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Light Rail - Experiences from Germany, France and Switzerland

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Glossary

Barrier effects – Effects caused by barriers like a tram track.

Congestion – Traffic crowds, mostly for individual traffic

Corridor effects – Trams serve as transportation for a zone not a line.

Deficit - Yearly lost of money, in our cases for transport systems.

DUWAG – Former manufacturer of trams.

Grooved rail – Rail with a groove, used in the city for trams.

Individual traffic – Traffic like cars, motorbikes and trucks on roads.

LR - Light rail a developed modern tramway.

LRT - Light rail transit = is a modern tram system.

LRV – Light rail vehicle, which is modern, trams

Metro – Underground train system in cities.

Public transport – Can be trains, trams or buses.

Renewal – Modernised

Relay car parks – Place to park your car in order to change transportation mode

Right-of-way – Type of traffic accessibility

Rolling stock – Vehicles used for a tram or bus system

Traffic congestion – Vehicles get crowded and speed is strongly reduced

Tram – City train that runs on the streets

Transient effects – Problems with new systems due to lack of knowledge and that disappears with time.

Preface

Our intentions with this thesis work were to bring knowledge about modern tramways from Europe to Sweden. In order to do so we had to abounded Sweden for foreign countries where trams are more common. This was done from January to May 2000 in Kaiserslauten Germany for the Traffic division at Luleå University of Technology.
The method used for this thesis was an information gathering. We have search for information in archives, the Internet and mostly by speaking to people.
Björn Gunnarsson and Andreas Löfgren have taken the most pictures in this thesis, other pictures have a reference given below them.

Supervisor was Glenn Lundborg, lecturer, and examiner is Professor Ilja Cordi, both at the Traffic division at Luleå University of Technology.
We would like to thank:

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Abstract

Modern trams, ”light rail vehicles” (LRV), have become more and more popular since the 1980ies. To give a definition of “light rail” is not easy. Since all tram systems are different depending on the city they are in. Light rail is usually tram systems that can go on both tram tracks and train tracks.

During the first half of the 20th century trams where common in European cities but disappeared during the 1960’ies. Motor traffic took over and tram tracks were replaced by road. Later, when cities got environmental and congestion problems, several cities choose to reintroduced trams.

This thesis work is an information gathering about modern trams, not only about ”light rail”. Which also was one of the most important criteria’s when choosing case study cities. Saarbrucken and Karlsruhe have typical LR systems, Mannheim has an upgraded tram system, and Strasbourg has a completely new trams system, finally Zurich who has a more old fashion tram system.
The fact that all cities have tram systems so unlike the other ones means that most possible information could be gathered.

Saarbrucken has had trams since 1890 but they were removed on behalf to motor traffic. In the early 1990ies a decision were made to build a new tram system with a LR system. Some lines are still under construction.

Mannheim has had trams since the end of 19th century and has modernised the system with time. They have recently bought new trams and have also rebuilt the tram stops.

Zurich has an old but huge tram system and will soon have to exchange their vehicle fleet. In Zurich trams and motor vehicles use the same space have therefore developed an efficient traffic system. This has increased the travel speed for trams.

Strasbourg built a completely new tram system in the 1980ies. The city used a lot of resources to make the tram a human friendly transport by special trams, stops and lots of threes along tram routes.

Karlsruhe was the first city in the world that introduced LR. They have since the start extended their LR system not only within the city but also to the whole region. Karlsruhe had an old tram system in the city, which were used together with train tracks. (In Saarbrucken they had to build tracks in the city.)

One of the most important reasons to why many cities have reintroduced trams is the environmental advantage. In a city there is a huge demand of transportation, if everyone would travel with cars congestion and pollution would be an extensive problem. With buses and trams you will get both lower congestion and pollution.
The energy it takes to run trams is much less per personal kilometres compared with a car, which makes it a more environmental friendly alternative. The energy used by a tram comes from electricity which better than petrol and reduces pollution.
Trams are a very space efficient transportation mode, which is important since land often is in shortage in cities.

An environmental problem that is common in cities is noise pollutions. Tram produce less noise than cars and the noise level becomes even lower if grass is planted between the tracks.

Modern trams have proven to be a safe transportation mode in the city, with low accident rates both for passages and other traffic groups. The accident types that is most common for trams are collision between trams and cars. These are especially common in cities where cars and trams share the same space. On the other hand these collisions are rare in cities with separated space like in Saarbrucken.
On the place where most accidents occur are around the tram stops. There are different designs of tram stops and they are more or less safe.
Trams are generally safe and only few accidents result in lethal outcome.

Sammanfattning

Moderna spårvagnar, så kallade ”light rail vehicles” (LRV) har blivit allt mer populära sedan 1980-talet. Att ge en definition på vilka spårvagns system som är ”light rail” eller inte är inte helt lätt. Varje stad har sitt speciella spårvagnssystem vilket är olikt andra städers. Light rail system kallas vanligtvis de system som både går på spårvagnsspår inne i staden och järnvägsspår utanför staden.

Efter att spårvagnar under första hälften av 1900-talet praktiskt taget funnits i varje stad i Europa försvann de till stor del under 1960-talet. Konkurrensen från biltrafiken gjorde att gjorde att städerna i stället satsade på vägar. På senare tid, med miljö och transport problem har många städer återinfört spårvagnar vilket har visat sig framgångsrikt.

Detta examensarbete är ett informations samlande arbete om moderna spårvagnar dvs. inte bara ”light rail” system. Vilka städer som valdes till fältstudier gjordes så att olika typer av spårvagnssystem fanns med bland fältstudie städerna. Så att olika typer av spårvagns system tas med. Saarbrucken och Karlsruhe har typiska LR system, Mannheim har ett uppgraderat spårvagns system, Strasbourg har ett helt nytt spårvagns system och Zürich har ett gammalt spårvagnssystem.
Genom att städerna har så olika spårvagnssystem kan mesta möjliga information samlas in.

Saarbrucken hade ett spårvagnar under första hälften av 1900-talet men dessa togs bort till fördel för biltrafik. Under början av 1990-talet så togs beslut att återinföra spårvagnar med ett LR system. Spårvagnar är så nya att alla linjer ännu inte är färdigbyggda.

Mannheim har haft sina spårvagnar sedan slutet av 1800-talet och har ändrats allteftersom tiden har passerat. De har nyligen uppgraderat sina spårvagnar och arbetar aktivt för att förbättra transporterna t.ex. genom att göra hållplatserna bättre.

Zürich har också ett gammalt men också stort spårvagnssystem och ska till med att byta ut sina spårvagnar. Här delar spårvagnarna gatorna med annan trafik och därmed har det satsats mycket på effektivt trafiksystem så att pauserna vid trafikljusen minimeras.

Strasbourg byggde ett helt nytt spårvagnssystem under 1980-talet. Staden satsade mycket på att skapa en människovänlig transport med stora satsningar på hållplatser, spårvagnar och grönska runt omkring spåren.

Karlsruhe var den första staden i världen som införde LR. De har sedan starten byggt ut sitt spårsystem så att det inte bara täcker staden utan också flera närbelägna mindre städer. Till skillnad från Saarbrucken hade Karlsruhe redan ett spårvagnssystem när de började satsa på sitt LR system.

En av de starkaste orsakerna till att många städer åter har satsat på spårvagnar är de miljömässiga fördelarna. Med den mängd av människor som förflyttar sig i en stad blir det trängsel och stora avgasutsläpp om alla ska sitta i en bil. Med buss eller spårvagn minskar man trängseln.
Driften av en spårvagn är väldigt miljövänligt, dels för att den drivs av el och även att den förbrukar lite energi per person kilometer jämfört med biltrafik. Vilket ger minskade avgasutsläpp och därigenom påverkar växthuseffekten.

Spårvagnar är ett väldigt utrymmeseffektivt transportsätt vilket är bra eftersom mark ofta är en bristvara inom städer.
Ett miljöproblem i städer är ljudutsläpp. Även här är spårvagnar bättre än biltrafik och blir än bättre med gräs mellan spåren.

Moderna spårvagnar har bevisat sig vara ett väldigt säkert transportsätt i staden, med låga olyckstal både för passagerare och omgivande trafik. De olyckor som spårvagnar oftast är inblandad i är kollisioner mellan spårvagn och bil. Dessa är särskilt vanliga i system där motortrafik och spårvagnar delar utrymmet på gatorna. Däremot om spårvagnen har egna spår är olycksstatistiken mycket lägre, ett exempel är Saarbrucken.
Ett av de ställen som är mest påverkat av olyckor för en spårvagnslinje är hållplatserna. Här finns även många olika alternativ för hur hållplatsen kan se ut. Beroende på utformningen blir olycksrisken olika.
Generellt sker inte så många dödliga olyckor med spårvagnar utan det är oftast mindre farliga kollisioner.

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I. Introduction

This is a thesis work about light rail, which means modern trams, and its traffic safety and effects on the environment. It was done in Kaiserslauten Germany during the first part of 2000 for the Traffic division at Luleå University of Technology.

I.I Background

Light rail has become more and more popular in the world the last 15 years. Many cities have built new tram system and cities with old systems have modernised them. There have been several reports made to show whether trams are economically feasible, but few concerning traffic safety and environmental effects. The knowledge about modern tramways in Sweden is limited to the tram system in Göteborg and Norrköping.

I.II Purpose

Since modern trams are so common in Europe and Sweden have lost much of our knowledge about trams, we want to gather information about light rail in some European cities especially within traffic safety and environmental effect.

I.III Boundaries

We have limited our thesis to focus on five cities in three different countries in Europe. It will be an information-gathering thesis and not a scientific one. The main topics of the thesis are light rails' effects on traffic safety and the surrounding environment.

I.IV Method

The methods we used for finding information were mainly literature studies and case studies. Information was also found on the Internet and in articles mainly on the Internet. A part of our case studies was an international workshop and study visits to our case cities. During the workshop and study visits we interviewed many people to get deeper knowledge. The thesis is an information gathering rapport.

1. History

From the beginning people used horses and wagons for transportation in cities. The ones who could afford it had their own horse and wagon and often someone to drive the wagon for them, and some had neither. But people who wanted to travel with wagon and could afford it became larger and larger but did not want to own a horse and a wagon. The need and market for transportation was born.

1.1 The 18th century

It started with a single horse and carriage; soon “transportation companies” noticed that many people travelled along the same routes. So they started to use bigger wagons, horse-drawn omnibuses. Now they could offer more people transportation to a lower cost. These kinds of vehicles were operating around London as early as in 1798. France was the first nation to use them in inner city areas. Muller, G. (1994).

But there was one problem, the more people the carriage could take the more horses were needed, so they had to come up with a solution to increase capacity. It was well known by this time that a steel wheel on a steel rail had a lower friction. The railroads had been in use for some time, so the technology already existed. So they laid tracks in the cities and let the horses draw carriages with steel wheels, horse-drawn trams.

1.2 The 19th century

The first horse-drawn “street railway” opened in New York in 1832, the line ran from Harlem to lower Manhattan. A couple of years later, New Orleans opened a horse-drawn tramway, but they were the only cities that had a horse-drawn tramway for almost two decades. In 1856 Boston builds a system and was followed by five other cities. The explanation of the sudden interest for horse-drawn tramways was that the grooved rail was introduced. In 1852 the first grooved rail horse tramway in New York opens and a French engineer, Alphonse Loubat, built it. In 1853 Mr. Loubat opened Europe’s first horse tramway in Paris, but the European horse tramway development did not really got under the way until the late 1860ies.

This technology had of course its limits and problems; and the capacity roof were soon reached. The horses were expensive to purchase, stable, and feed, and were soon worn out of the street work. Their sensitivity to diseases was dramatically demonstrated in 1872 when thousands horses died in the Great Epizootic, an equine-influenza epidemic, the carriages had to be powered by something else.

There were some attempts in England year 1821 to 1840 to use steam-powered engines but they were not suited to the inner city environment. The trams became very noisy, slow, heavy and bulky. They attracted few passengers from horse-drawn trams while working the same route and became a commercial failure. Later the same century developments of the steam engine led to a renewed interest but even then it never became successful for inner city use. Other attempts to find an alternative source of power were “fireless steam engine” and the Mekarski compressed-air system, but none of these engines succeeded.

The first electric powered rail guided vehicle was shown in 1837, it was build by a blacksmith from Massachusetts. The following year Robert Davidson ran his locomotive on Scottish railway with a top speed of 6 km/h, both of these vehicles had a battery. They were never successful because of high costs and low capacity.

In 1870ies the dynamo and the electric engine were developed by Werner Von Siemens (1816-1892), Z. T. Gramme, C. F. Brush, Pacinotti and others. This became to be a turning point for electric powered rail guided vehicles. In 1879, Siemens firm, Siemens & Halske, built a demonstration electric railway for the Berlin Trade Fair. Two years later were the world's first electric streetcar line developed by the same firm and opened at Lichterfelde near Berlin.
A similar railway was opened in Brighton (England) in 1883.

There was a problem, using exposed conductors in public streets had its disadvantages. The conductors had to be protected by fencing. This limited the use of electric power source and the electrification of tramway routes therefore proceeded very hesitantly.
Siemens & Halske put a lot of effort to solve this problem and for the Paris Exposition 1880 they presented overhead copper-wire conductor, which was set inside a slotted pipe.

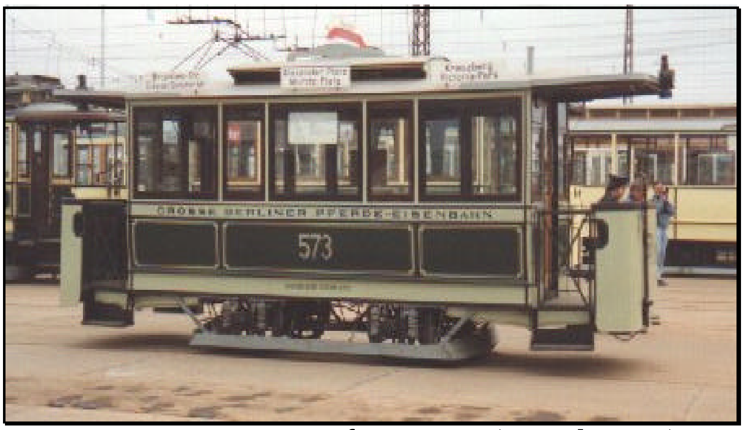


Figure 1. A "Wagen 573" from 1885. (www.lrta.org)

In most American cities the electrification of tramway had a more direct development. The technology being used was overhead-wires. A lot of transportation companies, entrepreneurs, started to build tramway systems without esthetical aspects and only few safety regulations. The fact that the entrepreneur's activities generally happened to be beneficial to the general public was in such cases of secondary importance in the minds of urban politicians steeped in the ideology of "free enterprise" and material progress. There were some exceptions. Old cities like Washington, Boston, Philadelphia and New York had a bit more European way of develop tram systems, sometimes with very strong regulation. For example in Philadelphia the Transit Company had to maintain all streets on which its streetcar ran.

In Europe planning of tramway systems was considered to be a governmental issue, they felt that streets and square should not be wrapped in an untidy web of overhead wires and believed that further technical work would yield a feasible and visually unobtrusive alternative to the American overhead trolley system. So the manufacturers had to come up with something better. There were three main alternatives that were explored: battery traction, continuous-contact conductors in underground conduit, and surface-contact systems.

There were a lot of problems to find a reliable, efficient and economical solution, in the end the overhead system became accepted by the public and the authorities. This because they recognized the fact that the electric tramway offered positive social benefits, resulting primarily from greatly increased travel speed and reduced fares. Vuchic, V. (1981).

1.3 The 20th century until today

In the beginning of the 20th century trams were in use in most large and medium-sized cities. Some early streetcar fleets had special summer cars with open sides and some others had convertible car, design for pleasure. The typical streetcar was 2-axle, wooden-body and pretty short, up to 10 meters and was the most common streetcar until after the World War 1. Gradually it was replaced with 4-axle vehicles, 12 to 16 meters, and by 1920 the dominated most transit systems in the larger cities.

