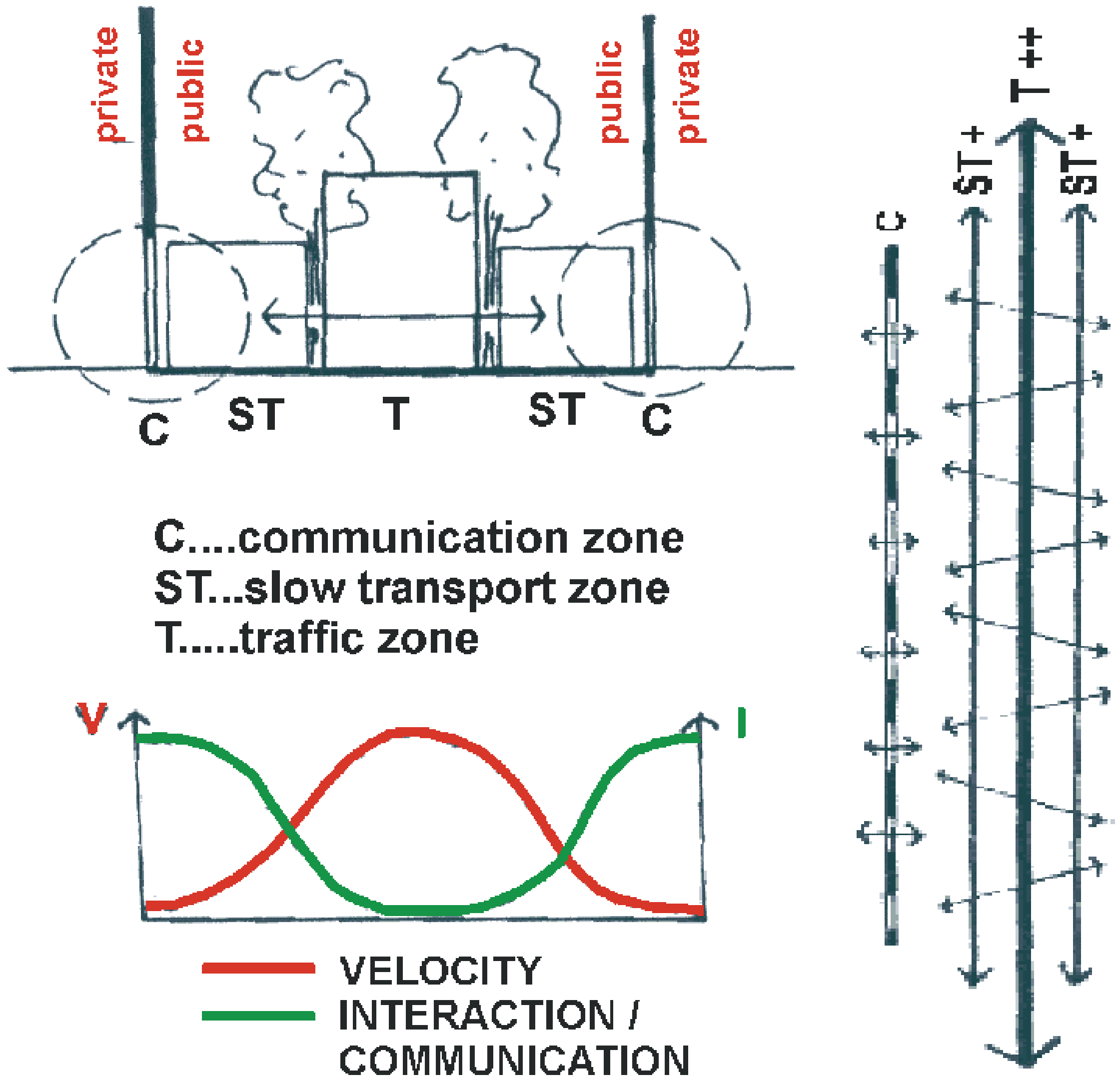


Fig. 34: Different inner-street velocities. (Besier 2002)

Although many cities with “tradition in tramways” clearly prove that LRT and pedestrians do have a peaceful coexistence, still in some/many places pedestrians are seen as an “obstacle for LRT”. And even in newly built systems pedestrian routing devices like zig-zag fences, hedges and fences, over- and underpasses are being constructed for the alleged safety of pedestrians and operations.

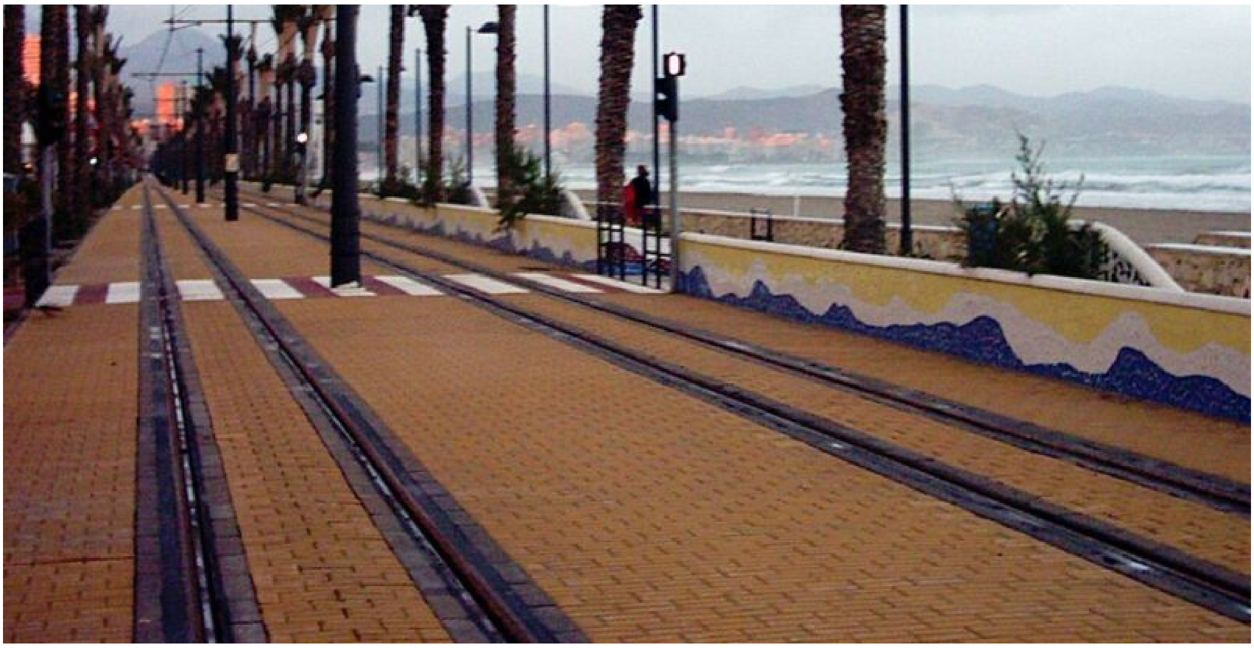


Fig. 35: Pedestrian protection wall at Alicante's newly built LRT system. (photo by D. Moncholi)

But actual behaviour and planner's fears seem to be diverting as the experience from England's newest LRT show. (Debell 2004): *"Ensuring public safety ... , and the importance of pedestrians using designated crossing places. In fact, Nottingham's citizens seem to have adapted pretty easily to living alongside a tram and incidents have been rare."*

What should be taken care of in terms of safety, is the provision of enough lateral clearance within pedestrian precincts so that delivery and city utility vehicles do not block the ROW or endanger the pedestrian use of these "bottlenecks". (UITP 1989) Quite self-evident, in these bottlenecks or in other dense pedestrian traffic areas velocity restrictions should be imposed on all mechanised transport including the tram.

For example. In Bordeaux the alignment in narrow streets is either located in a pedestrianised street or on physically separated ROW. (Groneck C. 2004)

Track separation

As already described in the introductional chapters of this thesis, separation of LRT and other transport modes is a crucial issue. Track separation is a wide spanning term, ranging from drive-over curb structures to tunnels. Although the peak of the dogma of building LRT tunnels under narrow CBD condition dates back into the 60's, it is still often seen as inevitable: " Planners seek to separate tracks from all other traffic as much as possible. In many central areas of large cities this means, that LRT has to be routed through tunnels." (VDV, et al. 2000)

The message that PT ROW ought to be separated from MIT lanes as much as possible to provide safe and undisturbed operation is true, but the vertical separation issue is to be seen more differentiated, because even (UITP 1989) says, that the best means for separation are separated

ROW and signal prioritisation. See also (Schmidt 2003). Outside the CBD, usually the LRT ROW is an exclusive one to provide sufficient operations quality. (Besier 2002)

(UITP 1989) names the means of separation: markings, drive-over curbs, lateral physical demarcation with hedges or fences, separation by means of independent ROW or "green strips" and gates.

But separation may not be only hard measures. In pedestrian precincts a barrier free ROW should be provided with only different surfaces for ROW and purely pedestrian areas. (UITP 1989) Better than curbs are bollards for ROW demarcation because the streetscape can be easily crossed at will by pedestrians, but not by automobiles. So the softer measure can be the arrangement of different modal areas by different surface materials used. (Besier 2002)

Regarding CBD tunnels

In the classic, machine oriented doctrine, maximum grade separation by means of tunnel sections was envisioned. What is superior for operators (Fox 1978), it offers higher running speed and reliability, is at the expense of increased station access time and effort for PAX and a smaller affordable network.

The original motive for bringing LRT below ground, to gain additional space for MIT, becomes increasingly obsolete (Brändli 1995), although many projects still include more or less extensive underground sections.

Regarding the impact of pedestrian precincts on LRT alignments and operation within, PAX usually experience advantages in comparison with tunnels or CBD bypasses. This are the reduction of travel time; reduction of walking distance, increase of attractiveness and convenience between LRT stop and trip destination/origin. (Schmidt 2003)

Stops

The stop is the primary interface, the greeting element between the LRT and the customer. There the customer enters and leaves the system. They are, or at least should be, "unmistakable signs" within the cityscape acting as an advertisement (Besier 2002) for the use of the LRT system. The design should draw the inhabitant's attention to the boarding possibility and improve the prestige of PT beyond the"loser's image", which is possible and often to be found. Therefore a high amenity quality during every day and night time is required. By this the waiting period should not be experienced as a nuisance. Light colours, security promising lighting, climate protection, "means of boredom protection", … are leading to the correction of the rather bad valuation of waiting time. (Besier 2002)

Besides the direct positive influence on actual and soon to be travellers, stops reflect the city's attitude towards an attractive PT and sustainable urban transport planning. Especially the stop's equipment can represent the transport modes' modernity and attractiveness.

The additional sub categories and the different types of stops are described in appendix B:

- **Surface redesign - traffic calming**
- **Line element succession**
- **Construction and track types**
- **Catenary design**

3.3.3.2. City structure redesign

City development of pre industrial eras was characterised by close spatial and functional interweaving of living and working, by a relatively low extension and compactness versus the sparsely populated hinterlands. (Felz 1989) The city structure was dominated by pedestrians, but increased motorization intensified the spatial separation of living and working. The major adverse impacts of transportation improvements were neighbourhood disruption, adverse land use impacts like housing dislocation, disruptive use of park land and the likes. (Dallam, et al. 1982)

So, resulting from this, many city centres lack their function as market, trading and communication centres. "Healthy" city compounds show a variety of uses: living, working, culture, education, leisure and trade are vital for functioning city centres. The problems visible nowadays in many city centres are: decrease of variety of uses, decline of living and trade, increase of environmental pollution due to MIT. (Felz 1989)

One indicator for the need of "severe city structure reshape" is given in (Pikarsky 1982) although probably not intentionally: *"Many people drive to PT stations (P&R) or have to drive, as the spatial distances of these trips are generally less direct than those made by auto alone, so a dual-mode trip may save little or no energy at all."* When the LRT stop has to be reached by a rather long car trip, then such a city structure reshape is severely needed although probably accomplished only under difficulties.

Urban sprawl and degradation of city cores is directly dependant from the average spatial velocity within the system. The higher the velocity, the longer are the trips due to the human travel time budget, that is consistent on average (see Knoflacher 1996, Schafer 1998, 2000). The introduction of LRT and the accompanying measures help to reduce this spatial velocity. Together with the orientation along the alignments, this helps to decrease or revert the spatial spread of the city and the car dependency connected with it.

By means of redesign of city structure this is often being re-introduced with a new quality in areas reserved for pedestrians. A revival of city centres is aimed at, especially as the LRT can be seen as an identity creating entity for the agglomeration along with the measures of urban renewal. (Groneck C. 2004) The implementation of LRT into the cityscape can be used to spark the realisation of necessary or long overdue plans to change designated public surfaces. (Hoffmann, et al. 2002) And the need of a positive contribution of PT to re-attract the city or parts of it, is evident. (Besier 2002) The contribution is not only needed, but also vital for success as the tram is an integral part of the new surface structure and layout. The factors responsible for PT's share of revitalisation of cities are velocity of PT, reliability of PT, comfort of PT vehicles and stops and the accessibility of stops. (Felz 1989) To guarantee a maximum benefit from redesign some kind of uncertainty in "urban insertion" of the LRT has to be prevented by any means, so that a human and liveable city, claiming high quality of urban design, townscape, transport facilities and their immediate surroundings can be provided. (Besier 2002)

Especially valid for precincts on the brink of degradation is, that by installation of PT and pedestrian zones, the dangers of inner city obliteration can be averted. (Felz 1989, UITP 1989) And urbaneness, which is variety, high density of uses and corresponding pedestrian frequencies, can be brought back. (Mouvement Ecologique 1999) For example:

> *"… tramway route along … would help a lot to give Norrköping an even more urban flair." (Schmidt, et al. 2001)*

Pedestrianisation

The old-fashioned ways of planning have had only one model of pedestrianisation in mind: clear the surface of traffic and move the LRT tracks below ground. In (VDV, et al. 2000) the arguments for this kind of way of thinking are noted:

- The eviction of LRT poses a chance for a completely pedestrianised city district in the making;
- Green areas on top of underground facilities improve quality of an area for residents and leisure users;
- Construction of underground rapid transit systems creates opportunities for the regeneration of entire city districts. Very often the case for the "weak side" of railway stations and their accompanying districts. (VDV, et al. 2000)

But this kind of approach is a "black or white only" one, without any nuances in between. Many examples, e.g. described in (Schmidt 2003), show, that pedestrianised areas are compatible with LRT systems. They are not only compatible, but the multi-use character of ROW is the expression of typical urban densities and mixes of use, high attractiveness of narrow and winding cityscapes and the co-existence of environmentally compatible modes. (Besier 2002) According to (Felz 1989), only restrictions or the complete removal of MIT in combination with PT improvements created the basic preconditions for the redesign of city centres.

And the consequences of pedestrianisation are similar to the opening of a chess game – complex, widespread and unique in detail: improvement of city shape, intensification of socially-communicative relationships, modernisation of dwellings in the pedestrian zone and the modernisation of business premises. The attainment of urban planning, economical and ecological goals of city becomes evident explicitly, where larger street sections have been pedestrianised. The access of extensive pedestrian precincts in larger cities would not be possible without a effective PT system. (Felz 1989)

Effects of LRT implementation

(Mouvement Ecologique 1999) explicitly states, that LRT is city structure shaping like every rail-bound transport system. In contrast to buses, which, due to missing or only marginal presence of ROW, do not have such positive impacts on the built environment in its vicinity. See the closely connected "rail-bound bonus" of LRT in section 3.3.1.3.

Due to its massive influence, LRT is not to be looked at separately, but as multiply mingled with urban structure development. (UITP 1989) The tram serves as a point of crystallisation and initial ignition for new/better urban development. For example by "internal consolidation" of precincts with scattered or disintegrated structure. Not only intra-neighbourhood effects can be observed, but also the possibility for e.g. two slightly separated parts of town to merge them into an appealing one, exists. (Mouvement Ecologique 1999)

The investments, that are a result of new construction works (VDV, et al. 2000) and modernisation programmes are:

- being carried out before, during or after LRT construction;
- made by public bodies: pipe and cable network reconstruction, alterations to other transport facilities;
- made by privates: construction and/or modernisation of office, business, retail and residential developments.

The development of LRT systems in cities sized between 150.000 and approximately 1 mill. inhabitants is expected to be the best prerequisite leading to desired urban developments. The importance of a functioning PT for the renewal and revival of detracted centres was recognised. American cities without high-performance PT systems could not end or slow down the negative developments in CBDs. The increased "city escape" and settlement of businesses in suburban regions lead to loss of urban variety of uses. (Felz 1989)

primary effects	secondary effects
• reduction of MIT • reduction of accident numbers and severity • reduction of air and noise pollution • improvements in city ecology • reduction off barrier effects	• improvement of urban planning boundary conditions • increase of variety of functions and uses • improvement of economic boundary conditions • investments by private or public sector • changes in economical, social and urban structures

Tab. 15: Chart of effects due to LRT introduction. (Felz 1989)

Besides the direct LRT construction and surface redesign, also accompanying measures of LRT and non-motorised transport promotion ought to be taken to provide the required prerequisites for a change in city structure, e.g. Göteborg (Felz 1989):

- Reduction of parking space for commuters (**21.000 → 17.000, -19%**) and for visitors (**10.500 → 9.500, -10%**).
- Transfer of **3.000** parking lots into CBD adjoining border sectors and increase of parking fees by up to **100%** in the CBD.

LRT increases importance and function of street space by running along it. A street becomes an artery and axis of orientation, a central square crossed by two or more lines becomes a junction and focus in the urban texture. (Besier 2002)

House demolitions

Through some of the previous sections one absolutely basic principle gleamed through: the LRT system needs to be integrated into the city cautiously, considering and including numerous local aspects, to become a success.

One superior goal of city planning should be the preservation of the historical city ground plan, the protection of monuments, protection of city-, precinct- and street ensembles. (Felz 1989) To provide the superiority the city enjoys over transport and to realise the goals of social sustainability as low a number of houses as possible should be demolished. The less the city structure is being harmed, the better the transport networks adapts to the existing structure and the more intelligent planning, i.e. adjustable to changing challenges, is needed.

This does not seem to be as much a no-brainer as one might think. In almost every city are examples to be found, where city heritage, either as buildings or as an assembly of them, or even simple houses were destroyed for transportation means sake. Especially under the auspices of MIT facilities. (see Knoflacher 1996)

In Nottingham the prevention was celebrated with the following proud statement: *"The whole route has been built without demolishing a single building."* (Debell 2004)

Transit oriented developments

Transit oriented developments, short TODs (eaue.de 1996, Porter 1998) are the manifestation of foresighted policies: a closely toothed transport- and city planning. New districts or/and developments should in the best case scenario from the very beginning include a LRT line. New settlements should follow LRT alignments, not vice versa. (UITP 1989) From this perspective LRT offers the unique chance to influence settlement enlargements in a environmentally protective way.

For example, in Nantes 31,5 % of LRT users considered the immediate availability of PT for the choice of their dwelling. (LRTA 2003) Further examples are compiled in appendix B.

3.3.3.3. Attractiveness of stop access and egress

According to (Boesch H. in Besier 2002) the attractiveness of a stop comprises of the design, the used materials, greenery, street furniture and the surroundings and it's interweaving with the stop. From this perspective stops should be more than just the possibility of PT boarding and alighting, they should be centres of communication and information within the urban texture. (Coffey, et al. 1992)

Also of high importance for stop attractiveness is social control. It is by no way only a single directional relationship. Social control of the stop's facilities causes emotional safety and by thus attractiveness. And wherever there's an attractive public space with a lot of life taking place, this causes additional social control.

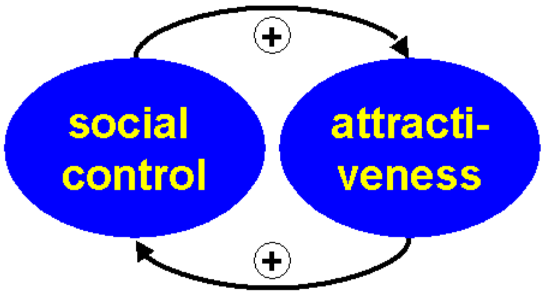


Fig. 36: The feedback loop of social control and attractiveness.

Pedestrian access

Pedestrian barriers at stops and on the potential access routes are numerously to be found. Although most of these barriers are directly resulting from the established hierarchy of motorised transport over non motorised transport, some are in existence due to the solicitous efforts to allegedly easy the "soft modes'" lives. Such barriers are e.g.:

- limited access over MIT lanes, like single pedestrian crossings;

- out of level access, like over- and underpasses over car lanes. But according to (UITP 1989) the can be provided, but only in exemptions. Without naming the circumstances in which the forcing of pedestrians to overcome vertical niveau differences would be justifiably.
- *"the use of fences to keep pedestrians off car lanes or to separate PAX from different modes should be done for safety sake."* (Etzold 1999a)

The barrier effect of long access path is quite often to be found at stations with vertically separated alignments. So, if underground stations, then provide the shortest possible access tunnels below ground. Short and easy to survey "approach paths" to the stop by means of signposting of routes to the stop and choice of stop distance according to the minimisation of trip times (door to door) for PAX should be arranged. (UITP 1989)

The safety concerns for accessing and egressing passengers are stringently connected to the location of stop within the road, if on the side or in the centre of the road and mainly in respect to the location of car lanes. The provision of traffic lights for pedestrians programmed to provide safe car lane crossings for people in hurry and lower level of attention/precaution is according to (VDV, et al. 2000) one practicable option.

Cycling access

The barriers for cyclists trying to approach or leave the stop are quite similar to the ones experienced by pedestrians, especially with altitude differences if they are not passable by riding.

Therefore, to decrease barrier effects, following measures should be provided (eaue.de 1996): short routes to the stop (no detours), secure and easy to use bicycle storage facilities, high levels of theft and vandalism protection, effective weather shelter;

This is of immense importance as cycling increases the coverage of the PT stop beyond the high attractiveness area of pedestrians (**300 - 1000 m** from stop). So in case that sufficient cycling facilities attract many cyclists, the stops can also be positioned slightly further apart. (Schmidt, et al. 2001)

Coherence with surroundings

The surroundings of stops are not only important from the access/egress point of view, but also from the "stationery" one, as stays at or around PT stops are inevitable for PAX. (Schmidt 2003) Riders with other modes at choice must not become bored or feel annoyed as waiting time is rated over proportionally low. Therefore it's important to provide design, information, … and entertainment by appealing surroundings at the stop and its immediate vicinity.

When designing the surroundings, the whole street should be planned around the stop regarding visibility, direct routing, sufficient waiting areas, tactile paving, cycle lane routes, measures to prevent disorderly parking and so on. (VDV, et al. 2000) And stops should be designed transparently and optically light for the reason to not interfere to strongly with the historical townscapes they might be included in. (Schmidt 2003)

The further design parameters can be looked up in appendix B.

- **stop design**
- **platforms**
- **passenger information**
- **interchange matters**

3.3.3.4. Preferential treatment within the transport system

Over the first century of existence of tramway the treatment within the transport system has changed dramatically. Once treated with the same care and "respect" as its big brother and enjoying priority over the other traffic participants, this scheme has been turned around completely during the time of arising mass motorization and is lasting on into nowadays. Quite too often the tram has to yield to MIT and therefore experiences low commercial speed, lack of reputation and bad economical conditions. (Besier 2002) The shortest possible running time between both line termini is being elongated to almost double extent due to various hindrances. These delays are caused by 50 % by congestion and MIT obstacles and unnecessary stops in front of traffic signals. (Käfer, et al. 1994) A homogenous travelling velocity (commercial speed) cannot be reached. Therefore, the opportunities offered to passengers by attractive services on separate track formations at ground level cannot be fully exploited, if rail vehicles are not given priority at the unavoidable road crossings. (VDV, et al. 2000) This situation is even worse if the tramway has significant sections of MIT lane-bound service running within the stream of cars.

Although prioritisation of LRT has been pursued in the last decade more and more in some places, the self justification nimbus remains, as car oriented groups including the media accuse the LRT of causing congestion. But the leading principle to give the rare event (rail bound vehicle) priority over the almost permanent stream of events (cars), as it is practised with heavy rail, remains valid for the tramway. It is therefore a traffic engineering like, characteristical treatment of the rail bound service, the tram. (Brändli 1995) Provisions for flawless operations can be made either hardware or/and software wise.

Priority (details see appendix B) can be provided either by:

- **layout design** or
- **signalisation measures**

3.3.3.5. Environmental impact

As (UITP 1989, Käfer, et al. 1994) put it, the politico economic benefits of rail-bound city transport, namely high transport capacity with low area use and car relief of cities, also have ecologically positive results:

- low noise and air pollutant emissions;
- low energy expenditure per PAX;
- low environmental impact for energy provision;
- treat scarce city space with care.

Emissions

The emissions of local exhaust gases directly in the street space by rail vehicles are zero. Unless due to the type of line, diesel-electric hybrid vehicles are used, with their diesel engines running e.g. on regional rail lines. The reduction of exhaust emissions in already heavily burdened metropolitan areas leads to better air quality.

This outstanding balance for LRT has to be corrected, because the pollution output of power generation, if not by waterpower or other renewable sources, has to be included.

Noise

In many inhabitant surveys referring to LRT re-implementation (Brate 1990, 1997, 2001, Dekleva 2002, tie 2003) the people's primal fear is the resurrection of "the noisy and squeaking trolley car" of old times. Rail vehicles usually produce two basic type of physically transmitted sonic waves:

- vibrations;
- sound/noise

Both types of annoyances experienced radical improvements due to new vehicle and track technologies like: quieter engines, better running bogies and gear, better matching rail and wheel profiles, cushioned running gear, more exact track positioning and geometry and cushioned trackage.

Energy

mode	operating energy [kJ/pkm]
average car (1,2 pers.)	5160
carpool (3 pers)	2410
LRT	**2460**
bus	1711

Tab. 16: Operating energy of different modes. (Pikarsky 1982)

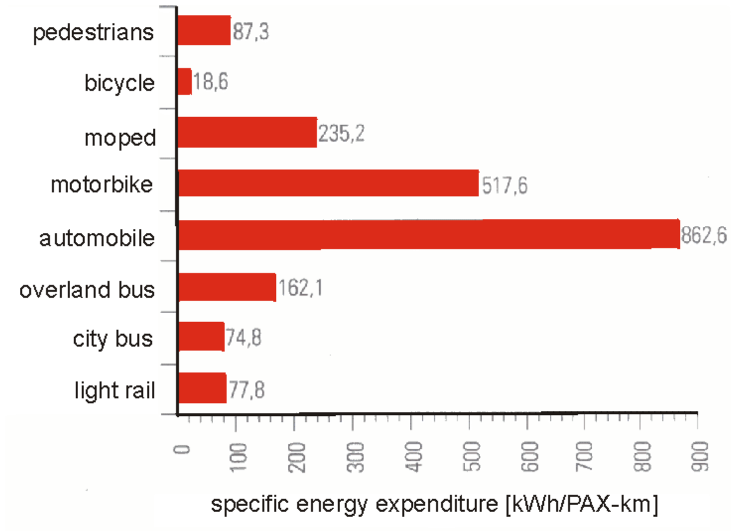


Fig. 37: Energy consumption of different modes. (Käfer, et al. 1994)

Further, detailed diagrams on the interconnection of commercial and running speed, stop distance and energy consumption can be looked up in appendix B.

3.3.3.6. Use of space

Although the use of space is primarily an environmental impact, it is nonetheless a crucial issue for the basis of a sustainably compatible transport system and will therefore be dealt with separately. Space is a valuable and restricted resource within the townscape, at least in the centres of organically grown cities.

LRT uses its place very effectively. The width of a single track ROW - the exact measurement is depending on the width of the used vehicle - is similar in cross section to a car lane. Both are about 3m wide. From the absolute figures for ROW there is only a small or almost no difference. But when considering the much higher number of persons transported by LRT, the space effectiveness advantage of LRT is evident. (compare to fig. 38 in the transport capacity section) The advantage of LRT in curves and turns is shown by (Käfer, et al. 1994) as space savings by LRT can be facilitated there in comparison to the bus and it's vehicle path.

But there is not only a cross sectional point of view but also a longitudinal or spatial one. There is the possibility to reduce "opportunity area demand" through the reduction effects by LRT on motorization. A good PT accessability reduces the demand for space for vehicle lanes, parking lanes and lots. (Felz 1989) And therefore the modest amount of space required by PT makes it possible to recreate open areas and squares in city centres and reintegrate historical buildings into cityscapes. (VDV, et al. 2000)

The LRT by this succeeds twofold. An increase of transport capacity is accompanied with an increase of townscape quality and life. (Besier 2002) The extent of reaching these two objectives shows how much unpopular measures emphasise the importance/seriousness of policymakers to promote PT. (UITP 1989)

The German concept of "Stadtbahn" often minimises/d the inner city surface area demand for transport means by vertical separation into the underground and construction of a pedestrian zone on the surface.

3.3.3.7. Transport capacity

In terms of transport capacity per lane and hour the LRT is way ahead of MIT and buses, as figure 38 shows. In tab. 18 the capacities of different single vehicles are given and tab. 17 shows empirical mean real values of daily patronage of different kinds of PT.

	transport mode	mean real patronage[PAX/d]
rail: line operation	metro	100.000 – 200.000
	suburban rail	20.000 – 120.000
	LRT	**20.000 – 100.000**
	tramway	**10.000 – 30.000**
	regional rail	2.000 – 5.000
bus: line operation	city bus in built-up area	2.000 – 15.000
	regional bus	1.000 – 3.000

Tab. 17: Mean real patronage of different city transport modes. (Fox 1978, VDV, et al. 2000, Besier 2002)

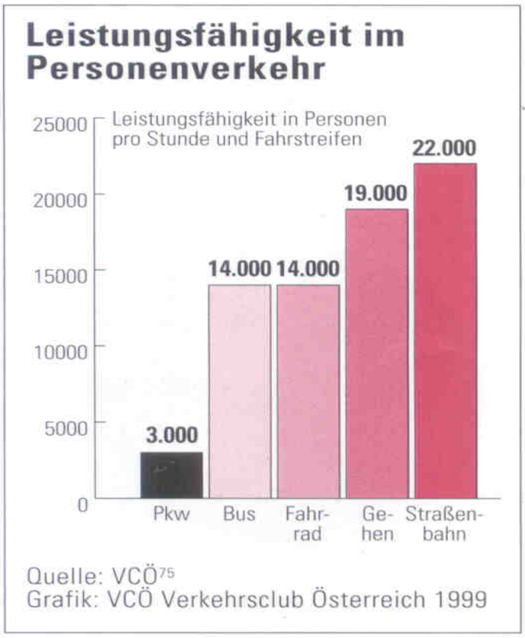


Fig. 38: The capacity of transport means per lane and hour. (Niedler, et al. 1999)

vehicle	PAX capacity
ULF (24 / 35 m)	150 / 230
Linz (6 / 10 axle)	~100 / ~200
England (24 – 35 m)	160 – 250

Tab. 18: Passenger capacities of different vehicles. (Käfer, et al. 1994, Framenau 2002, Groneck C. 2004, Young 1995)

According to (Brändli 1995) the tendencies towards increased vehicle widths lead to maximum possible capacities of approximately ***350 - 400 PAX*** per consist. This logically includes the LRT's ability to couple two or more vehicles together into one consist. This higher capacity of LRT in comparison to buses is also important for personnel disposition, as one light rail driver can carry more PAX than three to five bus drivers. The practical passenger carrying capacity of one light rail line is dramatically higher than that of one bus lane. (LRTA 2003) A high occupancy can be reached only by measurements increasing the attractiveness (Felz 1989), the harmonisation of transport capacities of LRT and supplementary/feeder systems and with complementary measures like limitation of parking space, reduction in available car lanes, as the following examples show. (UITP 1989)

In Bordeaux on the Pont de Pierre two of previously four car lanes were reconstructed into a grade separated LRT ROW. (Groneck C. 2004) This increase in transport capacity was contested heavily, as it limited the car lane number. But like in Strasbourg the new virtue of urban development can be characterised as an ongoing restriction of car use. (eaue.de 1996)

In Strasbourg something similar took place: a four lane collector road was reduced to a two track ROW plus two MIT lanes along a park like green space. (Besier 2002)

3.3.3.8. Influence on the modal split

The attractiveness of PT in the whole city has crucial influence on the modal choice. And measures taken to improve the attractiveness and capacity lead regularly to a distinct increase of PAX numbers and by thus lead to a relief of vehicle traffic in cities or at least city centres. (Felz 1989) PT not only has to be made faster and more capable but also pleasing for humans with stylish designs, playing a part of city lifestyle, etc. PT therefore needs high psycho-social attractiveness to overcome the public image of deficit, dirt and unreliability that too often clings to it. (Besier 2002)

As the new tramway/LRT system almost always serves as a backbone of PT, the task of attracting PT is carried by it. (eaue.de 1996) Some of the effects are:

- More frequent journeys taken by passengers who already used PT services before (VDV, et al. 2000);
- Creation of a travel demand on PT by the improvement of service supply, and with it change of modal split in favour of PT (Heinemann 2003);
- A "transfer" of trips from other modes (i.e. MIT) to PT (i.e. LRT), which is particularly significant in immediate surroundings of LRT lines (VDV, et al. 2000);
- Traffic calming, e.g. the installation of ped. precincts, is aiming at the reduction of MIT and usually causes increase in pedestrian numbers. (Felz 1989)

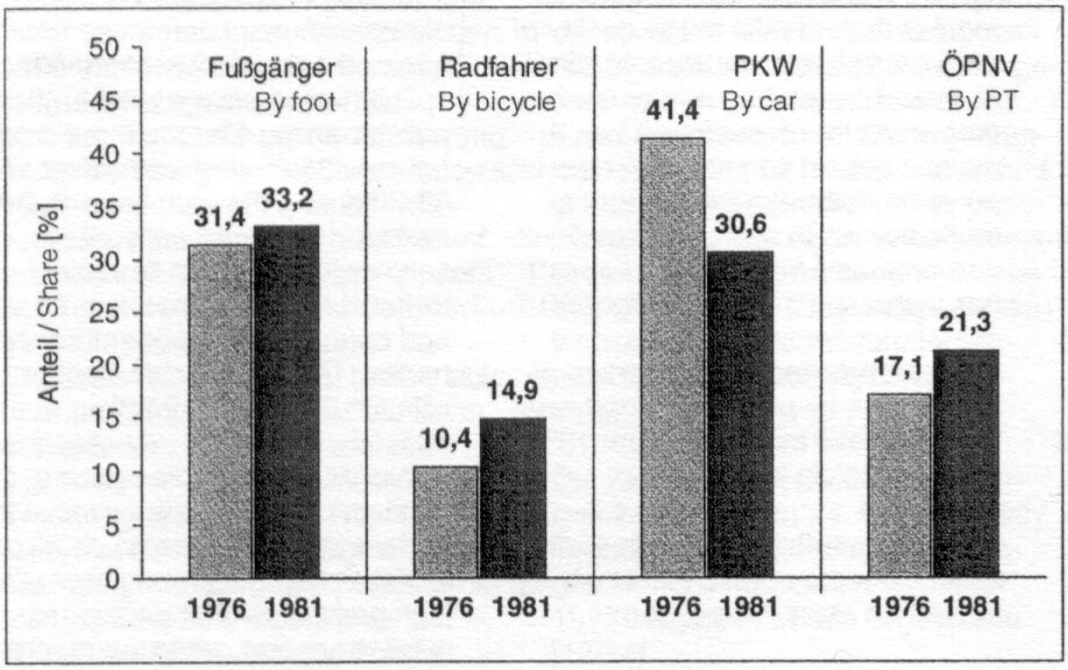


Fig. 39: The effects of LRT construction on the MS in Hannover. (VDV, et al. 2000)

A change in modal split is often included in governing and accompanying policies like the regional transport plan of Mulhouse, which aims at a shift in MS towards environmentally beneficial modes. (Framenau 2002) Or as a non-qualifying criterion related to ridership within a assessment of regional options like for the "Twin Cities" (Dallam, et al. 1982): "An LRT line should increase overall transit usage in the region over the existing system."

The example of Nantes shows the PT's impact on modals split: a decrease of the MIT share by **2 %** took place due to the LRT introduction. (Besier 2002)

Two further example diagrams of PT's modal share in different cities are shown in appendix B.

3.3.3.9. Right of way

The design of the ROW has a special meaning, as it is one of the two entities of a LRT systems, besides the vehicle, that has primary publicity. (Besier 2002) One of the major features of LRT is the ability to vary the type of ROW sequentially, according to the need. (Fox 1978) The ROW should be designed as a clearly identifiable zone with different kinds of materials and designs along the route, differing according to type of urban environment (Besier 2002):

- Embedded within the street/road surface (integration into pedestrian areas);
- Separated (physical vs. optical separation of ROW against other transport modes);
- Central or side position in street;
- Surface bound, elevations and tunnels (previously often used in CBD and to cross below central railway stations)

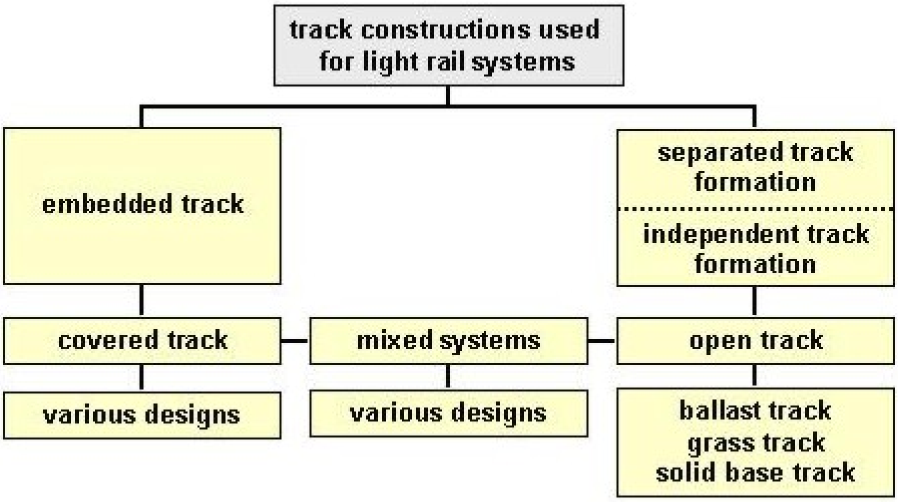


Fig. 40: Scheme of ROW types. (VDV, et al. 2000)

- Concrete slab, water compacted (MacAdam), concrete block, cobble stones;
- Grass track: brings additional greenery within city streets serving for improvement of microclimate, dust filter, noise reduction, townscape. The construction is typically a ballastless track that usually does not fit into densely built up areas. The relation of tunnel ROW cost to grass track has to be considered, as there is often no hesitation in drilling tunnels, but in providing sound and matching ROW surfaces for savings sake. (VDV, et al. 2000, Besier 2002)
- Ballasted track: It is "rather cheap" in comparison to the other more sophisticated constructions. But it has adverse optics and barrier implications. (Besier 2002)

3.3.4. Economic aspects

In the last of the four major categories of factors, the economic aspects of LRT will be dealt with. By no means the claim is laid to fully cover the economic aspects of such a fundamental and extensive impact, as the construction of a LRT system for the city is. Only the most important economic aspects are touched upon.

3.3.4.1. Costs

Costs are a major concern for a public transit system. As (LRTA 2003) describes, in the UK the government and the authorities are very sceptical about the costs and benefit ratio of such investments, although PT is in need of serious, sustained capital investments.. In most cities the "cheap-fix" of privatised road-bound PT with rather low running costs, but also less impact on transport figures is favoured above the implementation of LRT systems. Light rail schemes have to create the infrastructure and provide vehicles as well, which makes them inevitably cost large sums of money. Nevertheless some LRT systems exist in the UK, whereof the costs were included in the following diagrams.

LRT planning and construction is normally a public agenda as the returns for the long-term-cautious private sector are not achievable within a normal time span and at the extent to be attractive for private corporations. This is confirmed by the “Twin Cities” LRT study’s (Dallam, et al. 1982) findings, that the break even year of annualised capital costs and operating costs ranged from **15 years**, for the best corridor and circumstances, to **51 years**, for the worst corridor and conditions, without the consideration of intangible, indirect or secondary benefits. The costs of LRT systems can be basically divided into four large groups:

capital costs	line construction and utilities
	vehicles
operation costs	infrastructure maintenance
	rolling stock and personnel

Tab. 19: Basic types of costs of LRT systems.

Infrastructure

In the following two different types of costs will be distinguished and used. At first are the construction costs. There are included all costs of constructing a state of the art ROW, usually with two tracks. The second one are capital costs including all primary and secondary costs to provide a system able to work. This includes the construction costs, costs for real estate, costs for utilities like sheds and storage facilities, costs for vehicles and other.

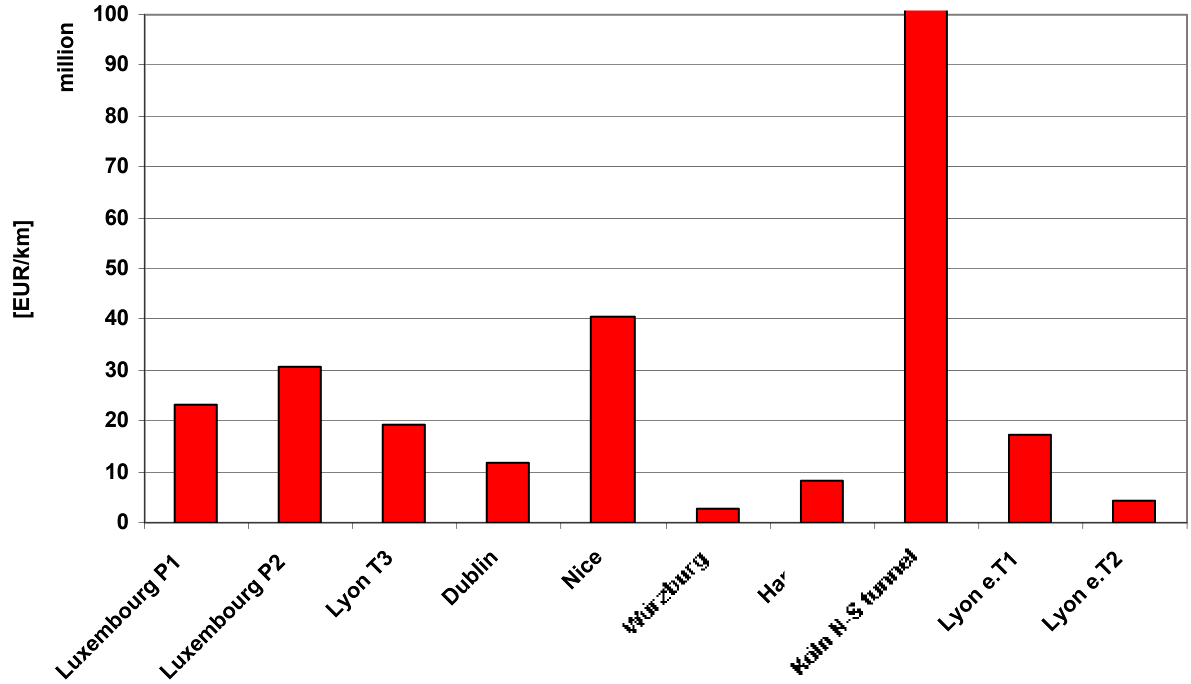


Fig. 41: Specific construction costs of LRT systems.

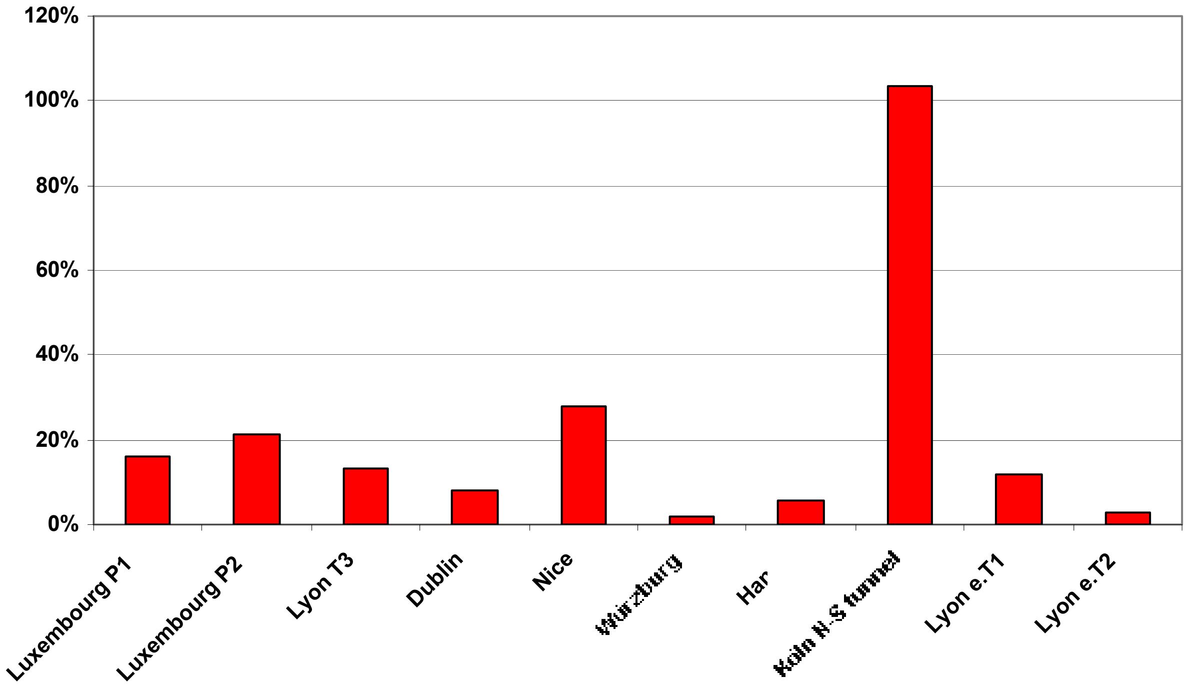


Fig. 42: specific construction costs in comparison to Vienna U3.

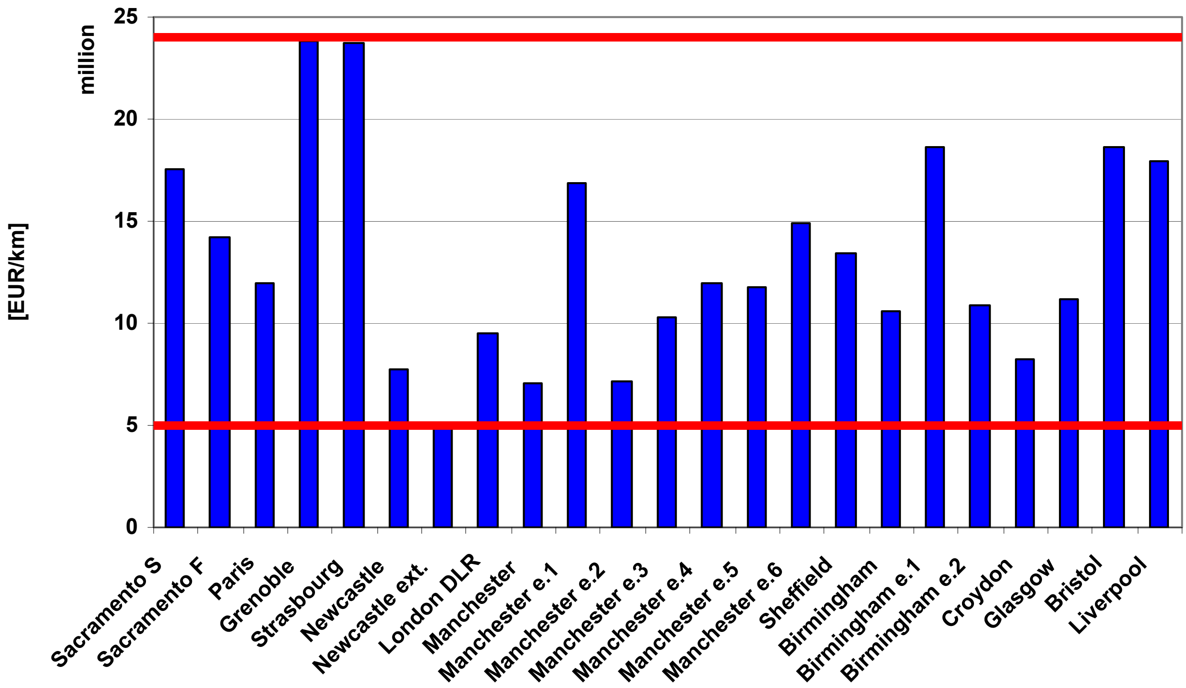


Fig. 43: Specific capital costs of LRT systems.

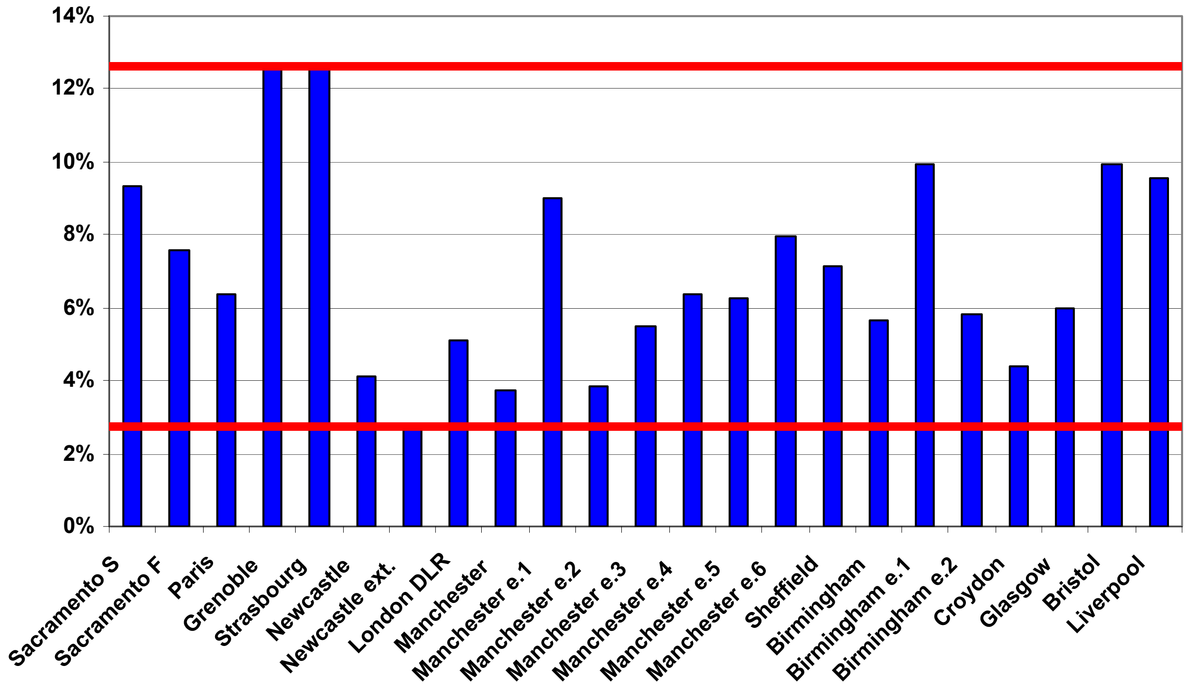


Fig. 44: Specific capital costs of LRT in comparison to metro Vienna U3.

As can be seen in figs. 42 and 44 the cost of LRT systems are very much lower than the costs of full metro systems. The costs of surface LRT systems still may vary remarkably, depending on the circumstances. Like, if it is a new built system or a system using partially rebuilt, but already existing, tracks. The construction of a network or expansions of a network is normally realised in phases according to the ranking of options and the available funding.

In accordance with the results in figures 41 and 43 (Young 1995) sums up the capital costs of British LRT systems. They range from 6,8 to 14,0 mill. USD/km - which makes at date 5,5 to 11,3 mill. EUR/km. The cheapest systems were Manchester and Croydon with 7,3 and 8,6 mill. USD/km [5,9 and 6,9 mill. EUR/km] where former railway ROWs could be utilised.

Vehicles

According to (LRTA 2003) within the last 15 years the high number of 25 different low floor vehicles have been designed. The result are unnecessarily expensive vehicles due to the fact that LRV producers have not achieved the economies of scale that were achieved in e.g. car and bus industries. Figure 45 gives an compilation of different vehicle’s prices, including two non LRVs (Vienna and Toulouse).

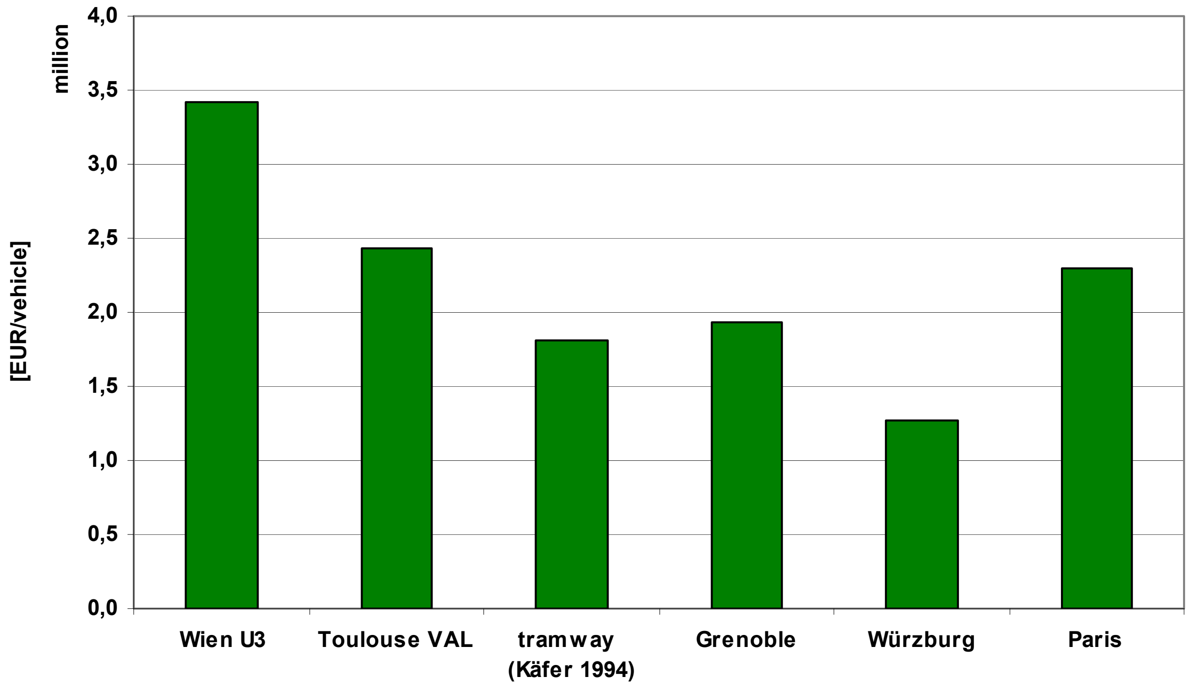


Fig. 45: Costs of vehicles within different systems.

The sources for fig. 41 - 45: Käfer 1994, Young 1995, Jenkins 1997a, 1997b, Groneck Christoph 2003, Beckendorff 2002, Wansbeek 2002, Hoffmann 2002.

Operation

A LRT system should be designed with the principle in mind to decrease energy use and maintenance expenditure during operation. (UITP 1989) This has to be applied also for the operation of stops and secondary facilities.

As the diagrams above show, tunelling is about ten times as cost intensive as surface constructions. In the beginning of the LRT renaissance era, when tunnelling was forced intensively, the follow-up costs of sub service operations were not paid attention to. (Brändli 1995) Annual operation costs for stops are stated in (VDV, et al. 2000):

- surface LRT stop: 15.000 – 20.000 DM/a (7.700 – 10.200 EUR/a)
- underground LRT stop: 80.000 – 120.000 DM/a (40.900 – 61.400 EUR/a)

The **four** to **six** times higher costs of underground stops put additional financial burden upon the operator due to sub-surface operation. The higher costs result from escalator and lift maintenance, cleaning and energy consumption.

The operational costs of vehicles consist of maintenance, capital costs, depreciation, energy use and personnel. (UITP 1989) The ability to build trains leads to increased transport capacity – in comparison to buses – because LRT can carry more people with fewer operators and complete more trips in less time resulting in lower labour costs than for buses. That operating costs are substantially important are shown in (Dallam, et al. 1982) with the criteria for the "Twin Cities" LRT project:

> *"The annual operating cost per passenger of an LRT line must be less than the annual operating cost per passenger of the existing bus service or less than the system average annual operating cost per PAX. A proposed LRT line should be more cost efficient than either the existing service it replaces or a non-LRT alternative."*

To keep the maintenance costs low, also the vandalism issue (UITP 1989) has to be approached rightly:

- usage of materials with increased vandalism resistance;
- creation of a friendly atmosphere with sufficient social control and immediate damage repair

Financing

As the implementation of a LRT brings benefits for all city inhabitants, the financing should be organised accordingly. In France the "versement de transport" was introduced. This is a tax usual in French conurbations on all employers with nine or more employees. In Strasbourg the tax is 1,75 % of wages (eaue.de 1996, Topp 2004), in Mulhouse 1,45 %. (Framenau 2002)

3.3.4.2. Economic effectiveness

A properly designed LRT scheme will likely have two types of benefits for the economy, an external and an internal. The external effectiveness is related to the cityscape and it's inhabitants, whereas the internal one is focused on the economic performance of the operator. If the operator is a publicly owned one, the circle closes and the inhabitants profit from it a second time.

City related

Tramway insertion and the often accompanying pedestrianisation of the immediate vicinity is almost always opposed by different groups within the city. But most resentfully it is done by merchants and restaurant proprietors, because they fear that the missing parking places in front of their shops will keep the customers away. But as examinations show, quite the opposite is the case. LRT is used for regaining or preserving the economic strength of CBDs in comparison to "greenfield" located, peripheral shopping centres.

The LRT is a comfortable way for visitors to discover the city on their own. (Besier 2002) It is a moving shop window (show case) including spectators more attentive to surroundings instead of the transport matters than car drivers. This opens up new, additional customer potential for shops and catering trades along of LRT alignments due to "advertising by vision" effective on LRT riders and waiting PAX at stops. (compare with Schmidt 2003) And besides that, the tram transports more customers than car traffic simply due to higher capacity with no need for parking space. Especially at PT stops, as they provide for high pedestrian frequencies for most of the time. (Mouvement Ecologique 1999) describes, that they are focal points for merchant's interests. The commercial success of precincts is closely bound to the presence of crowd-puller stores. These crowd-pullers for themselves preferably choose locations with high frequencies.

The example of Hannover (Felz 1989) between 1978 and 1985 shows, that LRT installation leads to an increase of store space by 7,1 % accompanied by an increase of turnover by 13,5 %.

According to Besier's (Besier 2002) examinations, in Lyon the redesign of the CBD and outskirts along the LRT is expected to increase Lyon's attractiveness for enterprises.

Operator related

The increase in commercial speed, besides the effects on attractiveness of the transport, is also important from the operator's point of view. It leads to denser intervals without the need of investments into new rolling stock or the demand for more personnel. The longer the line and the initial headway are, the easier is it to save one vehicle/rider or to compress the intervals. (UITP 1989) Operational time savings ought to be achieved by good stop design and efficient PAX boarding and alighting, but without increase in energy use or number of needed vehicles. In addition to this measures also a decrease of energy expenditure through minimisation of overall weight and maximum velocity and a maximisation of starting acceleration and deceleration can be achieved. (UITP 1989)

(VDV, et al. 2000) gives the example of Leipzig, where 26 % of travel time reduction along one single line lead to annual savings of 375.000 DM (approximately 192.000 EUR). To demonstrate the potential at the bottom of it: The network spanning increase in commercial speed from 18 km/h to 25 km/h would lead to 25 mill. DM (approximately 12,8 mill. EUR) annual savings in operation.

3.3.5. Summary of planning parameters

The planning parameters have been classified according to a scheme including four major categories.

In the first category "customer relation" all the important factors influencing the interplay between the LRT system and its actual and potential users are described. These factors have a big influence on human travel behaviour and comprise of: the transport supply that the LRT provides for the city's inhabitants; the handicaps and barriers that may impede the use; the increased attraction of riders due to the "rail bound bonus"; the expected ride comfort and safety issues.

The second category "spatial entities – network" deals with the factors concerning the interplay between city and LRT system. The factors described therein are: size and morphology of the city; the PT system's catchment area and the passenger potential that can be activated; the positioning of the line in reference to the city structure; stop spacing and distribution along the line and the issues of safety of system breakdown.

The "integration into the city" is described in chapter four, with regard to following topics: the design of surfaces along and next to LRT alignments; the redesign of city structure due to changing travel behaviours; the attractiveness of access to and egress from LRT stops; the possibilities to treat the LRT system with priority; the environmental impact changes due to LRT implementation; the characteristics of use of space; the transport capacity abilities of LRT systems; how to increase influence on modal split and finally the design of the right of way itself.

In the last category, an approach to "economic aspects" of LRT implementation, regarding the capital and operation costs and the impact of LRT on the city's economic effectiveness is made.

4. Description and analysis of different design plans

In the following sections four different blueprints, proposing three different schemes and the implementation into the Urban Development Plan (PPMOL) , will be introduced and described, to provide the structured basis for the analysis and the development of improvements in the following chapters. These sections will be structured in two major steps:

- In the key features of the blueprint section all the properties of the examined blueprints according to the descriptions in the available sources are listed according to the classification developed and intensified in chapter two.
- In the key argumentation section the key argumentation by the proposing party pro their blueprint is listed it is are used by the authors themselves.

It has to be stated in advance, that the amount of available and digestible material differs a little bit from project to project. The most material was at disposition for the project of TransportTechnologie-Consult Karlsruhe (TTK) and the PPMOL, where the original publications were at hand. The other proposal's descriptions base on project documentation excerpts and in depth newspaper articles.

The analysis is basically arranged in two subchapters. The first one will give an in-depth assessment and discussion of the four blueprints introduced in the previous chapter. In the second subchapter an comprehensive comparison of the parameters of existing planning and planning suitable for sustainable development, resulting from chapter three, will be made. This comparison is expected to lead to differences between the status quo and a modern approach, serving as a basis for further developments.

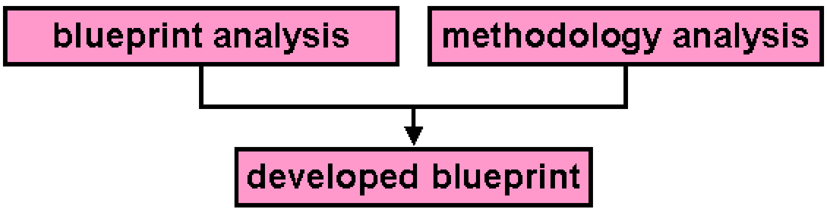


Fig. 46: The analysis process.

As already used in the status quo chapter, the networks are drawn in the unified topographic map of the city for the ability of comparing the networks. The positions of stops and their "circle of influence" with a radius of 220 m (see Peperna 1982) are drawn too.

4.1. The "Guzelj plan" from 1989

As already outlined in section 2.2. the first thoughts and discussions about a possible reintroduction of a rail bound means of PT emerged at the beginning of the 1980's. This happened as the limitations and shortcomings of the bus system in an ever increasing stream of car traffic became visible. In 1989 the Slovenian Institute of Urbanism (SIU), the construction and planning firm "*Slovenija Ceste Tehnika*" (SCT) and Ljubljana's municipal public transport provider "*Ljubljanski Potniški Promet*" (LPP) published their plans for a new LRT system. Although this blueprint may not have high topicality to be implemented anymore, it can nevertheless be seen as a part of the endeavours towards rail-bound city transportation and is therefore included in the further studies. All the features and argumentation in the following two chapters are taken from an excerpt of (Guzelj, et al. 1989).

4.1.1. Key features of the plan

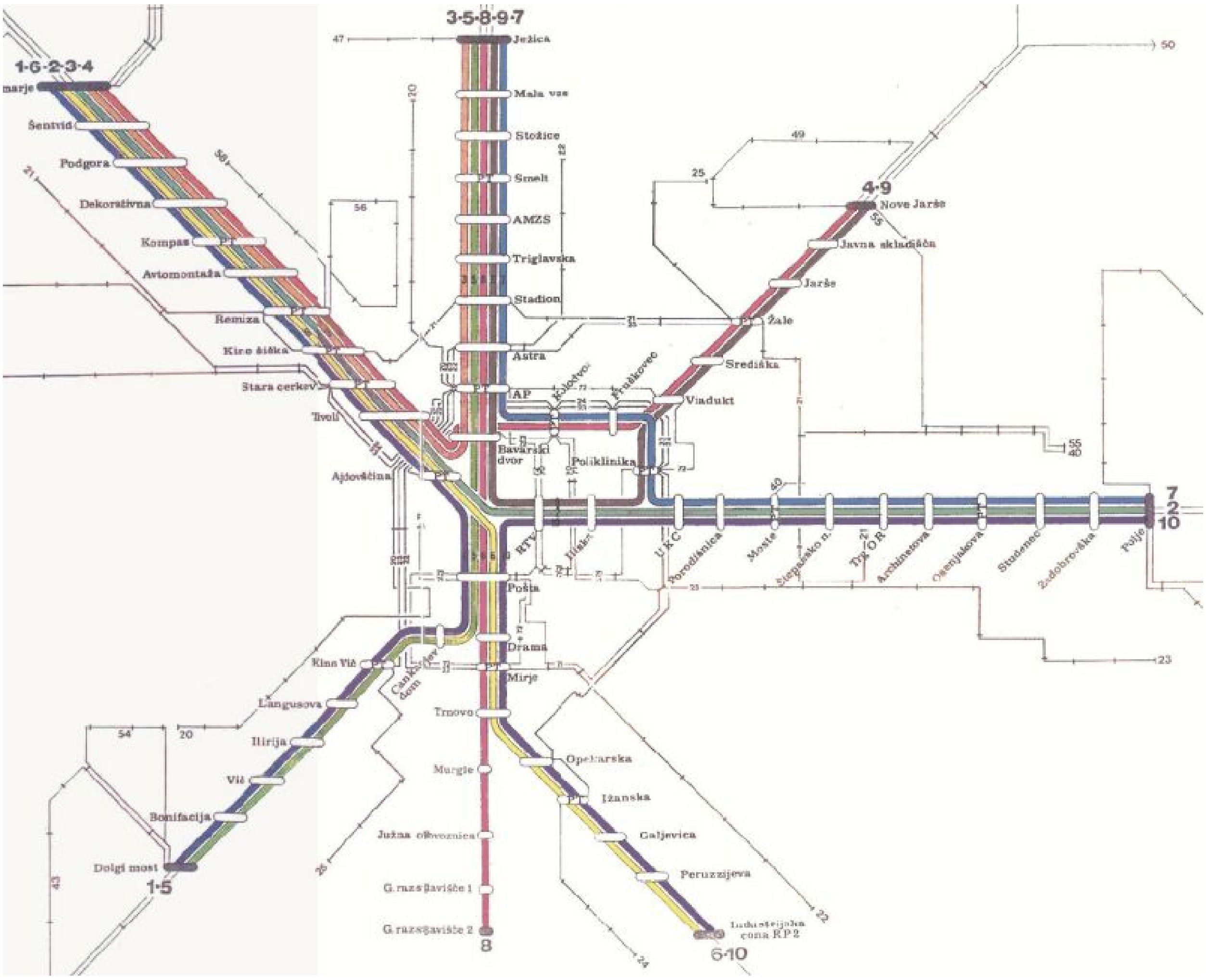


Fig. 47: Scheme of the "Guzelj plan". (Guzelj, et al. 1989)

► Customer relations

- The system, including all elements, moving and non-moving, will have a unique corporate identity.

► Spatial entities – network

- The envisioned PT densities for the CBD are 3,0 km of line per km² of city area, for intermediate districts 1,8 km/km² and at the outskirts 1,0 km/km².
- The key corridors for line placement are the main urban development axes.
- The LRT is assigned to the main corridors, buses on the secondary axes and tangential connections, as feeder services from the region to the city.

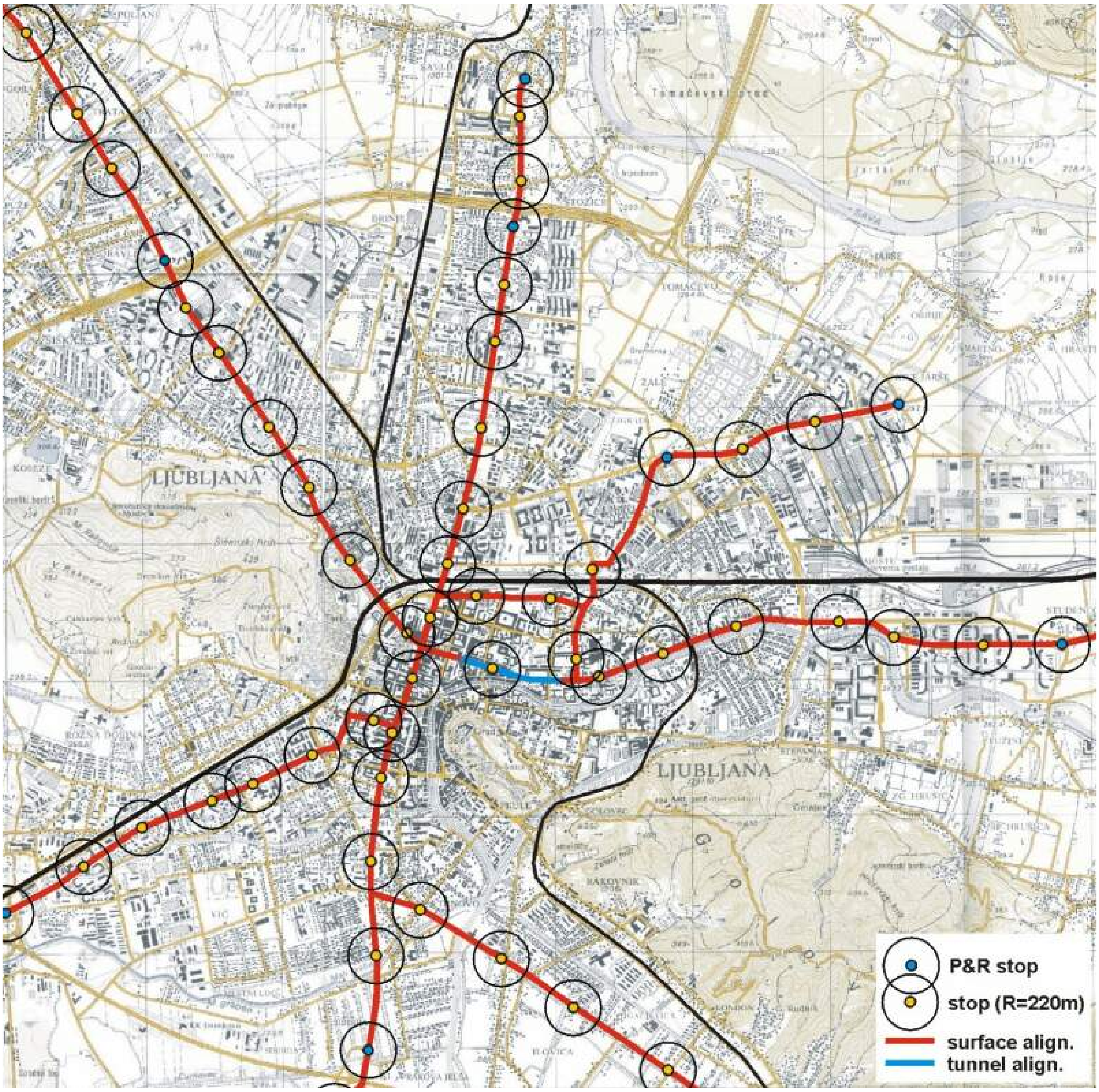


Fig. 48: Network of "Guzelj plan" in stage I.

- Approximately 75 % of PT ridership occurs along radial relations.
- A transition from a “homogenous” network of one single mode to a “inhomogenous” network with different modes is required.

The thick colourful strokes in fig. 47 represent the different LRT lines running along the five primary and two secondary axes of the city’s urban development. The thin, black strokes depict the connecting bus lines, which mainly serve as feeder branches into less densely populated areas off the main axes and as tangential connections between the LRT routes.

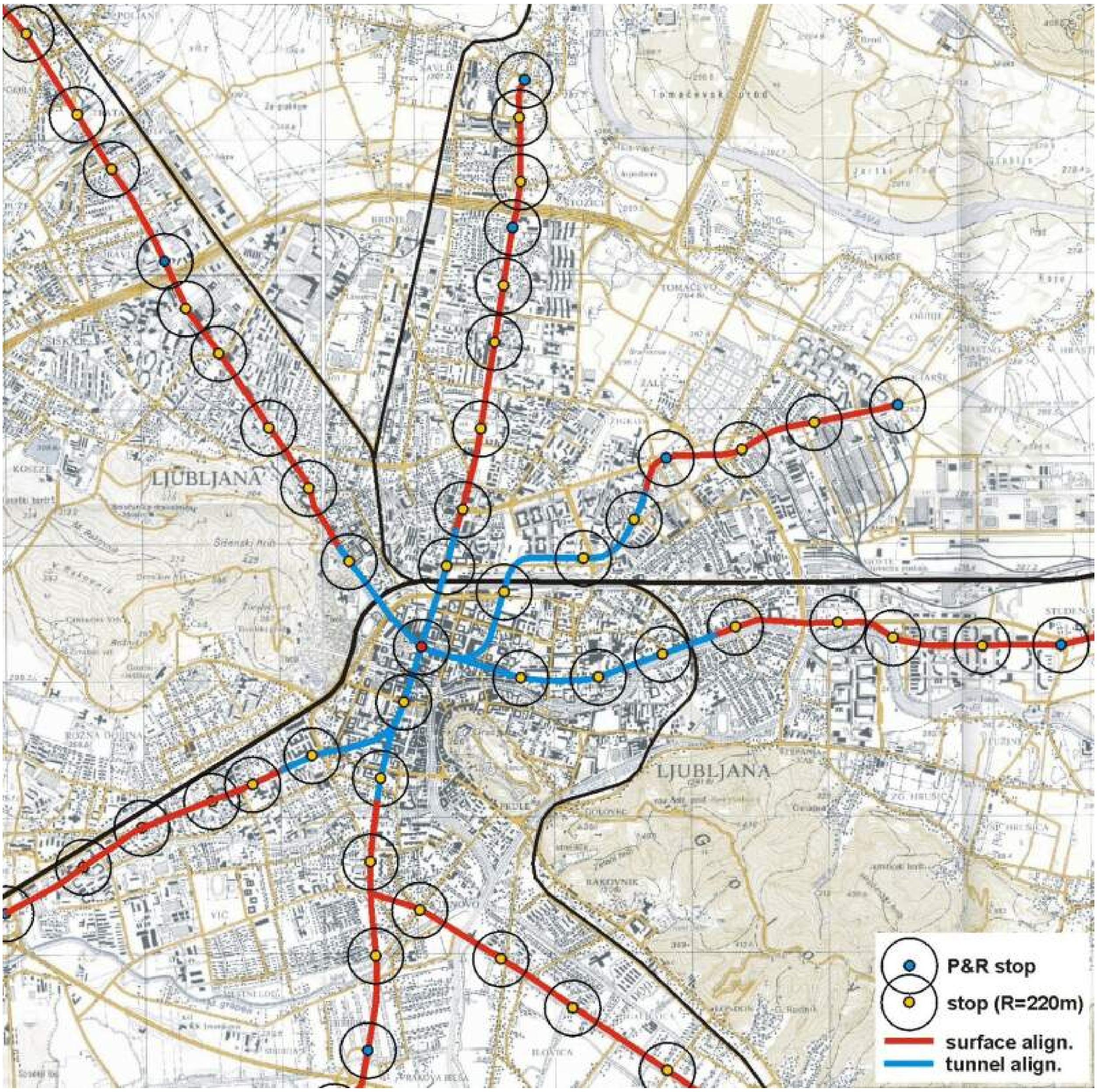


Fig. 49: Network of “Guzelj plan” in stage II.

The plan had a very sophisticated and interlaced approach towards implementation with three phases of development and four implementation stages.

The first phase of development was congruent with the first implementation stage, which was actually the construction of the whole tramway network at level in the streets. Only a rather short section was proposed to be underground at this stage already. Fig. 48 shows the network in it's first of four stages of implementation. The blue line in the middle of the map shows the first half km of below surface alignment.