Figure 2. A "Wagen 2990" from 1910. (www.lrta.org)

Even though trams played an important part in the cities with rising rider ship the companies had difficulties to achieve continuous financial success. The reason for this was the low fares. Regulatory bodies did not allow corresponding fares to the increasing operating and maintenance cost, which led to many bankruptcies. In 1920, after looking at the problems, the Federal Electric Railway Commission stated and set new recommendation to counteract the situation of the transit market. They succeeded in many ways.

During the 1920ies and early 1930ies the private automobile started to compete with trams and making an impact on rider ship. Congestion started to occur in streets and the tram had difficulties to compete with cars and buses in mixed traffic because they had too slow acceleration ability. With improved technology they continued their struggle against the automobile.
More and more traffic was set to be highway traffic and less to be rail transit, the most cities started to convert their inner city traffic to buses. This was discontinued during the Second World War and a few years after when the demand for transit service increased.

A couple years after the Second World War cars became more and more popular again, there started to be more congestion in the cities. During this period the trams was considered old fashion and ineffective. The conversion started again, but now even more rapidly. The patronage of tramways decline, more and more cities across Europe and USA abandoned their tramway systems in order to complete relay on cars and buses.

There were few cities across the world that kept their tramway systems, some in the US but most of them in Germany.

The space gained by removing trams from the streets had only a temporary effect, the annual increase of cars was too big so the congestion remained and got worse for every year.
Cars were thought to be the future so the cities had to be adjusted for cars; they build more highways and wider roads. The more they build the more cars were being used, and the more cars being used the more they had to build and so on.

Finally it came to a breaking point, they could not build more in the cities, there were no space left. The only alternative was to tear down old culture buildings and monuments. With a very strong local opinion against it the politicians and city-planers had to come up with another solution.
There were, and still is, cities with no or small congestion problems, these cities got a lot attention from authorities, politicians and city-planer from cities with congestion problems. These cities without congestion problems seemed apparently often have one thing in common; they had kept and developed their tramway systems into Light rail systems. (Light rail systems are also known as Light rail transit systems, LRT-systems.)

Figure 3. A modern LRV, the "Eurotram" in Strasbourg.

There should be pointed out that some of the cities that have kept their tramway systems have not developed them into LRT-systems. For further reading about the difference between light rail and trams see "Introduction to light rail". Vuchic, V. (1981).

Today there is about 350 trams or light rail systems all over the world. The total length of the systems is approximate 15 000 km with 35 000 vehicles operating on them. www.lrta.org

2 Introduction to light rail

2.1 What is a modern tram or light rail?

It will simplify the attempt to define modern tram and light rail, by starting to explain the different types of right-of-way. Because the main criterion to distinguish tram systems and LRT systems from each other as well as from metro systems is the type of right-of-way.

Shared right-of way means that the rail going vehicle have to share the space with other traffic modes in the street, such as cars, bicycles and trucks. There is no priority at crossings and intersections, and can be caught in traffic jams and bothered by congestion as any other traffic mode.
Reserved right-of-way means that there is a specific space left in the street for the vehicle, but other traffic modes is able to use this space, such as when cars have to make a turn to the left, but there is no physical barrier to prevent intrusion on the tracks. There can be priority in crossings and intersections. This right-of-way can be, but it is rare, bothered by congestion and caught in traffic jams.
Exclusive right-of-way have it's own space with physical barrier to prevent intrusion. It has priority in crossings and intersection and can hardly be bothered by congestion.
A traditional tram mainly operates on shared right-of-way, which over the years have made them more and more ineffective and unreliably the more traffic that have appeared. Shared right-of-way is the traditional trams main characteristic. A modern tram mainly operates in reserved right-of-way, this type of right-of-way have been developed through the years to increase the effectiveness for trams in modern society. The main characteristic for a modern tram is the combination of different types of right-of-way. Light rail emerges from these types of right-of-way to exclusive right-of-way, like a mini metro. Exclusive right-of-way is the main characteristic for light rail, but another characteristic for light rail is that it is flexible, so there can be other types of right-of-way in an LRT system.

As the name light rail suggests, there is some sort of definition in vehicle weight and size. Compared with a regional train a light rail is lighter and shorter, but compared with a modern tram it can be a bit heavier and longer. The border between a modern tram and light rail, in size, is somewhat fluid and can be considered an academic issue. Because many times it is the same type, model, of vehicle, but in the case of light rail they have coupled a number of vehicles together. A normal length for light rail is 80 to 100 meters; this of course depends on what kind of route it will traffic. It is not suitable with to long train on routes with a lot of reserved right-of-way.

There is a wide range from the traditional tram sharing space with car traffic to the light rail with its own right-of-way between intersections and its own signalling at intersections. In many cases light rail systems were developed from old tramways, extended or totally newly built. Modern bus systems have similar characteristics and in numerous cases there are mixed operations of light rail vehicles and buses on separate public transport lanes. In the large cities, light rail systems often have some underground routes within the city centre.
The biggest advantage of light rail and at the same time part of its definition is its flexibility. It can be operated as a traditional tram with shared right-of-way in outer parts of the city and

also as a metro on a separate railroad with segregated or even exclusive right-of-way in the city centre with all other types of right-of-way in-between.

As an example, Hannover was one of the first cities to open a light rail system; it was opened in 1975. Their system is combined light metro running underground within the city centre and an advanced tram system in other parts of the city. They use retractable steps on the vehicles so they can be adjusted to stations with high and low platforms. The system in Hannover have proved it self to be very flexible, offering full use within every stage of its development from traditional tram to modern light rail. Total double-track length today is nearly 100 km, with 15 per cent underground, 60 per cent with segregated railroad and 25 per cent with shared right-of-way. 330 000 passenger are served daily, which is nearly 75 per cent of the total number of users/customers of the Hannover transport authority.

In Karlsruhe the light rail operates on very different types of track. It has shared right-of-way with car traffic in outer areas, where car traffic is limited to residents, service and delivery, shared right-of-way with pedestrians in two pedestrian zones, reserved right-of-way on transit lanes separated by markings or special surface, or by rumble ground strips. Segregated right-of-ways in the middle or alongside a boulevard with open rock surface, pavement or grass, and mixed operation with railway on railway tracks. An underground section with exclusive right-of-way under main shopping street, in addition to on-ground within the street was rejected by the population in a poll two years ago.
Hannover and Karlsruhe are two different examples that demonstrate the flexibility of light rail owing to the combination of different tracks with different right-of-way. A light rail system can be developed step by step from traditional tram on the street surface with or without its own right-of-way to a separated system. Each step of development can be the final step, which should admit further development if it is later considered. This flexibility and step-by-step development is the main characteristic of light rail compared with a metro system. (Professor Dr.-Ing Topp, H. 1998)

A very important feature of a street-level light rail system is that it should be able to be integrated into urban fabric. To be able to be that one can not try to achieve the same standard as a metro, because if one would succeed this achievement one would most certainly have ruined a lot of the townscape. One of street-level light rail systems major benefits is that you can transport a lot of people down a street and pedestrian still can cross the same street from one side to the other without become delayed by weeks. The importance of good integration of a system in a city of course applies to stops too, maybe even more. Because they have to provide comfortable access, convenient stay and personal safety when waiting people can observe other people and can be seen by others. This is a totally different quality compared with underground stations.

Above, Hannover and Karlsruhe have been used as two examples to show how different systems can be. They are different in several respects: the main feature in Hannover is the metro-like underground section in the city centre, whereas in Karlsruhe it is the use of railway tracks to connect the region directly with the inner city. Derived from such differences as well as from the way a system has developed, nine types of LRT may be distinguished:

Different types of LRT

Type 1:
Modernized tramway systems usually have shared or reserved, and in sometimes segregated, right-of-way. They run through pedestrian zones and have priority treatment at junctions. Low-floor cars are replacing old vehicles. Examples with extended network are Amsterdam, Oslo, Zurich and Vienna.

Type 2:
New tramway systems are based on low-floor vehicles, they are well integrated into to the townscape and a considerable part of the network is segregated from other traffic. Examples are Grenoble, Strasbourg and Valencia.

Type 3:
Evolutionary LRT systems are upgraded from trams, having segregated right-of-way over long sections or even underground exclusive right-of-way. Some were planned for final conversion into metro systems, as in Frankfurt and Stuttgart. Other examples are Gothenburg, Hannover and Rotterdam.

Type 4:
New LRT systems are similar to case three. Since they cannot use old tracks they usually consist of only a few lines. North America has the greatest number of these systems with Calgary, Edmonton, Portland and San Diego. In Europe, Utrecht and Sheffield fit into this category as well as Tunis, Kuala Lumpur and Sydney.

Type 5:
Mini-metro type LRT is fully grade-separated systems that usually include underground sections in the inner city. In fact, they represent mini-metros, with consequent loss of the flexibility that is one of the main advantages of tram/LRT systems. A recent example is Copenhagen.

Type 6:
AGT-type LRT systems are automatically guided and operated, as in Dockland London, Lille and Vancouver. Of course, they need exclusive right-of-way within their whole networks; here again, as in type 5, the flexibility of tram/LRT system is lost.

Type 7:
LRT-regional rail integrated systems use railroad tracks to expand service into the region. They can be based on a tram system as in Karlsruhe or represent transitional forms towards a metro system as in Manchester.

Type 8:
Regional trains on tram tracks is similar to type 7 but instead of adjusting a tram vehicle to operate on railroads a railroad vehicle is adjusted to run on public streets. Regional rail service, with light vehicles, is to be connected by tram directly into the city centre. It was introduced in Zwickau, Germany, in 1999.

Type 9:
Track-guided rubber-tired tram was developed by Bombardier and received approval at the end of 1997. It is supposed to combine a tram in the inner city with the flexibility of a bus at the periphery. It is guided by a monorail and supplied with electricity by overhead wires. It may be implemented in Caen, France.

When evaluating these different types of tram/LRT, Prof. Dr. Ing. H. Topp, University of Kaiserslauten, suggests that, for Europe, cases 1,2 and 7 will be the most interesting ones in the future. This is based on recent developments, and the estimation that advanced trams on-ground with segregated right-of-way wherever it is feasible, combined with utilizing existing railway tracks, represent an efficient form of public transport at reasonable able investment costs. A benefit analysis for Bologna, for instance, comparing an LRT system, with some underground sections, with an on-ground tram system was highly in favour of the tram. Two years ago it was decided that, after 35 years, a tram of 19-km length in the first phase and finally of 52 km will return to the city.

Trams and LRT ought to be integrated into urban life, because they represent a friendly mode for vibrant cities. This is what makes them so popular in Europe among planners and politicians as well as passenger and residents. Trams pass right into the city, whereas underground systems miss the urban life. The passenger recognizes where the trams operate, waits for the tram in a public open space, feels safe, sees the tram coming, enters easily without steps, experiences urban life and is a part of it.
Trams are preferred to buses even when journey times are the same and they are more frequently used. This effect is known as “tram bonus” and means more passengers owing to more comfort, originality and perceivability of the line within the street. This “tram bonus” could be observed several times when tramlines were opened: it amounts to up to 30 per cent. (*Professor Dr.-Ing* Topp, H. 1998)

2.2 Bridging the capacity gap between bus and metro

One of the most important features for a transit mode is the capacity; a LRT has a high vehicle capacity of about 220-250 persons per 35-meter long car. This can be compared with an 18-meter long bus, which only have half of that capacity, and a 12-meter standard bus, which only have a fourth of that capacity. In most LRT system you also have the opportunity to operate LRT vehicles in trains, which multiplies the capacity. All systems don’t have this opportunity because a vehicle longer than 40 meters is not suitable for operation in mixed traffic and shared right-of-way. In systems with separated rails and signalised crossings LRT-vehicles with a length of 80-meters are feasible, this gives them an unique opportunity to increase the capacity during peak hours with the same number of staff and lines.

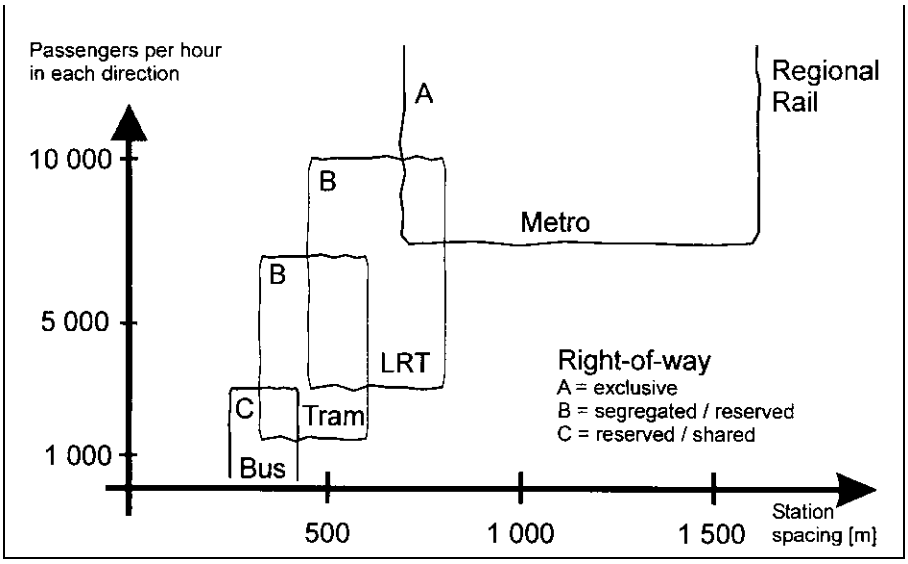


Figure 4. Passenger capacities for different transit modes. (Vuchic, V. 1981)

Light rail meets the capacity gap between buses and metro; with a practical line capacity of up to 5000 passenger per hour in each direction and a maximum trunk capacity up to 20 000 passenger. This can be showed in a capacity diagram, as in figure 1.
The capacity depends, as earlier mentioned on the number of vehicles but also on the stop spacing and the headway. More about stop spacing in chapter 2.3, the headway is often the parameter that gives a line its practical capacity. This is because there is a need of space between the vehicles, especially in the city centre. Light rail usually is sufficient to serve cities up to two million inhabitants. (Vuchic, V. 1981)

2.3 Tram and Light rail network

The normal stop spacing for a tram/LRT in a city centre is 400-600 meters; with a walking distance up to 6 min or 350 meters a stop covers approximately a strip of 700 meters. This can be compared with the metros stop spacing of at least 800 meters, if the metro stop spacing is less than 800 meters the advantage of higher journey speed is lost. The normal average journey speed for a metro is somewhat around 40 km/h and tram/LRT have an average journey speed at 25km/h.

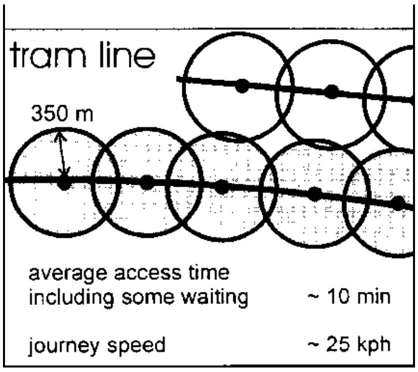


Figure 5. Stop-spacing. (Vuchic, V. 1981)

Take an everyday trip from the periphery of a city into the city centre, a door-to-door journey. The access time including waiting for the tram/LRT might be 10 min. Almost the same applies to the metro for people living within walking distance, but the majority living outside walking distance so the need access to a feeder bus. So for people travelling with the metro one has to add bus journey time, transfer to the metro from the bus and some waiting, this time can easily be 25 min. So when comparing the door-to-door journey one will find that the tram/LRT journey will be faster up to a distance of 15 kilometres. This radius easily covers a city with 2 million inhabitants, most parts of central Europe. This radius can probably not be applied to Swedish cities because of the low density.
The door-to-door journey will take about 45 min, and have to be considered appropriate for commuters as well as for other purposes. If one would increase the distance between stops in a tram/LRT system, the need of feeder buses would occur and a decrease would be inefficient for the system because it would slow down the average speed within the system.