The second phase of development was then the connection of the new, independent LRT network at suitable locations with the existing railroad network to provide for a transfer free transport between the regional towns and the capital's city centre.

The third phase of development consists of the transition from the first to the second implementation stage. The third and fourth implementation stage were scheduled to follow later on.

Approximately 30 years after insertion of street running LRT of first development stage the capacity and technological abilities is expected to be exhausted. Then the third phase will be implemented, which is the transition to the second implementation stage, producing 8 km of tunnel. With a potential succession by the third and fourth stage to gain a real underground/metro.

1st phase	implementation of city rail in 1st implementation stage
2nd phase	gradual connection of city and suburban rail
3rd phase	transition of city rail from 1st to 2nd implementation stage (=dig in)

Tab. 20: Overview over phases and stages. (Guzelj, et al. 1989)

stage	track separation
I	• only horizontal separation • mixing of LRT and tram elements • almost all crossings at level • priority at intersections
II	• partially horizontal, partially vertical • consequently LRT elements included • crossings partially at partially out of level • priority at intersections
III	• partially horizontal, partially vertical (major intersections) • consequently LRT elements included • predominantly crossings out of level • priority at intersections with signalisation and/or gates
IV	• predominantly vertical separation • consequently LRT elements included • out of niveau crossings only

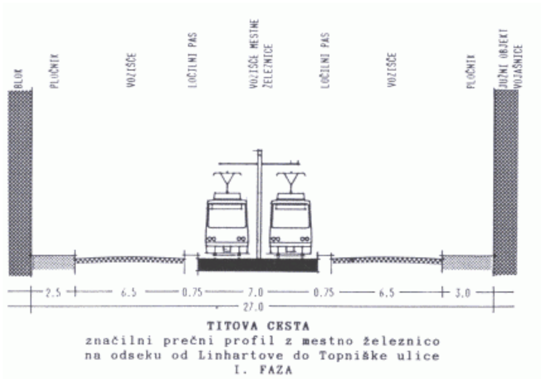
Tab. 21: Chart of separation process. (Guzelj, et al. 1989)

stage	network [km]	sub-surface [km]	share [%]
I	35	0,5	1,4
II	34	8,0	23,5
III	34	14,0	41,2
IV	34	26,0	76,5

Tab. 22: Chart of implementation stages with corresponding underground sections. (Guzelj, et al. 1989)

As can be seen in tab. 22, the initial system, which is almost completely above ground, will be dug into the ground subsequently with the implementation stages' progress. As the sub surfacing program goes on, a number of previously street oriented alignments is given up for independent, spacious and curvaceous below surface alignments. No need to mention, that due to this realignment of routes also stops need to be positioned newly. See for instance the route changes in the vicinity of and at the railway station area. But not only in the densely populated CBD is the tram alignment positioned below surface, also along the urban development axes. The higher the stage of implementation is, the longer are the underground sections. This leads in stage four to the remarkable fact that more than three quarters of the network would be situated below the surface. (see tab. 22 and fig. 65)

► Integration into city



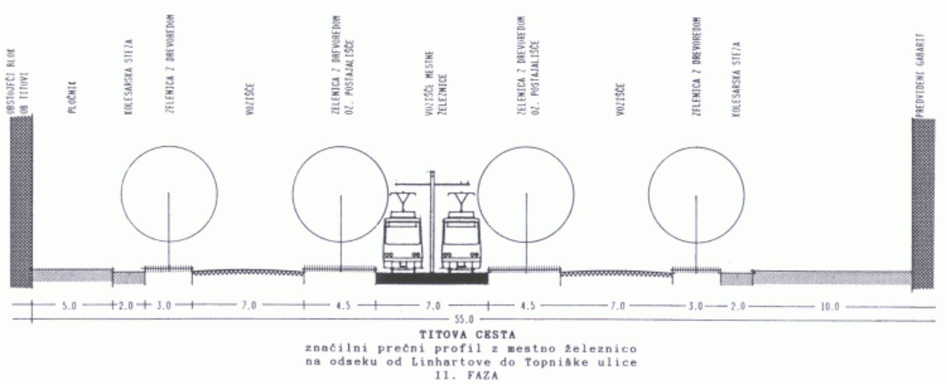


Fig. 50: Cross section before and after proposed "city shaping" reconstruction. (Guzelj, et al. 1989)

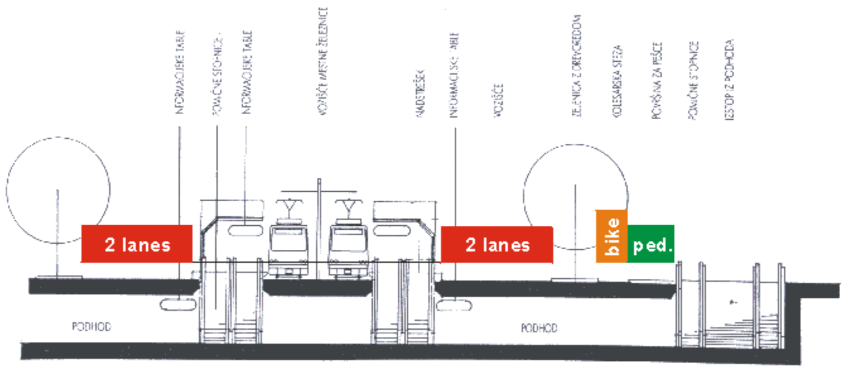


Fig. 51: Scheme of proposed pedestrian subway stop access. (Guzelj, et al. 1989)

- The acceptable walking distances for the stop's catchment area for Ljubljana are designated: in the CBD: for LRT 400 m, for bus 350 m; in intermediate areas: for LRT 475 m, for bus 400 m and in suburban areas for LRT & bus up to 750 m.
- The resulting optimal distance between stops is for LRT: (400 -) **500 - 600**(- 800) m and for bus: (300 -) **400 - 500** (- 600) m.
- In areas where widening of streets is required, this will be done by impacting the existing buildings. Impacts will be larger in areas where the existing street space is comparatively narrow. This are older districts at the CBD limit. These impacts in some places will have to be radical.
- Widening of corridors: e.g. *Dunajska c.* between *Linhartova c.* and *Topniška c.* was planned as 2 tracks, 4 MIT lanes, 4 rows of alley trees and 2 lanes for cyclists and pedestrians each. This resulted in a street width of 55 m and would have required in this section 80 houses to be demolished. *Celovška c.*: 66 m wide, 61 houses demolished; *Tržaška c.*: 47 m wide, demolition of 59 houses; *Zaloška c*: 55 m wide, partially 71 m, 114 houses to be demolished. In sum some 300 object are designated to be demolished.
- At least at 10 major road intersections the LRT will get only partial priority.
- Due to the reconstruction, impacts on surface layout and the built environment "cannot" be prevented.
- Other users have to be included into public street space: pedestrian, emergency services, delivery, access to parking lots/houses, cabs, cyclists and general traffic. The last one can be excluded completely in designated cases. In the CBD, along major routes, MIT will not be allowed.
- The implementation of LRT requires new surface design. In the urban axes, *Masarykova c.* and *Njegoševa c.* this can and will be achieved by a "widening of the corridors".
- No obstacles for LRT, neither through other transport players nor somebody/something else, will be allowed. This means an exclusive ROW by means of construction, organisation or

traffic technologies. On the other hand LRT has total priority at intersections with lower importance but only limited priority at very important intersections.

► **Economic aspects**

- As an operation economics statement it is said, that a LRT system needs maintenance personnel for infrastructure and facilities. In comparison to the bus, where this burden of maintenance is carried by the public body (in most cases).

4.1.2. Key argumentation

Although the published project deals with a lot of considerations, the self-assessment is remarkable and surprising: *"This long stage program sets the foundations to solve problems of PT and transport in general for good!"* (Guzelj, et al. 1989)

- The system is designed to provide space and time related coverage of the area by PT.
- All axis roads will be transformed to alleys or boulevards, which will provide a higher quality of the urban motive.
- The widening of transport profiles is in harmony with the development of the transport system and with the existing and the expected city size respectively.
- The LRT has to improve the accessability to the city and town centres.
- Improvement of the CBD, the urban axes, the areas around primary and important secondary interchange stops is expected. This will consolidate and emphasise the typical appearance of Ljubljana's urban fabric.
- PT is considered as an option of choice, which should be used by people, not in need to use the car, if they don't want to. PT is supposed to be so attractive, that people will be kept off actions which are repugnant to society benefits.
- LRT will not only bring socio-economic, social and transportation benefits, but will also have an impact on the city's future appearance. It will improve the city's "readability" and provide a clear identification of the key urban development axes, the cityscape and the city's local centres.
- The high operating speed, frequency and safety requires for a separation of LRT and other transport participants.
- In an example calculation for seven inbound routes the speeds and time savings for passengers for the year 2010 are calculated and benefits through time savings are derived. The results are, that the LRT commercial speed is by 23 % (1^{st} stage) and 43 % (2^{nd} stage) higher than the MIT's one. The travel time savings of LRT vs. MIT towards the city centre are 15 % (1^{st} stage) and 19 % (2^{nd} stage).

- From the initial time savings accumulated time savings for four scenarios are calculated, considering the time needed for all motorised urban travel (car, bus and LRT or not according to scenario). The subsurface LRT version requires less running times than the surface LRT version, which again saves a lot of time in comparison to the status quo and the MIT only scenario. In comparison also the amount of per day saved work hours for the scenarios is calculated. Both proposed LRT versions produce a lot of saved hours, which may mean an increased productivity.
- The ROW with catenary posts will be an optical guideway for the corridors; the entrances into the alleyways will each provide a kind of town gate.
- The plan is designed to be able for expansion and development for the future and to be able to reach stage IV, the highest grade of separation envisioned.

4.2. The blueprint of the "Bajželj group"

The "Bajželj group" (name was given by the author for easy identification sake) is a group, who examined the feasibility of a underground scheme for rail-running means of PT in the late nineties. According to (Bajželj, et al. 2002), the group's main members are professors, docents and experts of engineering: *Uroš Bajželj* (geotechnical engr.), *Vladimir Drusany* (mechanical engr.), *Anton Jeglič* (electrical engr.), *Anton Gunde*, *Jakob Likar* (geotechnical engr. and mining), *Boris Gaberščik* (urban planning).

The group promotes its ideas through publication of articles in e.g. Slovenia's major, daily newspaper "Delo" (28.04.1999, 10.11.1999 and 22.08.2001) (Bajželj, et al. 1999a; Bajželj, et al. 1999b; Bajželj, et al. 2001) and the publication of a brochure called "Underground tramway in Ljubljana – yesterday ..., today ..., tomorrow ...".

Additionally to this written statements, the group also introduced their plans to the public at the "Enquete"/public discussion on May 2nd, 2002 within the scope of the exhibition "*Lej ga, tramvaj – Udobno, hitro in varno po ljubljanski regiji*" (Look, the tramway – Convenient, fast and secure travel around Ljubljana's region. (MOL 2002)

4.2.1. Key features of the plan

► Customer relations

These were not explicitly stated in the available documents.

► Spatial entities – network

- The layout follows the "star-like" layout of the urban network along the major inbound routes.

- All branches join into one central artery via very curvy and spaciously aligned underground sections, which is especially valid for the south-western, northern and north-eastern lines. See fig. 52.
- Rather long distances between stops in the city centre lead to a low density of stops within the area with the highest densities of population, working places, administrative institutions and public life in general. See fig. 52 for position of stops and "circles of attractiveness" of stops.

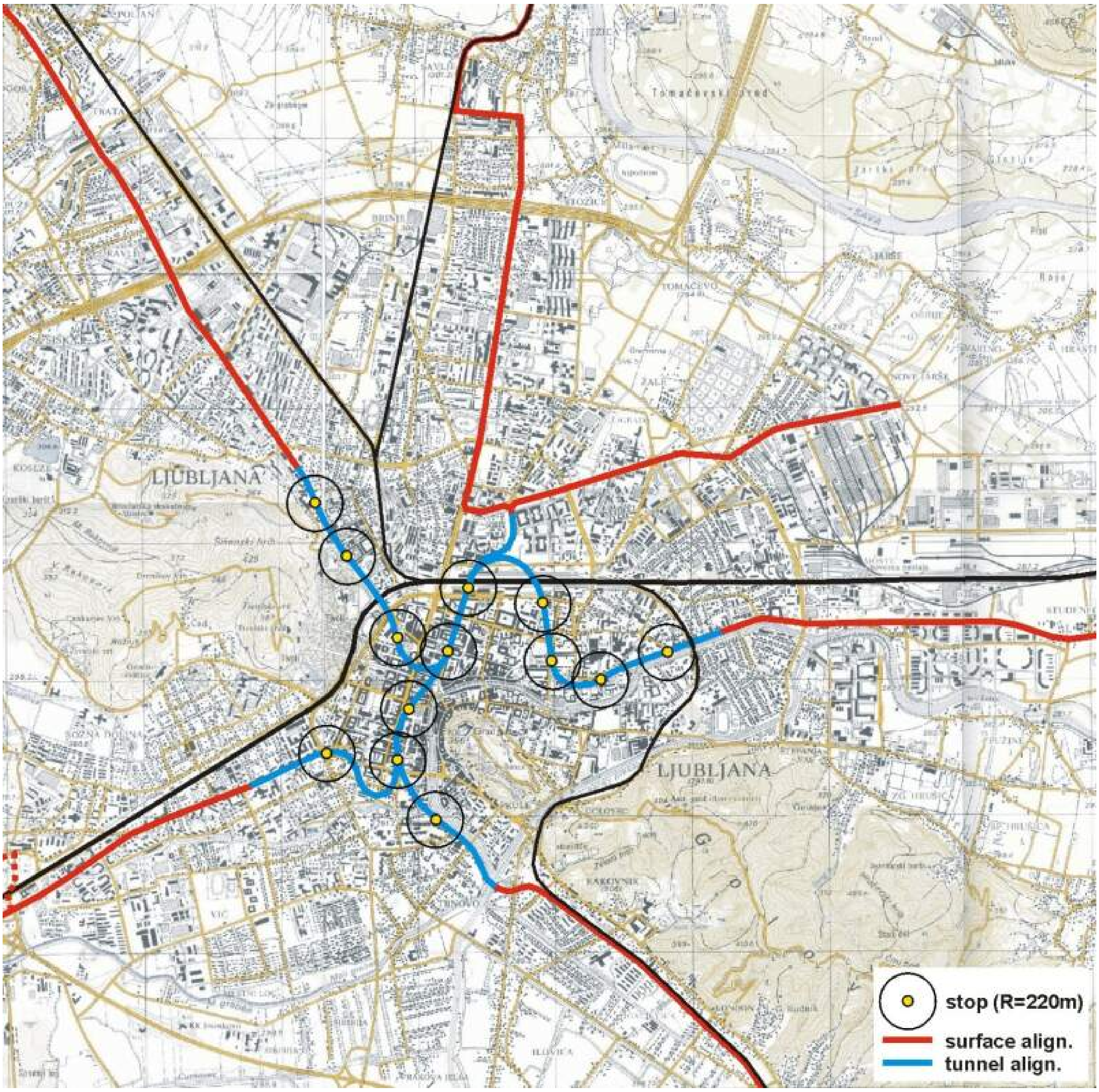


Fig. 52: Network of "Bajželj group" proposition.
According to (Bajželj, et al. 2002, Bajželj, et al. 1999a; Bajželj, et al. 1999b; Bajželj, et al. 2001)

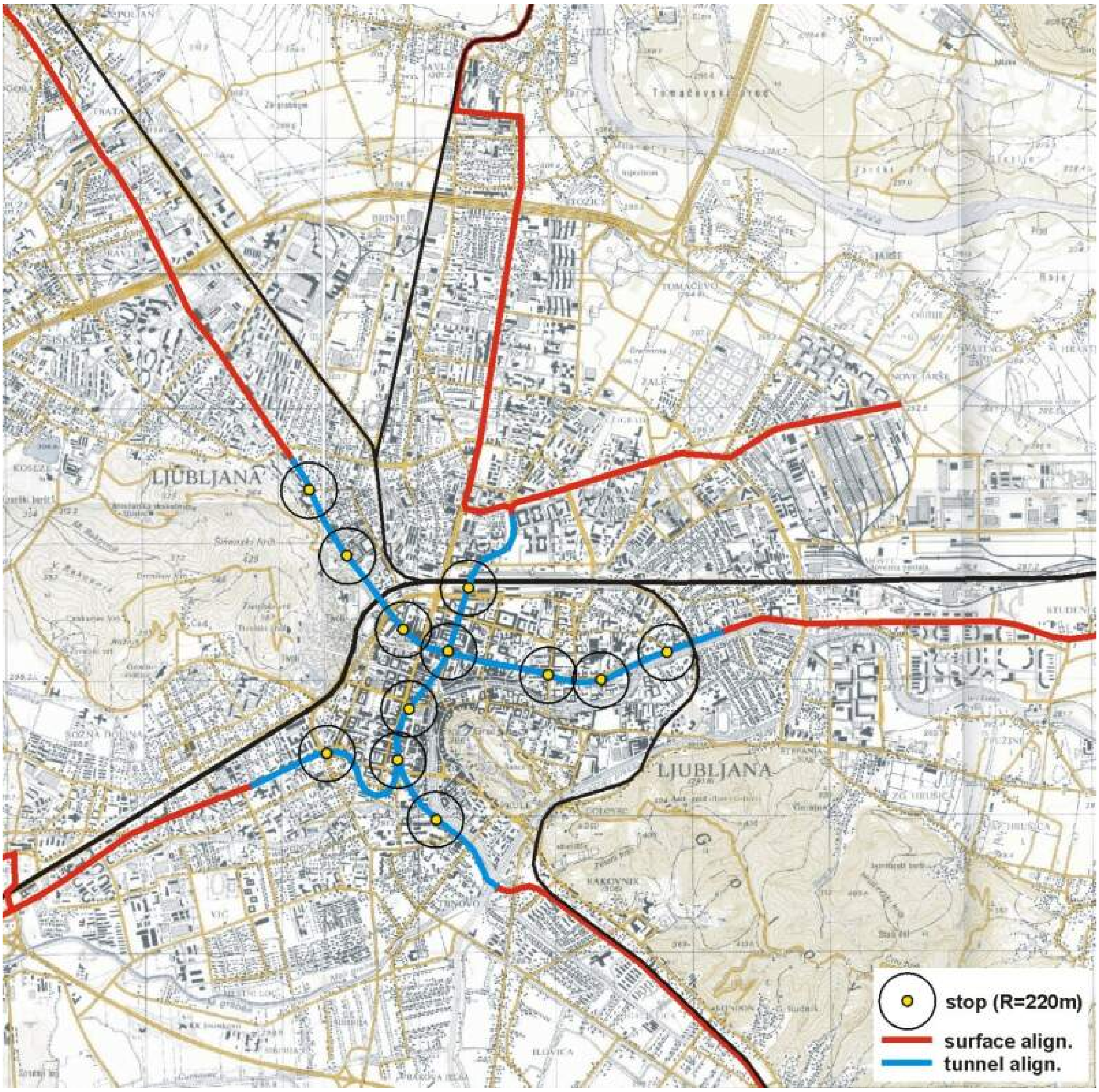


Fig. 53: Version 2A within the city centre. According to (Bajželj, et al. 2002)

- The draft provides 3 versions for inner city routes:
  - Version 1: parallel alignments of north-south and east-west directions between the central city station and the station serving the main railway station. This implies for the curvy alignment of the east-west route, as it has to re-align into north-south running direction.
  - Version 2A: the east-west line runs straight below the CBD. This route meets the north-south running route perpendicularly at the bi-levelled, sub-grade, central interchange station. The curvy subsurface sections of the north-south route and its branches remain unchanged in comparison to version 1.
  - Version 2B: No change in the north-eastern route's alignment, compared to versions 1 and 2A. The east-west connection is dramatically different to it's predecessor versions, as

it remains above ground throughout the line. This requires a completely changed alignment along the following streets:

– *Celovška c.* – *Tivolska c.* – *Masarykova c*. (railway station) – south along *Njegoševa c.* – east along *Zaloška c.* –

► Integration into city

- Within the city centre all alignments are strictly below surface.
- Descends below ground start outside the inner city road ring and railway tracks. The descend takes place along the major axial routes.

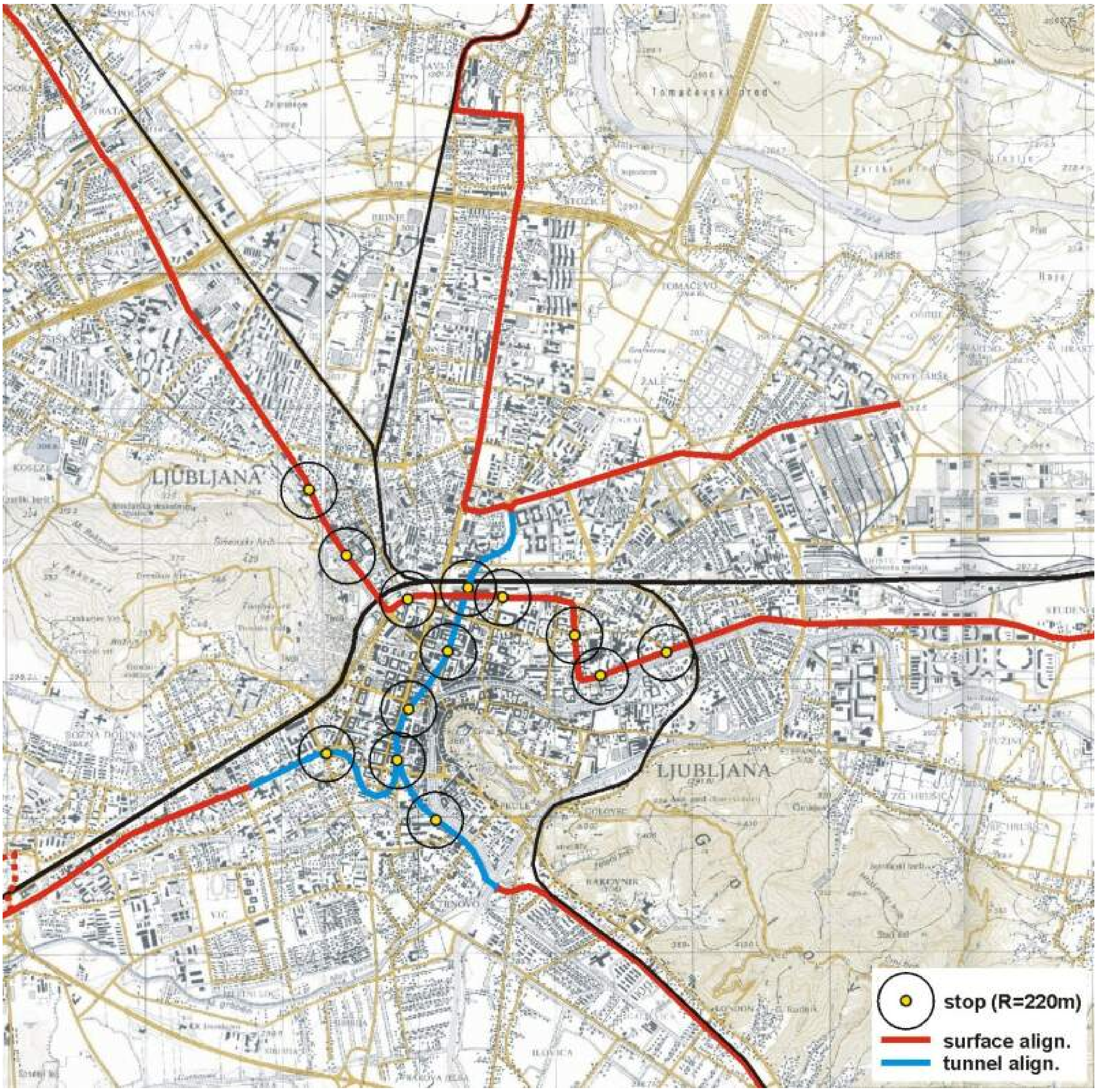


Fig. 54: Version 2B's changed east-west route alignment. According to (Bajželj, et al. 2002)

- Except for the sections of descend from street level to below street level, the routes do not follow the street alignment, but run “criss-cross” below the built up environment. This requires for tunnelling in mining technique, which is expensive and requires a great effort.

- The scheme proposes single track tunnels with sidings for train consists meeting in stations.

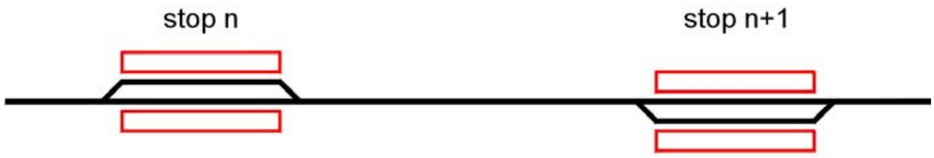


Fig. 55: Proposed scheme of underground ROW with single tracks.
According to (Bajželj, et al. 1999a; Bajželj, et al. 1999b; Bajželj, et al. 2001)

- The scheme provides independent ROW for the LRVs throughout the network, either by separated ROW above surface in the city’s outskirts or by tunnels in the city’s centre.

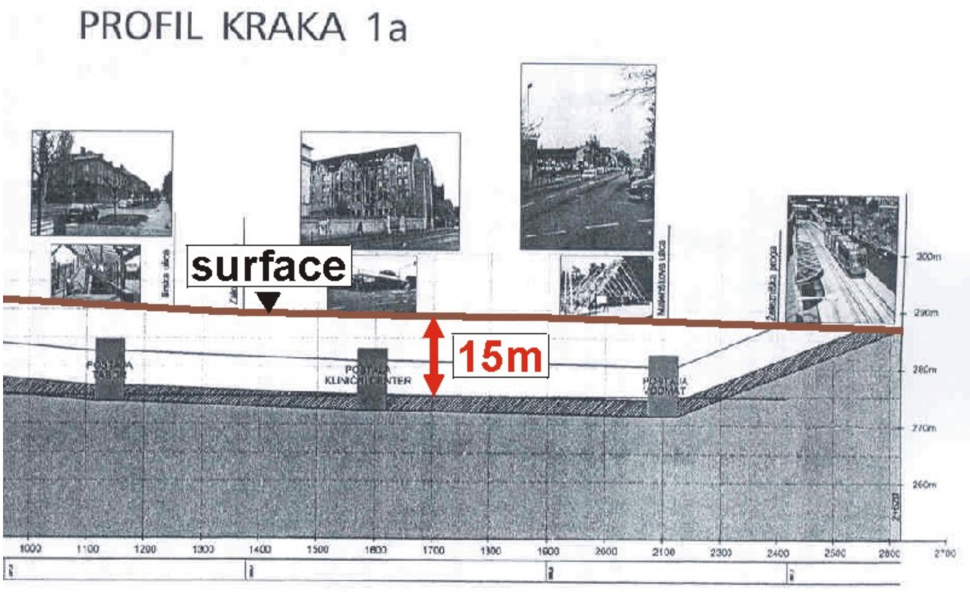


Fig. 56: Longitudinal section of version 1, east-west line,
to the east of the railway station. (Bajželj, et al. 2002)

► Economic aspects

These were not explicitly stated in the available documents.

4.2.2. Key argumentation

The following list comprises of arguments and explanations that are given in (Bajželj, et al. 1999a; Bajželj, et al. 1999b; Bajželj, et al. 2001).

- A nice and liveable city requires for part of the traffic to be banished below the surface.

- A comparison with and reference to similar medium sized cities that have a metro, namely Augsburg, Nürnberg or Bilbao is made.
- New obstacles for "traffic" (MIT is not named explicitly) like semaphors and subways are undesirable.
- PT system must be adjusted to the cities inhabitants' needs like: individual movement opportunities (more cycling and strolling paths, ...).
- Be independent from e.g. weather, age distribution of population, peak hours, cultural, political and sportive events and union strikes on the streets!
- The street space could be used for public events better, especially when the tramway is being cleared off the streets.
- Serving as a feeder to cultural events for out of towners.
- Increased safety for pupils and students is achieved as they wouldn't be exposed to today's traffic risks (above surface), but could arrive at their trip destinations safely (below surface).
- Decrease of air and noise pollution as the number of buses and cars on the streets would decrease.
- Increased safety and optics, as the city's streets wouldn't be spoiled with the catenary wires.
- Less traffic obstacles due to missing catenary maintenance works.
- The underground tramway will not only decrease traffic impediments (decreasedroad capacities by lowering the lane number or producedbottlenecks) but also gain all profits connected with sustainable development. Coming from the region and the city's outskirts respectively, the tramway will "dive into the ground" to avoid the high traffic in the city centre's vicinity.
- No need to redesign the surface layout due to track laying construction.
- No new separation of the city due to the tramway's new ROW.
- Risks due to "transport-incidents" are neglectable.
- No delays due to road incidents, garbage pick-up, or weather conditions.
- Due to the evasive removal of the PT from the streets and the resulting decrease in traffic in general, significant parts of the street acreage could be used for other uses, e.g. more lawns, gastronomy, bicycle lanes and recreation.
- The stops within the city should be so close one to each other, that the exertion for using the underground tram is lower than the exertion when using the own automobile.
- Commuting by car will be replaced by tramway rides.
- Shopping centres at the city's outskirts will be within easy reach without car dependency.

- Decentralised connections to the national railway network at prepositioned stations without overburdening the main railway station.
- To increase safety in the underground sections, every seat should be provided with an alarm triggering button.
- If a surface tram would be built, following implications would remain:
  - The need to build a large number of subways for pedestrians.
  - Crossing the main street *Slovenska c*. would become more complicated for pedestrians.
  - To the "urban border railway" another border "tramway" would be added.
- Construction of underground stops with direct access to all important points of interest.
- Sub-surface alignments are more attractive for gaining customers than above surface alignments.
- The higher costs (about five times higher in comparison to the surface ROW) are not important, because the solution below ground would solve Ljubljana's transport problem for up to 100 years or more.
- Ensures higher customer friendliness and higher traffic safety and does not burden the environment within the centre.
- The sub-surface alignments do not consume any areas above surface within the city and provide for new opportunities as underground shopping malls next to the LRT stops.

4.3. The most recent "TransportTechnologie-Consult" blueprint

The history of the plan derived by TTK begins back in the mid 1990's. The primary political agenda of independence had already been carried out to a major extent, as the city's and region's problems with transport cropped up again to public and political attention. The city commissioned a study which should examine

a) the improvement of railroads in the Ljubljana region, and

b) the feasibility of a rail link through the city connecting two railroads (named phase 1a).

The examined rail link, usable for tram-train style of vehicles, was supposed to connect directly through the city on *Slovenska c.* the north bound local railroad towards *Kamnik* with south bound local railroad towards *Grosuplje* via the main station, the city and the station *Ljubljana Rakovnik* (see fig. 57). This part was finished in 1997. (Ludwig, et al. 1995)

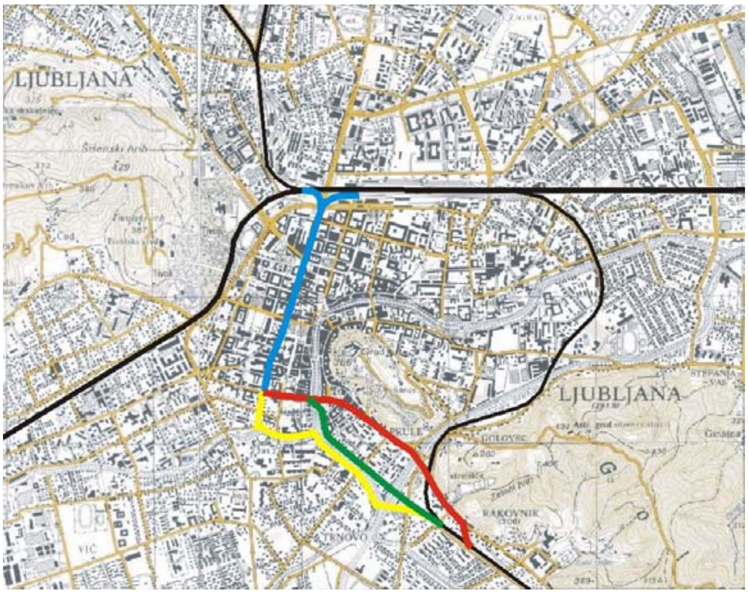


Fig. 57: Connecting the existing railroads with a city rail link. (Ludwig, et al. 1995)

Phase 1b, which commenced afterwards, was divided in two further parts. The first, phase 1b-A, focussed on the aspects of inner city transportation and network layout, whereas the second, phase 1b-B, discussed the first stage implementation more in detail.

The basis for the ongoing discussion of the "TTK plan" are the "Phase 1b / Preliminary Design Study" (Perez, et al. 2002b) and "Executive Summary" (Perez, et al. 2002a) parts of the "Public transport concept for the city and region of Ljubljana".

4.3.1. Key features of the plan

- It list basically the same arguments as the "Guzelj plan" according to the general network layout. However, the major difference is the lack of sub-surface sections.
- The envisioned objectives are:

  For the operator: provide tramway and tram-train vehicles to operate on city infrastructure and regional infrastructure and provide an urban infrastructure designed to cater for trams and tram-trains equally.

  For the customer: provide an integrated network; provide sufficient capacity under any conditions; provide convenient through services with as few as possible interchange needs and avoidance of the barriers due to interchange and non integrated ticketing and timetables.

► Customer relations

- Two thirds of trips for the city are inner city trips, one third is commuters from outside.
- For the urban part of the north – south route from *Ježica* to *Kosovo Polje* a service level of 5/5/15 min (peak/off peak/evening) is intended.

- At the platforms at least one ramp to ascend to 35 cm of height for mobility impaired persons is planned.
- A vehicle floor height of 38 – 40 cm is taken into account for the feasibility study. This makes the vehicle approximately 70 % low floor.
- The chosen vehicle capacity is 270 PAX/vehicle at 37,5 m vehicle length
- A global approach to fare integration in the whole conurbation, including all means of PT, is needed.

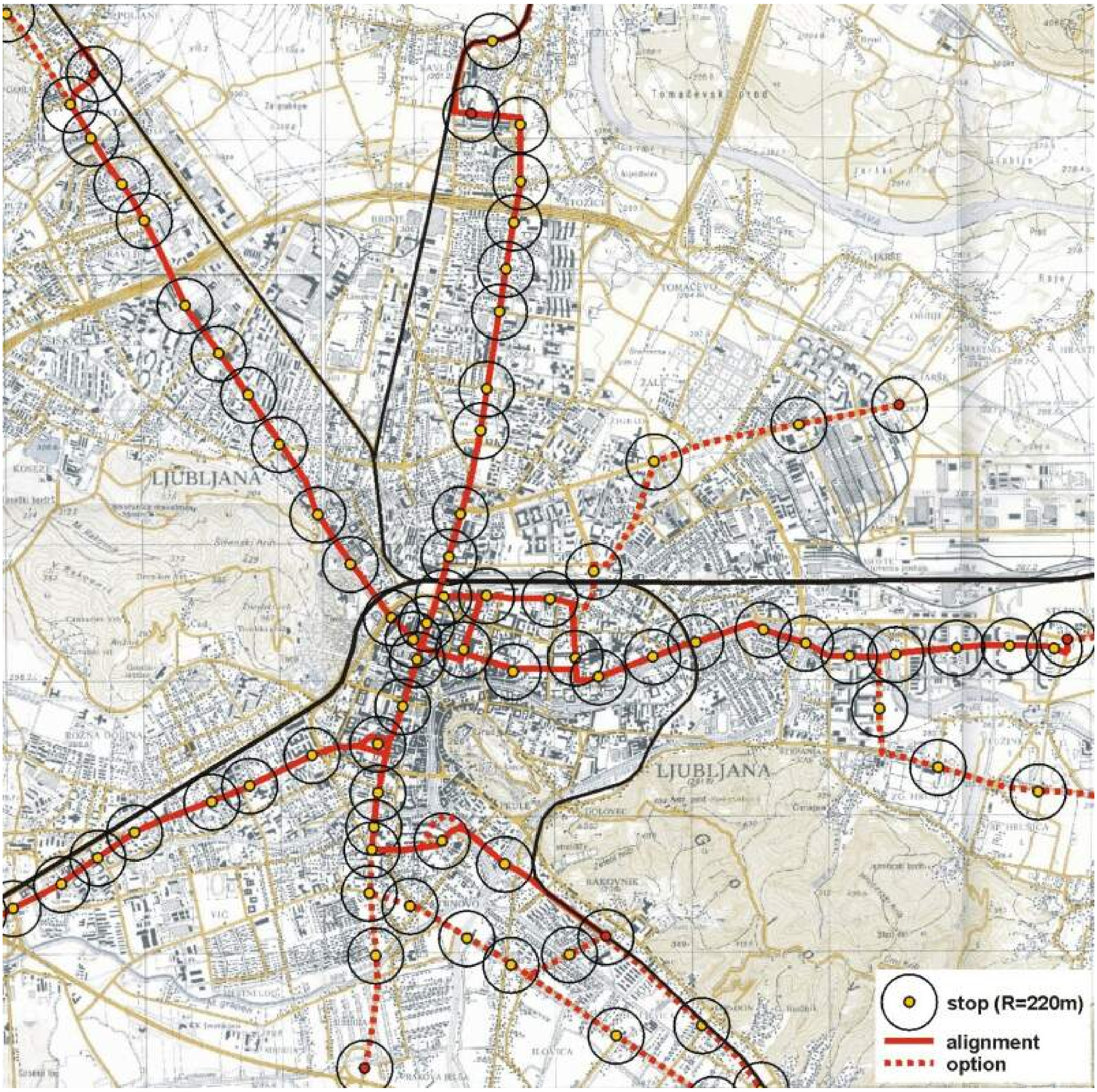


Fig. 58: The “TTK plan” track network.

► **Spatial entities – network**

- The need to install a regional planning “body” for management of planing between competing entities exists.