2.4 Level boarding and other vehicle features

To be able to attract commuters, keep and gain patronage the trams/LRTs have to offer a comfortably, pleasant and fast ride. So the vehicles have not only to be practical and useful but also have to look good and appealing to the eyes of the inhabitants. The issue of beautiful and appealing design will not be dealt with here, just commend as an issue where the manufacturers have put in a lot of man-hours and succeeded. This text will mainly focus on the practical parts of the tram's/LRT's design.

One of the most important changes in tram/LRT operations is the vehicles floor height, a small change have given the transit mode large benefits, and still the idea goes back as far as to 1894 in Vienna. It was here the first low-floor was developed. A low-floor vehicle have an entry height of about 290 to 300 mm above the top of the rail, this can be compared with the traditional trams with an entry height of about 560-mm. The modern low-floor vehicles are using free wheel boogies, where there are no axle between the wheel pair, and every wheel are driven by it's own electric motor.

Figure 6. No good boarding height.

Low-floor gives easy mental and physical access to the vehicle, it feels easier to board the vehicle, one do not have to climb onboard, as was the case with old trams with three or four steps to get in. It is easier for handicapped people to get on board the vehicles and it is easier for people with perambulator to enter, easier entry, and easier exit. Low-floor combined with somewhat wider door's gives shorter stop time at each station and a more efficient system, 3 to 4 percentages efficient compared with a system operated with high-floor vehicles.
With low-floor comes low platform, not only are they easier to fit in the urban environment and make less intrusion in the city, they are also easier to get up on, both physically and mentally. The numbers of doors on the vehicles have also increased, which also contributes to easier and faster entry and exit time, and following less dwell time.

Some cities have gone even further in developing the low-floor vehicles, Vienna for instance have developed ultra low-floor vehicles (ULF), with an entry height of 197 mm top of the rail, this to increase the advantages low-floor have. It is most interesting that a city like Vienna does something like this because they run one of the world's largest tram networks with 36 lines, 254-km double track and 1000 stops, metro and buses is not included. An Austrian based group, SGP/ELIN/SIEMENS, was chosen to cooperate with; the first vehicles have been in traffic for more than a year. (Professor Dr.-Ing Topp, H. 1998)

Earlier the driver sold tickets on board; nowadays there are tickets vending machines on the platform instead, so the time for buying tickets does not affect the vehicles journey time.

2.5 Tram and LRT in pedestrian zones

Trams have a long tradition of operation in pedestrian zones, because it was here where the first routes were laid and it was here were people gathered. There are few accidents and problems, pedestrians and public transportation are in good coexistence.
According to Prof. Dr.-Ing. H. Topp, trams/LRTs and pedestrians fit together, better than buses and pedestrians. This because of trams and LRTs owing to the rails. But buses routes through pedestrian zones are no problem as long as the bus headway is clearly marked by special pavement and/or small kerbs.
In Germany the maximum speed of vehicles in pedestrian zones is generally 7 km/h, but public transportation often gets an exemption to 20 km/h like in Mannheim, or 25 km/h like in Karlsruhe and Freiburg.

The capacity doesn't seem to be a severe problem, in Bremen for example 88 tram and 30 buses pass through the pedestrian zone per hour in each direction. The street width is 20,5 meters.

But there can be to many trams/LRTs in a pedestrian zone, in Karlsruhe during peak hours, 144 trams of six different lines passes through the main shopping street, which is about 22 meter wide. Some people in Karlsruhe felt like that the trams were like a wall, so the question was raised if there should be a tunnel under the tracks instead. The voters recently rejected the tunnel project, and now a new tunnel is being planed a bit further south. (Professor Dr.-Ing Topp, H. 1999)

2.6 Utilizing railway tracks for tram and LRT

In order to expand the service of trams and LRT to the city surroundings and the region some operators have started to use railway tracks. Bye doing so, they can offer a very fast and direct journey to the city without changing modes at the railway station. From customers polls it is known that a direct ride together with a short journey time and reliability are the most important factors in attracting passenger. The first city to use railway tracks for LRT was Karlsruhe, who introduced the world's first dual tram in 1992

In using railway tracks for LRT vehicles, several cases can be distinguished:

1. An abandoned track is used. This means a d.c. electricity system usually with 750 V has to be installed. Gauge width has to be changed if the tram/LRT uses a meter gauge instead of the "normal" gauge of 1435 mm. Platform height and edge need to be adjusted, maybe combined with adjustments to the vehicle such as retractable steps or ramps.

2. The railway track is still used by some freight trains with diesel propulsion. In this case the necessary adjustments are basically the same, though maybe they are more restricted. For instance, in case of a meter gauge a three-rail track is needed; for adjustment of the platform edge in the case of Kassel, Germany, even a four-rail track was used within a station to handle the different widths of freight trains and LRT vehicles. The electricity, of course, will be direct current for the LRT, which means that normal tram/LRT vehicles and diesel locomotives can use the same track.

3. The third case considered is mixed operation of the tram/LRT and passenger service of the railways with diesel propulsion. Adjustments are similar to those with freight train, but an additional problem arises with platform height and edge.

4. The most complex case realized so far has been mixed operation of the tram/LRT with direct current and passenger railway trains with alternating current. In addition to all the adjustments mentioned above, a dual-current vehicle is needed. This case was the first realized in Karlsruhe in 1992.

5. There might be an even more complex case if the tram/LRT is considered to operate on different railway systems with different electricity supplies. This will happen with the planned tram/LRT for Luxembourg, which is supposed to run within the city and on the

railway tracks of the Luxembourgian, French, German and the Belgian railways. This adds up to four different electricity systems.

In both Karlsruhe and Saarbrucken the first four cases can be found in the same system, and there are at least three similar projects going on in Germany, (Aachen, Chemnitz and Zwickau), but there is numerous of examples of single case systems through out all of Germany. Luxembourg will probably be the next city to introduce a tram system according to the Karlsruhe model. (Prof. Dr.-Ing. Topp, Hartmund H.)

2.7 Easy access and usability

Stops have to meet a number of demands, these demands can be easy to access, a comfortably access, be identifiable for as far as possible, of course without to intrude on the townscape, be a shelter against wind and rain. People have to feel safe when they are waiting on the tram or LRT. In order to do so there have to be good lightning, there should be more people around as waiting passenger can see and be seen by. So to place a stop nearby a kiosk, a store, a phone, have several benefits. The new platform for low-floor vehicles simplify the adjustments made to increase the accessibility for handicapped. A stop should have easy-to-read information, actual information by a dynamic board announcing the next tram or LRT.
When placing a bicycle garage nearby a station, theft-proof is to prefer, one increases the catchments area with almost nine times, and of course there have to be one or more vending machines there. Vending machines contains money, which attracts thieves, vandalism is usually a problem, and in order to avoid this many operators are developing “cash-less” payment solutions and electronic tickets.

3. Case study cities

To get a deeper knowledge about the general concept of light rail and modern tramways five case cities were chosen.
There are many cities with trams in Europe so some specifics were needed to select the right cities. Our parameters were chose to be geographical location, size of city, age of the tram system and others.

Geographical location means were in Europe the city is located. To get as much information as possible about different kind of light rail systems we want to have our case study cities in at least two different countries. We decided that the city must be located in the central part of west Europe. The circle on the picture shows our geographical limitation.

Figure 7. Map over Europe
(www.maps.com)

There are cities of many sizes that have light rail systems. Sometimes a city is big enough to have both a metro and a LRT system. We would like our case study cities to vary in city size. A LRT is usually suited for medium size cities and not big cities. Our aim is that our case study cities should have a population between 150 000 to 1000 000 inhabitants.

Age of the tram system is also important for us. Many tram system in Europe are old, they run on their tracks as they did for 100 years ago. Only minor changes have been made at most of tram roots. This is not what we mainly want to look at. Most of our case study cities should have a new or upgraded LRT system. But also at least one city has an old fashion tram system.

Other things that can be special about the system could for example be dual systems were the light rail vehicles could run on both railway and normal tram tracks.
Countries to chose from; Belgium, Netherlands, France, Germany, Italy, Switzerland, Austria, Czech republic and England.

In these countries there are still too many cities with trams so we only focus on the counties who have lots of LRT systems and are close to Germany. That leaves Austria, France, Germany, Netherlands and Switzerland.

From that we look at some cities in each country and their LRT.

Austria

City	Description	Start year	Special	Length (km)
Lambach-Haag	Light Railway	1901	1 line	26.3
Graz	Tramway	1878		30.3
Innsbruck	Tramway	1891	Small	36.0
Linz	Tramway	1880	Small	15.3
Salzburg	Light Rail	1886	1 line	34.0
Wien	Tramway	1865	Large	188.0

France

City	Description	Start year	Special	Length (km)
Grenoble	Tramway	1987	Medium	18.5
Lille	Tramway	1874	Small	19.0
Nantes	Tramway	1985	Medium	26.2
Paris	Tramway	1992	Small	20.4
Rouen	Tramway	1994	Small	15.8
St Etienne	Tramway	1881	Small	9.3
Strasbourg	Tramway	1994	Small	12.6

Germany

City	Description	Start year	Special	Lenght (km)
Augsburg	Tramway	1881	Medium	26.7
Berlin	Tramway	1865	Large	178.0
Bremen	Tramway	1876	Large	58.6
Dortmund	Tramway	1881	Large	75.5
Dresden	Tramway	1872	Large	129.6
Freiburg/Breisgau	Tramway	1901	Medium	23.5
Halle	Tramway	1882	Large	77.1
Hannover	Tramway	1872	Large	103.4
Heidelberg	Tramway	1885	Medium	19.7
Karlsruhe	Tramway	1877	Large	149.9
Köln	Tramway	1877	Large	188.5
Mainz	Tramway	1883	Medium	21.9
Mannheim	Tramway	1878	Large	58.0
Oberhausen	Tramway	1996	Small	8.0
Rostock	Tramway	1881	Medium	22.3
Saarbrucken	Tramway	1997	Small	17.5
Wuppertal	Light Rail Monorail	1903	Suspended	13.3
Würzburg	Tramway	1892	Medium	19.4

Netherlands

City	Description	Start year	Special	Length (km)
Amsterdam	Tramway	1875	Large	138.0
Den Haag	Tramway	1864	Large	128.1
Rotterdam	Tramway	1879	Large	67.0

Switzerland

City	Description	Start year	Special	Length (km)
Basel	Tramway	1895	Large	85.7
Bern	Tramway	1890	Medium	17.6
Bex-Bévieux	Tramway	1898	1 line	3.4
Genève	Tramway	1862	Small	10.2
Lausanne	Light Rail	1991	1 line	7.8
Zermatt-Gornergrat	Light railway	1898	1 line, rack	9.4
Zürich	Tramway	1882	Large	108.9

Source: www.lrta.org

After having reviewing all cities interesting, these were finally chosen as our case study cities.

1.Saarbrücken (Germany) A city, which has reintroduced a LRT system in the city, is following the Karlsruhe model.
2. Mannheim (Germany) A typical German tram system which in recent years have been upgraded with new vehicles.
3. Karlsruhe (Germany) has a big region LRT system that has been named "The Karlsruhe model" in an average size city.
4. Strasbourg (France) A very new LRT city, which have had a huge success.
5. Zurich (Switzerland) One of the most effective tram systems in Europe, an older tram system.

Figure 8. Case study cities (www.maps.com)

By choosing these cities our aim is to get information from LRT system that is not like each other and by that way get much information as one can get from five systems.

3.1 Saarbrucken

Saarbrucken is one of several German cities that have reintroduced trams. Saarbrucken is a city with a population of 190 000 which makes it both the biggest and the capital city of Saarland.
Saarland is located in the west part Germany on the boarder to France and Luxembourg; this is a region that has belonged to different countries through history.

3.1.1 History

From the end of the 1900th century until the middle of the 1960ies Saarbrucken had a tram system like most cities in Germany. In the 1960ies the general opinion among city planers were that transportation should be on roads and not rail, especially in cities. Trams disappeared in many cities, not only in Germany but also France, Great Britain, USA etc. One reason behind the disappearance of trams was that bus traffic was considered cheaper than trams. The lost of the tram system in Saarbrucken is typical of the development for that time (www.saarbahn.de).

3.1.2 The Saarbrucken Regional model

In the beginning of 1990ies the federal state capital of Saarbrucken took a decision to develop a new transit system based on the example of Karlsruhe. The reasons for this decision were based on:
1. Individual motor traffic had become a problem in the city.
2. Deutch bahn (The German railroad) had been privatised and put down several lines in Saarland.
3. The "Karlsruhe model" had proven that trams could be reintroduced successfully on regional base.

The new tram project (Saarbahn) would be a very small compared with the tram system Saarbrucken once had. It would involve regional public transport connections that don't stop were the city ends. The role model for the Saarbrucken project was the "Karlsruhe model", which were based on an existing tram system and regional rail system.
The "Karlsruhe model" has got a great deal of national (German) and international attention. The Saarbahn in Saarbrucken and it's surrounding provides an example that it is still possible to develop a LRT system for the region without the existences of a tramway system.

Of Saarbruckens 190 000 inhabitants more than 60 000 commute to and from work every day. Even when public transports stand for a very high share (25%) of overall inner-city traffic flows, the disturbance cause by traffic is serious. Another problem is that cars make most trips to and from Saarbrucken. Together these two problems have made the roads in the city congested.

Figure 9. The tram train in Saarbrucken

With this background, the city council developed a concept to decrease the individual traffic with 20%. This means that the public transport capacity need to increase with 65 % to handle all the new passengers. Earlier experiences have shown that buses could not provide an environmental friendly alternative. At the same time one of the major roads in the city centre was turned into a pedestrian area, which made it important to increase the public transport passing the centre.

The city council decided therefore unanimously to develop a regional LRT network. From the decision that was taken in 1992 until the tram system was opened for traffic it only took 5 years, the opening was in October 1997. Which is one of the fastest planning and construction periods for a modern tram system in the world.

The use of existing regional rail is an important factor for the Saarbahns development. Saarbahn's first line is between Sarreguimines in Lorraine (France) to Lebach in the middle of Saarland. At present the line is not complete, the last part is under construction. The line will be 45 km when it is ready and has three different kinds of stretches.
From Sarreguimines to Saarbrucken the tram run on old railway and uses normal electricity voltage from trains, 15 kV, 16 2/3 Hz.

The second part is the new build link trough Saarbrucken; this part is like a normal tram track with complete right of way. 5 km of the 15 km planed section are now in service, which includes part in the downtown area.
The last part up to Lebach is mainly on single-track with full right of way, these track already exist but need to be electrified (Professor Dr.-Ing Topp, H. (1998)).

The idea of combining existing stretches and right of way with newly built sections through the central axis has advantages, particularly in terms of costs. It is fairly certain that total reconstruction of the whole stretch of line would not have been financially viable given the circumstances found in the Saarbrucken area.

3.1.3 System Components

The trams in Saarbrucken are dual system light rail vehicles, which means that they can run on both train tracks and normal tram tracks. This is due to that there are special engines that run on 750 V DC (downtown area) and 15 kV 162/3 Hz (train tracks). The trams are also low-floor which means that the door opening is 40 cm above the ground; this with special platforms 35 cm high makes the entrance to the tram very comfortable.

The vehicle has three car sections and is around 37 m long. The central car is carried by two bogies, doesn't have any doors and has a floor that is 80,5 cm above ground. Between the boogies of the middle section, the current feeder components are housed under the floor. Over its entire length it is 48% low-floor area. A single axle motor drives all eight of the vehicle axles that produce 960 kW.

Figure 10. Closed door

Figure 11. Open door

Since the tram will stop at both train station and tram stop the doors have been specially constructed to make the entrance easy at both places. When the tram stops at a rail station an extra step folds out which covers the gap between tram and platform.
Saarbruckens light rail vehicles meet requirements both from the national railway inspection org. and the regional technical supervisory org. Something that is especially important since the tram will go on stretches where trains run as well.

All downtown sections are twin track and run either centrally or laterally. There are no single-track sections, as this would preclude the tight service headways during peak hours in. Further away for the centre this will not be possible. The smallest radius for the track is 30 m.

The new stops in the central of Saarbrucken have a 75 m long platform, which makes them long enough for two-tram set coupled together. These long tram sets are necessary at peak hours. At each stop there are shelters and a digital timetable that say how long until next tram will arrive. Ramps for people in wheelchair are also on the stops, which make the tram access easy for everybody (Mrs Del Savio, Saarbahn).

The overall concept involves service intervals of 7.5 minutes, all day in the central areas. To Sarreguimines there is a tram every 30 minute.
The price for a one-way ticket is 3 dm for a one-way ticket or 55 dm for a month pass within the city. In appendix 1 is technical information about the tram.

3.2. Mannheim

3.2.1 History

In 1678, the first public transportation was instituted by the city of Mannheim in the form of a horse-drawn coach connection from Mannheim to Frankfurt am Main. In 1700 the first public transport service in the city, began operating, this was a horse-drawn coach.
The first discounts were granted in 1749 for two-way rides with the horse drawn coaches operating within Mannheim. In 1878 the first horse-drawn streetcar service was opened. It was electrified the 10th December 1900 and the track gauge was change at the same time to 1 meter gauge. Before that it was 1435 mm, the reason they changed was because of the system in Ludwigshafen had a 1 meter gauge. After 1900, there was a two-phase expansion of the network with a route from the main train station to the Neckarau West district.
The bus has been used since it was introduced in 1928.
The only time when the trams and buses not have worked was in the end of the Second World War. Almost 90% of Mannheim was destroyed of the bombs from the allied. In May 1945 the trams started to operate on parts of its original stretching, the next year the bridge over the Rhein was build up again. The tram could then connect Ludwigshafen with Mannheim again. (Dipl-Ing. Werner Rabe. MVV)

3.2.2 System today

The total number of inhabitants in the area where the system is operating is 625 000, there is 328 000 inhabitants in Mannheim, 165 000 in Ludwigshafen, and 140 000 in Heidelberg.
The system that Mannheim Versorgungs- und Verkehrsgesellschaft mbH (MVV) operate have over 60 millions passenger every year. There has been an increase in number of passengers every year since 1990, when they had 45 million passengers per year. This gives a yearly increase of 1.5 million passengers during the last ten years. The exact reason why this increase has appeared is not clear, but it is very pleasant. (Dipl.-Ing. Werner Rabe. MVV)

Figure 12. A truck passing the tracks in Mannheim.

Travelling speed is 20 km/h within the city, in pedestrian areas; Mannheim transit authorities have an exemption from German law. The German laws saying that the highest speed in pedestrian areas should be 7 km/h, which have to be consider as a way to low speed. On the outside of the pedestrian areas there is stretching with 50 km/h and 30 km/h depending on the tracks. The average speed is 23 km/h within the system, which have to be considered quite good.

There are 57.2-km double tracks and 7 km single track within Mannheim.

MVV don't only use their own tracks, on some parts they use tracks who belongs to Oberrheinische Eisenbahn Gesellschaft, (OEG), which is a outer regional train company. This is a great advantage for the service but has been, and still is, a problem. It gives MVV and OEG problems how to divide the track cost.

The total number of routes is 7, and the average distance between stops/stations is about 560 meter, the maximum distance is 800 meter. They have 312 stops, bus stops included.
25 stops have newly been rebuilt and made better for disabled persons. This work will continue as soon as possible, i.e., as soon as they have the money for it.

MVV have five cameras shifting in the vehicles and cameras at vending machines, to document scrawls and vandalism. They bring the pictures to the schools and with help from the teachers identify the youths. The youth that are caught have to help them clean the vehicles, if someone reaches more than 30 days of service, the errand will be turned over to the local police authorities.

MVV have "bike and ride" facilities at approximately 35 tram stops, and are planning to install an additional 35. The government in city of Mannheim provided the funding for these facilities. There are no "park and ride" facilities in Mannheim because the regional structure is not suited for it; the three cities are very close to one and another. Mannheim is very well served by its transit system. Only before Christmas was passengers offered "park and ride" opportunities.

The operating costs in Mannheim is about 130-140 millions DM, the deficit from the vending machines is about 60-70 million DM which gives a deficit rate of about 50%.
The running deficits most are borne by each individual city in Germany itself. In general, and as is the case with Mannheim, such deficits are financed by profits from the electric power, natural gas, water, and from the district-heating business.
Companies in Mannheim have the possibility to buy "job tickets" for their employees, which is quite popular. The companies consider the space saving to finance the tickets.

The bus network is located to the periphery of Mannheim; that is, passengers must transfer to trams in order to reach the inner city. They operate their bus system with 54 buses, of these buses 45 is their own. The total number of seats is 3 705, and the total number of routes is 18.

3.2.3 Rolling stock

MVV have 50 low-floor trams, which are 30 meter long, 23 trams with a low middle section (26 meter long) and approximately 15 older articulated trams, (19 meter long). The total number or seats is 13 751.
They have 10% extra rolling stocks, this is to be able to cover up for trams that break down or become damaged in accidents.
The old vehicles, from late 60's shall be removed before 2004 and replaced with trams from Adtranz, the "Vario-tram".
The only major problem Mannheim has had with their vehicles is with the new vehicles, the one from DUWAG, they are too stiff in the boogie. So in curves with small radius, which there are a lot of since the network in Mannheim is old, it scrapes against the outer rail. This has been, and still is, a very expensive problem. Another problem with the vehicles from DUWAG is that the wheels can't be turned like the wheels on the other vehicles this would be

really needed when it is always scraping against the rails. So instead of turn the wheel they have to replace it with a new one, which are quiet expensive.

MVV have their own workshop where they can repair their vehicles. Other cities nearby also have their vehicles to be repaired there. This is something that has become really important for Mannheim because of the bankruptcy of DUWAG's tram section. Because of this bankruptcy DUWAG haven't been able to fulfil the 10-year guarantee for their vehicles. MVV have to, and still do, repair their own vehicles but they send the bill to the DUWAG concern. (Dipl.-Ing. Werner Rabe. MVV)

Figure 13. A DUWAG tram in Mannheim.

MVV have had to install oil shock absorber to minimize the vibration and noise in the vehicle. The rail is also affected of this, it is exposed for larger horizontal force, which leads to a higher tear and wear on the construction and gives a higher cost to maintain the network. The surface on the rail is getting bumpy which leads to a higher tear and wear on the wheels. There are two more German cities that have DUWAG trams and both have reported the same problem. In appendix 3 is technical information about the tram.

3.3 Zurich

3.3.1 History

The Roman customs post "Turicum" (= Zurich) was established in 15 B.C. and have had a city status since the 10th century. The Zurich assembly was ousted by Rudolf Brun in 1336, and replaced by a guild constitution. Zurich joined the Swiss federation in 1351. Huldrych Zwingli initiated the reformation in 1519. The 19th century saw the city rise to become the financial and business capital of Switzerland.

The first efforts to establish a tramway network in Zurich date back to the year 1864, when several railroad companies tried to start operations. In 1881 the communities of Zurich, Enge, Riesbach and Aussersihl organized a joint venture to establish a horse or steam tramway service. One year later the joint-stock company "Aktiengesellschaft der Zürcher Strassenbahn" was founded and three standard-gauge horse railway routes were built with London Meston & Cie. as general contractor. All three lines were opened to the public in 1882.

The "Elektrische Strassenbahn Zurich" (ESB) company, established in 1893 started serving the higher-lying suburbs of Zurich using meter-gauge electric streetcars as had been done in the Vevey-Montreux-Chillon line.

The municipality of Zurich took over the tramway network of the ESB after the incorporation of several neighbouring communities in 1896 and established the first community tram network in Europe, operating as the Zurich City Tram Company (StStZ). The horse-drawn tramline also merged with StStZ in 1897 and was converted into a meter-gauge network in 1900. (www.vbz.ch)

Many new tramway routes were built in the inner city area around the year 1900 and several private companies began to serve the outlying areas. For example, the "Zentrale Zürichbahn" company opened the Bellvue-Kirche Fluntern and Platte-Oberstrass routes in 1895 and the Rigiplatz-Seilbahn Rigiviertel route in 1901. The "Strassenbahn Zurich-Oerlikon-Seebach" followed by inaugurating streetcar service on the routes from Central to Oerlikon and Seebach, from Oerlikon to Schwamendingen and from Seebach to Glattbrugg. Other companies established new routes linking the industrial areas of Höngg, Dietikon and Albisgütli.

Numerous private companies merged with StStZ after the turn of the century. Many new routes were built in the 1920ies, which include the connections to the Zoo and to Triemli, Wollishofen and Albisrieden. Unfortunately, some routes were taken out of service in the 1930ies: like the ZOS lines to Glattbrugg and Schwamen-dingen and the Schlieren-Weiningen section. (www.vbz.ch)

The StStZ was renamed to "Verkehrsbetriebe der Stadt Zurich" (VBZ) in 1950. Service on route 1 and the route from Farbhof to Schlieren was abandoned in 1954. In the following years several subway projects failed to pass the plebiscite and were not realized due to the pre-eminence of the automobile. A new combination highway-tram tunnel in the Milchbuck area was opened in 1986. Because platforms are located between tracks, the trains run on the

left-hand side, deviating from the remaining VBZ network. Hence, the tunnel entries are of special interest: due to the grade-separation the Milchbuck portal is a two-level crossing and the Schwamendingen entry is a grade-level crossing. The operator today, still is Verkehrsbetriebe Zurich, VBZ.
Buses were introduced in Zurich in 1927, and have been in use ever since it's introduction, nowadays mostly outside of Zurich and in the region.
Switzerland have most person-kilometres with rail going vehicle per year and citizen in the world, they have 1817 person-kilometres per year and citizen. (GVF, 1998).

3.3.2 City of today

The city of Zurich is situated at the northern end of the lake of Zurich on Switzerland's central plain, in the heart of Europe. The charming old city is clustered around the banks of the Limmat River. The city covers a total area of approx. 92 km^2; its highest point is 871 m above sea level (Üetliberg/Uto Kulm). The Zurich Lake is 27 km long, up to 4 km wide and 142 m deep, and safe for bathing.

Zurich City center has today 360,000 inhabitants, and is Switzerland's largest city, and there are 960,000 inhabitants in the Zurich conurbation (city plus 100 surrounding localities).
In total there are 1.2 million inhabitants in the canton of Zurich.

Zurich has over 100 hotels with 10,000 beds. In 1999 more than 1 million arrivals with more than 2 million overnight accommodations were registered. 82% were foreign guests. Categorized by country of origin, most were from Switzerland itself, with visitors from Germany and the USA in second and third place. In addition, some 25 million day-trippers visited Zurich. 11 km away lays the city's gateway to the world, the airport at Zurich-Kloten: it is among the largest and most efficient airports in Europe, as well as being one of the safest in the world. The train journey from the airport to the city centre lasts just ten minutes. Most major European cities have good railway connections with Zurich. (Infas AG, 1997*)*

3.3.3 System today

The system have 280.9 millions of passenger every year, 187.9 of these travels with trams, 78.5 millions travels with buses, 1.9 millions travels with the neighbourhood buses and 12.6 millions travels with the regional buses.

Figure 14. Grass-covered exclusive "right-of-way".

70 km is double track. Total length of the tram system is 109.3 kilometres.

30% of the track is separated with exclusive right-of-way with physical barriers to prevent cars and other traffic modes to cross the tracks; most of it is located outside of Zurich. 50% is separated but vehicles such as cars are able to cross the tracks when turning left.

The tram system in Zurich is very old, and therefore some of the radius in curves is very small, the smallest radius in the system is 14.50 meter. When they plan new routes the minimum radius is 18.00 meter. This affects the speed within the system. At some points, small radius and old switches, the tram can only travel with a speed of 12 km/h. This speed is adjusted to the case when the switch doesn't work like it should, then the tram driver shall be able to stop before the switch. This is very important because if the tram doesn't stop before a broken switch there is a big risk that an accident will happen.

Figure 15. Small radius in Zurich.

The newest route in Zurich was build in 1986, it is the line to Schwamendingen and Inkraftreten. VBZ introduced a new route concept with exclusive right-of-way with physical barriers and some stops underground, like a metro.

Trams have 18.228 millions vehicle-kilometres with trams every year, which is 57% of all public/transit vehicle-kilometres in Zurich, the autobus stands for 5.197 millions vehicle-kilometres and the trolleys stands for 5.178 millions vehicle-kilometres. The total amount of vehicle-kilometres is 32.252 millions. http://www.vbz.ch

There are 13 tram routes, 7 trolley routes, 16 autobus routes, 7 neighbourhood-bus routes, and 22 regional bus routes. The autobus routes is 81.2 millions km and the trolleys routes are 57.8 millions km. http://www.vbz.ch

VBZ have a deficit of 35-40% and a renewal of 487 505 million Fr. the losses is covered by the city's water and heat businesses. This is a very common way to cover losses in Europe, but forbidden in Sweden, according to "kommunallagen". (Mr. Berger)

3.3.4 Rolling stock

VBZ have 230 powered tram vehicles and 125 wagons, this gives a total number of tram seats to 53 002. They also have 83 trolley buses with 12 895 seats and 148 regular buses with 17 182 seats. http://www.vbz.ch

VBZ possesses three different kinds of trams, including vehicles from several generations. Almost all vehicles are painted standard white and blue, with advertising trams being the exception. Because of the route alignment and passenger loads, various vehicle types are in service on the different routes. The "Tram 2000" type is the largest series and so is generally seen followed by the series 1601 - 1690.

VBZ have ordered new Cobra vehicles five years ago, but Adtranz have not delivered them yet. Adtranz seems to have some technical problems to solve and there is some speculation of that Adtranz want to deliver their own models instead. Cobra is originally designed of a manufactory from Switzerland that Adtranz bought.
VBZ and Adtranz is working with an idea to construct a soft front for the vehicles and at same time make it impossible for pedestrians whom is hit by a tram to get under it. (Mr. Berger) In appendix 5 is technical information about the tram.

Figure 16. A tram in Zurich.

3.4 Strasbourg

Strasbourg is a city in eastern France, and the capital of Bas-Rhin Department in Alsace. It is located near the Rhine River and Germany. Strasbourg is a commercial, manufacturing, transportation and cultural centre in Alsace.

3.4.1 History

The Ill River divides Strasbourg and Ills arms and canals surround the oval-shaped central district, which is the old section of the city. The famous Cathedral of Notre Dame of Strasbourg is situated in the southeastern part of the old quarter. Construction of the cathedral was begun about 1015, but only the crypt and part of the choir remain from this period. The Romanesque choir dates from the 11^{th} and 12^{th} centuries; the Gothic nave was reconstructed in 1275, and the western facade, begun in 1270, has a tall spire that was completed in 1439. Other features of the cathedral include stained-glass windows, an astronomic clock, and numerous sculptures. Among additional points of interest in the city are the Gothic church of Saint Thomas (13^{th}-14^{th} century); the Palais de Rohan (1731-1741), now housing the municipal art museum; and the Hôtel du Commerce, the best example of Renaissance architecture in Strasbourg.

The city is the seat of the Universities of Strasbourg (1538, reorganized 1970) and the Council of Europe. Strasbourg is a meeting place of the European Parliament, an organ of the European Union.

By the time of the Reformation, in the 16^{th} century, Strasbourg was a prosperous community, and its inhabitants accepted Protestantism at an early date (1523). In 1681Louis XIV of France took possession of the city, and the Peace of Ryswick recognized the right of France to Strasbourg in 1697. The city passed to Germany in 1871 as a result of the Franco-Prussian War but was returned to France in 1919, following World War I. It was occupied by the Germans and badly damaged in World War II (1939-1945). Population (1999) was 264,115 (www.strasbourg.fr)

3.4.2 The tram system in Strasbourg

The first line of the tram system was opened for traffic in 1994, and it run 10 kilometres to connect the Hautepierre district (to the west of Strasbourg) and the town of Illkirch-Graffenstaden (to the south), via the station and the city centre. Twenty-six trams serve eighteen stops, one of which is an underground stop. The trams run 24 hours per day with one tram every 2.5 minutes at peak hours and one every 10 minutes at night. The reason for the high number of trams at night is that the inhabitants in Strasbourg feel safe with opportunity to always have a tram around. (Muller. G 1994)

Strasbourg had early plans for a subway in the city, but they were put on ice because of the high costs. In the end of the 1980ies the discussion was brought up again because motor traffic were a problem and there was a need to be reduced this kind of traffic in the city. A decision was taken in 1989 that the city would build a new tramway.