- The considered area of study lies within the polygon *Kranj – Kamnik – Litija – Grosuplje – Borovnica – Kranj*.
- The average stop distance in the urban area along north – south route (*Ježica Savlje – Kosovo Polje*) amounts to 402 m.
- Connections to the heavy rail network: northern branch at *c. Bratov Kunovarjev*; south-west branch after *Kosovo Polje*;

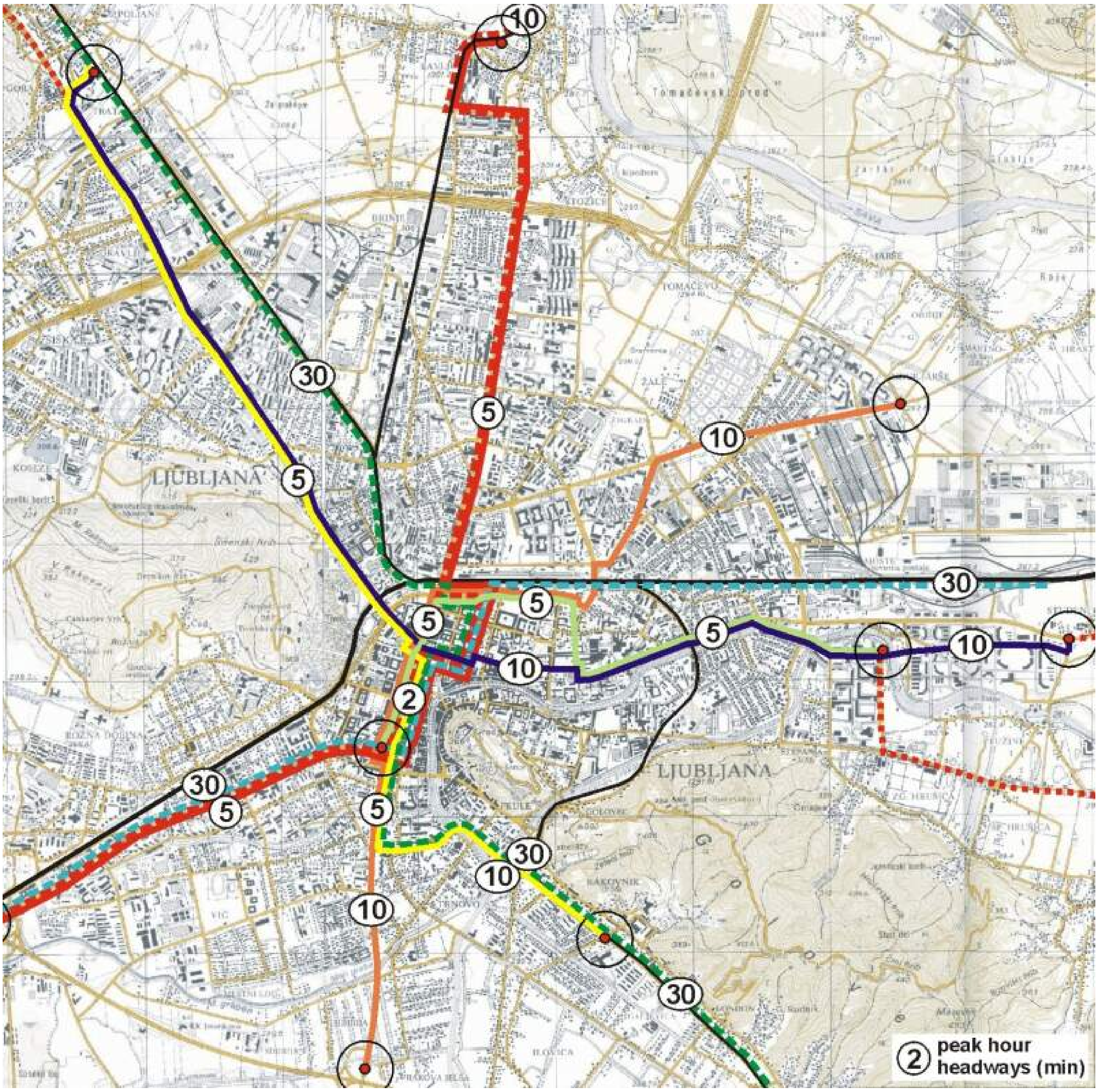


Fig. 59: The "TTK plan" line network.

- All turning options at termini and in between are conceived as turning loops for mono-directional vehicles although of course also usable by bi-directional vehicles.
- Regarding modularity. Phase 1, running north – south from *Kamnik* via the city to *Vič* will be implemented in four sections *Kamnik – Črnuče – Linhartova c. – Igriška c. – Kosovo polje*. Phase 2: *Šentvid* – city – *Nove Fužine* and city - south.

- In phase 1 four connections from tram network to rail network are planned or could be provided for tram-trains:

  1.) Connection of the north running branch at Bežigrad to the Kranj/Kamnik rail line dividing point;

  2+3.) Connection at the main station from *Masarykova c.* to the *Litija* railroad and temporarily to the *Grosuplje* railroad. This connection is temporary, because the final connecting point of tram network to the rail line will be at the rail line south of the city;

  4.) South-western branch at *Kosovo Polje*.

- <u>The vehicles needed are:</u>

  1.) For city transport LRT as “tram” a normal 750 V DC tram is needed.

  2.) For regional LRT as “tram-train”. This is a difficult issue as two types of hybrid vehicle will be needed: a 750/3000 V DC hybrid for the use on electrified heavy rail lines and a 750 V DC / diesel hybrid for the non electrified lines to *Kamnik* and *Grosuplje*.

- The connection LRT – regional network will take place partially via interchanges, so that passengers have to alight and re-board vehicles and partially as physical links between these systems, for dual mode vehicle us.
- The bus network of course needs a reshaping where at strategic points of the network high quality interchanges to the LRT will be provided.
- For special, big events services supplementary track connections within the network will be provided for special lines.
- <u>station access:</u> Along *Tržaška c.* at level by pedestrian crossings. The stations *Fajfarjeva ul.* and *Kosovo polje* will have a pedestrian subways below the mainline railway. North-west section: all urban stops get level pedestrian crossing access only *Šentvid Stanežiče* with pedestrian underpass below main railway tracks.
- The implementation will take place in two phases: phase 1 is the north - south line (*Kamnik - Vič*) and phase 2 are the east - west line, the north-east – south line and the south-east branch.
- In the first phase of implementation, all lines are destined to pass the main railway station.

► Integration into city

- The compatibility with road traffic flow was analysed.
- North branch runs in the middle of *Slovenska c.*, two + two lanes for MIT!
- South-west branch runs in the middle of *Tržaška c.*, two + two lanes for MIT!

- The platform measurements are designated: height = 35 cm, length = 80m and width = 2,0m
- Traffic calming and pedestrianisation:
- Traffic calming: *Illirska c. Hrvatski trg.*, *Zaloška c.* (*Njegoševa c. – Grabloviceva c.*) in front of hospital. Further traffic calming sections will be in *Gregorčičeva c.*, *Rimska c.* and *Igriška c.* There is a partial split up into two short single track sections and a following rejoining due to lack of street space.
- Pedestrianisation of *Slovenska c.* between the intersection with *Dalmatinova/Gosposvetska c.* in the north and *Šubičeva c.* in the south is proposed.
- Standard gauge will be used for simpler and much cheaper integration of LRT into heavy rail network.
- Track radii are kept above 25 m to limit noise emissions which are very likely for smaller radii.
- The route along *Galjevica* is single track to save a lot of houses from being demolished.

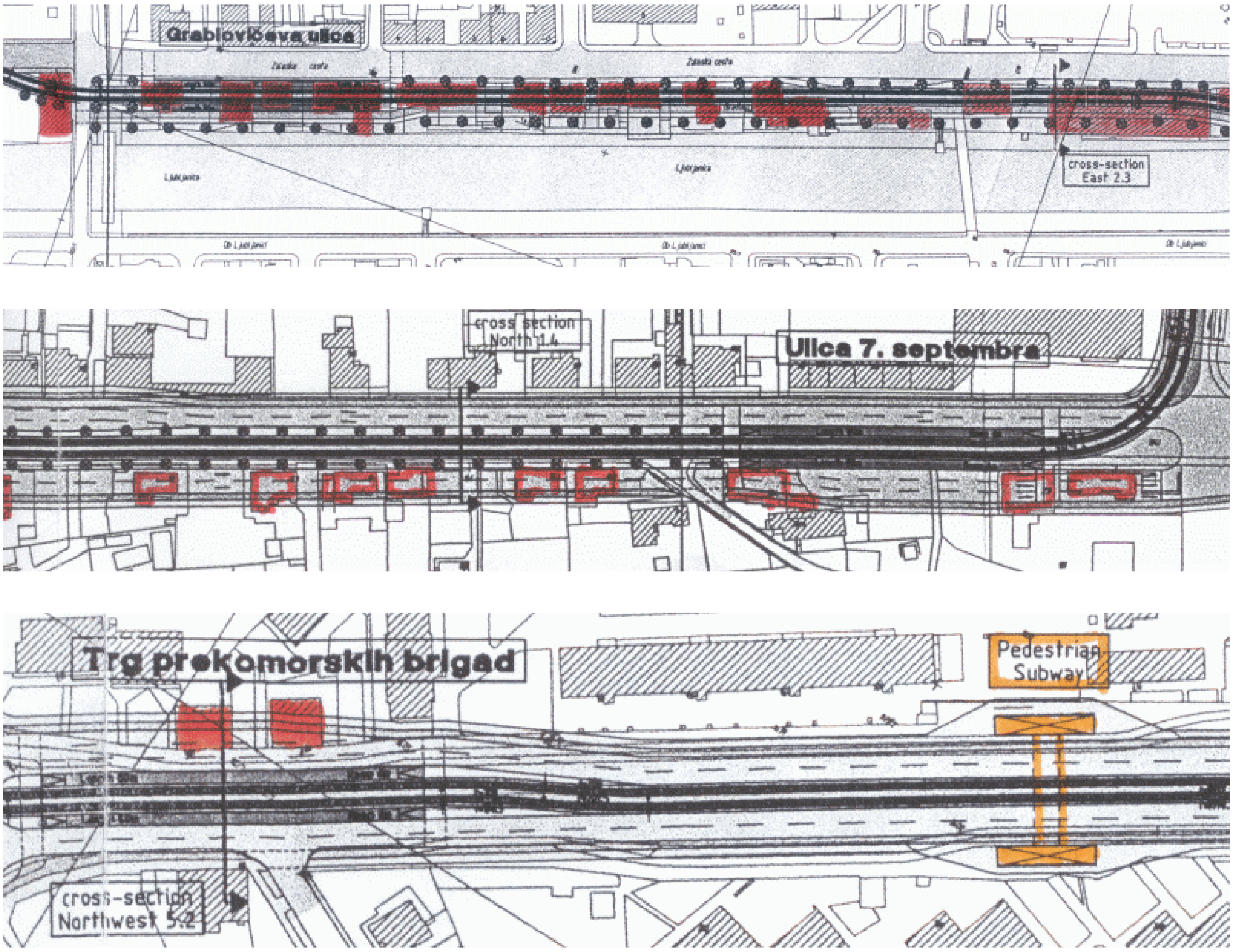


Fig. 60: Object demolition along the LRT alignment. (Perez, et al. 2002b)

- Stations are positioned at junctions to avoid any pedestrians crossing the street "illegally not in between zebra crossings", because they would reduce the capacity of the MIT lanes.

- Regarding safety. Crumple zones (for energy dissipation) at the front and rear end will provide passive safety in case of an accident LRV vs. heavy rail vehicle
- The level crossing of *Zaloška c.* with the Ljubljana – *Grosuplje* railway line requires sophisticated solutions. Two are envisioned: a level crossing of LRT and railway and the rail line will be lifted to level +1 while the tram would stay at street level.

► **Economic aspects**

section	costs [EUR/km]
north (*Linhartova c. – Črnuče*)	8,6 – 11,2 mill. [1)]
center (*Linhartova c. – Igriška ul.*)	11,1 mill.
south-west (*Igriška ul. – Kosovo polje*)	12,9 mill.
east (*Zaloška c.*)	15,9 mill.
south	14,5 mill

1)…according to chosen version

Tab. 23: Construction costs estimations for different branches.

- The vehicle cost are estimated at 2,5 mill. EUR/vehicle.
- The existing, non-electrified railway route *Črnuče – Kamnik* would require 1,8 mill. EUR/km for modernisation and electrification.

4.3.2. Key argumentation

- The aim of the study is to find priorities of investment to stop and revert the declining modal split of PT, which started in 1992.

year	urban	region	sum
1994	30,8	20,6	27,5
trend 2010	22,4	14,9	20,0
target TTK	38,6	28,2	35,3

Tab. 24: Modal split of PT in LJ and region in [%]. (Perez, et al. 2002a)

- One key principle for planning is to reduce the number of house demolitions to an unavoidable minimum. The study, in comparison to the "Guzelj plan", is less radical regarding urban design aspects: No houses are demolished for tree rows, pedestrian and bicycle paths. Instead of that mixed areas are provided in narrow situations.
- The example of reduced MIT lanes in Strasbourg is presented to emphasise the ideas of traffic calming and pedestrianisation.

4.4. The tramway system within the urban development plan (PPMOL)

In the year 2002 the Department of Urbanism published the new urban development plan (Cerar, et al. 2002) "*Prostorski Plan Mestne občine Ljubljana*" (PPMOL) which should be the city's comprehensive guideline for the near future. Two sections within this plan are dedicated to rail-bound PT.

4.4.1. Key features of the plan

The plan begins with the problems, aims and measures concerning transport in general.

- <u>These problems were identified:</u>
  - The public bus system is not competitive to MIT, because it has long travel times; it is overloaded during peak hours; it offers a low transport quality; its commercial speed is below 10 km/h and the respective travel times are 30% longer than those of the private car.
  - The space for pedestrians in general is too small; at least 30% of the city's pavements are too narrow.
  - The quality of city life is decreasing due to increasing noise and air pollution.
  - The overall economics of the transport system are bad.
  - A continuously increasing amount of urban space is required for car traffic and parking.
  - The regional PT's modal share is identified to be too low with 13%.
- <u>These aims that were defined:</u>
  - a decrease in car dependency;
  - a increase in safety;
  - a decrease in negative effects of transport on environment;
  - to enable equal opportunities of mobility for everybody.
- <u>The following measures were proposed:</u>
  - implementation of effective, qualitative and attractive means of rail bound city transport;
  - limitation of the MIT usage in CBD and in residential districts;
  - implementation of a system of transfer stops, "where all kinds of transport will united into entity".

► Customer relations

- Provide simple usability and clean facilities with easy access.
- Trip times of LRT users must be below those of car users.

- Provide a sufficient "seat supply" during off peak periods for trips longer than 15 min. and a minimum of 0,25 m^2 of space for each standing passenger.
- The LRVs will have a capacity of approximately 180 PAX.

► Spatial entities – network

- The plan states, that PT is in the future going to be based on LRT. The city's "star-like" structure calls for a similarly shaped LRT structure. The LRT will run along the major inbound routes, as they are within the gravitational centres of the urban development areas.
- LRT operations are according to findings justified on the four major axes: *Dunajska c.*, *Celovška c.*, *Zaloška c.* and *Tržaška c.*
- Probably suitable for LRT operations are the following streets, also gravitational linear centres of their respective development: *Šmartinska c.*, *Litijska c.*, *Barjanska c.*, *Jurčkova pot* or the railway *Dolenjska železnica* to *Grosuplje*
- The LRT lines end at the city's boundaries, from there elongations further into the region are most probable to the north (*Kamnik*) and to the south (*Grosuplje*) on existing heavy rail trackage.
- The backbone of regional PT will be the regional railway system, which will connect LJ with other urban entities, all within the wider region. The interchange to city PT will take place on primary interchange stops, which will be the termini of the city LRT.
- Bus services will complement the LRT and regional rail with independent or connecting lines and the mini-bus line in the city centre.
- For intra-CBD travel a separate mini-bus system, in addition to the LRT and regular bus, is proposed.
- At every terminal stop of LRT and at the "intersection" of urban axis and circular highway, P&R facilities will be provided to "invite" car drivers to change to PT.
- Regional and city transport have a polycentric scheme of intersection: the main railway terminal and the interchange stops at the outskirts.
- LRT has to cover all major city development areas, and 90% of the overall city has to be covered by PT.
- Several P&R facilities will be provided: seven at line termini and six in between.
- Buses will run on the secondary network, which requires less capacity and buses will run on mixed surfaces. This means that no priority lanes will be provided.

For the inner city alignment, two options are considered. The first one, surface PT, is based on the "TTK blueprint", "phase 1b-B" (Perez, et al. 2002b). The second one, sub-surface PT, is based on the "Bajželj blueprint".

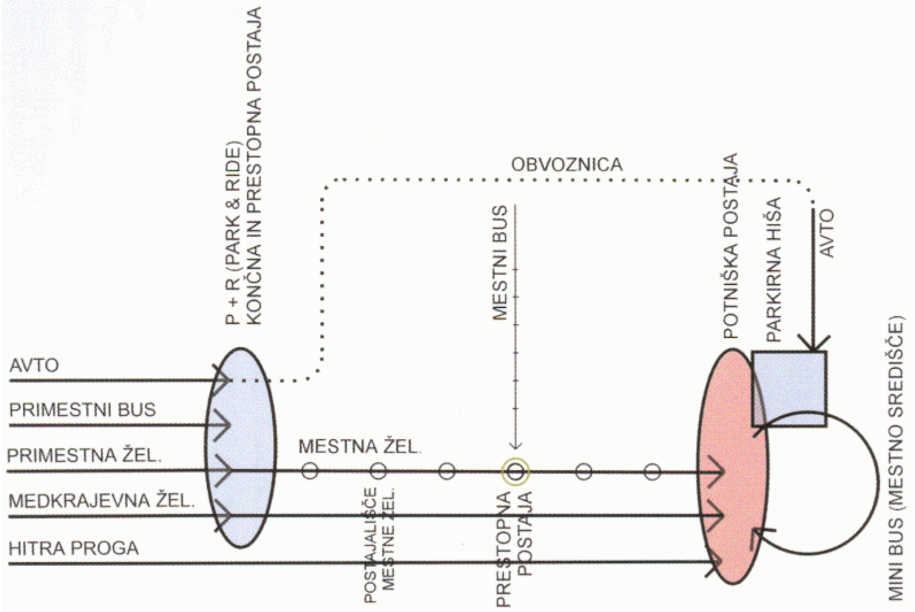


Fig. 61: The organisational scheme of modes. (Cerar, et al. 2002)

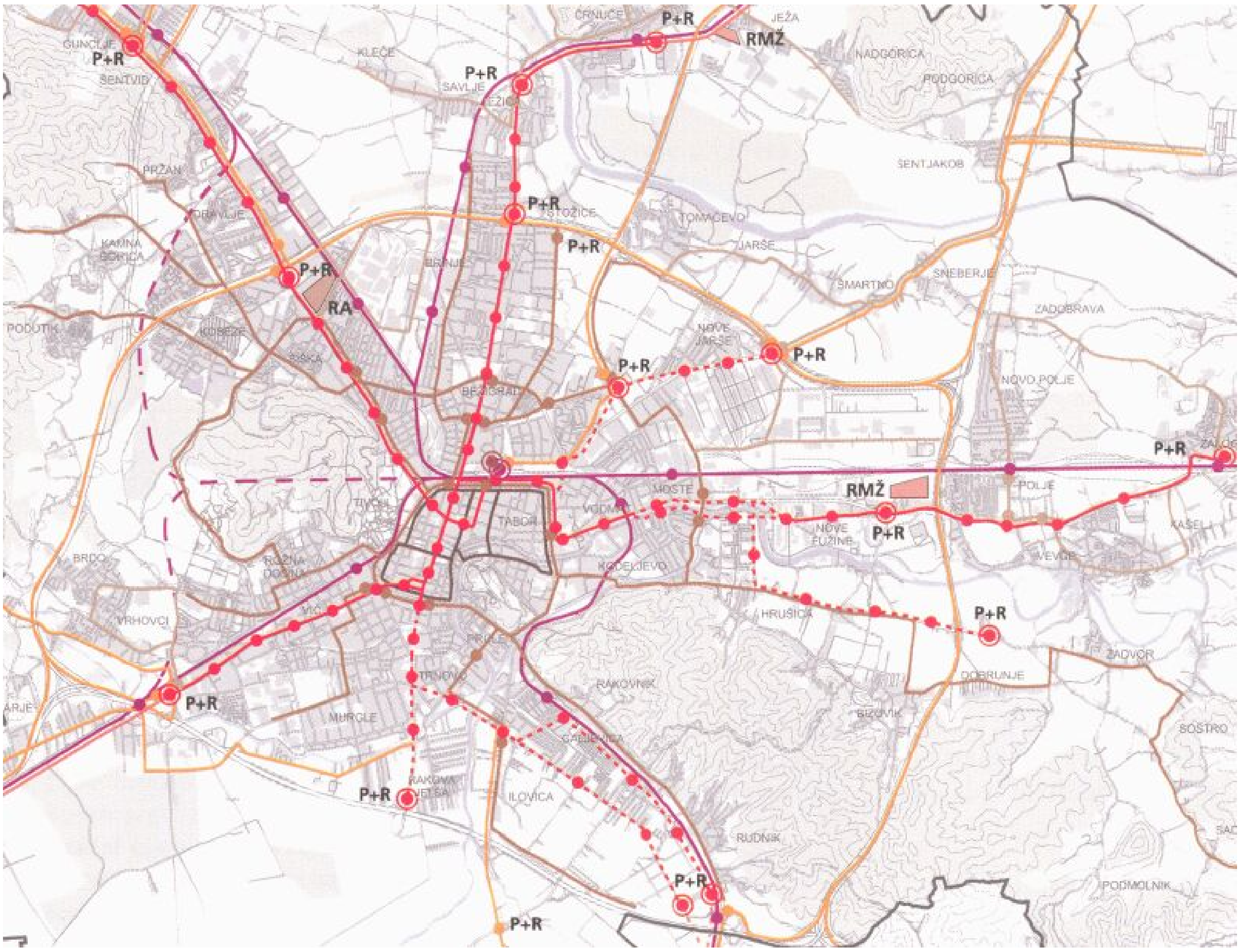


Fig. 62: The PT network layout. (Cerar, et al. 2002)

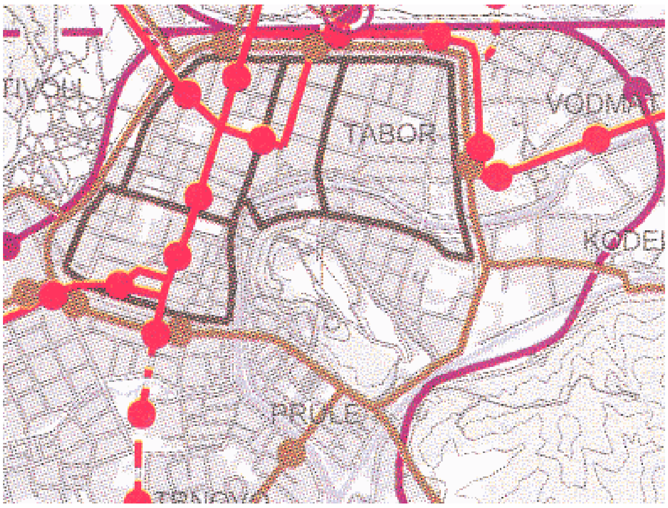


Fig. 63: The intra-CBD mini-bus network (dark brown lines). (Cerar, et al. 2002)

	ROW length [km]		nr. of stops		v_C[km/h]
	above surface	below surface	above surface	below surface	
surface version	35,5	0	68	0	~25
sub-surface version	25,2	9,5	47	17	~30

Tab. 25: Specifications of both network versions. (Cerar, et al. 2002)

► **Integration into city**

- LRT is supposed to run on independent ROW throughout.
- The primary PT carrier is LRT, the secondary is the bus or mini-bus respectively.
- The whole system will have an automated train control (ATC) system and LRVs will receive priority at intersections.
- LRT system will be included spatially into the city in a harmonic way.

► **Economic aspects**

No absolute cost statements are stated, but in the case of the inner city sub-surface version, a relative cost comparison between those versions is made. The costs will be remarkably higher, approximately 40 % of the surface version, not including underground stop construction and underground operations.

4.4.2. Key argumentation

- Sustainable mobility requires for implementation of a modern, powerful and qualitative PT.
- PT implementation will provide a strengthening of the CBD.
- The tram will be powerful and comfortable. As an integral part of the city fabric it will strengthen the city centre's development possibilities.

- The blueprint provides solutions that will decrease car dependency, especially within the city centre, where emphasis is given on PT and cycling.
- The scheme will change the modal split in favour of PT.
- The intra-CBD mini-bus is expected to increase accessability within the inner district.

Surface version

- The commercial speed of 25 km/h represents the lowest to be accepted level for quality city transport
- In the eastern section in *Zaloška c.,* next to the hospital district, a substantial limitation of MIT has to be carried out and *Grablovičeva c.* has to adapted as a bypass of the hospital district.
- The *Grosuplje* railway has to be lifted, so that an out-of-niveau intersection of LRT and railway at *Zaloška c.* is possible.

Sub-surface version

- The implementation of the surface version will increase the overload of street intersections at the CBD’s limits. This would lead to a disruption of the distributive effects of the ring road.
- The surface version interferes with the functionality of several buildings, which therefore need to be removed.
- The sub-surface version enables a good connection between important destinations, such as the train station or bus station.
- Underground stops can be conveniently interlinked to adjoining objects by pedestrian tunnels.
- Although the stops are less in number, the city is covered in a better way.
- A redesign of *Grablovičeva c.* and the *Dolenjska* railway is not required.
- A higher running velocity is achieveable than in the surface version.
- Better access is provided.
- Provisions for a higher likelihood, that the modal choice will be in favour of PT.
- This solution presents no hindrance to the MIT at the “important” intersections and in the city centre.
- More space is provided for pedestrians and cyclists on the street surface.
- There is no need for cuts into the existing city structure.
- A strengthening of the city centre, as cellars of building along underground stations and connecting pedestrian tunnels will be filled with shops, catering trades and other businesses.

4.5. Analysis of the described blueprints

Before the discussion of the blueprints the statement has to be made, that due to the differing data that was available for the four blueprints, the discussion cannot cover all areas completely for all blueprints.

As a pre statement, the basic similarities of all four schemes – five schemes if the PPMOL versions basing on the “Bajželj“ and “TTK” solutions are counted separately – need to be mentioned.

- as expected by the urban tissues layout, all blueprints follow the major axes with only very little variation (5-7 radial lines provided);
- 3(4) schemes include sub-surface alignments;
- all schemes aim at stopping and turning around the PT’s declining modal share;
- in 3(4) schemes a lot of pedestrian barriers remain.

4.5.1. The “Guzelj plan”

This blueprint exceeds all other plans in terms of argumentation, size of facilities, construction expenditure, long term network transformation plans and others.

► Spatial entities – network

All major development axes are covered by LRT and the secondary network is covered by buses.

Although the plan argues with “spatial availability”, it has only a very low density of stops in the inner city due to the concentrated subsurface alignment, which actually in the latest phase results from the fact, that in the city centre no “real” network is provided. Only the heavily loaded arteries are crossing each other in the central station. In addition to that, rather large stop distances are planned. This may be resulting from the acceptable access walk length of 400 m (see Guzelj, et al. 1989), which is almost double the length of Peperna’s 220 m findings (Peperna 1982).

The argumentation is mainly focused on the calculated trip time savings for the whole city due to increase in travel speed of LRT and the easing of congestion. The fact, that within the whole transport system due to the constant personal daily travel time budget no time can be saved, is not taken into consideration. In this case, the operational travel time by the transport system is set equal to the travel time spending of the population, which is a basic mistake. (Schafer 1998, 2000)

► **Integration into city**

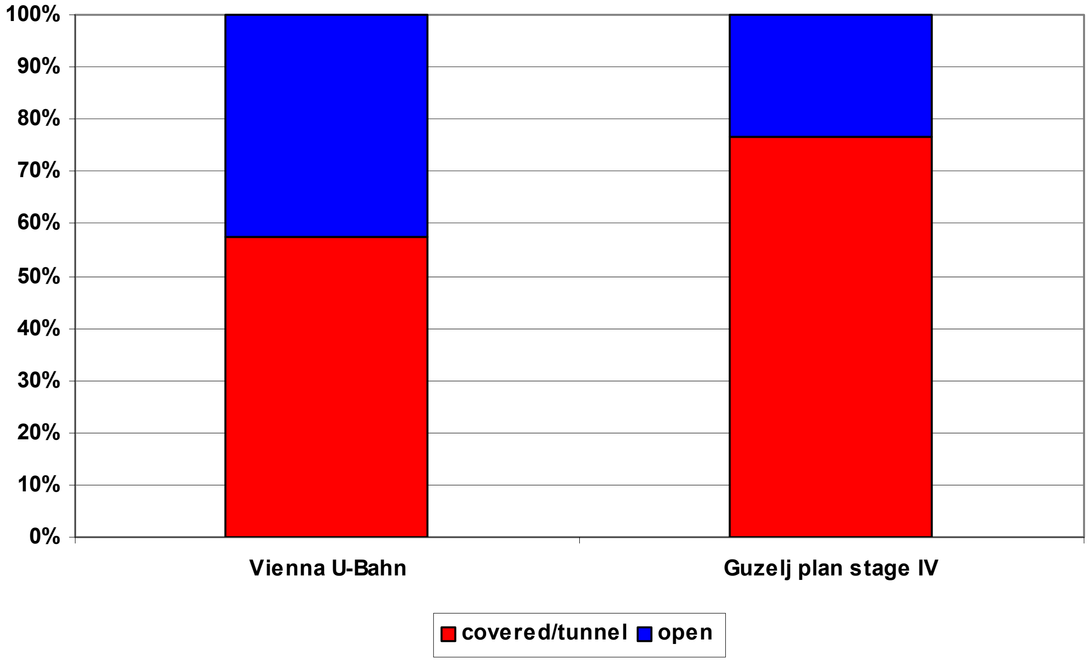


Fig. 64: Comparison of Vienna U-Bahn and the stage IV of the "Guzelj plan". (Vienna numbers from Ossberger 2004)

The stages of development intend the implementation of a complete and working LRT system above ground into the cityscape. This includes the design of street cross sections and the prioritisation at intersections, although major sections are planned to be only "partial priority". and it includes the reshaping of the urban axis into wide avenues. It is forecasted, that the system will reach its transport capacity in approximately thirty years. To increase the transport capacity then, the plan proposes to convert the system above surface into a system below surface. Due to the big construction works and measures (temporary traffic reorganisation, …) such a transformation requires, it is planned to do this subsequently in stages, from the inside out.

This means that the LRT system, fully integrated into the streetscape, is then taken out of the street space and a sub-surface running pre-metro is installed instead.

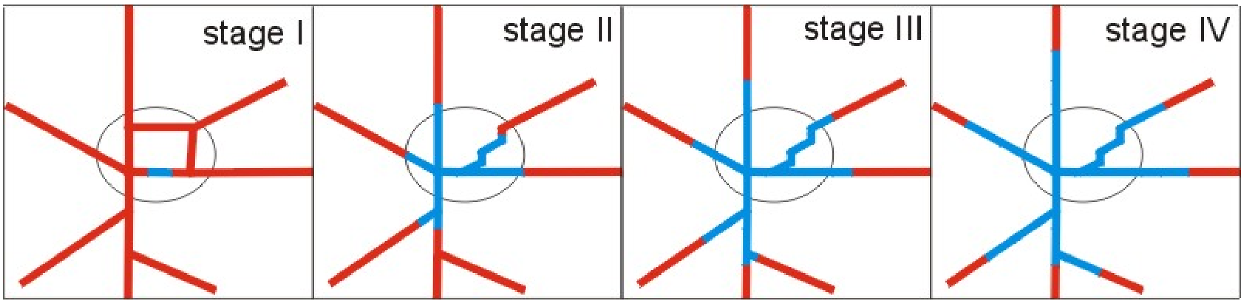


Fig. 65: Scheme of the four developmental stages. (red = above surface, blue = tunnel)

When the system running above ground works well, which it is supposed to do, why then not extend the working concept by means of line extensions, network consolidation or full prioritisation? Instead of digging it into the ground with a great amount of money and under great exertions, with low or no marginal benefit. Especially under the perspective, that in phase one the CBD has been pedestrianised and the avenues have been reshaped. What is done with the surfaces, that will become free, when the LRT has been relocated below the surface? This is a very rigid plan of executing the before set dogmatic objectives of the four different development stages.

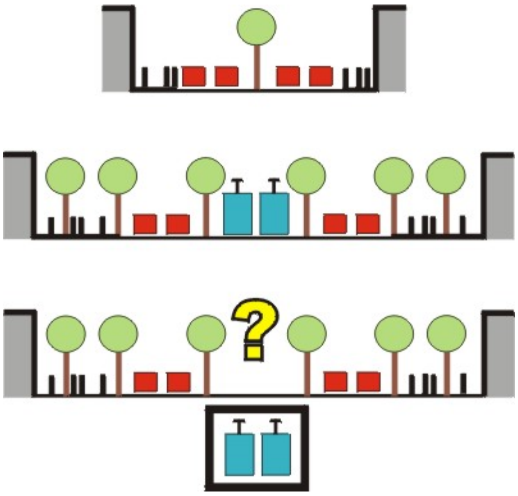


Fig. 66: Cross section development through stages.

This would provide a real metro for the city in the last phase as it for example exceeds the share of underground alignments of the Vienna metro where a lot of metro lines run criss-cross below buildings. In the "Guzelj plan", the long legs along the urban axes would follow directly the street median and would therefore by no means collide with any buildings. Nevertheless they are planned to be dug in.

The blueprint has a very rigid approach to cross sections in terms of designing the axial roads to boulevards of remarkable width. The "required radical impacts" on the built up environment result from the inflexible, hardly changing cross section layout along the road.

► Economic aspects

The construction of a full surface running system and then the subsequent dig-in will not only require significant construction costs two times for the same line – the second time remarkably higher – but will also increase the costs of operation of sub-surface facilities. (see 3.3.4.1.)

4.5.2. The "Bajželj group" plan

► **Customer relations**

If the safety for pupils/students will be increased, because they will ride and walk mainly underground, away from dangerous traffic, then this contradicts to the statement, that "the removal of PT from the street and the resulting decrease in traffic will free space for additional lawns, pedestrian and bicycle use and other, better use of the street space". This would actually make the surface more safe, than it is now.

The statement that LRT ROW would be an urban separator, a barrier for pedestrians can be falsified in many real-life examples, especially when compared to the separation effect of multi-lane streets. Quite the opposite is true: a well integrated LRT ROW is an integral part of the pedestrians cityscape (see 3.3.3.1.)

For the sections between stations single track tunnels are proposed. Although this would be less expansive than double track to build, it would be also prone for delay and failure and therefore a risk.

► **Spatial entities – network**

All major urban development axes are covered by LRT, but no statements about the secondary network are made.

An uncritical comparison to existing small metro cities, "we are of similar size as they, so we need a metro too", is basically not justification enough. The flaws of these systems like few interchange free connections into the city core, missing connections and long walking distances due to large distances between metro stops (for Nürnberg see Schmidt 2003) are not being noticed.

The long and curvy underground sections – only the third version provides surface CBD sections of one line – with long distances between stops in combination with the altitude differences decrease the spatial stop coverage and by thus the access attractiveness, which is not mentioned at all.

Unfortunately only driving velocities (maximum, and average) instead of customer trip times, which are strongly depending on stop distance, are discussed

► **Integration into city**

The available material states only vague, often contradictory, opinions about "What to do with the street surfaces in the CBD?" Although at the beginning the dogmatic statement, that a liveable city requires one part of transport to be brought below surface, is made. That it has to be the PT, that is banned below the surface, is justified with fewer new obstacles to MIT and optical pollution due to the catenary.

The underground stops are advertised with the opportunity to design appealing sub surface, shopping mall like passages which will improve city life and be more attractive to passengers. This in some cases may be true for the first few years. But as time goes by, the actual examples of the three existing passages crossing the *Slovenska c.* and the basement facility at the Maxi Market department store show, that this imaginative state does not remain for long, and the sub-surface facilities experience a rapid decline in amenity value.

By the way, it does not make sense to hide the brand new vehicle and facility design below the surface. Instead the city's new jewellery should be exposed and serve as an advertisement for itself.

► Economic aspects

The statement, that higher costs of construction are irrelevant, as the scheme will be a solution for the next 100 years to come, may be true. But nobody knows if this scheme will be "The Solution". If not, the higher construction costs would have better been saved, especially as cities tend to run on tight budgets. The cost are not only higher than in other cases, the whole process is designed to maximise construction volumes and expenditures. First construct a complete system including the surface design, this is including the widening of the axial roads. And in the three further stages, step by step almost the whole system is being partially dug in.

4.5.3. The "TransportTechnologie-Consult Karlsruhe" plan

► Customer relations

Qualitative pedestrian access to the stops is in the CBD in majority guaranteed due to pedestrianised and traffic calmed areas at and around the LRT alignment. In the outer lying sections access to the stops, mostly in between of two MIT lanes each, is via pedestrian crossings. The platforms have the designated height of 40 cm above rail and therefore have platform access ramps that relieve access barriers for handicapped. Unfortunately a few existing pedestrian subways below the roadway are left, instead of promoting a more pedestrian friendly scheme.

► Spatial entities – network

The major axes are covered by LRT.

Although being mentioned in some places as potential goals for extension, the towns of *Logatec* and *Vrhnika*, parts of the outer conurbation spheres in the south-west, are not included into the study. It is true, that the commuting numbers from the south-west are smaller than from the north and east, but they are in between them and the south-eastern figures (see fig. 24).

In comparison to all other proposals, where extensions into the region are treated as options without any further consideration, the extension into the region is in the case of phase one, in the north towards *Kamnik*, not only seen as option, but included in detail.

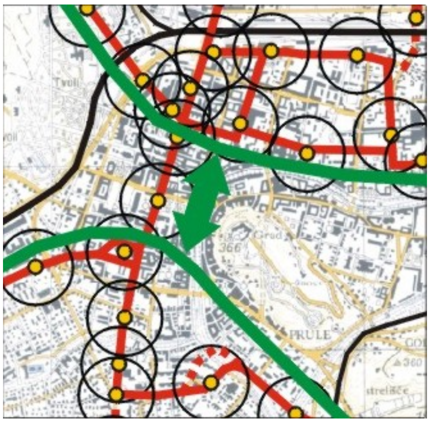


Fig. 67: The potential separation of northern and southern network parts.

Another property distinguishing this blueprint from the others is the small, "real" network between the railway station and CBD. By this a small variety of lines running through the town normally or in case of incidents is provided. One flaw remains. The northern and southern branches still remain to be connected only over one line on *Slovenska c.* south. This leaves the city parts around the castle hill without tram service. The supplementary track connections for extraordinary services – cases of incidents or special services for large events – are provided. See also fig. 67.

► Integration into city

On one hand pictures of Strasbourg before and after LRT introduction are shown as model – with less MIT lanes – but on the other hand for Ljubljana no MIT lanes along the major inbound routes are reduced. It is true, that the decision of street layout design of the major streets is one of the city's urban planning department (in PPMOL) and not of TTK. In the PPMOL the regulation is stated, that all major routes (blue marks in fig. 16) need to have two + two MIT lanes. But on the other hand the study repeatedly points out, that "no houses will be demolished for alleyways". What is not mentioned is, that houses will be demolished for keeping up two + two MIT lanes or increasing the lane numbers before intersections, although the transport capacity will be increased dramatically with the introduction of the LRT. (see chapter 6)

The available documents show in three versions a rather generous pedestrianisation and traffic calming of the CBD, e.g. *Slovenska c.* in the heart of the city, between the railway station in the north and *Šubičeva c.* in the south.

► **Economic aspects**

The construction costs of 11-16 mill. EUR/km are common for surface running schemes like this. (compare with section 3.3.4.1.)

4.5.4. Urban development plan (PPMOL)

Within the rather extensive transport section of the PPMOL the problems, goals and probable solutions of many modes are being dealt with. This are PT, rail, MIT, parking, cycling, nodes for passengers and goods. But the section regarding pedestrians is missing within the transport chapter.

► **Customer relations**

The statement, that trip times of LRT users ought to be below car users is correct, but basically includes two possibilities. The increase in attraction of PT and the decrease in attraction of MIT. The latter one, as the LRT should under no circumstances provide any additional hindrances to MIT, is not considered. The transfer constraint of changing the mode at the CBD's borders, transferring from mini-bus to bus or to LRT and vice versa is hardly suitable to increase attraction by means of minimisation of transfers. (see tab. 10 in chapter 3.)

► **Spatial entities – network**

In addition to the two papers (the "TTK" and the "Bajželj blueprints"), that provide the basis for the PT network measures, some additional fundamental propositions are made.

1.) There are additional, possible alignments being studied. This is a second route out east, running along the *Litijska c.* south of *Zaloška c.* and a second route on the south-eastern branch, running along the very low populated areas next to *Jurčkova cesta*.

2.) For the CBD an additional city transport mode – besides LRT, bus and tram-train – is introduced. This is an intra-CBD only service (see fig. 63 in the blueprint description chapter). Unfortunately, according to the PPMOL, only the north – south and partially the east – west LRT routes traverse the CBD. The regional and city buses run along the routes that circle around the CBD. By the invention of this additional mode, with only limited range, the primary purpose of limiting transfers due to "Karlsruhe principle" connections to the region is contradicted.

► **Integration into city**

Of the two possible versions, named within the document for being practicable for implementation, the sub-surface version is given more attention. And the surface version is directly and indirectly branded as a burden to MIT within the CBD.

A lot of arguments, why the sub-surface version would be of greater benefit, are presented. But also a lot of these arguments do not comply with the actual findings and experience from other places and the city itself or are not explained any further. E.g. it is not explained in detail why a system with lower stop density, thus resulting in longer access walks and a vertical separation, should provide better access or be better suited to influence the modal split in favour of PT. Contrary to the common experience, that sub-surface pedestrian structures and malls, as can be easily observed in the city itself, tend to degrade over time, a colourful picture of long underground tunnels and malls connecting the sparse stops in the city with all kinds of places is drawn.

The approach to the modal split is only a invitational one, as the car users of nowadays should experience a great deal of positive charisma by the LRT and change the mode. As the road construction policy shows, only very few "push measures" to stimulate LRT usage are planned.

► **Economic aspects**

Although no specific information about costs is given, a general statement comparing the two versions for inner city routing is provided. The whole network with below surface CBD version is expected to be about 40 % more expensive, than the above surface version.

4.5.5. Summary

The "Guzelj plan" was designed to bring the city a full metro service step by step in the long run. This goal should be achieved by a cost intensive long term scheme of building a surface system and then dig this existing system into the ground in stages. It seems, as if the scheme was designed to maximise construction and costs.

Topics like the comprehensive redesign of city transport for changed future travel behaviour, the LRT as its backbone and the efforts to stabilise city growth and shape are touched only distantly. Besides that some major, internal contradictions are included, e.g. within stage I the existing streets are widened remarkably, with the LRT running in the streets median. In the later stages, when the underground sections progress outwards, the LRT is along the existing median being dug in. No further statement about the remains of the median strip and the street width is being issued.

Due to its larger-than-life approach, the "Guzelj blueprint" is not very likely to be seriously considered anymore.

The "Bajželj blueprint" represents a very technology and construction oriented elaboration, where the issues of design, urban and social integration and all other "soft issues", which are psychologically very important, are barely considered.

Although the technical solutions may be feasible, the cost considerations, the accompanying measures and the general plans of urban integration are not consistent in measures and argumentation as the one safety example from above shows.

The "TTK blueprint" introduces a scheme, that is focused on providing the potential basis for a reliable and attractive PT for the city and the region. Although only the north to south running branch is covered in adequate conceptual detail, the remaining network is elaborated in satisfactory detail to prove the feasibility in terms of physical implementation and financial adequacy. But nevertheless some not necessary compromises, especially towards the automobile's dominating role remain. This still has grave implications for the buildings that do not comply with the envisioned, expanded street widths. The agenda of the pedestrian as the feeding roots of every PT system needs to be pursued with more fervour.

In general the statement, that PT has lost in share over the last decade is being made in PPMOL, but no probable reasons for this state are given. It is stated, that the municipality is going to bear the responsibility of implementing a sustainable city transport system. The plan is made, that PT should become ***the*** means of transport for the future and that the PT's share of modal split should improve. Besides all the measures for PT, the PPMOL does not deviate from the dogmatic demand for two + two MIT lanes and includes additional road construction, two new road tunnels, better and more frequent connection of city streets with the highway and other MIT capacity raising measures. In accordance to the general objectives issued at first, the measures aiming at least equally, if not increased, at MIT and PT are contradictory.

4.5.6. The blueprint analysis chart

The following chart summarises and analyses the four presented blueprints according to the four tiered classification scheme.

parameter	Guzelj	Bajželj	TTK	PPMOL
general aim	build a metro system in several phases	provide a PT system with high speed	increase PT capacity + regional integration	increase PT and MIT capacity
customer relations				
transport supply	tunnel construction = long period without availability	tunnel construction = long period without availability	surface construction = short period until available to public	according to version; tunnel construction = long period without availability
handicaps and barriers	sub-surface operation = additional access barriers; unchanged number of MIT lanes remain as barrier	sub-surface operation = additional access barriers; unchanged number of MIT lanes remain as barrier	increased MIT lanes remain as pedestrian barriers	according to version: if sub-surface operation, then additional access barriers
safety	no declaration	contradictory statements about surface safety; one tracked tunnel line with turnouts = risk factor	no declaration	no specific declaration
spatial entities - network				
network	7 branches	6 branches	6-7 branches	6-8 branches

CBD network	in phase 2 only two perpendicular, crossing lines	only one route	small network between CBD and railway station	very small network between CBD and railway station
CBD alignment	tunnel	tunnel	surface	surface/tunnel according to version
stop spacing and alignment	low density in CBD	low density in CBD	higher density in CBD	according to version; tendency towards low density
system breakdown safety	no alternative routes through CBD	no alternatives in CBD	partially alternatives in CBD	very few alternatives in CBD
time aims	high travel speeds; overall saved daily time is calculated	high travel speeds will bring overall time savings	overcome time losses of buses due to congestion	increase travel speeds for MIT and PT
integration into city				
surface design CBD	pedestrianisation and traffic calming of CBD considered	vertical separation of modes; not clear, if surface reconstruction; massive structures for sub surfacing	pedestrian precincts on main street	no specific declaration
surface design ex CBD	partially sub-surface alignment; axes will become „boulevards“	LRT within 4 laned MIT axis	LRT within 4 laned MIT axis	LRT within 4 laned MIT axis
demolition	300 houses	no declaration	abt. 100 houses	abt. 100 houses
combined transport capacity	MIT remains at status quo	MIT remains at status quo	LRT as bus replacement; MIT according to PPMOL	increase in road network capacity planned; all major roads worth mentioning "need" 2+2 lanes
LRT - MIT interface	LRT must not be obstacle to MIT	LRT must not be obstacle to MIT	MIT restrictions will be necessary	restrictions in CBD planned, but extended road construction outside the CBD
modal split	improvement in favour of PT desired	improvement in favour of PT desired	improvement in favour of PT desired	improvement in favour of PT desired
economic aspects				
construction costs	≥150 mio EUR/km	≥150 mio EUR/km (statement: "at least 5 times of surface costs")	11 - 16 mio EUR/km	10 – 15 mio EUR/km
operation costs	stop: 41.000 – 61.500 EUR/year	stop: 41.000 – 61.500 EUR/year	stop: 7.000 - 10.000 EUR/year	stop: 7.000 - 10.000 EUR/year

Tab. 26: The blueprint analysis chart.

4.6. A comparison of transport policies and design measures

The four stage classification is also applied for analysing the status quo of LRT planning due to the integrated link to the objectives of transport policies with, e.g. a consideration of the principles of sustainability. In the following chart the status quo column is fed with the according results of mainly chapter four and section 4.5.1. - 4.The sustainability column's cells are fed mainly with the sections 3.1. and 3.3. The difference column sketches the corresponding instructions, which will be used in chapter 5 to design a modified network.

parameter	status quo	sustainability	*difference*
primary	provide means of transport; tendency to evade the constraint to declare oneself responsible for environmental solutions	provide healthy ecosystems and safe life conditions, e.g. for humans; transport is subordinate	rate life conditions of residents higher

customer relations			
rail bound bonus	will be experienced	intentionally use it as a transport system shaping tool	use it as MS influencing tool
pedestrians	two tiered: on one side pedestrianisations, on other side all kinds of barriers	pedestrians = passengers; increased pedestrianisation of surroundings; no barriers	provide maximum possible pedestrian attractive surrounding
pedestrian safety	tendency to protect pedestrians from LRT (fences and walls)	LRT is safer for pedestrian than MIT	provide safe surroundings without barriers
energy	increase en. efficiency per transported person (LRT vs. car)	sameo; design system to increase en. efficiency of city in a long term	set measures for long term restructuring of settlement energy expenditure
pollution	decrease noise and local exhaust gases	same	—
spatial entities - network			
velocity	increase system velocity	decrease system velocity for short trip distances; importance of punctuality and connections	decrease system velocity for a better bond of urban compound and strengthening of the CBD
network properties	optimisation/minimisation of trip times, transfers and vehicle kilometres	same; additionally minimisation of the human travel effort, especially during transfer.	minimise human trip efforts
time savings in system	increased system velocity saves a certain amount of time within the system	the time savings in a system due to increased speeds is zero; $\Delta t_{SYSTEM} = 0$	increase of the linear PT speed needs a decrease of spatial speed
time savings operator	homogenous and undisturbed rides increase productivity	same; and also increase attractiveness for PAX	—
CBD network	tendency to concentrate in one and heavily loaded main line	real network, multiple alignment, "spreads the LRT's positive effects"	provide a network with ≥ 2 line options for good area coverage
stop catchment area	300 m and up	220 m	rate importance of catchment area higher
stop spacing	tendency towards increased running speeds and lower stop densities	maximise the line's potential passengers through dense stop spacings in dense precincts	keep in sufficient urban densities stop spacings low for high access attractiveness
system breakdown safety	separate LRT from potential disorder sources	same; multiple system options for incident operations	enable "emergency" options for a resistant system
integration into city			
prioritisation	tendency, that priority only there, where no disadvantage for MIT	uncontested and absolute priority for LRT (and secondary PT systems)	PT relishes priority
influence modal split	change in favour of PT envisioned	sequential work towards a real shift in MS	apply effective and determined measures
impact on built environment	house demolishings are necessary sacrifice	absolute minimisation, no demolishing for dogmatic sake (social sustainability)	as transport is subordinate to life, socially sustainable measures are sought
city structure redesign	potential of LRT tends to be underrated	LRT is a means to shape the city structure towards the desired one (internal condensation and TODs)	promote all city structure redesign for TODs
transport capacity	under no circumstances reduce the MIT capacity	LRT means an increase; therefore decrease MIT lane capacity	think in transported persons instead of vehicles
CBD tunnels	in some cases constraints with MIT "invite" to dig LRT into ground	attractive LRT system as self-advertisement; gain positive public image	LRT should be at shortest available distance: at level
integration	tendency to de-coupled alignments; not only from MIT, but also from urban fabric, street space and pedestrians	integration of LRT in pedestrian areas as often as possible	provide ability of identification for people, therefore open and integrated design

integration - stops	tendency to over-construct stops - technoid, discordant integration	keep "platforms" in the streetscape as integrated as possible	simple, effective and integrated into public life
economic aspects			
investment costs	tendency to build big exists, mainly over-engineering	facilities providing best impact for the least necessary financial amount → financial sustainability	provide "finnancial efficient" solution in terms of investment …
operating costs	due to the tendency of sub-surface CBD alignments increased operating costs are to be expected	operation of facilities with the least financial and energetic expenditure should be aimed at.	… and in terms of everyday operations

Tab. 27: The methodology analysis chart.

The results of this analysis, the difference column of tab. 27, is the input for the development of a new scheme in chapter 5.

5. The developed blueprint

5.1. The Layout

The developed network, which of course can only be a first design study, takes pattern from the TTK network, from which the good features were adopted. These features are e.g. the line layout and connecting links from city network to regional networks of the tram-train system; the basic layout in the city and along the urban axes. But it nevertheless includes major changes and additions regarding alignments and organisation.

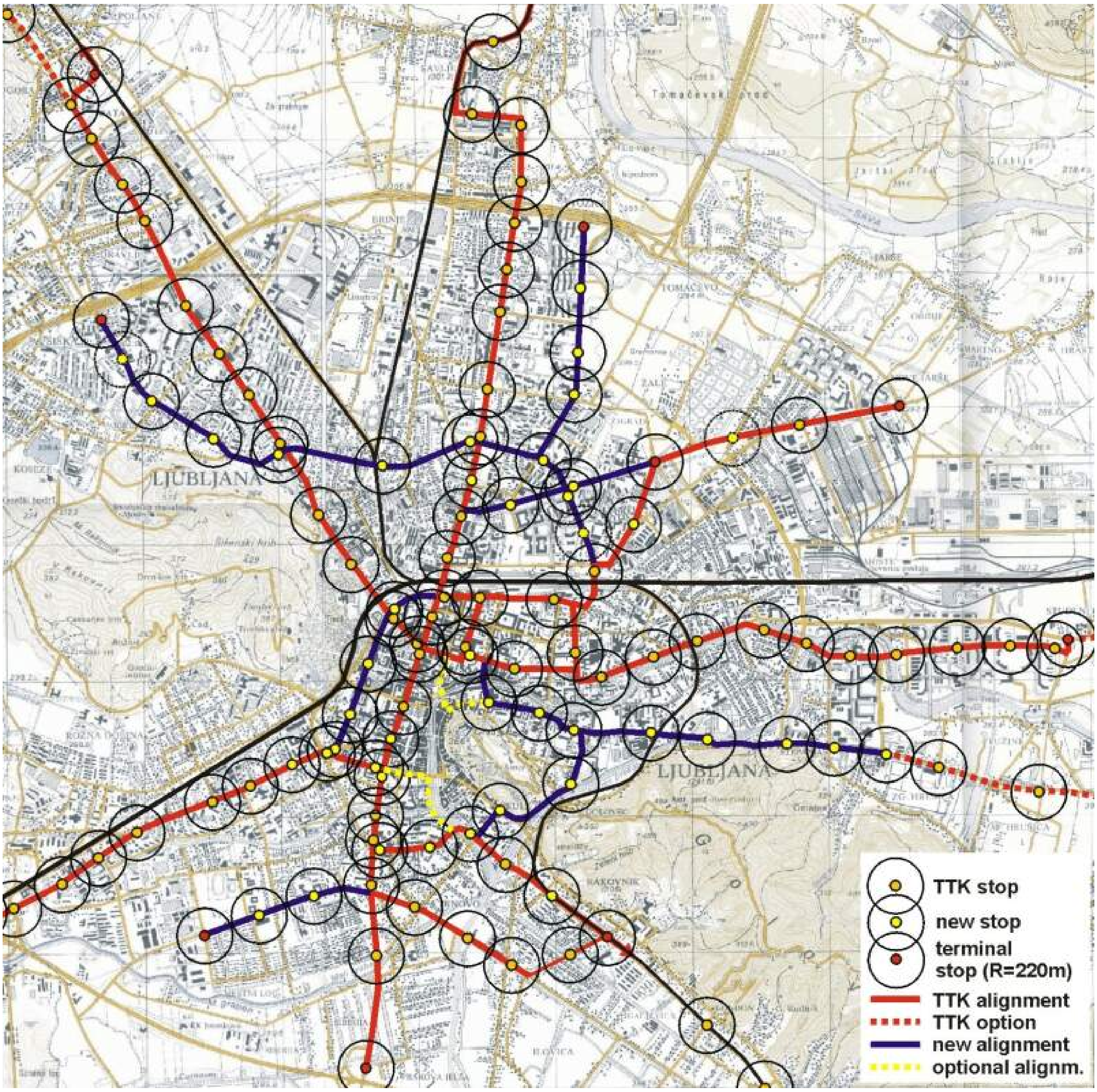


Fig. 68: The track network.

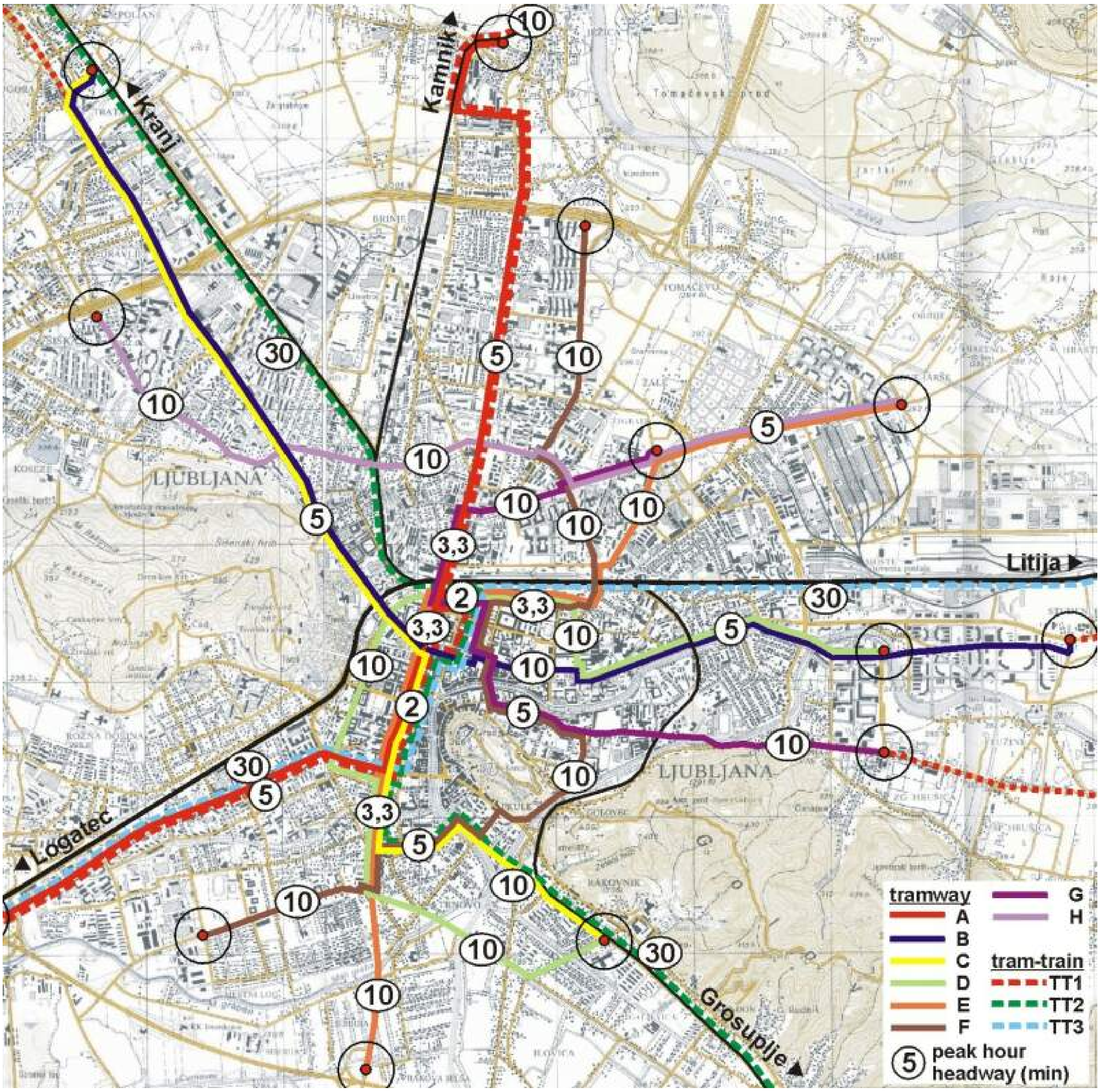


Fig. 69: The line network.

5.2. The Properties

In the developed blueprint all effort was given to provide a system with uncompromising orientation on sustainable development transport planning principles. Although two limitations were taken into consideration. The first one is, that the actual O/D matrices within the urban and regional system were not available and were therefore assumed. The second one is, that the according design of the secondary bus network and the connecting points between both systems was not carried out at this stage of detail.

► Customer relations

To increase the attractiveness of the new means of transport, it will provide a supply based timetable with dense intervals and an according redesign of the lines' immediate surroundings that will prioritise pedestrian use over MIT. By this, possible handicaps or barriers that could impede the unrestricted attractiveness of the most important part of a trip, the access/egress way, will be minimised.

Where LRT lines will be running on streets with probably less pronounced "urban flair" the "rail bound bonus" will provide:

a) increased ridership and by thus

b) the increase in importance of this street.

(For the functions of urban orientation and focus through rail infrastructure see section "rail bound bonus", 3.3.1.3.)

► **Spatial entities - network**

tram-train

As the tram-train network of TTK, consisting of three lines, covers all five existing railroad branches, it was adopted as it is.

tramway

The tramway network itself experienced some changes in alignment and the introduction of additional lines

additional lines

- Line F: from the "development area" of *Vič* via *Trnovo* around the castle hill, along *Poljanska c.* into the city, towards the railway station and to the north through eastern *Bežigrad*;
- Line G: an additional axis, from the southern end of *Štepanjsko naselje* along *Litijska c.*, via *Kodeljevo* and *Poljane* districts into the city, past the railway station, to the north along *Slovenska c.*, turning east at *Linhartova c.* and running along this major route to the cemetery.
- Line H: "the northern tangent" running west to east: *Šiška – Bežigrad – Šmartinska c. – Nove Jarše*;

changed alignments of routes

- The north to south-west alignment of lines A, TT1 and TT3 will be re-routed over *Aškerčeva c.*, where major public points of interest (schools, universities and an infirmary) are located, instead of running through *Rimska c.*, and *Gregorčičeva c.*;
- The light green line D from northern *Štepanjsko naselje* along *Zaloška c.*, past the hospital and the railway station previously ran along *Slovenska c.* and was supposed to end at *Rimska c.* The new alignment proposes the line to run along *Tivolska c./Prešernova c.* at the western

CBD limits, turning east at *Aškerčeva c.* and running along *Barjanska c.* to *Rakovnik* terminus.

- The south-eastern branch of line D running from *Trnovo/Barjanska c.* along *Hladnikova c.*, *Jurčkova c.* and *Galjevica* to *Rakovnik*, which has been considered only as an option in TTK, will be implemented.

<u>two potential alignment options (yellow dotted lines in fig. 68)</u>

a) If the corner at *Mestni trg* is not too sharp, the routes coming from the east along *Poljanska c.* (lines F and G) may be routed over *Stritarjeva ul., Tromostovje, Prešernova c., Miklošičeva c*. to meet the east – west running line B.

b) From the *Slovenska c.* southern end an alternative routing over *Zoisova c.*, *Krakovski nasip* and *Trnovski pristan* and towards *Rakovnik* – for line D – could be realised optionally. This would provide the southern end of the city core a better coverage.

<u>These changes in network layout provide the following additional features:</u>

With this scheme now three north – south links instead of just one run through or touch the CBD. One line (D) is running at the eastern CBD limit along *Prešernova c.*, the other (F) is running on the east side of the castle hill and unites with line G.

The re-alignment of the city – south-west link along *Aškerčeva c.* instead of *Rimska c.*, as proposed by TTK, serves the schools and universities along *Aškerčeva c.* It furthermore provides for an interchange point at *Trg mladinskih delavnih brigad* between lines A, TT1, TT3 and line D coming from *Prešernova c.* and the route can be easily used by line D as a connecting route from the *Prešernova c.* alignment to *Barjanska c.*

The original TTK blueprint leaves the districts around the caste hill, between the *Ljubljanica* and *Gruberjev prekop* waterways without any LRT services. This is now changed with the alignments of line F and G. The first one provides a tangential service throughout, the second a radial service on the secondary axis of *Litijska c.* But both provide a remarkable increase in service quality for the sports and education facilities in *Kodeljevo* and *Poljane* districts and the area around the market square *Vodnikov trg* and *Krekov trg*.

The areas of future dwelling expansion (compare with Cerar, et al. 2002) and internal condensation like *Kodeljevo* and east *Bežigrad* will get a link too.

The extensive school facilities located in east *Bežigrad*, between *Slovenska c.* and *Vojkova c.* and the large housing projects in the north of it will receive a quality link.

The PPMOL's (see Cerar, et al. 2002) proposition of an alignment along *Jurčkova c.* is temporarily forfeited. It is nevertheless considered as a serious option, due to the planned future settlement activity along the south-eastern axis. But the premium task of the LRT introduction is, to turn away such peripheral developments, because they evolve into entities not economically serviceable by PT.

The inner city part south-east of the castle hill is still left blank and will have to rely on bus PT. Unless the option b) from above with a routing along the Ljubljanica river is not realised, which would ease up this situation a little.

► Integration into city

The TTK blueprint avoids alignments where a clear prioritisation of the LRT against MIT would be required. For example the route through *Rimska c.* instead of *Aškerčeva c.*

In the developed scheme, solutions from the other blueprints like the following are not tolerable and will not be adopted: Demolition of objects instead of MIT restrictions like the alignment on the *Ljubljanica* embankment along *Zaloška c.* to "keep the roadway clear of LRT obstacles".

In the developed scheme, the priorities are clearly set. The LRT runs there, where major origins/destinations of journeys are, to bring maximum benefits to the city's inhabitants. This priority is a multi-tiered one, regarding alignments, the ROW, intersections and signalisation.

The whole network is designed to run above ground.

Wherever there is sufficient space, the LRT runs on exclusive ROW. For example along the major axial roads. **Due to the increase of cross section transport capacity through the LRT itself (see chapter 6), the need to keep two + two MIT lanes will be forfeited. Therefore no need to widen the street cross sections arises and no buildings need to be demolished. Simple, one lane per direction streets will be provided.** To prevent buses, that in some cases eventually may run parallel to LRT, from sticking in congested lanes, the use of LRT ROW is designated.

In the city centre, e.g. along *Slovenska c*., *Dalmatinova ul*., *Komenskega ul*., … the alignment will run through pedestrianised areas.

Where there's not enough place to provide separated MIT lanes and LRT ROW, the LRT will be given priority through transport organisation and signalisation measures. By this the speedy and uninterrupted travel will be secured.

E.g.: The eastern section along *Zaloška c.* between the railroad crossing at *Grablovičeva c.* and the crossing of the *Ljubljanica* river at *Pokopališka ul.* will run on the roadbed instead of the river embankment, where the existing houses were scheduled to be demolished.

The Karlsruhe principle of running regional services into the city centre without the need to change, which is a loss in attractiveness, needs to be applied consequently. Therefore additional LRT routes are designed to run through the dense areas, instead of an intra-CBD running additional mode, which would require transfers for travellers travelling to and from locations within the CBD but off the major LRT route.

Although not all origin/destination relations can be served, the attempt to spread the lines in the CBD increases the premier transport modes' coverage of the inner city. (see chapter 6)

In addition to the physical layout and implementation of the network's components, important measures regarding the organisation of transport need to be executed:

- **Adoption of the PPMOL concept of parking garages at the circumference of the inner city district with an adoption of the principle of equidistant access distance from dwelling to either parked car or public transport stop. (see appendix C)**
- **As a consequence, reduction of parking space on streets in combination with pedestrian friendly redesign.**

► Economic aspects

The specific construction costs will be approximately the size of ten to fifteen mill. EUR/km. Due to the lower price in comparison to sub-surface variants, not only in construction – eight to 25-times higher for sub-surface construction (see fig. 42) – but also regarding maintenance, the saved money can be invested in additional alignments and surface reconstruction compatible with pedestrian use.

The goal of increased cost effectiveness of the whole and the partial transport systems will be at reach due to the better exploitation of the city's resources.

The economic performance of the city centre as a market and trading place will be improved due to the focus of transport activities towards the CBD.

5.3. Comparison with previous blueprints

In this section five basic results will be presented and discussed.

- coverage of the city centre
- stop distance
- system breakdown safety
- transport supply
- cost estimations

5.3.1. Coverage of the city centre

As can be seen in figure 1, the number of stops within the city centre could be doubled in comparison to the TTK blueprint. This could be achieved due to the distribution of additional alignments throughout the city centre, not only along the major axis of *Slovenska c.* The number of stops for the two underground schemes is much lower.

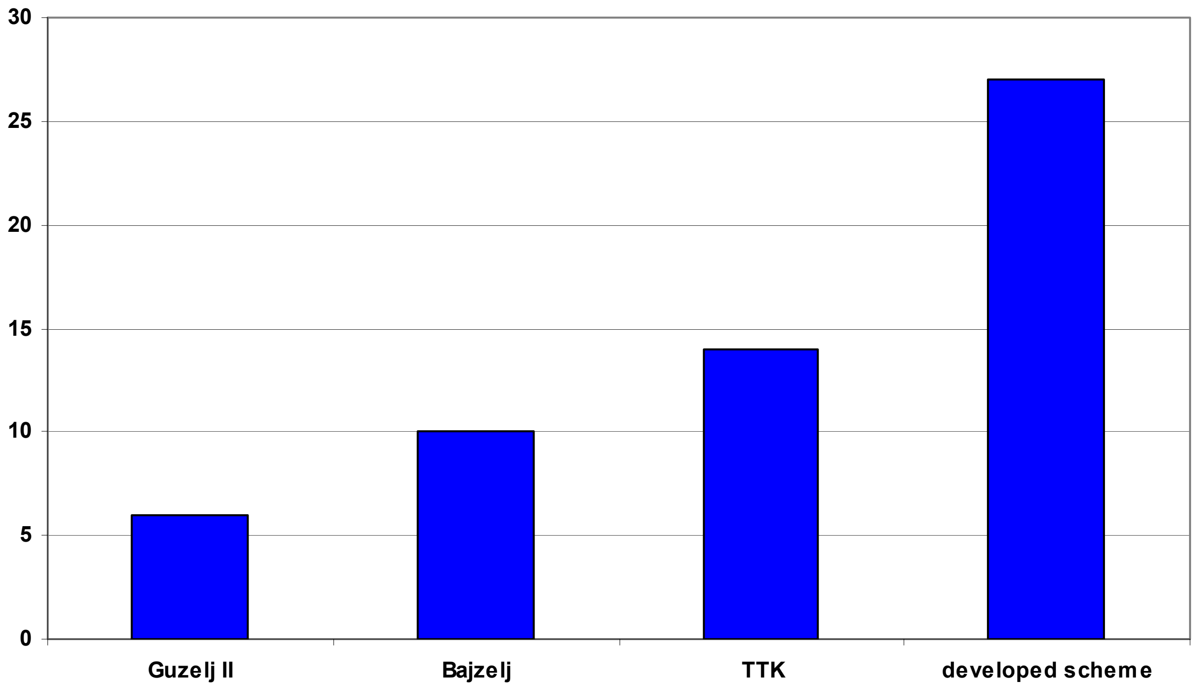


Fig. 70: Number of stops within city centre.

The figures 71 and 72 now depict this increase in area coverage for the “TTK plan” and the developed blueprint. Besides the second north – south route, the service quality could be drastically improved in the south-east corner, next to the castle hill. The looked at area is bordered by the railways and *Tivolska c.*, *Aškerčeva c.*, *Zoisova c.* and *Karlovška c.* to the south.

The increased area coverage in combination with the surface redesign (chapter 5) over-proportionally increases the likelihood of acceptance of the transport means. This leads to PAX load increases and because of that to a higher profitability. Which by itself improves the economic effectiveness of the transport operator and decreases the need for public subsidies.

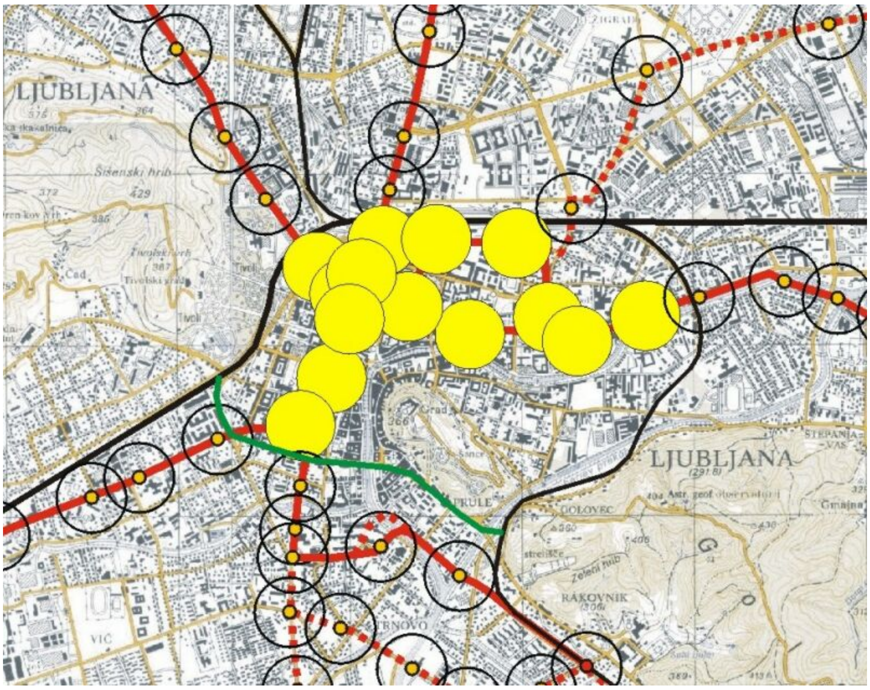


Fig. 71: Inner city stop coverage - TTK blueprint.

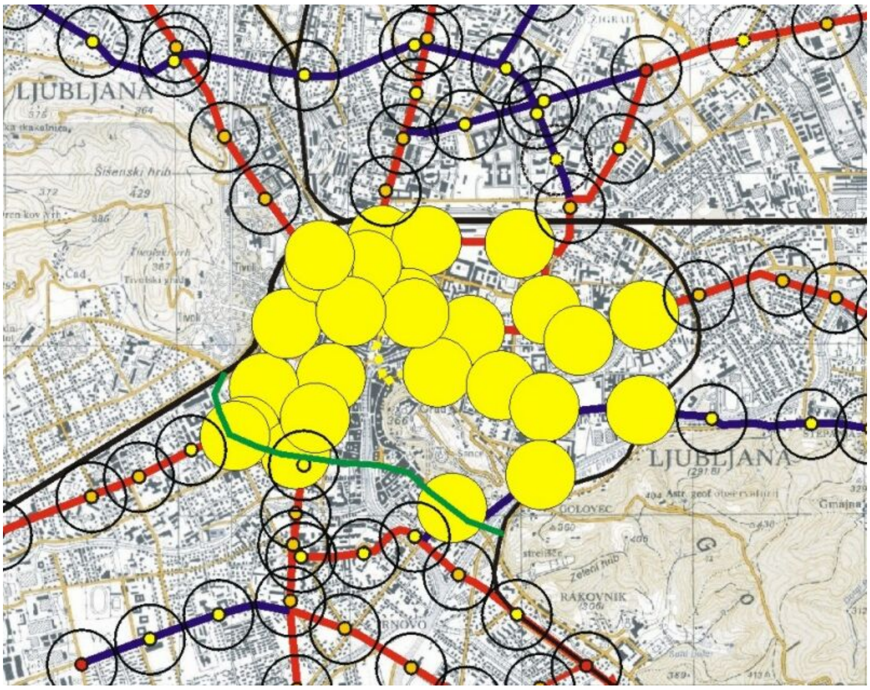


Fig. 72: Inner city stop coverage - the developed scheme.

5.3.2. Stop distance

Not only the number of stops in the centre section could be increased but also the stop distance could be decreased. Fig. 73 shows the maximum, average and minimum values of stop distances of the three existing plans and the developed scheme. Fig. 74 shows the international comparison.

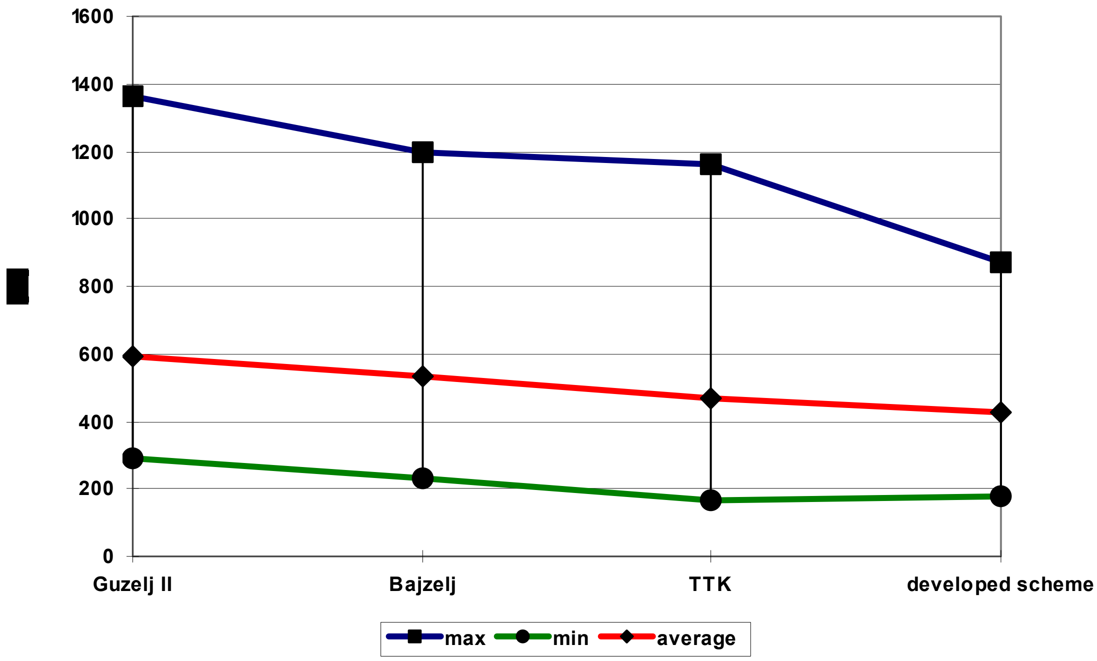


Fig. 73: Stop distances of blueprints.