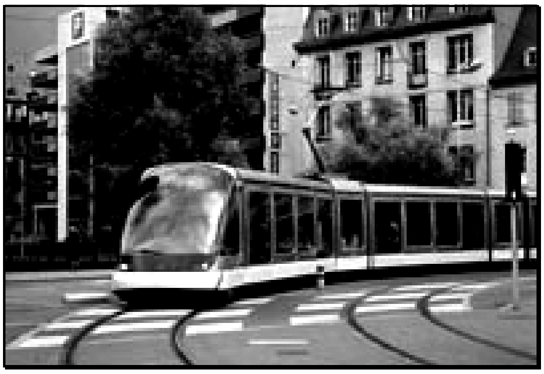


Figure 21. The Eurotram

The trams in Strasbourg are called Eurotram are modern, fast and non-polluting, not more than what the electricity produces. They are distinctive both due to their technical efficiency and their original architecture. As the first trams in France with low floors, they provide freedom of access, which is much, appreciated by disabled and elderly people. Their enormous windows make them almost transparent. From inside the cars, passengers have a mobile panoramic view of the town.

The appeal, comfort and the modern design of the trams are certainly some of the reasons for the great success Strasbourg have had with their tram system. The tram system transports 60,000 people every day, which is far more than the original forecast.

The complete design of the whole tram system was of highest significant for the city council. To make the light rail a part of the city there was big constructions around the tracks, which has made the centre of Strasbourg more beautiful. In fact as much money that was spend on tracks and trams were spent on the appearance of the system; stops, trees around the track (1600 new trees were planted), grass in the track and electrical wiring. The total cost was about 2 billion French francs (Muller, G. (1994)).

3.4.3 About the trams

Strasbourg has a completely new tram called the Eurotram built by several companies where Adtranz was the biggest and most known. Several demands were placed on the trams by the city of Strasbourg. The city felt that the appearance of the tram was very important to how the inhabitants in the city would welcome the new way of transport. So unlike other trams the Eurotram is 100 % low-floor for the passengers, this makes the entrance and exit very easy. The doors are not like on other trams, instead of two doors on each exit, the Eurotram has one big sliding door.

Figure 22. Sliding door on Eurotram.

The advantage with this is that one can have a big window on this door, which not is possible, if there are two doors. The feeling of space in the tram is another new thing that the constructors have thought of. Even though the tram is only 2.40 m wide it feels spacey due to the big window that are along the whole tram except the boogie.
Improvements to reduce the noise level were also made with new engines and in particular with new suspension.
In short this tram put up new guidelines for what a tram could look like. In appendix 7 is technical information about the tram.

3.4.4 Relay car parks

Its success is also due to an innovative system - at least in France - called relay car parks, whereby people can have quick access to the city centre by combining the use of their private car and public transport. Relay car parks are common in USA and in Japan they have relay bike parks at some metro stops.
For a flat, all-in charge of 12 F (1,83 Euro), you can park your car in any one of the three relay car parks and obtain return tram tickets for all the people in the car, regardless of how long your car is parked. The benefit is less car traffic in central areas in the city (Conseil de Communaute Urbaine de Strasbourg (1999)).

3.4.5 The tramway will be extended

As planned at the outset, the tramway will be extended southwards up to the Illkirch-Graffenstaden University campus. A second line is already built and the first part of the B line will be opened for traffic the 1 of September 2000.

The B-line will run to the north, and serve the National Theatre of Strasbourg, the university library, the conference hall and the fair ground, banks and European institutions, and then continue towards the towns of Schiltigheim, Bischheim and Hoenheim. At the same time, the line will go eastwards to the Esplanade district and the Strasbourg University campus.

Eventually, by 2010, a cross-shaped system will provide access by tram to all the districts of Strasbourg and its close suburbs.

Since 1992, the overall offer of public transport has increased by 30%. Finally, the launch of the tram system was also an opportunity to rethink the bus network so as to provide optimum client service and ensure that buses and trams complement each other to the full. Since 1992, the overall offer of public transport has increased by 30%, which is a performance unequalled by any other French town. With a fast transport available at all hours the tram have become popular in the city among the inhabitants, 97 % of them say that they are happy with the tram. (George Muller)

3.4.6 Galerie à l'En-Verre & the Homme de Fer

To further decorate the city special effort was put in the central tram stations. The tram station located 17 meters under the Station Square communicates with a shopping gallery, called the Gallery à l'En-Verre, via stairways, escalators and lifts. This 3,700 m^2-shopping gallery is parallel to the station building, and is embedded into the ground. It is covered by a glass top, which brings in natural light. A fine geometrical construction of glass panels increases the light and makes the gallery transparent, as it is intended to be. In this way, the station building can be seen from the underground gallery.

Figure 23. Tram stop Homme de Fer

Last, at the Homme de Fer tram station, a shelter designed by Architect Guy Clapot gives the square its scale. At a height of 8.5 meters above the square, the Rotunda looks like a glass crown with a 35-meter diameter, supported by a circular framework, which is it supported by eight twin posts. The entire structure is made of metal, and painted in anthracite grey.

3.5 Karlsruhe

The city of Karlsruhe is located in the south west of Germany close to the river Rhine and the French border. It is located at the northern most tip of the famous Black Forest.

3.5.1 History

Karl Wilhelm is well known as the founder of the city of Karlsruhe. He was born on the 18th January 1679 in Durlach (his first residence), and died in Karlsruhe in 1738. He belonged to the protestant line of the House of Baden, which he wanted to reunite for the sake of political stability.

In 1803 universal compulsory education was introduced in Baden. This ‘Reading revolution' created the basis for the politicisation of the lower classes. In 1848 the French February Revolution lit the spark in Germany. The German uprising began in Baden, and ended here in 1849 with the bloody suppression by Prussian troops of the first, short- lived republic on German soil. In the liberal Era Baden became the ‘Model State' with respect to many issues, with the universally popular and admired Prince Friedrich I (1826-1907) at the helm.

In spite of the educational development of the population, in the 19th century Karlsruhe was still a town in which the court, the civil service and the garrison determined the way of life. Karlsruhe became the cultural centre of the Grand Duchy: Johann Peter Hebel and Viktor von Scheffel achieved literary recognition for Karlsruhe in the beginning and middle of the century.

The first polytechnic in Germany was founded in Karlsruhe in 1825, following the French model. Karlsruhe's first main station was opened in 1843. The industrialization of the town, which was to have a big effect on its development, began on the ‘Tracks of progress'. The development of industry quickly reduced the importance of the residence for the town. The cultural sphere continued to be influenced by the palace, however, e.g. the founding of the Applied Arts School and the Majolika Factory.

Figure 24. The palace in Karlsruhe.

After 1918 and the abdication of the last Grand Duke, the state maintained the cultural institutions of the days of the Grand Duchy. The Baden State Museum was set up in the palace. During this time the state of Baden became a republic and Karlsruhe lost its status as the royal residence.

After a war begun by the National Socialists and after more than fifty air raids, 35 % of the city was destroyed.
Since then the townscape has changed: the civil service city, the former capital of Baden, became an industrial and economic centre with 276.000 inhabitants (1997). Karlsruhe became the "Residence of justice" with the opening of the Federal High Court in 1950 and the Federal Constitutional Court in 1951. Petrochemical and electronic industries have settled here, and the Hi-Tech area is meanwhile becoming ever more important. The ‘Technology Region' of Karlsruhe and the Technology Park of Karlsruhe was founded in1987, and the Centre for Art and Media was opened in 1997.

The city of Karlsruhe has today about 270.000 inhabitants and 42.000 working places, and the region have about 950.000 inhabitants.

The system started as a horse-drawn carriage system in the 1890ies and became electrified around 1900. They celebrated 100 years anniversary in the year 2000.

3.5.2 Todays light rail system

There are several system interchanges:

- At Durlach Bahnhof (station) in the east (routes to the east and north),
- At the Albtalbahnhof (near the main railway station) for the routes to the south,
- At Knielingen in the west.

From Knielingen, the trams travel on the railway route over the Rhine Bridge to Worth. Here they leave the railway again and ride on a street in the village for about 1 km. Due to the distance between tracks and buildings 15 kV a.c. were used in the street instead of the normal 750 V d.c. Furthermore there is a single-track system interchange in Ettlingen West (the Oldest), which at the moment is not in use for passenger traffic.

The Light Rail in Karlsruhe is classified as a type 7 Light Rail. This class consists of Light Rail whom is integrated with regional train, using regional train tracks to extend the service into the region. In Karlsruhe´s case it is based upon a dual-current tram system and was the first dual-current tram system in the world when it was introduced in 1992. A dual-system means that there is two different type of voltage. The vehicles are equipped with on board transformers and rectifiers that convert 15 000 V a.c. that are used by heavy rail to 750 V d.c. which do trams use. This gives the opportunity for trams to travel on “heavy rail” as long as they have standard gauge, which is 1435, (the same as in Sweden).

Figure 25. Different types of LRV's in Karlsruhe.

The growth of the Karlsruhe public transportation system and the number of passengers are impressive.

Figure 26. Information about Karlsruhe trams system.

Year	Track length (km)	No of stops	Motorcars
1975	82,7	100	98
1980	86,5	109	96
1985	88	112	128
1990	112,3	144	140
1995	140,5 (plus 110,2 DB)	200	175
1998	179 (plus 88 DB)	201	185
1999	195,9 (plus 88 DB)	202	185

The total number of passengers (yearly) grew from 55 million in 1985 to 80 million in 1995 and over 100 million in 1998. Just imagine the extra number of cars on the road without the growth in public transport!

During peak hour in Karlsruhe, 144 trams on six different routes pass through the main shopping street, which is 22 m wide. The traffic has reached the point were the pedestrian's feel that the traffic is a wall in the street, a barrier. A tunnel for pedestrians is being planed; the exact position is not yet decided. The population in a toll a couple years ago, in addition to on-ground within the street, rejected an underground section with exclusive right-of-way under the main shopping street.

In Karlsruhe the LRT operates on very different type of tracks. It has shared right-of-way with car traffic in outer areas (where car traffic is limited to residents) service and delivery. Shared right-of-way with pedestrians in two pedestrian zones. Reserved right-of-way on transit lanes separated by markings or special surface, pavement or grass, and mixed operation with railway on railway tracks. The exact percentage for the different types of right-of-way is not exactly known, but approximately the reserved right-of-way with some physical barrier is 50%, and when rebuilding they try to build this type of right-of-way.

KVV have been very successful when planning and starting new routes. During 93-94 they opened 3 new direct routes, from outer areas to Karlsruhe centre.
The route S4, from Bretten-Karlsruhe had in 1993 2000 passenger; this route went from Bretten-Karlsruhe main station. One year after the introduction (1995), when it started to run

to the city center it had 7400 passengers, and has further grown since.
The route S31 Bruchsal-Menzingen, grew from 2000 to 4500 passengers daily, and the route S5 Worth-Karlsruhe, the number of passengers has doubled from 1993 to 1998.

Three factors facilitated this growth: higher frequencies, a single tariff and (most) the direct rides into the city centre. 20% of the passengers switched from car to public transport. It is worth to notice here that the main station in Karlsruhe is located about 3-4 km from the inner city centre were the most people work, get education, shopping and visiting culture events, and it was to this point the trains arrived earlier.

The trams/LRVs run at a speed op 25 km/h in the pedestrian areas, 50 km/h to 70 km/h on free tracks in the urban area and 90 km/h or 100 km/h on the railway tracks.

3.5.3 Rolling stock

The rolling stock in Karlsruhe have a variation from old tramcar from the 1940-1950’s to modern LRV from 1997, the new vehicles have dual-voltage system on board and it is these vehicles that runs like the “Karlsruhe model”. The oldest vehicles run within the city centre as traditional trams.

The vehicle from 1997 was bought from Duwag/ABB, and is not totally “low-floor” vehicles, there is a middle section that is low-floor and the rest have normal height, semi low-floor. The major concerns why they are made as they are are because the dual-voltage system uesa lot of space.

In 1999 and 2000 20 low-floor urban tramway cars (niederflurwagen GT 8-70 D/N) and 20 two-system semi low-floor tramway cars (mittelflurwagen GT 8-100 D/2SY-M) were added to the Karlsruhe tramway fleet. The first five-section low-floor trams are in operation one tramline 1. The new LRV’s will replace a number of old Duwag articulated tramcars, but are also destined for the new routes and to accommodate the growing number of passengers.

Figure 27. A mittelflurwagen GT 8-100 D/2SY-M in Karlsruhe

To buy new LRV is not cheap, a single vehicle costs about 3,8 to 4,5 million German marks, depending on the size and number of axle. Karlsruhe has bought both 6- and 8-axle vehicles.

The costs of new urban low-floor vehicles are dropping due to standardization. Recent orders, for example of Combino and the new DWA-vehicle for Kassel shows costs per vehicle of about 3 million German marks. In appendix 9 is technical information about the tram.

Karlsruhe has their own workshop where they repair and maintain their own vehicles, as well as others, such as DB (Deutsche Bahn) vehicles and Saarbruckens vehicles.

4. Environmental issues.

Trams are in many cities a so natural part of the city that the inhabitants take them for granted just like the police force or a hospital. The tram have even in some cities become the city's pride and symbol, examples are cities like Strasbourg or Karlsruhe. Cities that now are become famous for their light rails systems. During the last 10 years the interest for trams have increased and many cities plan to modernize and expanded their systems there are also many cities are building new LR systems. The reasons for cities to choose trams as its new transportation mode are many. Better capacity than buses are one but the most common are the environmental advantages. We will give it a try to examine what environmental impacts tram has in relation to other transportation modes (e.g. buses).
The environmental effects that will be brought up are:

- Environment esthetical including natural and cultural effects
- Barrier effects
- Energy consumption
- Air pollution
- Congestion
- Land area impact, consumption of land in the city.
- Noise and vibrations

These chapters will cover the most environmental effects that light rails have in a city.

4.1 Environment esthetical

Environmental impacts are pollution's, noise and energy consumption's but also the esthetical appearance of the tram system. People live in the city and it's important for them to have a beautiful city. Traffic with its roads and signs are often a problem when it comes to making the city more beautiful. Tram systems also have certain components that can be considered ugly. But the possibility to make the city better looking is possible easier for a LR track than a road.

What is it then that makes a town beautiful and what makes a town ugly?
The opinion if a city is beautiful or not changes with whom the judge is. Some thinks that some buildings are pretty while other hates them. A few things do how ever most people have in common they don't like desert like landscape in the city, big walls of concrete and asphalt. It is of course a matter of opinion and taste but not entirely otherwise it would be hard to plan a city that people like.

With light rail in a city there are some parts that specifically one can look at:
The tracks
A tram track or a road is not beautiful but for the tram advantage, it takes up less space. A normal road is ca 3.5 m wide and a track is about 2.65 this makes that it at least is less of tracks than roads.

Electrical wires is something that can be very ugly but are necessary for trams. It is therefore important to adjust them as much as possible to the surrounding environment and to not have more wires than needed. In Zurich, which has had, it's tram system for a long time one can see the lack of planning for the electrical wires. One good example how to place electrical wires is Strasbourg. (Mr Bessier).

Figure 28. Lots of wires in Zurich

4.1.1 Traffic in sensitive areas

Even in the city there is a need to have places with no traffic, places with some peace and quiet. It can be park or pedestrian areas. In many cities pedestrian areas didn't exist 40 years ago, everywhere there was a road there were auto traffic. Trams have proven to work in sensitive areas like pedestrian areas without being an obstacle (Hall, P and Hass-Klau, C.). In Mannheim trams are running on the major pedestrian street but with a low speed of 20 km/h which is both safe and give little disturbance to pedestrians. The big advantage with this is that one can literately take the tram to the entrance of ones favourite store.