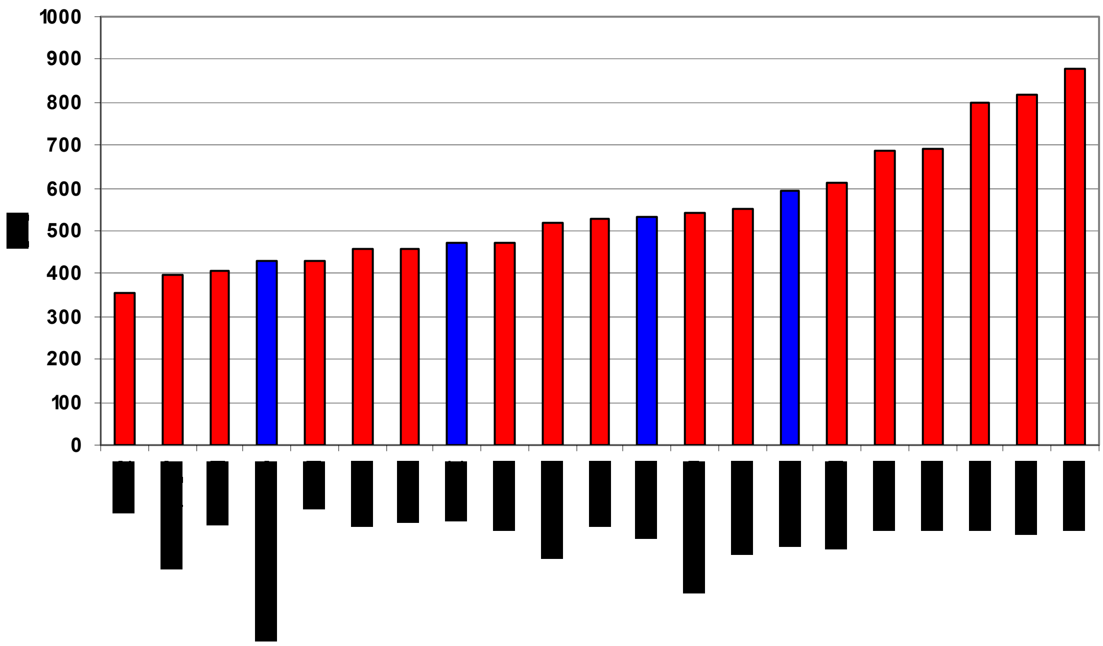


Fig. 74: Average LRT stop distance in comparison.

5.3.3. System breakdown safety

Due to the provision of additional links through the city, not only the catchment area could be widened, but also the system breakdown safety could be increased. As shown in the fig. below, now the number of optional connections has increased to 2+ for the case of incidents or emergencies, instead of being dependent on one line.

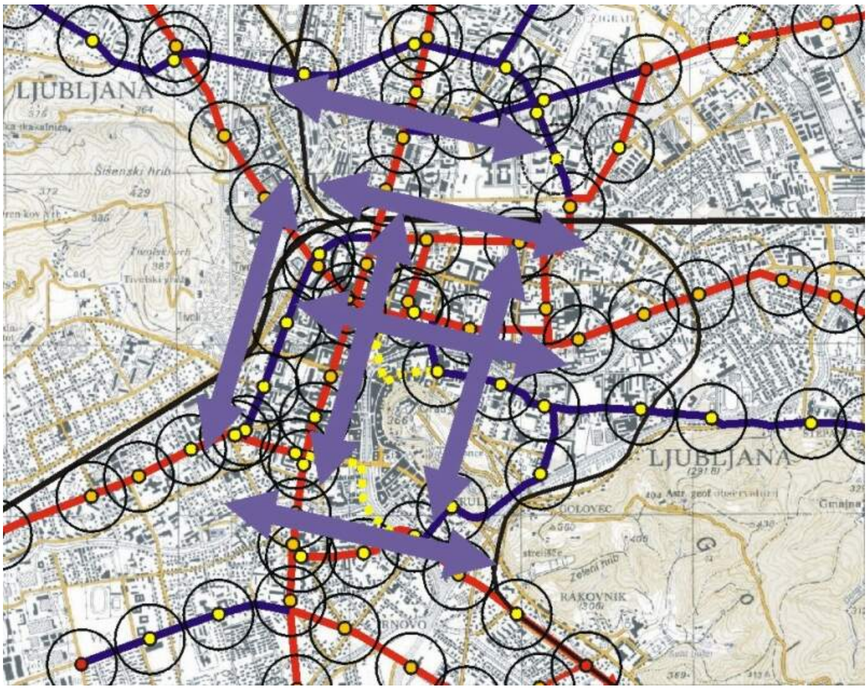


Fig. 75: Network redundancy, multiple options – the developed scheme.

5.3.4. Transport supply

As the table 28 and figures 76-78 prove, the theoretical transport capacity, as transported persons, of a major urban road, e.g. *Slovenska c.*, would be, if only one + one MIT lanes would be provided, still way above the up to date ability. In the case of the modified cross section the transport capacity is still 39 % higher, than available today.

	PT	MIT	PT + MIT
	[persons in both directions]		
status quo	10.800	25.200	**36.000**
TTK (PPMOL)	12.000	44.000	**56.000**
modified	6.000	44.000	**50.000**

Tab. 28: Transport capacity of Slovenska c. According to (Niedler, et al. 1999)

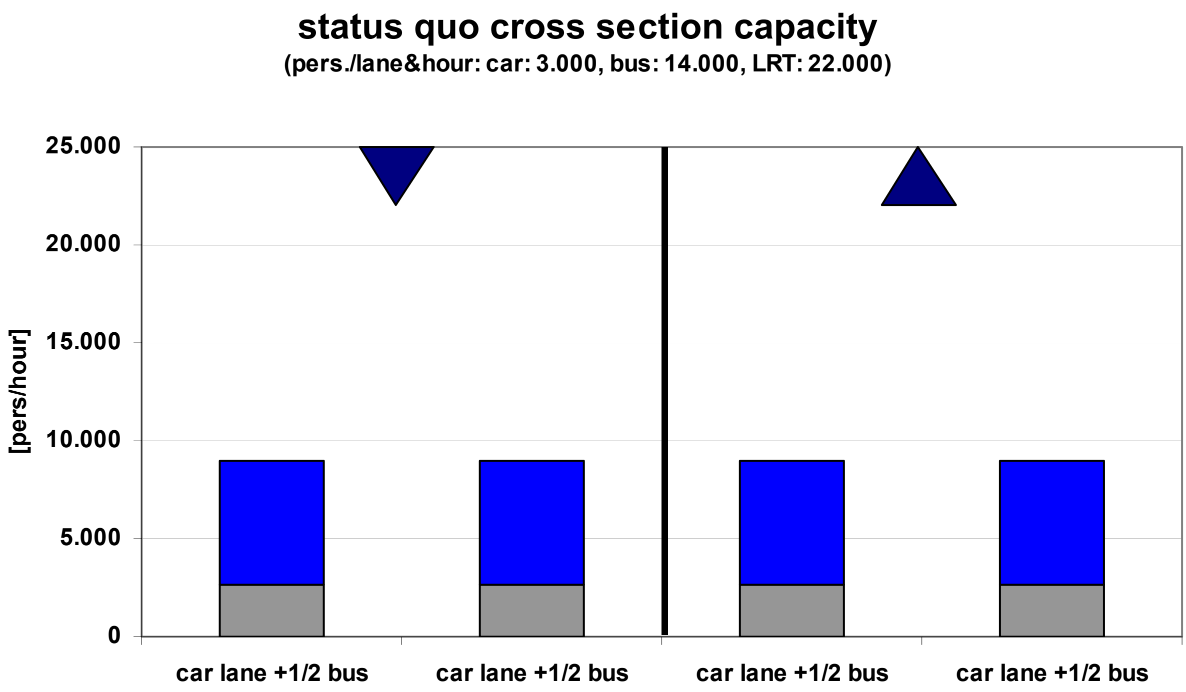


Fig. 76: The passenger carrying capacity of *Slovenska c.* at present. According to (Niedler, et al. 1999)

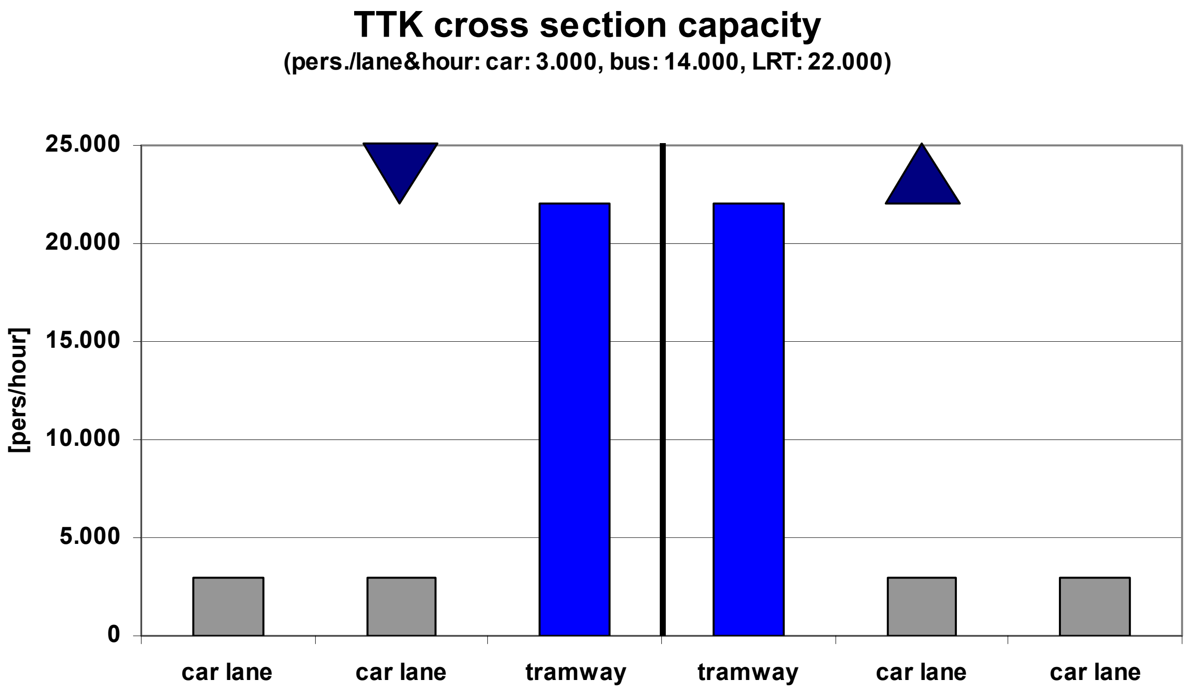


Fig. 77: The passenger carrying capacity of Slovenska c. (TTK plan). According to (Niedler, et al. 1999)

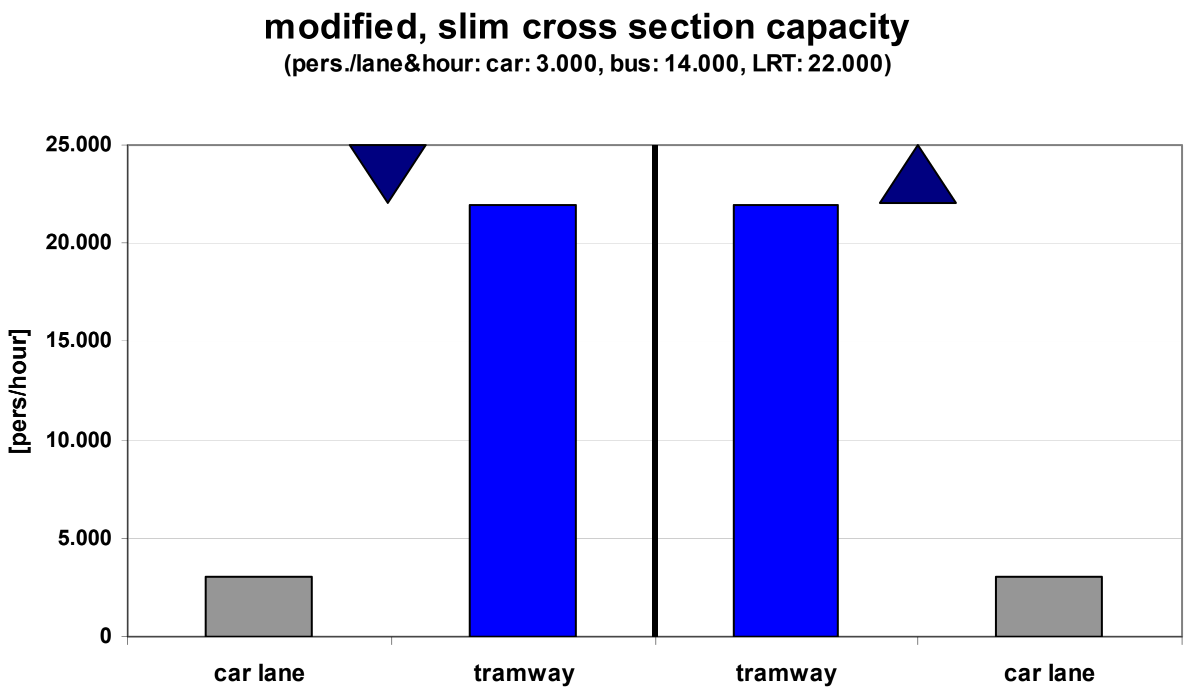


Fig. 78: The modified passenger carrying capacity of *Slovenska c.* According to (Niedler, et al. 1999)

5.3.5. Cost estimation

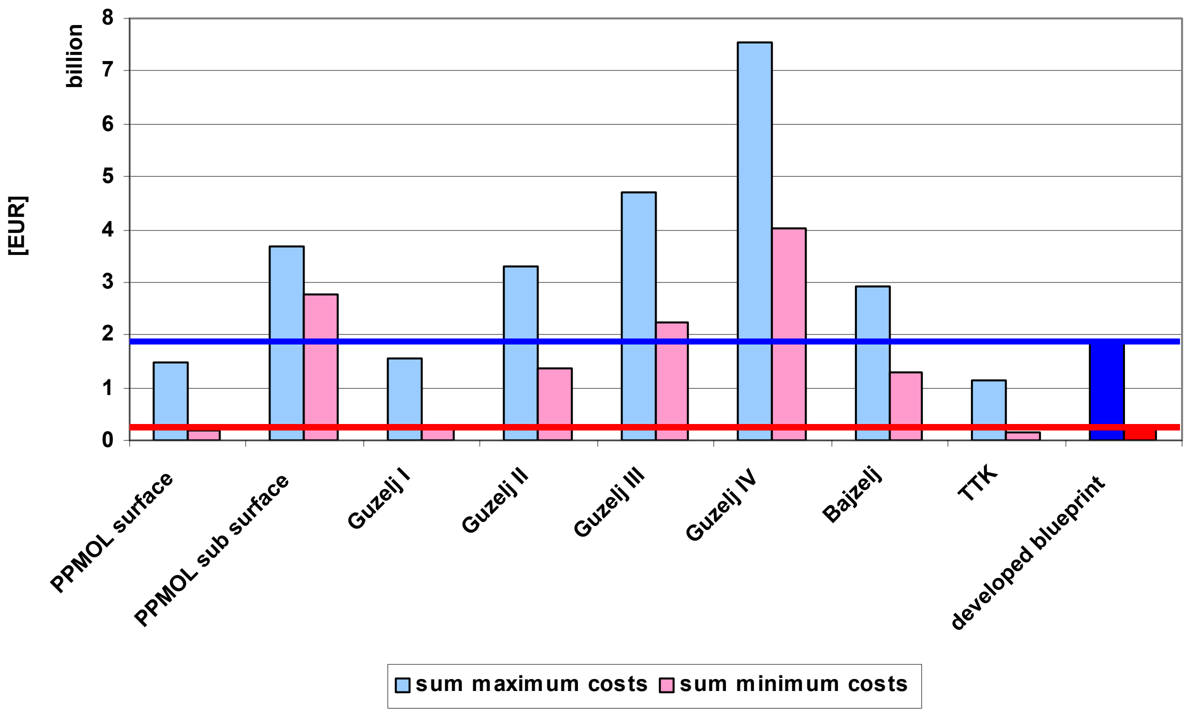


Fig. 79: Capital and stop operation costs estimate. (30 years)

To provide basic information about the financial scale of all the existing blueprints in relation to the developed blueprint, a simplified, coarse estimate was carried out. In this estimate the costs of construction (either below or above surface) and for the maintenance of stops over an exemplary period of operation of 30 years were included into the calculation. The maximum and minimum values were taken from chapter 3.3.4.

Fig. 79 shows the order of magnitude of costs that was estimated for the schemes. The surface only schemes (PPMOL surface and TTK) are below the developed scheme simply due to the fact that they are smaller in extent. The schemes with sub-surface sections (PPMOL sub-surface, Guzelj I to IV and Bajželj) are more expensive than the developed blueprint and they cover a smaller area.

6. Conclusion

From the analysis and the comparisons from Chapter 5 the following conclusions can be summarised:

The municipality of Ljubljana is currently thinking of reintroducing a light rail transit system. Since the replacement, i.e. the bus system, is decreasing in modal share and reaching its current capacity. This is only one major point in the whole analysis from a technical perspective. But for a functioning PT system connections to the policy decision making level and human transport planning should be made.

Although the transport policies consider aims such as quality of life, protection of environment and climate and responsible use of resources, the differences between the defined aims and the accomplished aims have actually increased. This happens mainly due to the fact, that the aims on the policy level are not followed by measures on the implementation level.

Instead of a focus on the transport system, the primary focus should be on the human travel behaviour, from which the parameters for the transport system can be developed. This means, that the required parameters for the transport system should be firstly defined from a travel behavioural perspective, based on physiological and psychological factors, and then implemented into the light rail system. For example the stop distance. Peperna could show, that the 100 % access probability occurs at an access distance of 220 m, which should then be aimed at as stop distance for the light rail network.

Further improvements would be also in regard to people's perception, so that a frequent usage and strong street presence of the light rail system provides improved feedback for the travel behaviour of the people.

A similar analysis has been undertaken in regard to the existing blueprints. It could be shown, that the plans still lack the determination to significantly change the transport regime into a sustainable one. The most recent plan includes already several aspects of an ecologically and financially sustainable transport system. Although the need of changing the transport regime and behaviour is identified in the urban development plan, superior to the light rail plans, the measures section still includes a lot of measures, which actually are responsible for the problems of the last decades. Such measures are additional lanes and tunnels for motorised transport, additional access points or housing demolition for transport needs.

The analysis in regard to the light rail system yielded, that the sub-surface versions' effects will substantially differ from the goals and claims in the corresponding documents. For example, the long sub-surface stop access corridors are expected to stay as attractive as in the beginning throughout the time. With existing examples of public pedestrian subways, it can easily be shown that this claims are unfounded. Another example is, although the surfaces need not to be redesigned, the attractiveness for pedestrians in the areas with less motorised transport will increase. In the urban development plan argumentations and descriptions of details are provided, that seem to include already a foregone evalution and conclusion.

However, the design of an effective plan can only be carried out in the context of historic evolution of planning ideas in connection with modern methods of planning. Therefore the historic development of Ljubljana's public transport and plans of rail-bound transit have been included.

A scheme was developed which includes parameters of comparison in regard to the general transport policies, human travel behaviour and technical parameters for the transport system. Among others, this includes area coverage, pedestrian friendly surface design, short stop distances with short access/egress walks or connecting interfaces to the region, which were identified as one of high priority.

To assure, that the provided LRT will be able to exploit its potential and be accepted sufficiently, important additional measures for restraining MIT need to be implemented, in addition to the already discussed reduction of MIT lane capacity along the major inbound routes. These measures are:

- Implementation of parking space management in the city, which is especially important for the CBD;
- Reduction of distributed in-street parking;
- Provision of concentrated parking garages – as already envisioned in the PPMOL – that are situated in the vicinity of PT stops to provide equal access opportunities for both modes.

In terms of economic assessment, the analysis has shown that the sub-surface variant is (not surprisingly) more costly than the surface variant, despite the fact that the newly developed variant includes also three additional lines.

Overall the results show that the surface network with the increased number of stops, the increased spatial provision of PT services and lower stop distances will serve the city in a better way and will also be much more cost effective. This will lead to a long-term and sustainable improvement in regard to the quality of city life, quality of city transportation and the proposed modal share of public transit.

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CBD	central business district
EU	European Union
LPP	*“Ljubljanski potniški promet”* – Ljubljana's municipal public transport provider
LRT	light rail transit
LRV	light rail vehicle
MOL	*“Mestna občina Ljubljana”* – municipality of Ljubljana
MS	modal split
NPVO	*“Nacionalni program varstva okolja”* – Slovenian national environmental protection program
OECD	Organisation for Economic Cooperation and Development
PAX	passenger(s)
PPMOL	*“Prostorski plan Mestne občine Ljubljana”* – city development plan of Ljubljana
PT	public transport
ROW	right of way
RS	*Republika Slovenija*
UN	United Nations
vkm	vehicle kilometers
HR	heavy rail
c.	*“cesta”* – street
MIT	motorised individual transport
pkm	person kilometers or passenger kilometers
TOD	transit oriented develoments
WWII	world war II
SCT	*“Slovenija ceste tehnika”* – construction firm
SIU	*“Slovenski inštitut za urbanizm”* – Slovenian institute of urbanism

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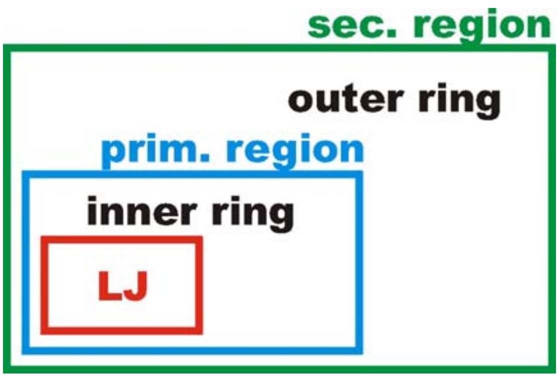
Appendix A (Chapter 2)

Population changes for the city and region of Ljubljana.

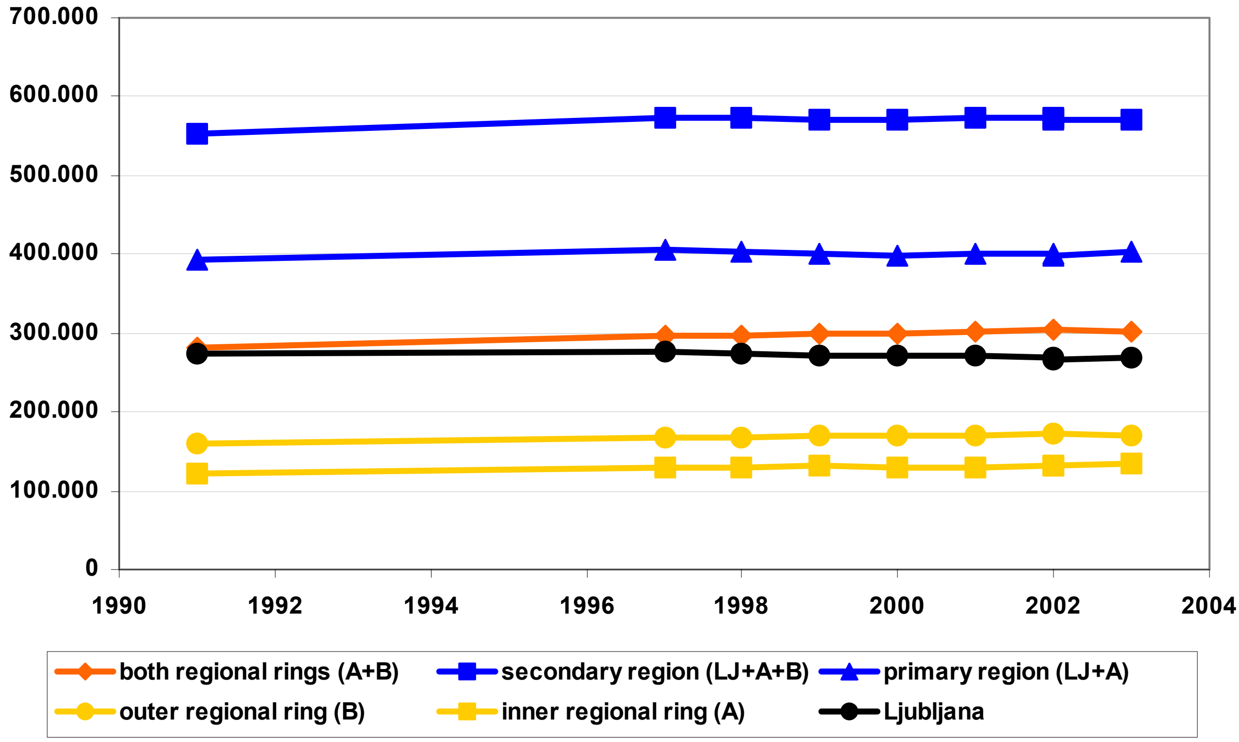
Although the overall amounts of movement are rather small in comparison to the stock of population, and the period of observation and comparison is rather small too, one effect is still recognisable. The decrease of the outer ring's population is caused by the dramatic losses of population in the municipalities of *Litija* (-25,1%) and *Šenčur* (-8,1%). Whereas the other municipalities in ring B like *Grosuplje* (+6,6%) or *Lukovica* (+6,1%) and others experienced remarkable growth within these three years.



App.fig. 1: Scheme of Ljubljana's regions

inner ring A		[%]
increasing pop.	*Škofljica*	+14,4
	Trzin	+14,7
	Brezovica	+6,8
	and others	
outer ring B		
decreasing pop.	*Litija*	-25,1
	Šenčur	-8,1
increasing pop.	*Lukovica*	+6,6
	Grosuplje	+6,1
	and others	

App.tab. 1: Extreme values of population change, 2000 - 2003



App.fig. 2: The population's development over the last decade. (SURS 1996 - 2003)

city/town	population								
	1991	1997	1998	1999	2000	2001	2002	2002	2003
both regional rings (A+B)	281.377	295.645	297.792	299.342	298.692	301.478	304.194	303.870	302.890
secondary region (LJ+A+B)	554.027	572.042	572.169	569.783	569.678	571.984	574.018	569.751	570.974
primary region (LJ+A)	393.920	404.721	403.911	401.074	399.445	400.836	401.771	398.146	402.087
outer regional ring (B)	160.107	167.321	168.258	168.709	170.233	171.148	172.247	171.605	168.887
inner regional ring (A)	121.270	128.324	129.534	130.633	128.459	130.330	131.947	132.265	134.003
Ljubljana	272.650	276.397	274.377	270.441	270.986	270.506	269.824	265.881	268.084
inner regional ring (A)									
Borovnica	3.579	3.702	3.727	3.727	3.781	3.814	3.805	3.839	3.795
Brezovica	7.789	8.518	8.696	8.859	9.009	9.146	9.326	9.334	9.623
Dol pri Ljubljani	3.740	3.986	4.040	4.112	4.163	4.269	4.324	4.341	4.423
Domžale	29.450	31.473	31.778	31.944	29.373	29.608	29.850	29.902	30.308
Ig	4.498	4.865	4.920	5.052	5.220	5.296	5.423	5.445	5.542
Kamnik	28.766	29.789	29.886	30.034	26.172	26.369	26.480	26.477	26.752
Medvode	12.739	13.569	13.701	13.774	13.958	14.195	14.374	14.161	14.281
Mengeš	6.201	6.568	6.543	6.523	6.582	6.637	6.690	6.662	6.718
Škofljica	5.123	5.800	6.028	6.198	6.432	6.764	6.979	7.119	7.359
Trzin	-	-	-	-	3.043	3.191	3.303	3.385	3.490
Vodice	3.505	3.652	3.707	3.771	3.801	3.848	3.876	3.871	3.951
Vrhnika	15.880	16.402	16.508	16.639	16.925	17.193	17.517	17.729	17.761
outer regional ring (B)									
Cerklje n.Gorenjskem	5.753	6.078	6.141	6.192	6.371	6.263	6.365	6.369	6.431
Dobrova-Polhov Gradec	8.208	8.684	8.766	8.871	6.411	6.505	6.622	6.691	6.737
Grosuplje	13.345	14.593	14.788	14.967	15.273	15.515	15.668	15.665	16.205
Horjul	-	-	-	-	2.604	2.643	2.655	2.622	2.643
Ivančna Gorica	12.101	12.700	12.860	13.042	13.222	13.421	13.546	13.567	13.804
Kranj	50.863	52.043	51.983	51.497	51.923	51.805	51.797	51.225	52.777
Litija	18.546	18.957	19.078	19.181	19.201	19.308	19.475	19.120	14.382
Logatec	9.764	10.435	10.583	10.794	10.988	11.103	11.254	11.343	11.464
Lukovica	4.350	4.621	4.675	4.718	4.801	4.857	4.941	4.972	5.120
Moravče	4.184	4.357	4.378	4.413	4.328	4.385	4.450	4.508	4.552
Naklo	4.497	4.761	4.797	4.787	4.826	4.890	4.928	4.899	5.010
Šenčur	7.563	7.995	8.064	8.156	8.245	8.354	8.464	8.531	7.578
Škofja Loka	20.933	22.097	22.145	22.091	22.040	22.099	22.082	22.093	22.184

App.tab. 2: The population of Ljubljana and region. (SURS 1996 - 2003)

city/town	population change					size
	Δ 91-01	Δ 97-03	Δ 91-03	Δ 03-00	Δ 03-00	
	abs.	abs.	abs.	abs.	[%]	[ha]
both regional rings (A+B)	**20.101**	**7.245**	**21.513**	**4.198**	**1,4**	**256.710**
secondary region (LJ+A+B)	**17.957**	**-1.068**	**16.947**	**1.296**	**0,2**	**284.201**
primary region (LJ+A)	**6.916**	**-2.634**	**8.167**	**2.642**	**0,7**	**121.936**
outer regional ring (B)	**11.041**	**1.566**	**8.780**	**-1.346**	**-0,8**	**162.265**
inner regional ring (A)	**9.060**	**5.679**	**12.733**	**5.544**	**4,3**	**94.445**
Ljubljana	**-2.144**	**-8.313,0**	**-4.566,0**	**-2.902,0**	**-1,1**	**27.491**
inner regional ring (A)						
Borovnica	235	93	216	14	0,4	4.230
Brezovica	1.357	1.105	1.834	614	6,8	9.117
Dol pri Ljubljani	529	437	683	260	6,2	3.328
Domžale	158	-1.165	858	935	3,2	7.972
Ig	798	677	1.044	322	6,2	9.875
Kamnik	-2.397	-3.037	-2.014	580	2,2	28.970
Medvode	1.456	712	1.542	323	2,3	7.746
Mengeš	436	150	517	136	2,1	2.246
Škofljica	1.641	1.559	2.236	927	14,4	4.335
Trzin	-	-	-	447	14,7	860
Vodice	343	299	446	150	3,9	3.138
Vrhnika	1.313	1.359	1.881	836	4,9	12.628
outer regional ring (B)						
Cerklje n.Gorenjskem	510	353	678	60	0,9	7.804
Dobrova-Polhov Gradec	-1.703	-1.947	-1.471	326	5,1	15.021
Grosuplje	2.170	1.612	2.860	932	6,1	13.380
Horjul	-	-	-	39	1,5	3.250
Ivančna Gorica	1.320	1.104	1.703	582	4,4	22.701
Kranj	942	734	1.914	854	1,6	14.794
Litija	762	-4.575	-4.164	-4.819	-25,1	32.188
Logatec	1.339	1.029	1.700	476	4,3	17.311
Lukovica	507	499	770	319	6,6	7.490
Moravče	201	195	368	224	5,2	6.257
Naklo	393	249	513	184	3,8	2.829
Šenčur	791	-417	15	-667	-8,1	4.325
Škofja Loka	1.166	87	1.251	144	0,7	14.915

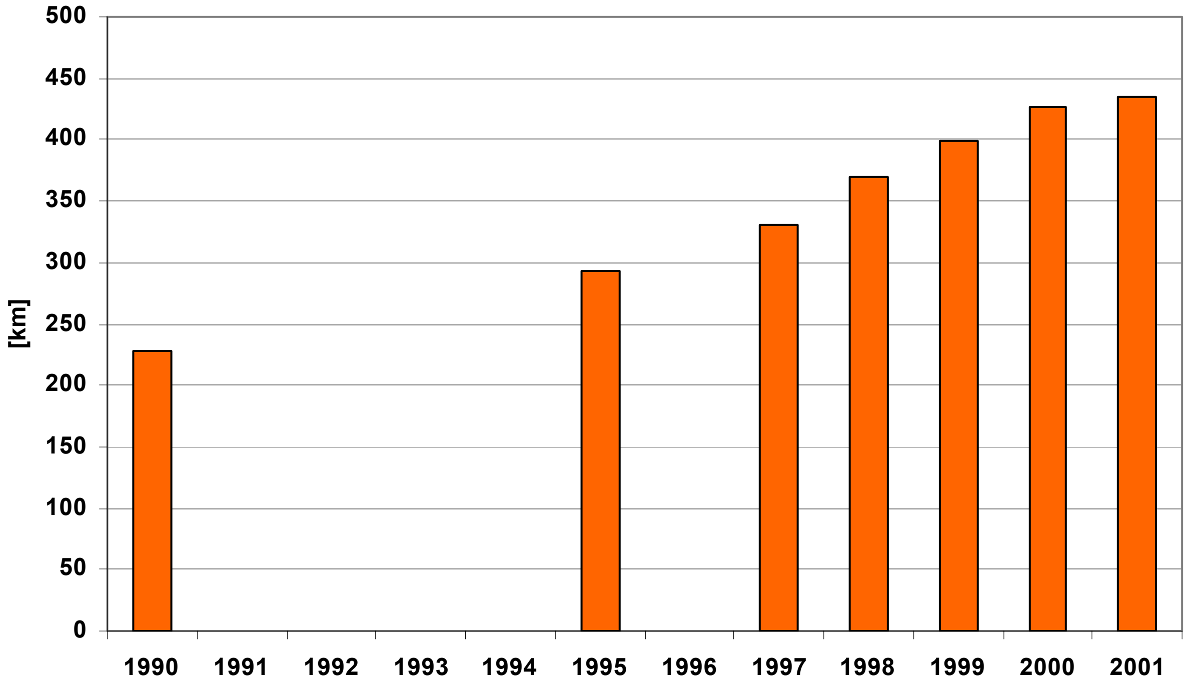
App.tab. 3: The population of Ljubljana and region continued. (SURS 1996 - 2003)

The railway system

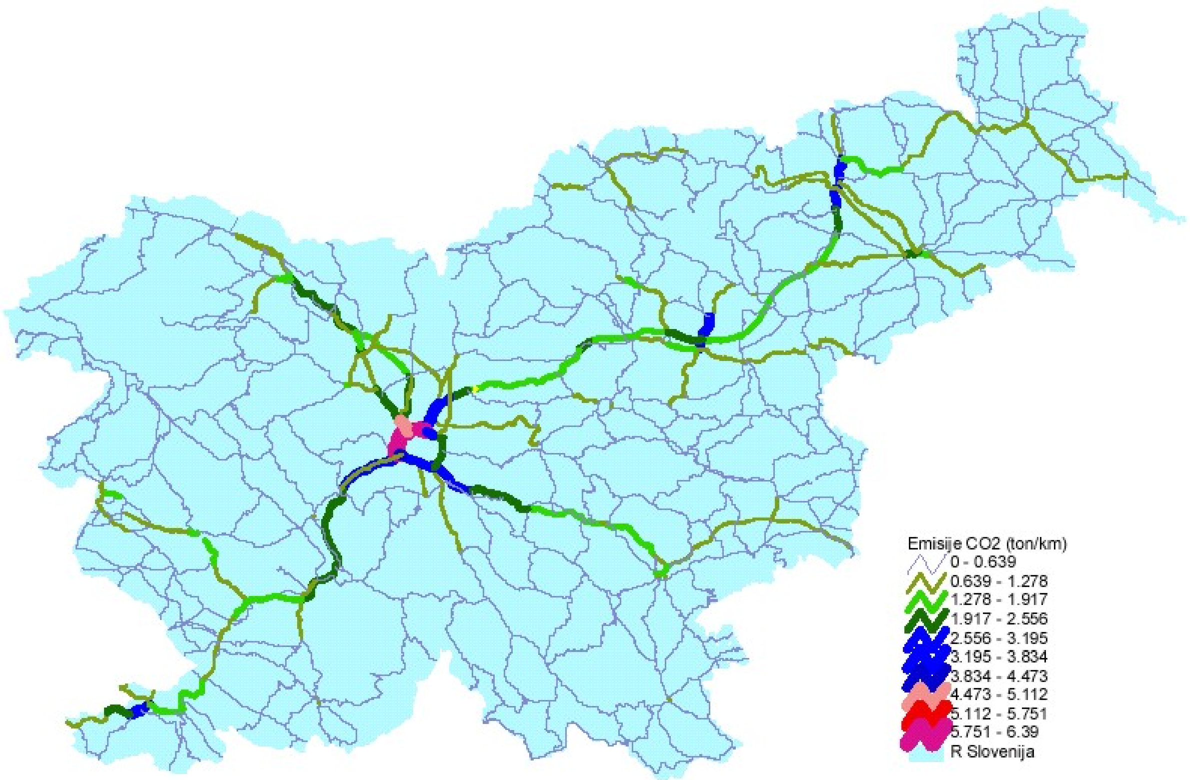
branch	km	station name	branch	km	station name
east	*0*	Ljubljana	**north-west**	*0*	Ljubljana
	6	*Ljubljana Polje*		3	*Litostroj*
	8	*Ljubljana Zalog*		4	*Ljubljana Stegne*
south-west	*0*	Ljubljana		6	*Ljubljana Vižmarje*
	2	*Ljubljana Tivoli*	**north**	*0*	Ljubljana
south-east	*0*	Ljubljana		3	*Ljubljana Brinje*
	2	*Ljubljana Vodmat*		5	*Ljubljana Ježica*
	4	*Ljubljana Rakovnik*		7	*Ljubljana Črnuče*

App.tab. 4: Synopsis of railway stops within Ljubljana. (SŽ 2002)

Motorised individual transport



App.fig. 3: Length of Slovenian Highways (SURS 1996 – 2002)



App.fig. 4: The CO_2 output on Slovenian streets. (MOP 2003)

App.fig. 5: Typical low floor, articulated bus in Ljubljana. (photo: B. Lokar)

Appendix B (Chapter 3)

Sustainable transport planning

Since its widespread introduction into professional and everyday language in the late 1980's and early 1990's, the terms "sustainable development" and "sustainability" in general have experienced a dramatic increase in popularity and rate of usage. Hardly any fields of profession and parts of life can be identified, where sustainability isn't an issue. Ranging from the financial markets and investment surroundings via the small scale implementation within business plans, the large scale development of economy, manufacturing, construction, city planning and many more, up to transportation planning.