4.1.2 Stops

Tram stops are maybe the part of the tram system where design matters the most. It only depends the amount of money that one is willing to spend for how it will look. Strasbourg has the maybe most know and photographed tram stops. Which both give information, protection against rain and are a piece of architecture. There is a picture of the stop under the Strasbourg section.

Figure 29. Tram stop in Saarbrucken

Figure 30. Information post Strasbourg

The ticket machine in Strasbourg is designed to also include information about the tram route and when the next tram will arrive on a digital screen.

4.2 Barrier effects

A barrier in the city can be many things; a house, a road, or a railway track. To evaluate the barrier effect of a new tram route in a city is not easy especially not if there were other transportation mode there before, (like a road or a bikeway).
Like a road a tram track will prevent people to move over the place at the exact moment the want to. Since a tram will pass there now and then. To try to show the difference in impact for a pedestrian on a road and a light rail track I will do a short mathematical example.

Let’s say that we have 4000 persons who want to travel from point A to point B, in one hour. Lets also assume that there are 1,5 persons in each car and that each tram can carry 150 persons. At one point between A and B you would like to cross but is that possible if 4000 people are passing by cars or trams?
Nr of cars passing the distance 4000/1,5 = 2670
Nr of trams passing that distance 4000/150 = 27

With traffic flows as high as 2670 cars/hour one need a two-lane road to prevent congestion. Now if how easy is it to pass the tram track compared with the road under the assumption that we don’t have any red lights on the distance and that both cars are coming with an even period.
These figures are assumptions
Road (one-way 2 files)

Width	7 m
Traffic flow	2 670 cars/hour (1 335 cars /file*h)
Length of one car	4.5 m
Speed	20 km/h

Time for one car to pass your cross place 3.6*4.5/20 = 0,81
Total time with cars in front of your cross place 1335* 0,81 = 2469 s = 18 min

Tram (one-way)

Width	3 m
Traffic flow	27 trams/hour
Length of one tram	40 m
Speed	15 km/h

Time for one car to pass your cross point 3.6*40/15 = 9,6
Total time with cars in front of you over one hour, 27* 9,6 = 288 s = 4,3 min

The time with cars in front of pass point 18 min of one hour or 30 % of all the time.
Time with trams in front of the pass point is 4.8 min of one hour or 7 % of all the time

As one easily can se it is far a very short time that there is a tram in your way and that after the tram have left one can safely pass. This is not the case with cars since they pass more often. To see how much time one really need to pass this road another calculation is made. That tells the time between each vehicle.
Tram (60-4,3)/27 = ca 2 min

Car (60-18)/1335 = ca 2 sec

Two seconds is in distance: 20/3.6 * 2 = 11 m

The conclusion of this small calculation is:
It is almost impossible to cross the road and still be alive. For the tram however it is very easy to pass. Therefore the barrier effect of a road is much greater than a tramway when the carry the same amount of people wants to transport from point A to point B.

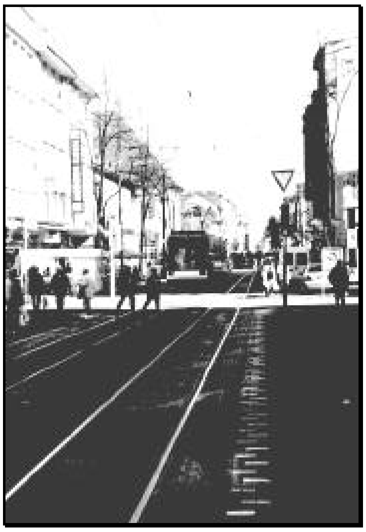


Figure 31. People crossing tracks in Mannheim

One thing that is included in the calculation is the possibility the cars in the two different lanes not are driving next to each other. This means that there could be even less time to pass if the cars in one lane is slightly ahead of the other lane. Also the distance to cross is much greater for the road 7 m compared with tram track 3 m. The road not only is harder to cross for pedestrians and bikers but it takes more space, which in a city is a very valuable and limited resource.

Our own experiences in different cities are that a tram is not a barrier as long as it is only tram tracks and not combined with a road. People can easily see when the tram comes and the distance to cross is much smaller.

4.3 Energy consumption

A calculation of how much energy it takes for one person to travel with a light rail wagon compared with bus or car.

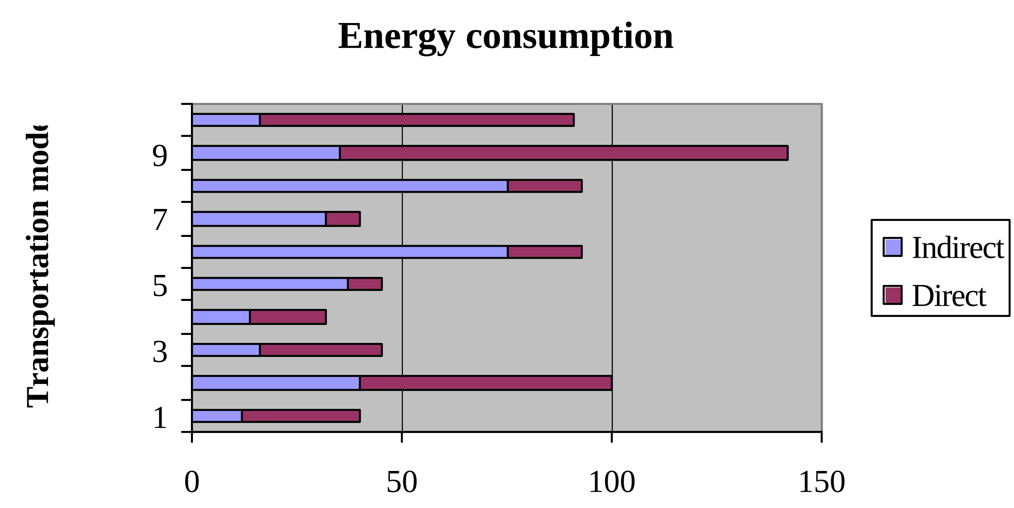
Data from statistics in Mannheim (MVV)
A tram energy consumption approx. 4 kWh / km
The average numbers of people on one tram ride:
Person kilometre / wagon kilometre = 221.2 / 5.698 = 39 persons
Energy consumption per person and kilometre travelling with tram:
4/39 = 0.1 kWh/ person * km

Bus consumption 0.38 l diesel/km energy content in diesel 1m^3 = ca 9900 kWh (Swedish petroleum institute) 0.38 l = ca 3.8 kWh
The average numbers of people on one bus ride. Person kilometre / wagon kilometre = 43.8 / 3.249 = 13.5 persons
Energy consumption per person and kilometre travelling with bus:
3.8/13.5 = 0.3 kWh/ person * km

0,3 / 0,1 = 3 three times higher energy consumption for buses than trams per each personal kilometre.

It takes a lot of energy to build a tram, bus or a car. The federal Department of environment, transport, energy and communication (DETEC) has given out a folder with statistics over transport in where there are some statistics over indirect energy consumption for transports:

This is statistics over energy consumption for different transportation modes per passenger kilometre (pkw). Private car is 100% which means 3.05 MJ / pkw. It is divided up in direct energy consumption and indirect.



	1	2	3	4	5	6	7	8	9	10
Direct	28	60	29	18	8	18	8	18	107	75
Indirect	12	40	16	14	37	75	32	75	35	16

%

Figure 32. Direct and indirect energy consumption for various transportation modes . Source: GVF Switzerland
1. Motorcycle 2. Private car 3. Bus 4. Coach 5. Trolley bus 6. Tram 7. Express train
8. Local train 9. Short distance jet plan 10. Long distance jet plan

One reason why the indicators vary so much depending on transportation mode is the nature of decision to be taken, in determining how far such impacts will need to be taken into account.

The environmental indicators are supposed to tell us about the different effects on the environment from different transportation modes. Higher indicator means bigger impact on the environment.

The reason behind the high-energy consumption for trams is not easy to explain. As shown of the diagram most of the energy consumed by a tram is consumed during the construction of the tracks and tram (indirect energy consumption).

The construction of a tram track takes long time and therefore consumes lots of energy. But on another hand the track for a tram last a long time, much longer than a road. Maintenance for tram track is also not higher compared with a road.

Since tracks are in the city the construction is more complicated than train tracks and might therefore use more energy. One can see that construction for tram and regional train tracks consume twice the amount of energy of what it does for an express train track. The explanation is for this is:

- Easier constructions for express train, no need to make it possible for cars to run on the same lanes. For trams there is a need for a concrete foundation and concrete filled up between the tracks all that demands lots of work and energy, all that not necessary for express train.
- More people travel on the express train tracks per day than on trams tracks, which does not seems likely since there often come one tram every five minute in Zurich.
- Low load factor for trams can be have something to do with the direct energy consumption but not with the indirect, which is almost four times as big as the direct energy consumption.

But it still does not give a good answer why the construction of light rail uses so much energy.

4.4 Air pollution's

Even when a tram has such a surprisingly high-energy consumption, it still has low pollutions. In appendix 13 you can see tables over how much pollution's different transportation modes produce. The amount in pollution from direct energy consumption are in these table zero which is because trams exclusively run on electricity and Switzerland have a very low part of its production that come from fossil fuels (oil, coal). For other countries the pollution direct energy consumption would be something different since they produce electricity differently. France has for example about 95 % of its electricity production from nuclear plants. It would be interesting to see how much nuclear waste the electricity consumption for light rail vehicles would cause in France.
The pollutions from indirect energy consumption are in all cases low both for CO_2, NO_x and NHMC in compassion with the total pollution for car traffic. Both construction and operation of trams are environmental friendly.

To build new rail tracks in a city is a complicated and expensive project that takes a long time. Even if one don't include the costs that a closed road means to a community is just the actual constructions costs huge (The European Conference of Ministers of Transport. (1994)).

4.5 Greenhouse effect

One of the major pollutions behind the green house effect is CO_2, which is produced in excess when oil fossil fuels (oil, coal etc) are consumed. Which happens when you drive your car. According to the environmental indicators trams only produce CO_2 during its construction phase according to the tables. This it not completely true since oil or coal is used in most countries to produce electricity (Appendix 1 shows pollution values for different transport modes). In Switzerland where these environmental indicators were made, fossil stands for ca 2% of electrical production. This is a very low figure, in Europe in average fossil fuels stands for 40-45 % and in Sweden it is 2.5 % (http://lwww.vattenfall.se).

4.6 Traffic congestion

Traffic congestion is one of the biggest problems in a city. A city relays on it transportation system to get people to work, with congestion this becomes hard.
Traffic congestion is the effect of too many vehicles on a limited road area. For a long time city planers solved the problem with congested roads by building more roads and parking spaces. That resulted in even more motor vehicles on the roads, which soon again were congested. This experience has among others Zurich made. The solution for the problem that Zurich picked was to increase public transportation and making it more effective, so that it became easier and faster to use trams, trolley buses or buses than your own car.
With effective traffic planning like the one in Zurich one can organize the public transportation without congestion that leads to less pollution’s. Congested traffic produce 250 % more pollution compared with traffic that runs without stops. Which has a huge effect on the city environment. Threes, stone buildings and pedestrians are the ones that in first hand are affected by the extra pollution caused by congestion (Dipl-Ing. Hondius, Harry).

4.6.1 Second hand effects

Second hand effect due to light rail can be increased or decreased traffic on surrounding roads. Not only on the road where a new tramline is located but also on roads parallel to where the tram is. The biggest second hand effect is when public transportation increases and individual traffic decreases. There are several cases when these have happened after a new light rail line was introduced. In Strasbourg there have been a huge increase in passengers since the opening of the first line in 1994. Also in Karlsruhe have the number of passengers increased with the regional tram system. Decreased individual traffic leads to less congestion and less pollutions.
When a tramline is introduced in a city, traffic flows will changes depending how the lines have been planed. In Saarbrucken they closed some roads for car traffic to make room for the tram, other roads were narrow from 4 lanes to two lanes. This reduced the traffic in the down town area but increased traffic on other roads, total there were a decrease in traffic with 2% in the city of Saarbrucken.

Accessibility for persons with handicaps (wheelchairs) is very well developed for tram stops in the German cities. In Saarbrucken there were special ramps for wheelchairs in order making the entrance as easy as possible. There are also special bricks on the platform that have a pattern, this works as guidance for people who are blind. These bricks were at all train stops we saw and tram stops in Saarbrucken, Strasbourg and Mannheim.

According to a questionnaire in Strasbourg inhabitants in the city felt more secure because of the tram. Since they knew that a tram passed often so that there always was an easy way to get home. This is one major reason why there is tram every teen minute at night (Umweltverträglichkeitstudie, (UVS)).

4.7 Land area impact, consumption of land in the city.

Land is one of the most valuable resources in a city. There are many different interests that are interested in using the land available. A good proof for this is to see how high the land prices are in big cities. It is therefore important to find a public transportation that uses as little land as possible. In big cities where the demand for public transport is big the obvious solution is to go underground and build a metro. This is not economical possible for smaller cities, and then light rail is a good alternative.

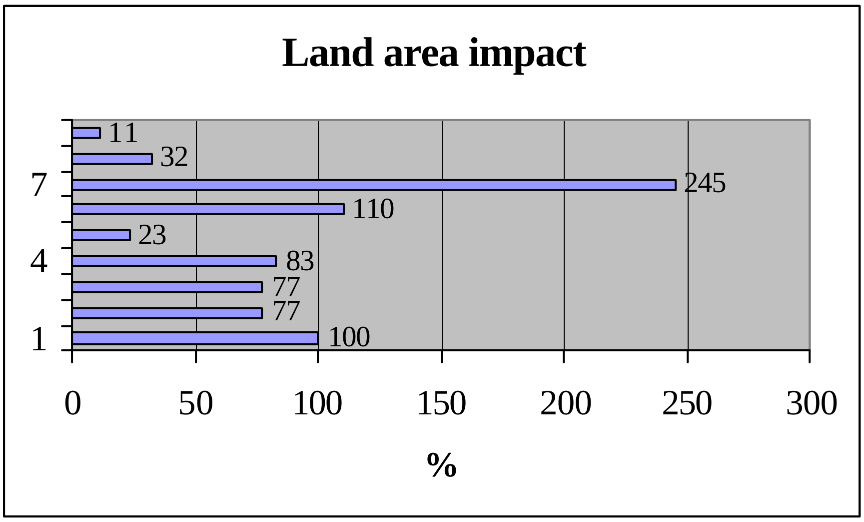


Figure 33. Source: GVF Switzerland

1. Car 2. Bus 3. Coach 4. Trolley bus 5. Tram 6. Local train 7. Regional Train 8. Short distance jet plan 9. Long distance jet plan Car = 100% = 0.0069 m^2*a / pkm

The table shows that trams use the least area of all ground-based transportations, only 1/5 of the space that car traffic uses.

4.8 Noise

Noise is one of the modern society's problems and one major source to noise pollution's are traffic. It is easy to feel the difference in noise level if one stand next to a pedestrian area and to a road. Noise is a part of a city but it is important to try to keep it at as low level as possible.

There are few vehicles that don't produce noise bicycle are one. There are even fewer when it comes to vehicles with engines. From that viewpoint it is natural that a modern tram produce noise. There is friction between wheel and rail, brake noise, engine noise; noise produced when the tram turns, bad rail transitions, and corrosion on the rail. These are just some reasons why a modern light rail vehicle makes noises. In an environment without any noise pollution any new pollutions would be a big impact. In most cases tramlines are in the road and replaces bus and/or car traffic. Places where noise already before was a problem.

Figure 34. Sharp curve for tram, which causes noise

What does happens when a tram rout replaces a heavily trafficked road when it comes to noise pollution?
Even if there still will be some car traffic in the area, there will be a significant lower amount of traffic. The light rail line will take up space from the former road so that the space for car traffic decreases. If a four-lane road would be transformed into a 1-2-lane road plus a tramline noise levels would change. It is1-2 lanes depends upon if there is a stop for the tram or not in that section.
Less road area leads to less traffic and less noise. One can argue that the tram will replace the noise produced by the lost traffic. Which is not true!
Before the construction of the new light rail system in Saarbrucken they investigated how the noise levels would change when a tramline was introduced in the road.

This noise study was part of an environmental impact study made before the construction of the new light rail system in Saarbrucken.

4.8.1 The Saarbahn Noise investigation

Source: Umweltverträglichkeitstudie, (UVS) 1995.
The investigation looked at noise pollutions for three cases

1 Analyse: Today’s road and rail traffic
2 Prognoses: With new tram traffic
3 Prognoses: With new tram traffic and road traffic.

From the German law regulations in the case of a new building or a substantial modification of railways, the noise limits are. (A modification is substantial after 1, because those in the following limit values exceeded are;

1. A railway around one or more continuous tracks is built or
2. By a substantial structural intervention of the traffic route outgoing traffic noise rises with at least 3 dB (A).

Further a modification is substantial after 1, if the evaluation level of at least 70 dB (A) at day or 60 dB (A) by night with a substantial structural or with a substantial structural change has been done.

Table 1. Emission limits. (UVS) 1995

Place for noise pollution	Emission limits in dB (A)	
	Day time 6-22	Nights 22-6
Hospital, school, rehabilitation home and day care centres.	57	47
Living areas	59	49
Villages-, and mixed areas	64	54
Business areas	69	59

4.8.2 Analyse: Today's road and rail traffic

The traffic analyses came from Joachim Schwarz's investigation bureau.
The heavy traffic proportions come of to the traffic volume of the Saarland from the year 1990. The proportions to overall traffic in the time interval come of at night the RLS-90 (2). The following traffic volumes were taken as a basis for the calculation.

Table 2. Emission analyses. (UVS) 1995

Road	Average traffic V/24 h		Heavy vehicles (%) Day/night	a_N (%)	V_{zul} Km/h
	Analyse	Prognoses			
BAB A1 To AS to Heydt	28 000	22 400	6,0/6,0	11,2	120
BAB A1 To AS to Heydt	27 600,	22 080	6,0/6,0	11,2	120

4.8.3 Noise calculation

The noise calculation that are made involves both motor and tram traffic. Emission levels for the tram noise are calculated for a distance of 25 m from the driving touching axle. According to the RLS-90 (2) the following influence are to be considered:
1. Average of one day's traffic.
2. Heavy traffic proportions over 2,8 t. total weight.
3. Allocation of the traffic volumes on the time intervals: day 6-22 and at night 22-6 o'clock.
4. Admissible rates of the passenger cars and trucks.
5. Carriageway surfacing noise.
6. Addition with pitch attitudes > 5 %.

The following emission levels were taken as a base.

Table 3. Calculated emission levels. (UVS) 1995

Road	Analyse dB (A)		Prognoses with tram dB (A)	
	Day	Night	Day	Night
BAB A1 To AS to Heydt	73,5	67, 1	72,5	66,2
BAB A1 To AS to Heydt	73,4	67,1	72,4	66,1

4.8.4 Results of the noise-level calculations

The noise levels for the surrounding areas from the tram were calculated for three representative emissions. Concerned of local parts are Heydt, Kirschheck, and Heinrichshaus. With the following values were the emission values for the tram calculated.

Table 4. Results calculations.

Emission place	Noise limit values Day/night	Evaluation levels dB (A)		Exceeding limits dB (A)	
		Day	Night	Day	Night
Kirschheck EG 1. OG	59/49	41 44	39 37	- -	- -
Heinrichshaus EG 1. OG	59/49	50 52	48 45	- -	- -
Heydt EG 1. OG	59/49	40 40	36 36	- -	- -

If one compares the today's situation with a future one, including the noise nuisances of the BAB A1, then the results are:

Table 5. Comparison between analyses and prognoses. (UVS) 1995

Emission place	Analyses only BAB A1 dB (A)		Prognoses tram + A1 dB (A)		Difference dB (A)	
	Day	Night	Day	Night	Day	Night
Kirschheck EG 1. OG	76 77	70 71	75 76	69 70	-1 -1	-1 -1
Heinrichshaus EG 1. OG	76 76	69 70	75 75	69 69	-1 -1	0 -1
Heydt EG 1. OG	54 54	48 48	53 54	47 47	-1 0	-1 -1

At the nearest buildings noise levels are reduced up to 1 dB (A) in the future prognoses with tram traffic. The metropolitan railway plays thereby a minor roll compared with today's motor traffic. The reduction of the levels is to be back-driven on the prognosticated reduction of the individual traffic.

The metropolitan railway runs thereby parallel to BAB A1. The emissions of the metropolitan railway are far under those causes by a motorway. The measured values are almost identical to the analysed situation.

The differences between analysis and prognosis are very small. At close range of the Saarbrucken light rail the sound-related situation changes only insignificantly. The change is caused by the reduction of the individual traffic.

4.8.5 What can be done to reduce noise from trams?

Noise reflects on hard surfaces and if one can lower the reflecting surface the noise level will decrease. In many cities grass have been planed between the tracks of the light rail. This for two reasons:
1. Esthetical appearance
2. Noise reduction.

Figure 35. Grass between tracks in Zurich

In Zurich they have measured the noise level with grass between the tracks and without, the result shows a big difference in noise level.
The result for different trams passing one section with grass and one without was like this

	Tracks with grass	Normal tracks with concrete
Tram A	73,5 dB (A)	85,5 dB (A)
Tram B	73 dB (A)	85 dB (A)
Tram C	73,5 dB (A)	86 dB (A)

As shown of the figures, the noise level decreased with 10 dB (A) for the different trams if there is grass between the tracks. Since noise if calculated logarithmically is a difference of 10 dB (A) half the noise to the ear (Mr. Berger, VBZ).

Figure 36. Tree along the tram track in Strasbourg

In Strasbourg the city have planted an alley of trees along some parts of the tram tracks. This is not only beautiful it is also practical. The trees give the trams shadow and works as a barrier for the road. The shadow is important since the trams in Strasbourg have such big windows, which work, as greenhouse. They make the tram too warm if the sun shines directly on the windows. Trees work like lungs in a city and absorb pollutions and even some noise (Conseil de Communaute Urbaine de Strasbourg (1999)).

5. Safety

5.1 Introduction/in general

Safety is a critical issue throughout any transit system. However, nowhere are safety issues more visible than around a LRT station. Four potential safety concerns are found here.
First is the conflict between pedestrians and street traffic. Whether station platforms are located in the middle or beside the road, pedestrians need to cross the road to get to the station. Passengers trying to catch an approaching train may pay little attention to car traffic.
The second conflict occurs between LRVs and pedestrians who usually are allowed to cross the tracks near the stations. Because a LRV may approach relatively rapidly and silently, passengers disembarking a LRV may fail to notice a train approaching from the opposite direction. Other pedestrians may fail to look both ways before crossing the tracks.
The third safety conflict is between LRVs and car traffic. Although this issue is not directly related to the station, on-street stations are often located at intersections where roads cross tracks. The overall layout of the station and intersection is integrated for safe LRT operation. Depending on the frequency of LRVs and the volume of the car traffic and pedestrians, these first three conflicts can be mitigated by visible crosswalks, clear roadway marking, physical barriers, signs, and signals for vehicles, trains, and pedestrians. In the most severe cases, grade separation may be used. (Walmsley D.A, 1992).

Personal security of passenger is the fourth safety issue at on-street stations. The on-street location of these stations provides more visibility and natural surveillance from the community than most off-street locations. However, in some cases, increased visibility, enhanced lighting, and/or emergency call boxes are suggested. If a station is even perceived to be unsafe, the patronage will suffer.

Can a LRV be too silent?
Well the question must be addressed. Because it seems to be the case when many operators choose to use signals, such as, flashing lights and bells on their vehicles when running through a pedestrian zone or a mall. The disadvantage of this solution is that it can be very disturbing for the people who live near by the area were it is being used. Nevertheless, it is important that the vehicle run smooth and silently during operation to keep and gain patronage.

5.1.1 Safety at stops

Stops are the “business cards” of public transport; they should be identifiable from as far away as possible and easy to access. But at the same time, they should fit well in the urban environment. The two major safety concerns is the conflict between trams and pedestrians, and between cars and pedestrians.

The conflict between LRV and pedestrians occurs often in the situation when pedestrians are on their way to a LRV or leaving a LRV. When trying to catch a LRV, the danger is often another LRV arriving or departure from the station, the pedestrians attention is drawn to the vehicle he/she is trying to catch. With some or little stress, a smooth and silent LRV can be very hard to notice. The same problem occurs in the conflict between cars and pedestrians. We will take a look on these different stations set-ups.

1. *Centre platform station in street median*
   Figure 41 shows a centre platform station located in the street median with LRT tracks on exclusive right-of-way. Access to platforms in this arrangement, like most median stations, is normally limited to one or both ends of the station. Care must be taken that pedestrians waiting on the median to cross do not block the tracks. If sufficient right-of-way is available kerbside parking can be located along the side of the street at the station or parking can begin beyond the station as tracks and roadways converge. Operation of LRV on exclusive right-of-way at the station limits the impact on the traffic and LRT operation, particularly if left turn lanes are provided.
   A similar layout with LRVs in mixed traffic at the station is also feasible. Left turn lanes are not practical with this layout. Operation of LRVs in mixed traffic at the station has a significant impact on traffic and LRV operation, LRVs may have to wait for cars waiting at the signal to move before stopping at the station and cars, particularly those turning left, must wait for an LRV to leave. Therefore such a layout is more useful where traffic is light and available right-of-way is minimal.

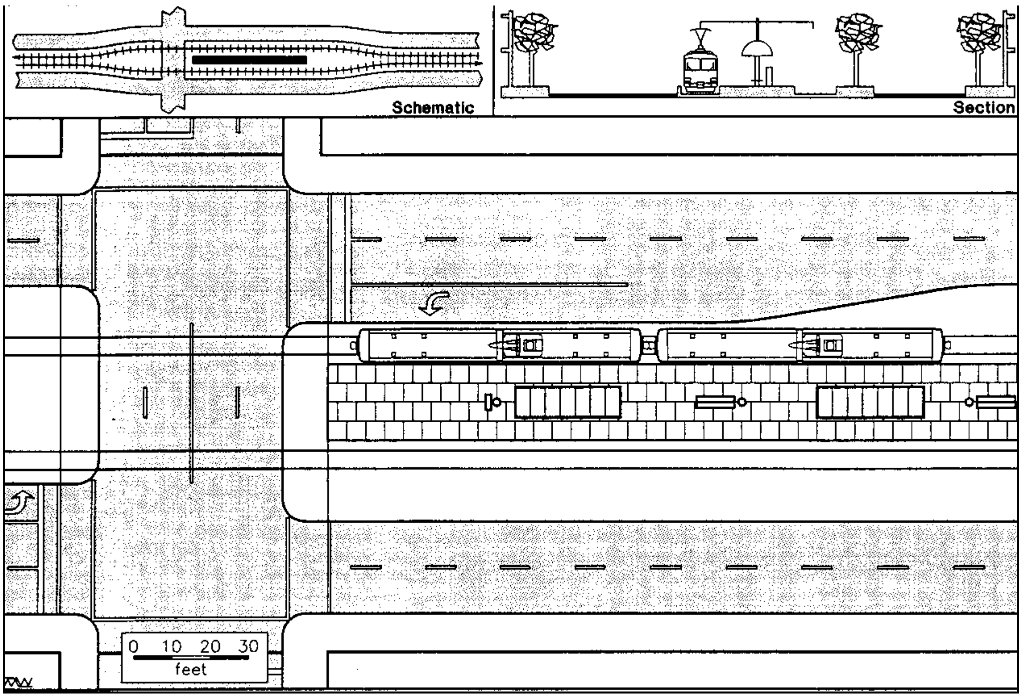


Figure 37. Centre platform station in street median. (Walmsley D.A, 1992).

At a stop like this it is important that the cars crossing the tracks in a left turn do it nearby the stop, because the LRV haven't such a high speed yet. This results in that the LRV is easier to discover for the car driver and it is easier to feel the presents of the LRV. One more advantage for LRV having low speed is that if there is an accident it will be less severe.
The major risk for pedestrians is the cars when they cross the road to/from the LRV station. One question that you have to think about is what will be most safe, to have a signal for pedestrians or to make a crossing zone for pedestrians?

2. *Side platform station in street median*
   Figure 37 shows a side platform station located in the street median with LRT tracks an exclusive right-of-way. Access to platforms may be limited to one or both ends of the station or, if traffic is light and low platforms are used, crosswalks to adjacent sidewalk

can be located along the length of the station. If sufficient right-of-way is available, kerbside parking can be located along the side of the streets at the station or parking can begin beyond the station as tracks and roadways converge. Operation of LRVs on an exclusive right-of-way at the station limits the impact of the traffic and LRT operation, particularly if left turn lanes are provided.

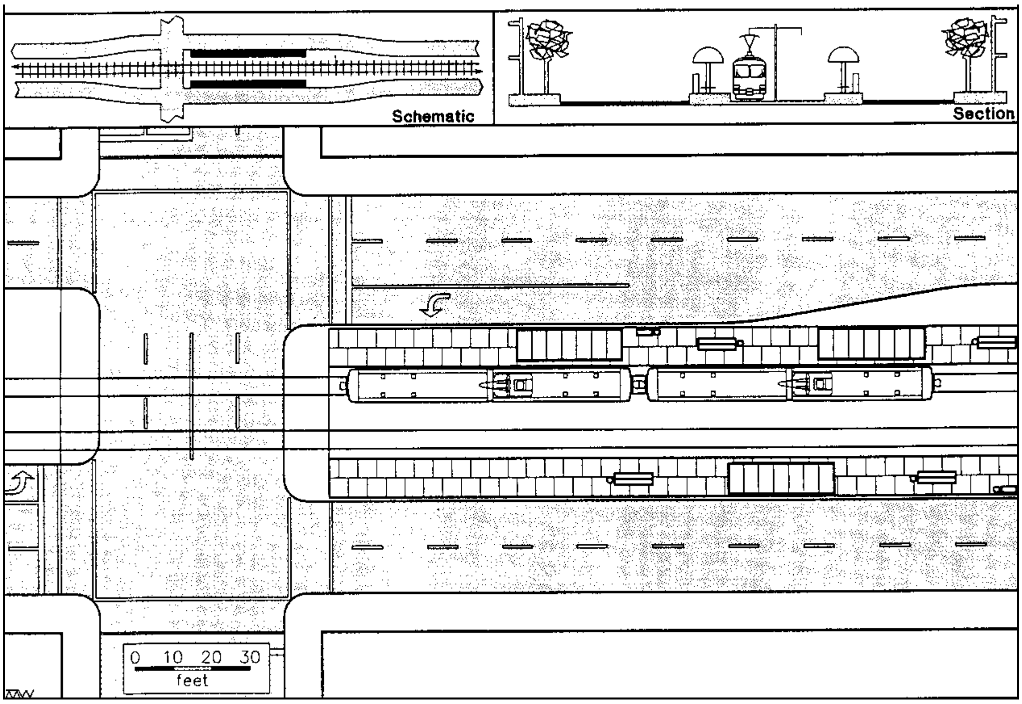


*Figure 38. Side platform station in street median. (*Walmsley D.A, 1992).

At a stop like this it is important that the cars crossing the tracks in a left turn do it nearby the stop, because the LRV have a low speed. This result is that the LRV is easier to discover for the car driver and it is easier to feel the presents of the LRV. One more advantage for a LRV with low speed is that if there is an accident it will be less severe. The major risk for pedestrians is cars when they cross the road to/from the LRV stop.