It can be said, that the sustainability issue started in 1987 when the "World Commission on Environment and Development", which was installed by the United Nations and chaired by the Norwegian Gro Harlem Brundtland, presented it's report "Our Common Future" to the world. (nachhaltigkeit.at 2003) For the first time it was ascertained in this report that environment and development cannot be separated. It criticised:

> *"As today's balances still may show benefits – our children will be left with the losses. Without intent and the chance to pay back, we are today borrowing future generation's environmental assets."* (BMLFUW 2002)

As a countermeasure the concept of sustainable development was introduced and explained:

> *"Sustainable development is a development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs."* (WCED Report in Tuuli 2003)

> *"A generation's management of its stocks of man-made and natural capital is sustainable, if its level of consumption can be shared by the next generation (in the sense of certainty equivalents) even if the latter abides by the requirement of sustainability."* (Asheim and Brekke in Tuuli 2003)

Sustainable development is a large scale concept to redirect the management of resources and the anthropogenically shaped world.

The EU Council of Ministers of Transport adopted the following partial description to tackle the issue of definition:

> *"Sustainable transport allows the basic access and development needs of individuals, companies and society to be met safely and in a manner consistent with human and ecosystem health and promotes equity within and between successive*

generations. Sustainable transport is affordable, operates fairly and efficiently, offers a choice of transport mode and supports a competitive economy, as well as balanced regional development. Sustainable transport limits emissions and waste within the planet's ability to absorb them, uses renewable resources at or below the rates of development of renewable substitutes, while minimising the impact on the land use and the generation of noise." (Tuuli 2003)

Sustainable transport in Slovenian documents

The NPVO

The national program for the protection of the environment (*"Nacionalni Program Varstva Okolja"*) passed the National Assembly in September of 1999. It includes the key objectives for environmental protection in Slovenia. The ones related to transport are (DZ-RS 1999):

- control over air pollution due to transportation;
- reduction of green-house gases (Kyoto Protocol);
- reduction of noise pollution caused by traffic.

No numerical values or time constraints for the achievement of the objectives aimed at are given, which makes them almost impossible to be verified and the measures adjusted. For influencing the transport regimes and procedures, some measures are given (DZ-RS 1999):

- more determinate redirection of transportation, preferably shifting the transit traffic from roads towards railway;
- consideration of environmental and natural assessments for the construction of transportation infrastructure;
- introduction of "co-habitative" development of transport networks;
- fiscal policy on energy;
- measures for increased attractiveness of alternative means of transport in general, increased quality of regional and urban PT in special;
- limitation of vehicle speeds;
- modernisation of PT and securing of its privileged role within urban transport modes;
- "complete parking management", including the increase of parking fares with cross subsidisation of PT;
- initiation of multi-modal transport

The PUTRS

The report on the implementation of sustainable development in Slovenia *("Poročilo o uresničevanju trajnostnega razvoja v Sloveniji")* is **the** compilation of all materials, plans and regulations handling sustainability issues in Slovenia. The transportation section is named "changing patterns of consumption – transport" and describes the existing and aspired policies regarding transport. Whereas standalone plans for the construction of railway and road infrastructure exist – but only the latter is being executed with increased speed – it's very honestly confessed, that Slovenia lacks a plan for long term transport strategies. (MOP 2002) The proposed measures for achieving a *"more sustainable"* transport are:

- decrease of transport induced emissions;
- faster modernisation of railway networks;
- supply with sufficiently dense PT networks;
- increase of attractiveness of PT;
- increase of environmental taxes on fuels;
- decrease of transit traffic and prevention of "non-necessary traffic".

The vision on Slovenia's (MPZ 2003) transport policy proposes:

- interconnection of urban centres and their regions with sustainable modes of transport;
- rational use of land;
- the preservation of regional characteristics;
- decrease of noise and air pollution;
- change of modal split.

The tramway and its siblings

Light rail

> *"The exact origination of the term light rail is unclear, however, the term light rail was reportedly used in the 1960's as an euphemism to avoid the terms: trolley or streetcar (US) and tram or tramway (UK). ... Regardless, the name appears to have been introduced to try to give the streetcar/tram/trolley a more upmarket image." (lightrail.com 2003b)*

> *"… the term light railway … which probably originated in Britain, where it is used to describe a railway constructed under the provision of the Light Railways Act. …*

permitted to use ungated crossings and unfenced ROW, operate without full signal protection and run in street ROW. " (Young 1995)

"Light rail is an electric railway system, constructed in the 1970's or later, characterised by its ability to operate single or multiple car consists (trains) along exclusive rights-of-way at ground level, on aerial structures, in subways, or in streets, able to board and discharge passengers at station platforms or at street, track or car-floor level and normally powered by overhead electrical wires." (lightrail.com 2003b)

The APTA (American Passenger Transit Association) glossary of transit terminology defines the term as follows:

"An electric railway with a 'light volume' traffic capacity compared to heavy rail. Light rail may use shared or exclusive rights-of-way, high or low platform loading and multi-car trains or single cars. Also known as streetcar, trolley car or tramway" (lightrail.com 2003b)

The Transport Research Board's definition is:

"Light rail transit is a metropolitan electric railway system characterised by its ability to operate single cars or short trains along exclusive rights-of-way at ground level, in aerial structures, in subways or occasionally in streets, and to board and discharge passengers at track or car-floor level." (lightrail.com 2003b)

Due to the relatively important influence of German tramway developments, the German term *Stadtbahn* (light rail or city railway) also differs from the original *Straßenbahn* (tramway). In Germany the term *Stadtbahn* appeared in the late 60's early 70's as many cities, those not definitely wanting to close down their systems, were in need to modernise them. As the cities wanted to minimise the tramway's obstacle on motorised traffic, i.e. avoid bottlenecks, sections of tramway tracks were re-routed into the underground to form the so called "subsurface tramway". Other improvements included changes in route alignment and operating format to gear the capacity more towards metro but without the loss of tramway-like operation on other sections. (VDV, et al. 2000)

"Consequently, light rail systems in Germany are actually electrical railways for local transit that have developed on from tramways and whose capacities are between those of a tramway and a metro system." (VDV, et al. 2000)

As the citations from above show, the light rail concept is considered some kind of tramway with a range of possible additional features. But there is no strict borderline between the one and the other system. But the dividing line between tramway and LRT, both technically and linguistically, has become blurred. (VDV, et al. 2000)

The following description (Tolmach 1982) expresses an other approach, already hinting at the next modal category, with respect to American circumstances regarding settlement morphology. It therefore can't be adopted one-on-one to European boundary conditions, although the increased spatial and ongoing urban sprawl around Europe's cities is rapidly closing in on American conditions.

> *"The functional role proposed for most new systems is not to serve compact cities' local trips but to provide regional trunk services for the decentralised urban areas of North America, ... The purpose and meaning of light rail transit are not simply modern streetcars – it is the creation of affordable metropolitan railways to serve regional needs."*

Tram-train

The public transit system then includes three types of cars and operation. The classic heavy rail vehicles operating on their network, tramway vehicles on their and tram-trains operating on both systems. This needs according to the boundary conditions of both systems and their inter-systematic differences for sophisticated solutions vehicle and infrastructure wise. The differences are for example:

- different currencies, heavy rail parts probably without any electrification at all;
- different gauges, mostly LRT smaller than HR;
- different signalisation and control systems;
- different loading profiles and vehicular cross-sections;
- different platform heights and distances;
- different responsibility of ordinances and rules.

There are almost innumerable possibilities of differences and combinations thereof. The vehicles running under such diverse conditions are so called "two-system vehicles" and include technically and organisationally sophisticated solutions to meet the needs of both systems.

Semi-metro, pre-metro

> *"Semi-metro is a light rail transit system that uses exclusive ROW for much of its length, usually at surface grade but occasionally in tunnels." (NAS 1978)*

> *"Pre-metro is a light-rail transit system that operates in tunnels that are designed to be upgraded to rail rapid transit." (NAS 1978)*

In German the term of "Unterpflasterstraßenbahn", its implementation is to be found e.g. on some stretches of the Vienna tramway network, is used to describe the characteristic of sub ground pre-metro stretches.

Commuter rail, suburban rail

The Glossary of Urban Public Transportation Terms of the National Academy of Sciences defines:

> *"The portion of passenger railroad operations that carries passengers within urban areas but that differs from rail rapid transit in that the passenger cars are heavier, the average trip lengths are longer and the operations are generally run by railroad companies as part of their overall service." (NAS 1978)*

Commuter rail is included here for the purpose as it has an interface with light rail in the tram-train concepts. This will be an integral part of the upcoming transportation plans for Ljubljana.

Metro

Is also called "rail rapid transit" and stands for:

> *"A transit system that uses high-speed passenger rail cars operating singly or in trains on fixed rails in exclusive rights-of-way in underground tunnels, on elevated structures, in open cuts or at surface levels with very few, if any, grade crossings (at which rail traffic has the right-of-way) and that generally serves one contiguous urban area." (NAS 1978)*

Classifications

To provide a logical structure, all the criteria and factors considered in the planning and assessment process are classified. Two examples of possible arrangements:

The Seattle/Puget Sound alternative comparison criteria are covering 4 major transit areas (Kask 1982): • performance and operating factors, • cost factors, • urban factors and • environmental factors	Twin Cities examination utilised qualifying and non-qualifying criteria summarised within three categories (Dallam, et al. 1982): • physical impact criteria • transportation criteria and • economic criteria

App.tab. 5: Chart of example parameter classifications.

Benefits of LRT in general

"If PT is supposed to become the future mode of transport, the rail bound modes will have to contribute its positive share in re-attracting city and city transport" (Besier 2002)

"Measures taken to improve public transport, especially the construction and operation of LRT systems, have effects over different time scales in a wide range of areas. The benefits of LRT are manifold and they can hardly be described in general. They usually cover improvements of the traffic situation, complete urban revival and improvement as well as the extensive securing of workplaces in all areas." (VDV, et al. 2000)

consequences of investment in public transport		
short term	**medium term**	**long term**
• aditional passengers, more journeys • calming of traffic without impairing mobility • relief from flowing and stationery traffic • increased transport safety; fewer accidents • faster and better accessibility of centres of urban activity • less environmental damage	• stabilisation of PAX levels at a high level • urban regeneration; improved quality of urban life • new development and restructuring of "moribund" urban areas (e.g. at the rear of central stations) • improvement of the local economic structure; boosted turnover • increased value of property and buildings along the route • increased investment from the private sector	• lasting change in the modal split in favour of PT • relocation of large companies • kick-start to the construction of available housing in the city centre • regeneration of run-down residential areas • increased intensity of building around stops • use of undeveloped urban spaces • stronger emphasis on local transport networks in urban planning

App.tab. 6: Scheme of consequences of LRT investments. (VDV, et al. 2000)

Transport supply

Travel time and punctuality

A competitive commercial speed is decisive for the systems productivity and attractiveness. During the era of non scrutinised MIT promotion, and in some places even today, the commercial speed dropped dramatically due to discrimination of PT. (VDV, et al. 2000) Then the era of "LRT renaissance" started and commercial speeds within CBDs began to rise again above pedestrian levels. The causes are step by step implementation of improvements, of course not finished today. Like: decrease of hindrance by MIT and the MIT centred transport operation and signalisation systems. (Brändli 1995)

By the elimination of external sources of disruption and systematic handicaps (see also system breakdown safety section) the travelling time could be trimmed down, and the commercial speed could be increasing. By an increased commercial speed, the forced upon drawback in comparison to private transport can be reduced, so that the reachability of city centres can be improved essentially. (Felz 1989)

The decrease of journey times and punctuality unsteadiness and the increase of commercial speeds can be achieved by improvements like (VDV, et al. 2000): alignment on separated tracks, improved boarding and alighting conditions, traffic signal actuation, … Tabs. 33 and 34 show the betterment of service delays for different cities. In chart 34 the measure "LRT" means the German practice of "Stadtbahn" from the 70's and 80's, which not only means reserved track sections but also CBD sub-surface alignments.

city	before [min]	after [min]
Braunschweig	5 - 10	1 - 3
Karlsruhe	5	0
Mainz	3 - 5	0
Nürnberg	< 10	< 2
Würzburg	3	0

App.tab. 7: Decrease of delays due to introduction of separated ROW. (Felz 1989)

transport mode	city	measure	delays [min]	
			before	after
tramway	Braunschweig	sep. track	5-10	1-3
	Karlsruhe	sep. track	5	0
	Ludwigshafen	sep. track	0-20	0
	Mainz	sep. track	3-5	0
	Nürnberg	sep. track	0-10	0-2
	Würzburg	sep. track	3	0
LRT	Essen/Mühlheim	LRT	+/-2	0
	Frankfurt/M.	LRT	5-10	0
	Hannover	LRT line A	5-10	0-2
	Stuttgart	LRT (sect. 2&3)	0-7	0

App.tab. 8: Reduction of delays due to ROW alignment improvements. (VDV, et al. 2000)

Timetable issues

The provision of a powerful timetable proves crucial for the LRT systems attractiveness. Two basic types of timetables need to be differentiated:

- demand oriented;
- supply oriented.

The mainly demand oriented timetable is aiming at the satisfaction of existing travel demands of majorities and may include major time irregularities. E.g. the explicit satisfaction of commuter needs. In the morning several services into the city in the afternoon several services back. During the other time of day only very reduced or sometimes even no services are provided.

The supply oriented timetable should be integrated and synchronised and provide a backbone of regular headways with consolidations during high load periods of the day. This regularity also serves the travel demands of minorities, with travel behaviour not compatible to the majority and can by this provide the basis for increasing use not only for commuting, but also for other purposes. For LRTs according to (Brändli 1995) the headway should be possibly below 8 minutes, or if due to patronage not necessary, provide easy to remember 10 or 15 minute intervals

	headway [min]	off-peak	weak load
central town/city	core	10-15	20-30
	edge of core	15-20	30-40
	periphery	20-40	40-60
axes	major axis	15-20	30-40
	minor axis	20-40	40-60

App.tab. 9: Headway recommendations for LRT for off-peak and weak load periods. (UITP 1989)

From the author's view the recommendations in chart 35 provide the spectrums upper margins for smaller or at present less used systems. It is doubtful that LRT headways of 30-60 minutes are capable of attracting not only captive but also choice riders. Tab. 37 provides an orientation, how dense the services in designated periods should be to not exceed or remain under desired occupation factors.

city	daily PAX volumes		PAX increase [%]
	before	after	
Bremen/Arsten	5.300	7.000	32
Karlsruhe/Neustadt	1.700	3.000	76
Karlsruhe/Rheinstrandsiedlg.	7.000	8.600	21
Köln - Bonn	11.000	24.000	118

App.tab. 10: Increase in passenger volumes due to modernisation. (VDV, et al. 2000)

$$f_O = \frac{passengers}{seats + standing\ places}$$

App.fig. 6: The occupation factor (UITP 1989)

max. mean occupation factor	when
80%	20 min peak (peak period)
65%	peak hour (peak period)
50%	one hour (off peak period)

App.tab. 11: Occupation factor recommendations. (UITP 1989)

Handicaps and barriers

Physical barriers

At and around stops emphasis should be on prevention of a heavy rail type of ROW. This means no ballasted track and/or fences to "protect" or prevent users from unplanned uses. As already discussed in detail in the city integration section this provides a micro and macro barrier with only designated, often scarce crossing areas for users but also for grown social connections. Therefore bollards should be used instead, to separate the ROW from other MIT prone surfaces. (Besier 2002)

The lower vehicle floors at entrances are used, the lower need to be the platforms, and the less an obstacle they are within the streetscape and the easier they are reached from the pavement. Platform height should be about equal with vehicle step height or a tad lower. (Heinemann 2003) The minimum version is a level entrance with the platform not being as much higher as the curb. Streetcars/LRVs with boarding area floor heights below **500 mm** (above rail) are considered as low floor vehicles. (Käfer, et al. 1994) This is a rather high value in comparison with other examples like Chemnitz, where the platform heights is **200 mm** (Leonhardt, et al. 2003) or Vienna, where the curb high platforms are being matched by the new generation vehicles (about **170 mm**).

mobility and perception impaired persons

Required is the provision of usability for all the different user groups, especially for people with impaired mobility or perception like walking trouble, blindness, partially sightedness, deafness, hearing-impaired, people with heavy luggage, parents with children and/or strollers, the elder and children. (VDV, et al. 2000) This is often the only available/usable option of means of transport for these captive riders. According to (UITP 1989) the number of mobility impaired people should be estimated with about 10 percent of overall population.

When sub-surface or aerial structures are in use, the accessability for all humans leads to costly equipment and provisions like lifts, escalators and others. (UITP 1989)To provide maximum safety for all and recognisable perception for visually impaired, high contrast colour ensembles, especially in sensitive or dangerous areas should be used.

Organisational barriers

Organisational barriers are e.g. tariff incompatibilities between different means of transport or providers within one area, the lack of a transport association, an non-transparent tariff system, a missing dynamic stop at carriageway stops to provide a "time island" and by thus separating the potential confrontation of passengers and bypassing cars and similar obstacles.

Safety

Pedestrian safety

Although still very often installed, especially at newly installed systems, no fencing or barriers are needed. (compare to fig. 35 of Alicante in surface design section) LRTs are much more accepted in pedestrianised areas than motor vehicles or buses, as it is exactly predictable as to where they will go. (LRTA 2003)

In case, that the LRT alignment is located in the centre position of the street, in between MIT lanes, the crossing for stop access especially from backwards proves to be substantially dangerous. (see also stop access and egress section)

Passenger safety

According to (UITP 1989) user safety is per se higher than in buses due to the calm running properties and less jolts and unforeseen braking manoeuvres.

The example of Strasbourg (Besier 2002)shows, that although the alignment in the pedestrian precinct is discreetly included into the square's surface design, the ROW is respected as a zone of limited safety and mostly people step on the ROW only for crossing it.

In Montpellier the public emphasis was put one step further. The ROW runs through intersections with MIT lanes physically and optically to improve and underline the priority of LRT. For safety reasons a highly contrastive and alerting surface texture is applied. (Besier 2002)

Passenger potential – examples

London Croydon: Passenger increase within first 8 months of operation to **50.000 PAX/d** (Jahn 2003)

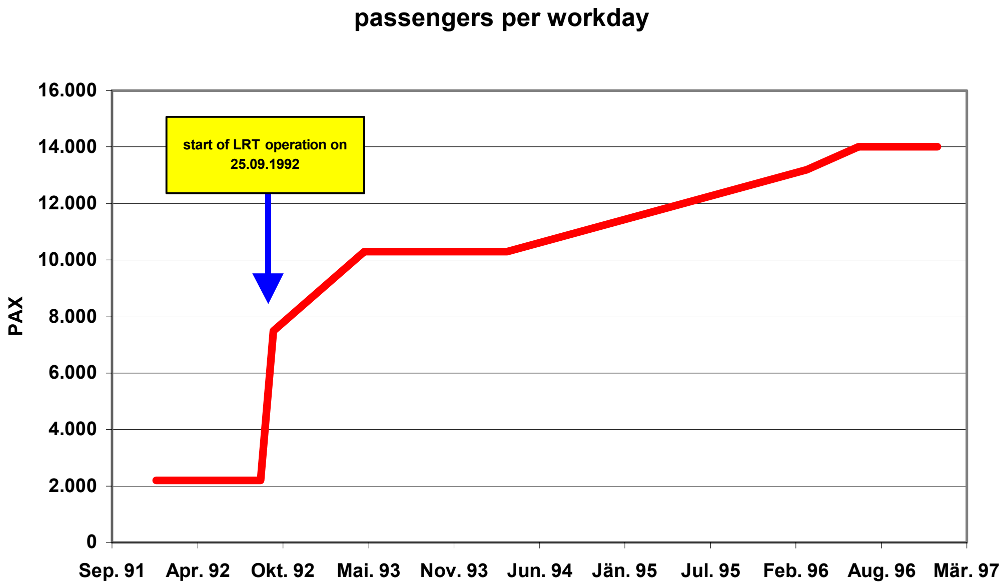
In Nantes the tram was introduced in 1985. Between 1984 and 1995 PT ridership (including bus and tram) increased by 65 %. 43 % of PT journeys are made with the trams. (LRTA 2003)

Strasbourg: In the period 1990-1997 **45 %** increase of PT ridership (LRTA 2003), while whole system PT ridership increased within one year of tram implementation from **32,3 mill.** (1994) to **41,2 mill.** (1995) (eaue.de 1996). In 1999 between **60.000** and **63.000 PAX/d** were travelling on line 1.

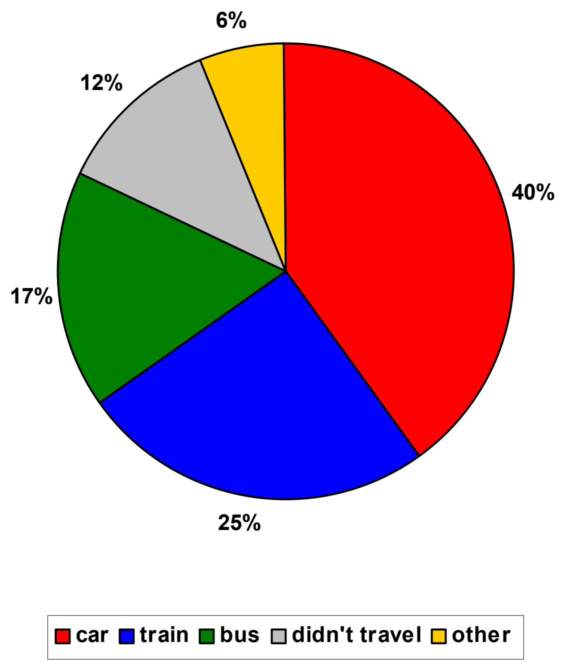
Rouen: The elongation of the first line by 4,2 km led to this development: **37.500 PAX/d** (1996) – **57.000 PAX/d** (1997) (Mouvement Ecologique 1999)

Grenoble: Between 1984 and 1999 PT ridership increased by **50 %**. (Mouvement Ecologique 1999)

Göteborg: Due to LRT improvements an increase of patronage in inner city between **38 %** and **44 %** could be observed. (Felz 1989)



App.fig. 7: PAX increase 1992-1997 on Karlsruhe – Bretten line. (Müller-Hellmann 1997)



App.fig. 8: Modal Share of LRT riders before LRT introduction. (VDV, et al. 2000)

Saarbrücken: Within one year of start of operations the daily patronage climbed to **27.000 PAX/d**. (Mouvement Ecologique 1999)

In Kassel the regional line into the Baunatal valley was included into tram-train services. Previously only heavy rail services at rather coarse headways of e.g. 60 – 90 min were running. Then the concept including connections to the CBD, new vehicles and a progressive schedule were realised and the patronage numbers soared.

mixed operation PAX increase	[%]
workdays	+42,5
Saturday	+58
Sunday	+103

App.tab. 12: PAX increase 1992-1995 on Kassel – Baunatal line. (Müller-Hellmann 1997)

Spatial ROW alignment in comparison to city structure

Typology of network

Basically a network can be of distributed or concentrated nature. This is strongly dependant on the city's physical structure and of course the remains of networks from the era of tramway creation. Cities for example like Zürich, Vienna, Amsterdam, St. Petersburg and the likes (still) have extensive networks with a distributed character. A lot of line criss-crossing the city. Mainly new built networks, actually they cannot be called nets at all, tend to be concentrated. E.g. several branches uniting into one line for the CBD section and after it dispersing again. (see also system breakdown safety section)

A very high patronage, mainly in CBDs, can lead to capacity problems with an excessive concentration of courses with already low headways in a single corridor (e.g. tunnel considerations for Karlsruhe's heavily loaded pedestrian sections). This can be avoided by relieving the overloaded section with a duplicate, displaced section, which increases the CBD's coverage by LRT, with lines serving each other as distributors. LRT networks should be aligned in the city structure without self impeding them Although the example is from a bus only network, it shows, that too high concentrations of vehicle and ridership in heavily loaded sections and at stops should be avoided. Therefore the bus system of Göttingen was rearranged. (Felz 1989) It had previously one single interchange stop, a hot spot of transfer, in the CBD. This hot spot was defused by the redistribution of the transfer load on three new interchange stops in circular formation in and closely around the city centre.

The example of Norrköping (Schmidt 2003) proves, what was mentioned already in the general network chapter. A modal split study from 1998 shows, that PT works much more efficient on the relation city district to city centre than the more spatial relations between different city districts.

Network design

When designing a network or substantial parts from scratch, one thing should be kept at the back of one's mind. (Fox 1978) The temptation to utilise "seductive ROW opportunities" should not prevail over the design of a "network to obtain particular objectives and achieve expected benefits" as they must be designated prior to all planing work. This "seductive ROW opportunities" will likely lead to prematurely decided alignments and may foreclose the opportunity to design an effective network. A network that suits its transportation task best. These "opportunity alignments" – often not catering the places the desired PT system should – permit in fact economical construction of LRT lines/sections but should never be proposed as an end in itself. Therefore the achievement of transport goals has to be appraised critically. e.g. railroad or freeway alignments are often not well located. An example could be a LRT line instead of a highway construction in a corridor probably remotely located to areas rich in potential riders. Or probably in an existing rail corridor with the similar problem of too big an offset to dwelling areas. (Fox 1978)

The best solution from the passenger's point of view is a service from one endpoint to every other endpoint at dense intervals. As this requires a decidedly high expenditure and is likely to be non-economical, it is not usual. To provide for passengers a minimum of transfers for cross-system trips, ideally every LRT line should connect with every other. (Fox 1978) So for cross-system trips good transfer connections, not only physically but also timely, are needed between those distinct single relation operation lines.

Under the ideal circumstances, which are to be found in practice quite often, transport corridors are often shaped like a slice of pie. (Fox 1978) To provide a service that is adequate to the decrease of population density and on the way out of the city, branching lines match this sector shape best. By this means also the relation of changing patronage and provided services can be adjusted properly. Also the staggering of services, the shorter ones not reaching the outermost terminus, can prove helpful in the task to provide economical services. The number of branches is limited due to headway constraints, as the headways of two uniting lines operating regularly are always cut in half. In such peripheral sections with comparably low transportation demand also single track sections with turnouts are a considerable option. Provided that the running times and meetings are generously, such sections impose only rather low risks to reliability and punctuality. (Hoffmann, et al. 2002)

To obtain a comparable service quality of LRT: The service quality (headway, PAX places, …) is being weighted with the population densities of the serviced areas. By thus improvements counting more, where more potential PAX are concerned by it, can be identified. (Schmidt, et al. 2001) This not only valid for intra-modal but also for inter-modal improvements.

By this a "tuned network" can be provided (Fox 1978):

- high level of regional coverage with as low as possible dependence on feeder services;
- service levels responsive to patronage demands;
- a CBD configuration appropriate to extent and loading of network that avoids overloaded sections and functions in the event of a link failure.

LRT/tram alignments

As the inspection of old-established tramway cities show (Besier 2002), tramway alignments within these organically grown cities show some peculiarities:

- In historical/medieval city compositions tram alignments prefer previous canals and ditches, that were filled before;
- They often run through historic "widenings". This being mainly distinctive single squares or a grouping of square like structural elements;
- They are often routed over modern urban "breakthroughs/piercings" from approximately the same period as tramway invention;
- And like all motorised transport means they run on streets with preferably linear character over irregular, narrow street network of medieval times.

But nonetheless LRT alignments are also to be found under "narrow" urban conditions. The options for such bottlenecks are:

- single track sections;
- intertwined sections and
- sections with a spatial split into two single track ROWs, e.g. running on parallel streets.

From the operations point of view one optimal longitudinal "cross section" can be identified. The stops should be at local peaks, with depressions in between which leads to shorter running times and savings in traction energy. (UITP 1989) This condition is easier to be fulfilled by sub-surface alignments than by a surface topography dependant means of transport.

Secondary network

The proper design and assignment of complementary feeder and distributor systems proves crucial, as the two following examples show. (UITP 1989) Parallel running routes of buses should not be provided under regular conditions, emergency or night time services excluded. (Heinemann 2003)

Newcastle upon Tyne: Five years after LRT installation **61 mill. PAX/year** where travelling in the whole PT system. In the mid nineties patronage dropped to **41 mill. PAX/year**. The reason was the dismantling of the integrated rail/bus feeder network due to liberal deregulation. (Young 1995)

Hannover's success is caused by the integrative use of all types of PT in the system. The LRT – with higher capacity than the bus – serves the city's major axes, whereas the buses serve as feeder/distributor and cover supplementary connections. (Felz 1989)

Modularity

As newly planned or built LRT systems can't hardly be completed all in one, the issue of modular construction needs to be addressed. LRT, not only less expensive, but also easier to expand than sub-surface systems, therefore allows for better adjustments for the future, keeping not yet determined extensions in mind. (UITP 1989, eaue.de 1996) The elongation of lines or networks and their temporary line termini is eased with bi-directional vehicles as no large-scale turning loops are needed. The turn-around can easily take place via "temporary" switches. (UITP 1989)

An other option is the approach of gradual construction that is being attempted in Nizza. Tram 1 is being built in the beginning, while the alignment of tram line 2 is being prepared for future tram use but is going to be used by buses for the time being. (Wansbeek 2002) This of course needs a strong determination in the future, that the temporary provisions won't become lasting ones.

Local and regional networks

To achieve as much "network effect" as possible, the integration or merger of different networks needs to be considered to provide mixed operations on different networks for transfer-free "supply". This is especially the case, if the following boundary conditions apply (Müller-Hellmann 1997):

- The railway station, e.g. terminus for regional railroads, is situated peripherally to the city centre.
- Important points of interest with high passenger figures in the centre and its vicinity need to be served from "outside".
- Regional railroads can be connected by "through-city rail" in a way that enables the opening up of new transport relations / transport products.

Under such circumstances it makes sense to connect regional rail/LRT e.g. into the main railway station to provide "hassle free" transfer options. E.g. as it is being practiced in Chemnitz (BRD) under the name of "Chemnitzer Modell", Saarbrücken, Karlsruhe, …(Leonhardt, et al. 2003)

Stop spacing and distribution

Location

The positioning of LRT stops within the street space is handled by different guidelines differently:

- RAS-Ö, VÖV: preferably at intersections, which implies an orientation according to the road network (UITP 1989);
- EAHV93: according to situation and under consideration of passenger, operations and location related matters also in between possible. (Etzold 1999a)

And on a microscopic level:

- RAS-Ö: generally before the intersection;
- VÖV: before or after according to operational requirements;
- EAHV93: to be decided in isolated cases specifically (Etzold 1999a)

To provide for convenient boarding and alighting, stations should be situated at ground level and in a straight line section long enough for the use of the longest planned train consist without interference with crossing traffic. Considering all modes! On a microscopic level, the one location within the potential stop area with the lowest local demand for pedestrians crossing the tracks should be chosen. Stops at intersections, junctions and branch-offs of lines should be grouped together under following considerations (Schmidt 2003):

- reduction of transfer walks and
- capacity restraints of stops regarding PAX and vehicles.

Stop importance

Although from the "passenger's interface to the LRT system" point of view there are no stops with more or less importance, a classification of stops with different functions within the network can be made:

- terminal stops;
- intermediate stops;
- transfer/interchange stops

This classification is of some importance, as passenger numbers differ heavily according to type. In (VDV, et al. 2000) experience figures for two different stop types are given:

- approximately **2.000 - 5.000 PAX/d** board and alight at an average, attractive LRT stop;

- up to **40.000 PAX/d** are boarding/alighting/transferring at central LRT interchanges.

Surface design

Surface redesign - traffic calming

The physical redesign and reorganisation of city streets is a potential means of traffic calming or can be seen in coherent use with it. (eaue.de 1996) puts this into a very direct context by stating: "The tram is better suited to serve environmentally compatible modes as the planning of new tracks goes hand in hand with the redesign of roads."

Because "the whole street layout, i.e. not just the immediate surroundings of the stop, can be redesigned to comply with current recommendations … " (VDV, et al. 2000) This can be done for example by reducing the number and width of MIT lanes, re-routing lanes of traffic or reducing the design speed for road traffic. The realisation of traffic calming measures (even if for example only at sporadic intervals along main roads) also improves the comfort for pedestrians. This is e.g. leading to the redevelopment of a run-down street as a boulevard or the construction of an LRT in a pedestrian mall. (Fox 1978)

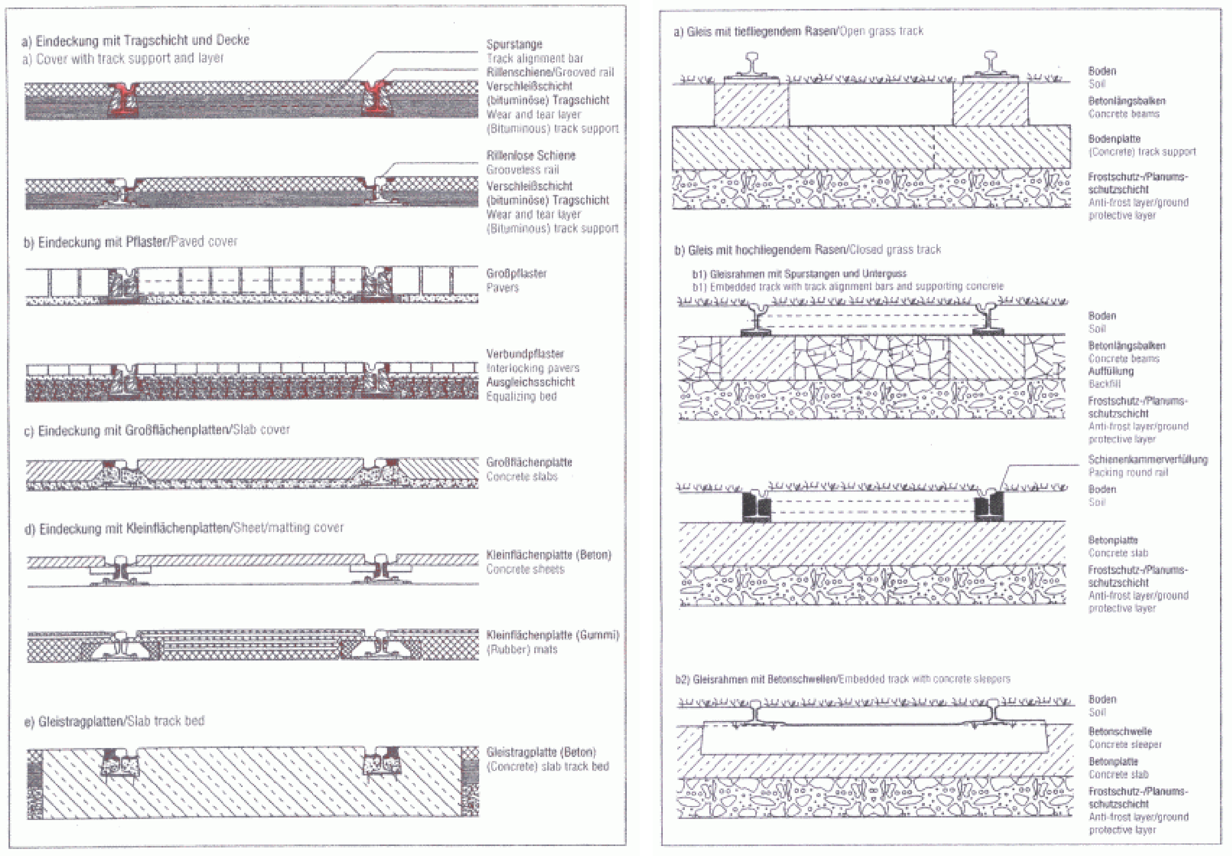
As integral part not only lanes for moving traffic but also space for parking can and should be reorganised. (VDV, et al. 2000) This includes a complete approach to where, how, when, to which extent and for how long the parking spaces should be provided.

Surface redesign does not only mean changes of surface layout at tarmac level but also vertical structuring within the three dimensional street space by means of tree lines, lanterns and the likes. (Schmidt 2003) This is illustrated by a Dortmund example (VDV, et al. 2000): "Thanks to the changes made previously to the tramway layout, **7,5 km** of tree-lined avenues could be created … permanent improvement in the city's microclimate. …"

The whole "redesign business" can't be seen from the single dimensional roads point of view only, but also has to include the two dimensional city texture elements, the squares. The main squares are, due to being the focus point of city life, the main target areas for reconstruction and the reshaping should be according to LRT, bus, bike and pedestrian needs. (eaue.de 1996)

Construction and track types

Different types of ROW construction can be used. Attention should be paid that not only constructional and technical needs are fed, but also the "part of the cityscape" perspective is given sufficient consideration . This is especially important for not making the LRT a new or an additional barrier within the street space. From this point of view classic, heavy rail like, ballast superstructure is not compatible for inner city road appliances.



App.fig. 9: Different types of LRT tracks. (VDV, et al. 2000)

Local construction measures, paired with the corresponding disturbances lead to sales decreases in neighbouring businesses. Therefore the period of impact has to be held to a minimum. (Mouvement Ecologique 1999) The construction time of tunnel sections is substantially longer than for surface alignment.

Line element succession

Basically two different and opposing approaches to create some kind of continuity along a line exist.

The first one is to provide a continuity with identically designed, always repeating elements. These elements, like stop shelters, are used and positioned the same way throughout the system/line no matter where and what kind of precinct is right there surrounding the alignment.

The other one is the approach to vary these entities by layout, design and placement. There are of course elements of corporate design that appear repeatedly and provide identification. But the ROW's appearance changes along the line, depending on position within the city texture. The same is applicable to stops. One example where individuality prevails is Portland, OR. The implementation of such a diversity oriented implementation would ideally include the following aspects:

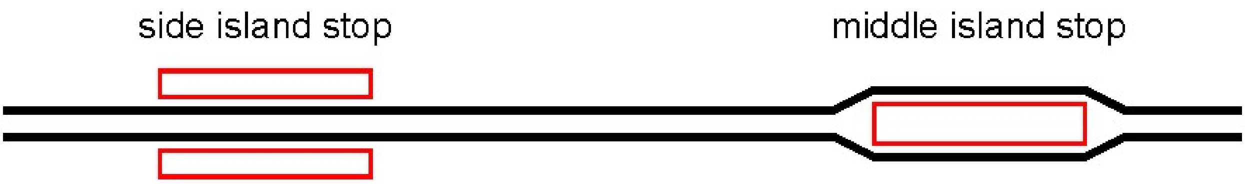
- Division of the alignment into sections of similar character regarding city structure, use, street width;
- The ”staging” of punctual, significant way points like buildings, squares, openings in the city texture;
- The inclusion of objects of identification on central, focal points of the city;
- The unwinding of the city scenery in front of the rider’s eyes as he rides along.

This underlines one important urban planning aspect of linear transport modes: the transition from one specific urban compound into another. By this e.g. the crossing of a period of promoterism boulevard, a previous fortification strip, is meant to produce “the gate effect” of access to the city or probably even a sequence of gates to the city. And besides the whole “tech talk”, which is indispensable, a creative upgrading of the passed space is required to increase esteem and acceptance of PT by “soft measures” for quality of life and housing. (Besier 2002)

Types of stops

A lot of different stops, now talking about surface facilities only, exist. The first classification needs to be made according to the alignment of the tracks:

- two joined tracks running in the middle of the road;
- two joined tracks running at one side of the road;
- two splitted tracks running on each side of the road;
- two tracks running off the road.



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App.fig. 10: Stop island types. According to (Etzold 1999a)

The basic layout of stops and the design of stop arrangement is in close connection with the type of used vehicle. If it’s a mono- or bi-directional vehicle. (UITP 1989) They are:

- one middle platform;
- two side platforms;
- regular curb side stops;
- cape stops & drive over cape stops;
- dynamic stops (time islands).

Dynamic stops are a separation of LRT and other traffic through time by means of pre-positioned signalisation. The advantage is an intelligent, efficient, multiple use of road space, particularly, where the space availability is limited. These stops lack of platforms, the platform is the carriageway. Therefore, due to insecurities of MIT transport and increased boarding height, this is not the best solution, but serves just as a "temporary or emergency solution". (VDV, et al. 2000)

Catenary

One significant characteristic is, that the LRT usually uses overhead catenary, no third rail, for electricity transmission with voltages ranging from **600 V** (old) to **750 V** (new). (e.g. Leonhardt, et al. 2003)

The "one single contact wire" type is to be preferred over a heavy rail like "double wire overhead catenary system" due to light, non-disturbing optics and better opportunities for lean city integration. (Besier 2002) A multiple use of catenary support posts as sign, signal and lighting rest is desired, because it improves the cleaned-up optics of public places.

City structure redesign – examples

Following are some real life numbers from examples, where the changes in city structure due to LRT, albeit often not too outstanding, could be observed.

Lyon: Not until the metro was introduced, the inner city could be freed of MIT. (Felz 1989)

Dortmund: "An apparently dying suburban centre was virtually 'woken up' by the construction of the light rail network and local residents and the city administration have filled it with new life through their joint efforts." (VDV, et al. 2000)

Portland: "… story about community building with LRT". It was scheduled from beginning as basis for CBD re-urbanisation. "The new LRT stops serve as points of crystallisation for new, PT oriented districts along the LRT route." (Besier 2002) The introduction of MAX triggered a lot of private and public investments especially along the riverfront section, but also a new shopping centre in Gresham, at the outskirts of Portland. Within the MAX sphere of influence approximately 230 mill. USD of investments were made (187 mill. for new projects, 42 mill. for reconstruction and rehabilitation). (Felz 1989)

Duisburg: "… An urban space was created in which the citizens can enjoy their city. Shopping, meeting friends, communication, relaxation, sightseeing and information are all catered for. … The construction of an entrance for the stop at Firedrich-Wilhelm-Platz triggered a complete redevelopment of this square in the heart of the southern part of the old city." (VDV, et al. 2000)

Strasbourg: A comprehensive cityscape renewal took place in the city centre along the LRT alignment. (Mouvement Ecologique 1999) City central squares and district squares were enhanced, because all other policy measures were subordinated to the tramway's concept goals: the re-planning of urban spaces in accordance with the PT system. (eaue.de 1996)

extent of objects	experienced
41%	some change
27%	a façade renovation
18%	a change in function

App.tab. 13: Townscape renewal along Strasbourg LRT line. (Mouvement Ecologique 1999)

Bochum: "…, the most important advance is the fact that, thanks to the traffic-related measures and the welcoming layout of the city centre, it is now a place where the inner city life can flourish, an essential resource for any urban community." (VDV, et al. 2000)

London: "The ability of the Docklands Light Railway to act as a catalyst for new development was greater than any expectations. When construction started…there were acres of derelict land and abandoned dock areas… .Today it is a new city with massive investment in offices and leisure activities." (Young 1995)

Nantes: A dramatic change in public opinion took place over the years. In 1985 50% of population were pro LRT. Until 1999 the share of inhabitants supporting the now integral LRT system rose to a magnificent 95%. In addition to the dramatically increased popularity, some housing areas added of up to 15% in value and the services sector's turnover in the CBD increased by two thirds.

inhabitant evolution 1990-2003	
whole city	+10%
re-urbanised city centre	+20%
outskirts	+2%

App.tab. 14: Inhabitant evolution in Nantes. (Besier 2002)

LRT corridor (2x400 m)
25% of new offices
13% of new commercial activities
25% of new dwellings

App.tab. 15: Share of Nantes' urban activities in 800m corridor along LRT - 1985-1995. (Mouvement Ecologique 1999)

Attractiveness of stop access and egress

Stop design

Stops can and should be used as a very positive and innovative contribution to the immediate cityscape's surroundings. Therefore the stop design should provide clear identification and an "appealing architecture" (VDV, et al. 2000) within the stress field of corporate identity vs. individuality. As massive constructions lack transparency and often also lack the human dimension, stops should not be given the appearance of monolithic constructions. (VDV, et al. 2000) Transparent materials should be used as extensively as possible.

The match of identity vs. indviduality in design is to be decided from case to case. Bordeaux e.g. chose to have stops with an identical, but unobtrusive design. (Groneck C. 2004)

Platforms

The less platform-like platforms are needed, the better for access, egress and traversing by pedestrians. And the easier the integration into the townscape. Therefore (Walker 1995, Besier 2002) a limitation of platform height to 25 - 30 cm due to a more difficult integration of higher platforms into the urban landscape is envisioned. 30 cm is approximately the double curb height which already poses a barrier for pedestrians and especially those with impaired mobility. The higher and the longer these platforms are the more a barrier they are.

Regarding the dimensions of platforms or waiting areas respectively, (Etzold 1999a) gives the following numbers for platform length and width:

- min. width: **1,50 – 2,00 m** (**2,50 m** if with shelter);
- min. length a): n-times the vehicle length, including security distances and widths for pedestrian crossings;
- min. length b): the needed length for the waiting area under consideration of available width and specific per capita area occupation (**0,5 – 1,5 m²/PAX**).

Passenger information

Passenger information is absolutely crucial as it not just informs the people, but in the case of online informations about operation conditions provides one effective measure to not bore or annoy people, and by this probably suffer image losses. Following informations are required (Etzold 1999a, Besier 2002, Schmidt 2003):

- basic information at stop post (lines, destinations, timetables);
- additional information for occasional users and foreigners (network plans, surroundings maps, easy to understand tariff info, information and emergency columns, …);
- devices for visual and acoustic announcements – dynamic arrival and departure screens – are required to provide sufficient disorder information also for sense handicapped persons.

Interchange matters

Interchange at LRT stops regards all boarding and alighting processes from subordinate and superior systems like walking, cycling, bus, private car, other LRT lines or systems, metro, suburban rail, heavy rail, … (VDV, et al. 2000)

Mostly these interchanges have the characteristic that rail-to-rail mainly takes place verically and rail-to-road mainly horizontally. (VDV, et al. 2000, Leonhardt, et al. 2003) Such primary interchange stops, where at least two important means of transport meet, should be designed accordingly to be recognised as very important places within the urban texture and the PT network. (Besier 2002)

To provide convenient connections by minimising the negatively rated waiting time, the harmonisation of arrival/departures of feeder services with the "primary" means of public transport (LRT) is highly desirable and required. (LRTA 2003, Framenau 2002) An the less transfer walks are needed the better. The exceptionally convenient cross-platform interchange is eased/facilitated with bi-directional vehicles. (UITP 1989)

Preferential treatment within the transport system

Layout

The most basic feature of unhindered operation is the physical separation, e.g. by provision of an exclusive ROW for the LRT. An accurate intersection design should provide for a high capacity (stream through the intersection) of consists per time. (Brändli 1995) This could for example be done by restriction of MIT turns. This are mainly left turns, producing a potential and actual hindrance to PT. (UITP 1989, Walker 1995)

Signalisation

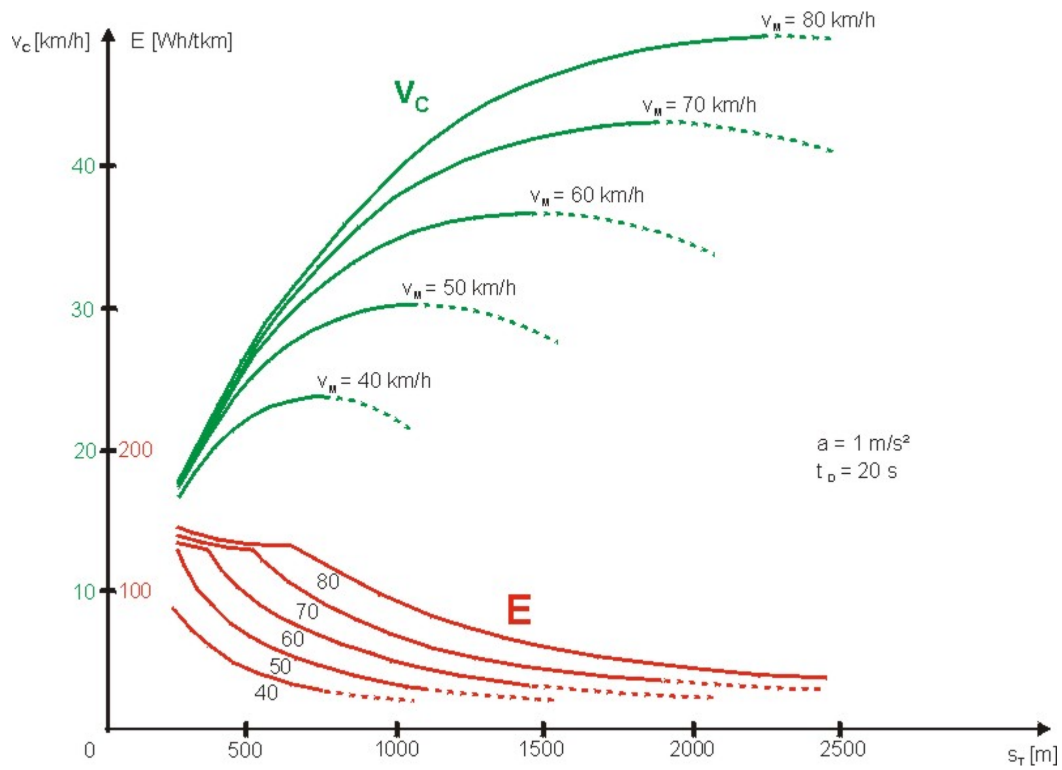
The software side of tackling this task is signal pre-emption. Due to signalisation procedures and sequences the ROW, either on a intersection or along a linear roadbed-bound stretch, is free for an undisturbed LRV ride. On a shared LRT and car ROW an intelligent traffic signalling system clears-out the cars in front of the LRV consist and thus enables a free route between stops. The optimal situation would then be a progressive signal system for the LRT with no additional stopping except at the designated stops. To provide this, the control of the traffic signal should be integrated into the transport company's operational control system, which highly improves the level of punctuality (VDV, et al. 2000) and causes a comparative time advantage over other modes, especially MIT. The installation of a computerised operational control system is actually a key requirement for largely undisrupted and reliable operation (VDV, et al. 2000) This is actually not a gaining of an advantage but a recapturing of an old and long overdue modus operandi.

Example <u>Hannover</u>: Before the implementation of preferred treatment of LRT extensive hindrances, losses of running time, frequent unpunctualities, extensive decrease of ridership and the likes could be observed. The cause was, that the inner city was heavily burdened by free flow traffic and parked vehicles. Commercial speed had previously fallen as low as **10 km/h** in the inner districts. By the installed measures the mean commercial speed could be raised from **18,7** to **27,2 km/h** due to reorganisation of inner city PT stretches. According to (Felz 1989) the precondition for inner city traffic calming was the building of a tangential road for MIT.

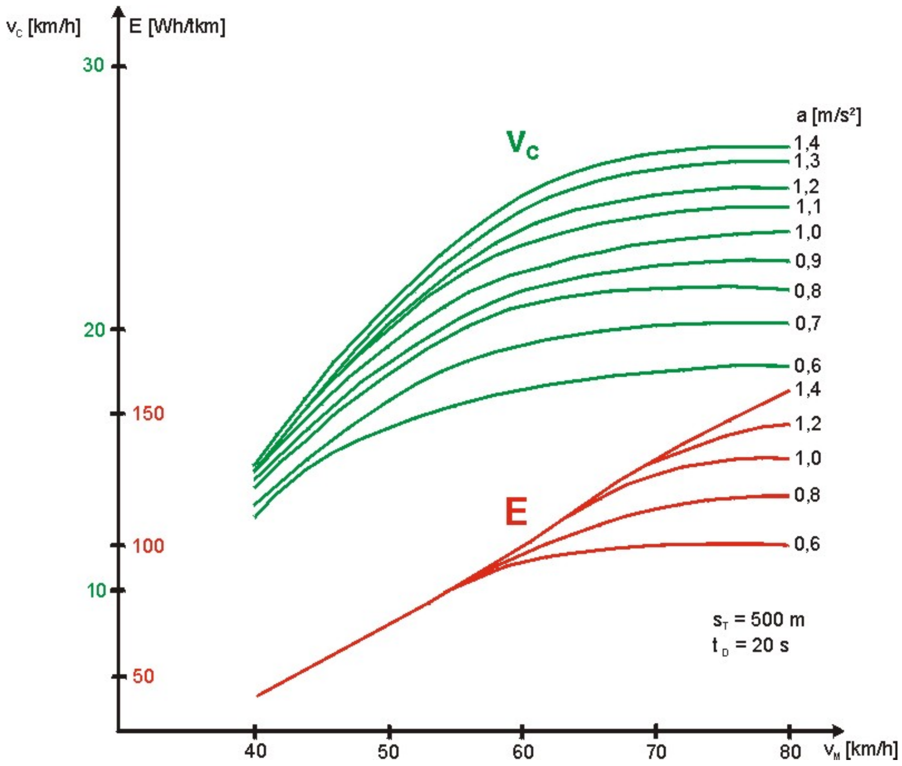
Environmental impact

Energy

Energy efficient operation requires for an energy efficient route design with corresponding operational parameters. In figs. 92 and 93 the further results of the example calculation from (UITP 1989) are depicted. In both diagrams parametric studies for commercial speed v_C and energy E are shown. In the first diagram v_C and E are plotted in dependence on the station distance s_T and the maximum speed v_M, a is the acceleration and t_D the dwell time in the stations. The second diagram shows v_C and E in dependence on v_M and a.

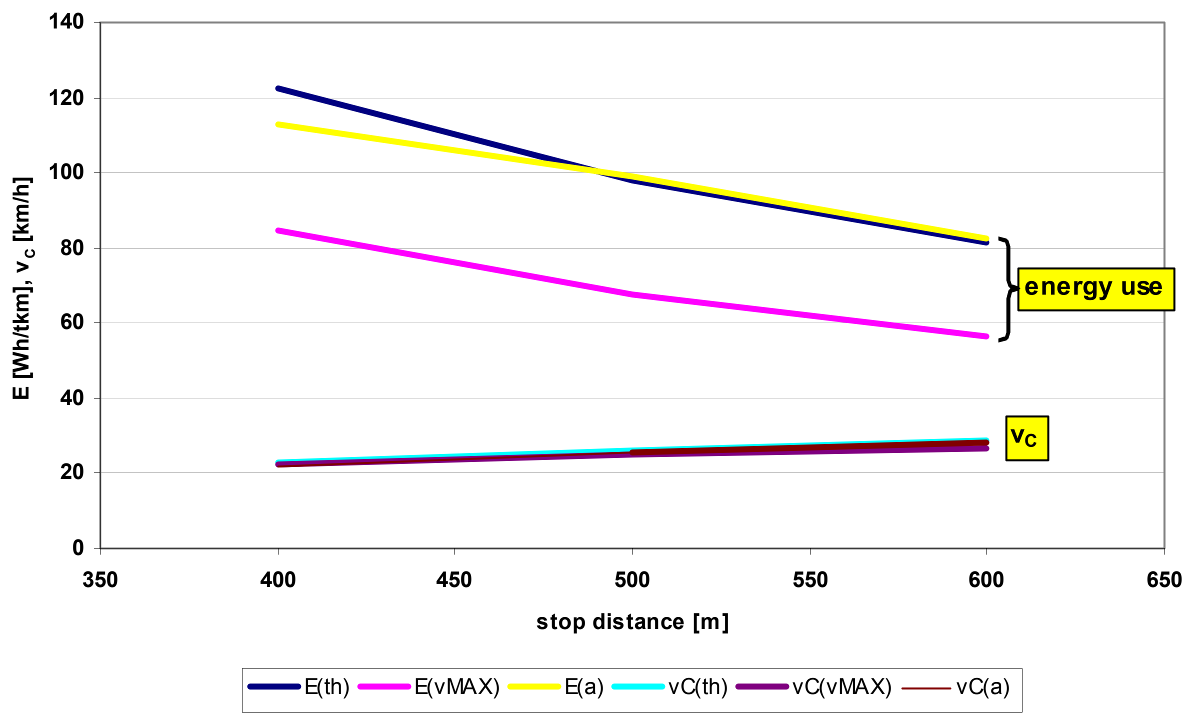


App.fig. 11: Energy and commercial speed 1. (UITP 1989)

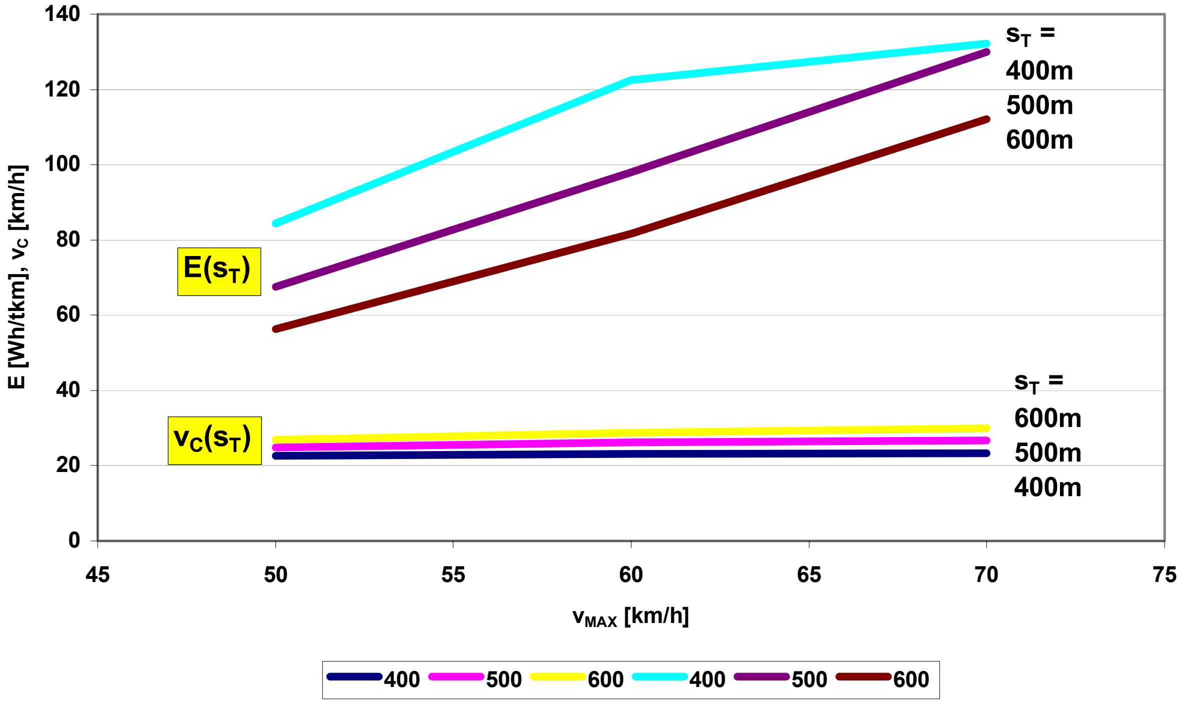


App.fig. 12: Energy and commercial speed 2. (UITP 1989)

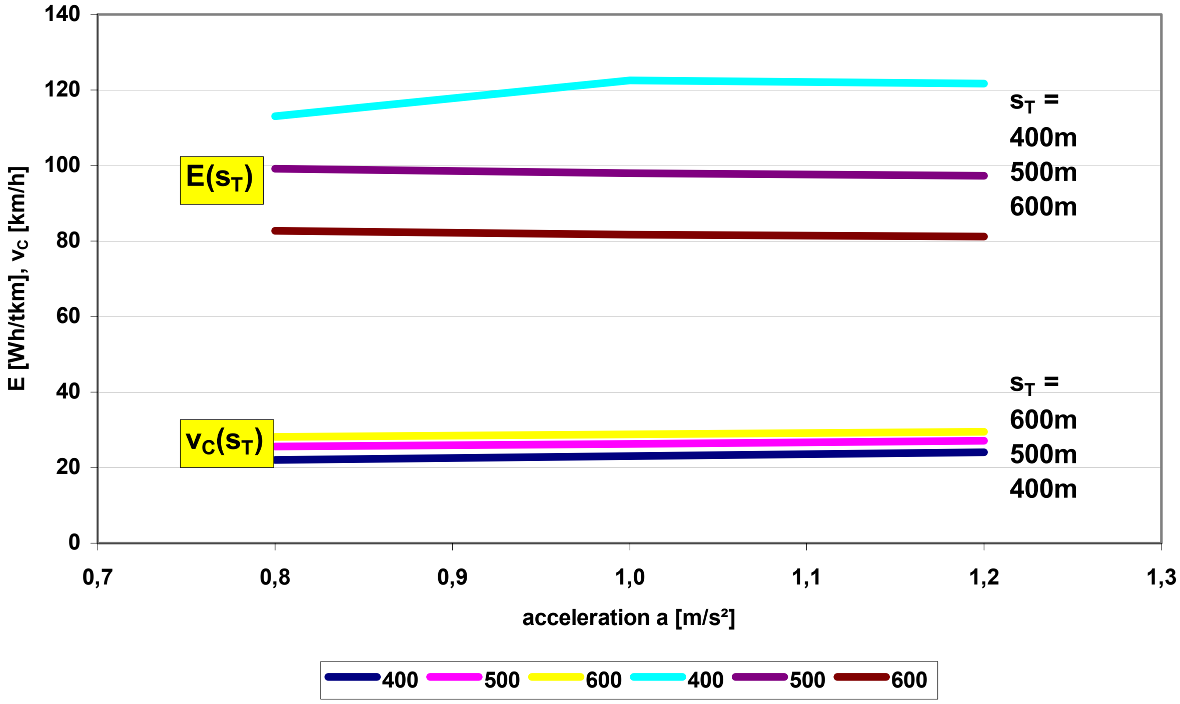
(UITP 1989):



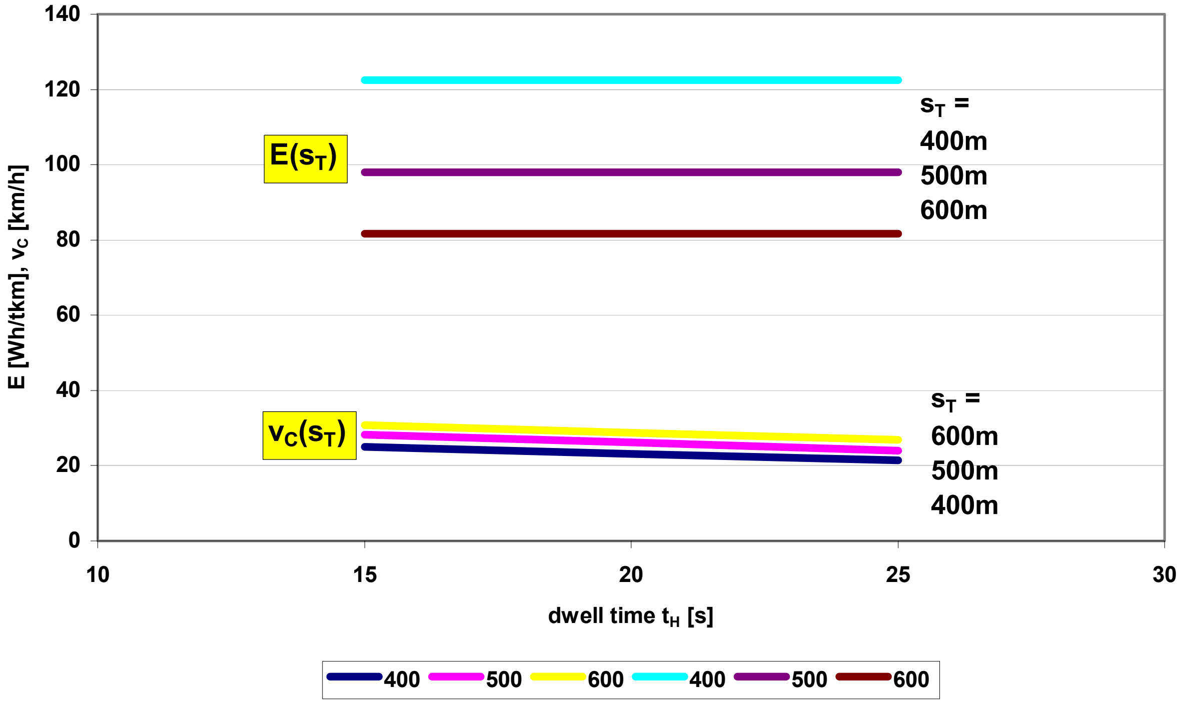
App.fig. 13: Energy use and commercial speed over stop distance. (UITP 1989)



App.fig. 14: Energy use and commercial speed over maximum speed. (UITP 1989)

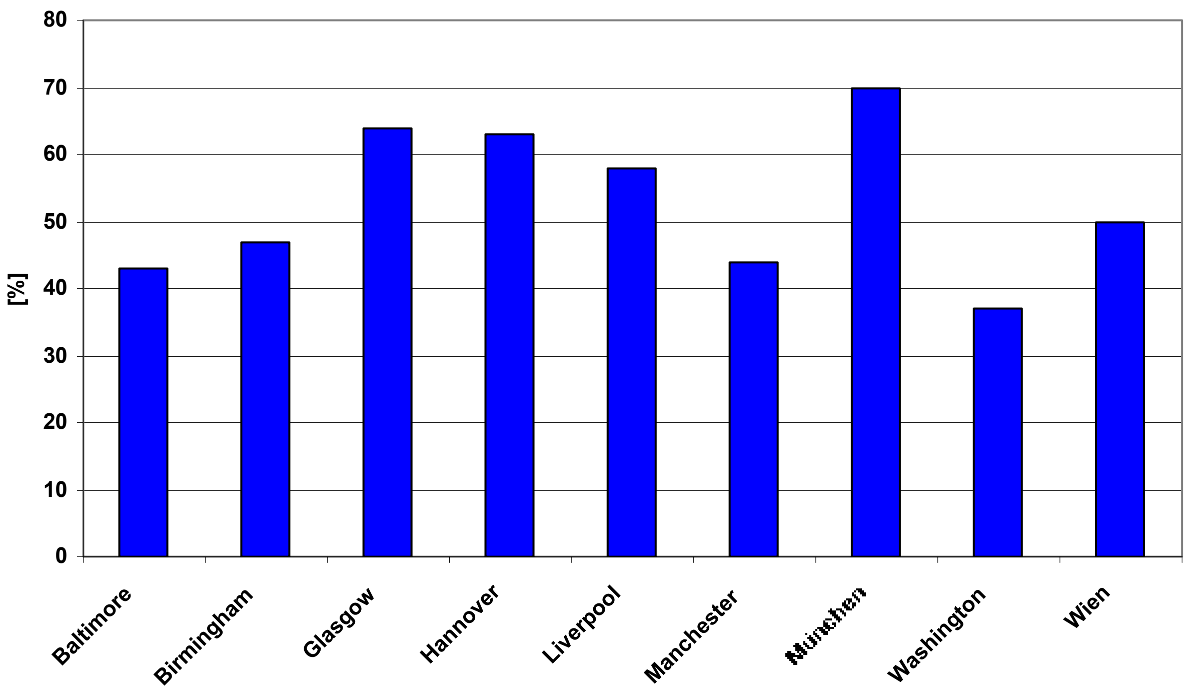


App.fig. 15: Energy use and commercial speed over acceleration. (UITP 1989)

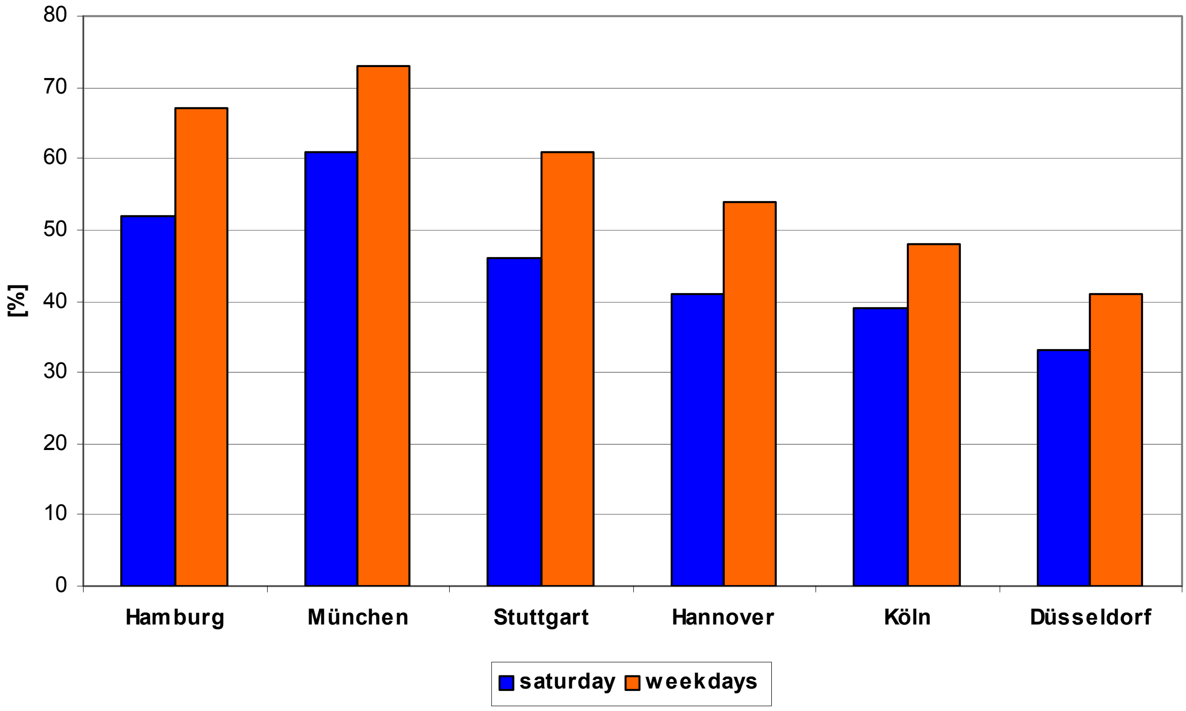


App.fig. 16: Energy use and commercial speed over dwell time. (UITP 1989)

Influence on the modal split

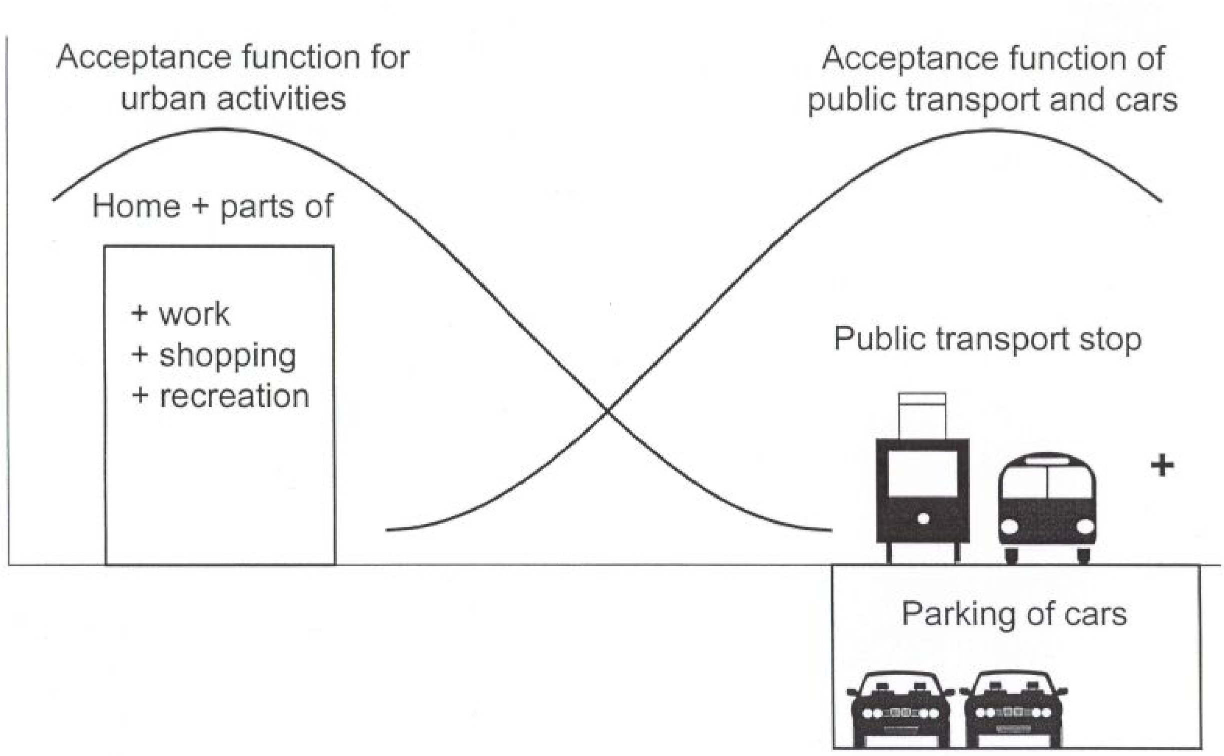


App.fig. 17: The PT's share of all motorised transport. (Felz 1989)



App.fig. 18: PT's share of shopping trips. (Felz 1989)

Appendix C (Chapter 5)



App.fig. 19: The equidistance of PT stop and parking access. (Knoflacher 1980)

scheme		ROW length [km]			number of stops			sum of costs [EUR]	
		above surface	below surface	sum	above surface	below surface	sum	max	min
PPMOL	surface variant	35,5	0	68	0	68	35,5	**1,47E+09**	**1,96E+08**
	sub-surface variant	25,2	9,5	47	17	64	34,7	**3,68E+09**	**2,77E+09**
Guzelj	stage I	34,5	0,5	55	1	56	35,0	**1,56E+09**	**2,64E+08**
	stage II	26,0	8,0	42	12	54	34,0	**3,29E+09**	**1,36E+09**
	stage III	20,0	14,0	32	22	54	34,0	**4,71E+09**	**2,25E+09**
	stage IV	8,0	26,0	13	41	54	34,0	**7,56E+09**	**4,02E+09**
Bajželj	variant 1	17,75	7,9	40	12	52	34	**2,93E+09**	**1,31E+09**
TTK	Vič - Črnuče west	10,6	0	23	0	23	12,19	**4,38E+08**	**5,91E+07**
	Šentvid - Nove Fužine	11,5	0	26	0	26	11,5	**4,76E+08**	**6,43E+07**
	LJ centre - Rakovnik	5,4	0	10	0	10	5,4	**2,23E+08**	**2,97E+07**
	sum	**27,5**	**0**	**59**	**0**	**59**	**29,09**	**1,14E+09**	**1,53E+08**
developed blueprint		**46,0**	**0**	**46,0**	**114**	**0**	**114**	**1,91E+09**	**2,60E+08**

App.tab. 16: The cost estimation results.

operational period = 30 years

capital costs		max	min	avg.
line above surface	[EUR/km]	4,07E+07	5,07E+06	1,89E+07
tunnel section	[EUR/km]	2,75E+08	1,51E+08	1,88E+08
operation costs		**max**	**min**	
stops above ground	[EUR/year]	10.200	7.700	
stops in tunnel	[EUR/year]	61.400	40.900	

App.tab. 17: The cost estimate's boundary conditions.