3. *Near and far platform station (with left turn lanes/ in minimum right of way)*
Figures 38 and 39 shows "near and far" platform stations located in the street median with LRT tracks on exclusive right-of-way. Figure 38 shows the layout with a straight track alignment and left turn lanes, whereas Figure 39 shows the layout with an S-curve but without left turn lanes. The primary advantage of these schemes is their minimal right-of-way requirements. "Near and far" platforms arrangements offer the narrowest right-of-way requirements. A layout in which the outside track on each side of the intersection is in mixed traffic is also possible. Access to platforms may be limited to one or both ends of the station or, if traffic is light and low platforms are being used, crosswalks to adjacent sidewalks can be located along the length of the station. If sufficient right-of-way is available, kerbside parking can be located along the side of the streets at the station beyond the station or beyond the station. Operation of LRVs on an exclusive right-of-way at the station limits the impact of traffic and LRT operation, particularly if left turn lanes are provided.

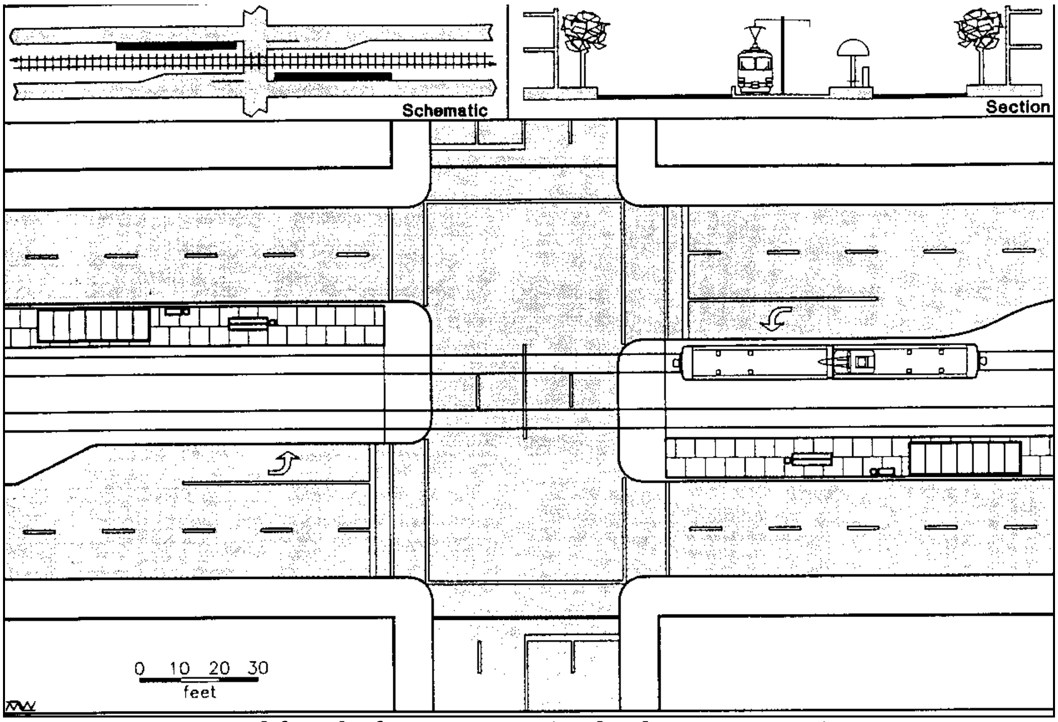


*Figure 39. Near and far platform station. (*Walmsley D.A, 1992).

A stop like this can be a bit more dangerous for pedestrians than stops with platforms side to side. Statistic say it is more common with accidents between pedestrians and LRV when the LRV is on it's way to the stop and not from the stop. So the further in front the platform pedestrians cross the tracks the higher is the speed. With higher speed comes less time to discover the LRV, react, and there will be a more severe accident.

4. *Sidewalk platform station with LRT along both sides of the street*
   Figure 40 present a sidewalk platform station with LRT along both sides of the street. This layout may be applied either with the LRT on exclusive right-of-way (as shown) or in mixed traffic. Platform may be fully integrated with sidewalks or may be separate, particularly if high platforms are used. The layout of the street and turn lanes is flexible with this arrangement but kerbside parking is not possible with either layout. Operation of LRVs on an exclusive right-of-way limits the impact on the traffic, whereas mixed traffic operation in kerbside lanes affect traffic and invites standing or disables vehicles to block LRVs. In either case, buses can stop at the platform, providing a direct LRT-to-bus transfer.

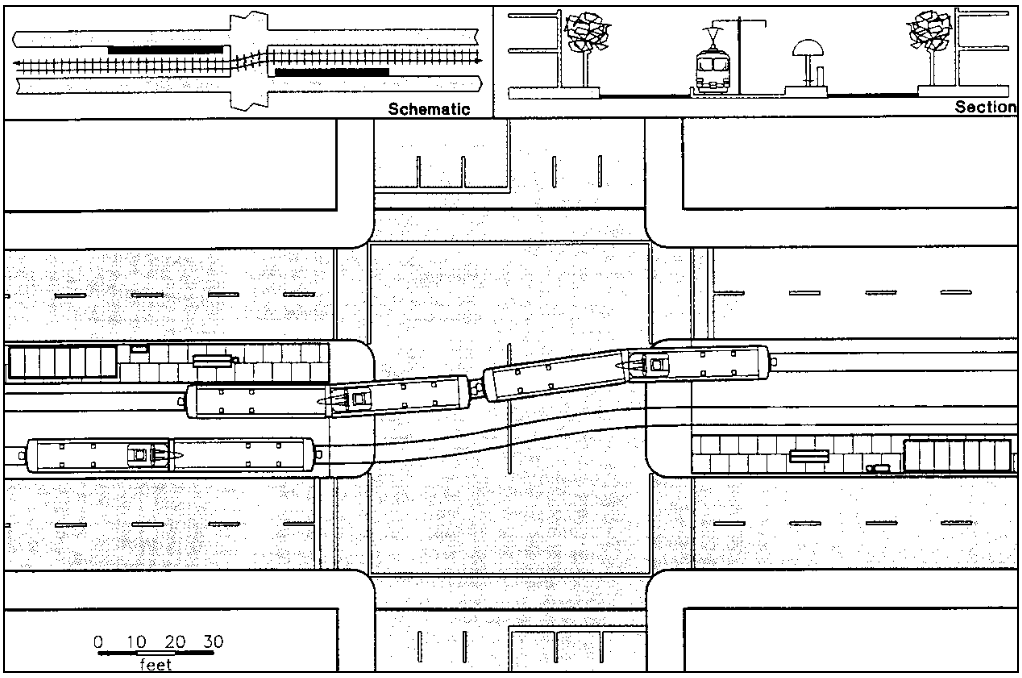


Figure 40. Sidewalk platform station with LRT along both sides of the street. (Walmsley D.A, 1992).

Here you have the same problems as for figure 43, with pedestrians crossing the tracks in front of the stop.

5. *Sidewalk platform station with LRT on the outside*
   Figure 41 presents a sidewalk platform station with LRT tracks located on the "outboard" on both side of the platforms and sidewalks are between the street and the LRT tracks. The layout of the street and turn lanes is flexible with this arrangement and operation of LRVs on an exclusive right-of-way limits the effects on traffic and LRT operation. Unlike the arrangement presented in Figure 40 the "outboard" configuration does not affect parking in the curb lane. Buses can stop adjacent to the station platforms, making for a direct transfer between LRT and bus. However, direct access to properties along the right-of-way is limited unless a parallel walkway is provided. This alignment is most useful where properties do not front directly on the street.

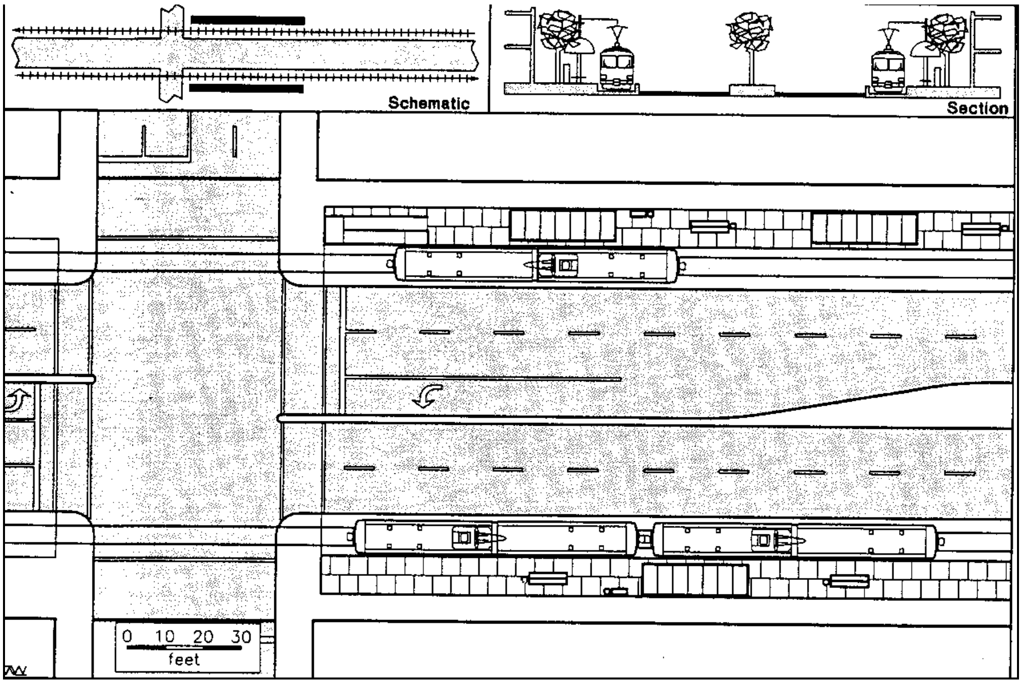


Figure 41. Sidewalk platform station with LRT on the outside. (Walmsley D.A, 1992).

The major advantage for this type of stop is that the cars cross the track, when turning left, more perpendicular. This is very good, because the car driver have a better view over the track, and somewhat more generous spacing.

6. *Centre platform station on one side of the street*
   Figure 42 presents a centre platform station where both tracks are located in exclusive right-of-way on one side of the street. Access to the platform is limited to one or both ends of the station. Care must be taken to pedestrians waiting at the end of the station to cross the street are aware of train and do not block tracks. Because one track is adjacent to the street, cars cannot park along the curb, and direct bus loading is not possible. Direct access to properties along the right-of-way is limited, making this arrangement most useful where properties do not front directly on the street. The layout of the street and turn lanes is flexible with this arrangement and operation of LRVs. An exclusive right-of-way limits the impact on the traffic and LRT operation.

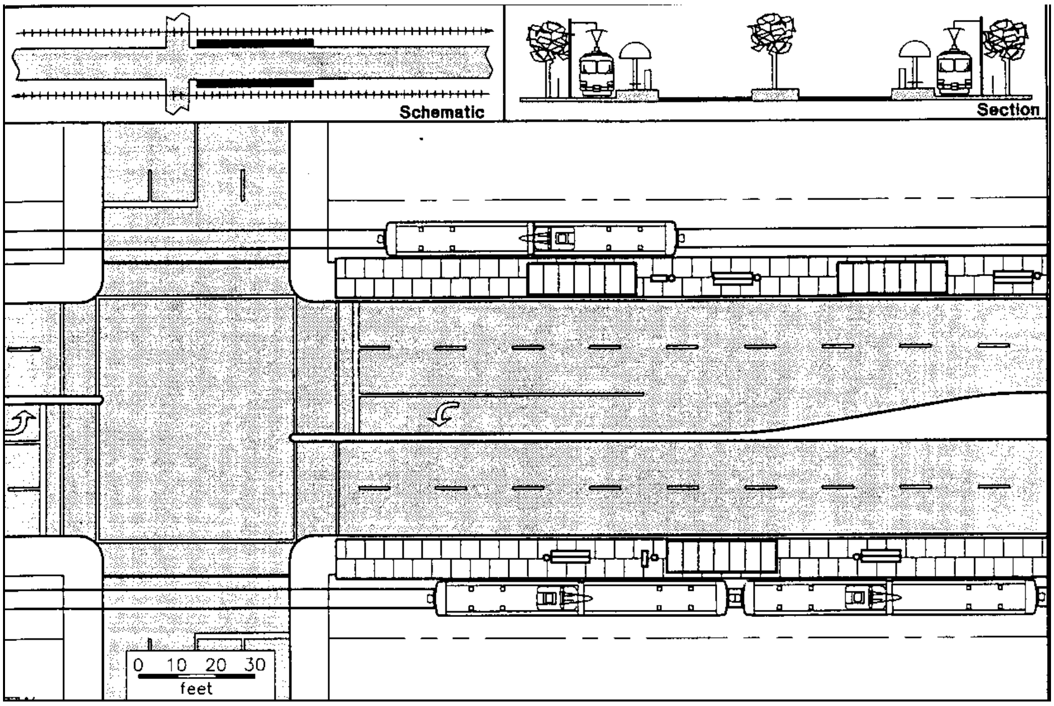


Figure 42. Centre platform station on one side of the street. (Walmsley D.A, 1992).

This kind of stop has the same advantage as for the stop in figure 40.

7. *Side platform station on one side of the street*
   Figure 43 presents a side platform where both tracks are located to one side of the street. Care must be taken to pedestrians that wait at the end of the station to cross the street are aware of train and do not block tracks. With side platform and continuous sidewalk between the roadway and the adjacent tracks, curb parking can be located along the side of the street. The station or buses can stop adjacent to station platforms, making for a direct transfer between LRT and bus. Access to adjacent properties is not limited by this arrangement, and the layout of the street and turn lanes is flexible.

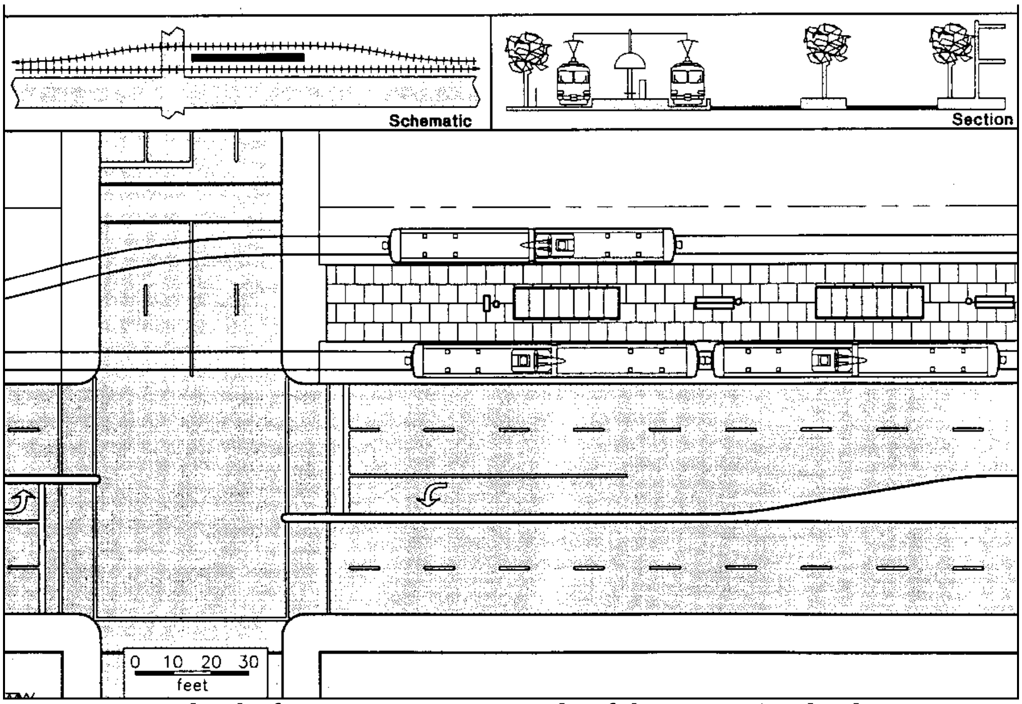


Figure 43. Side platform station on one side of the street. (Walmsley D.A, 1992).

Here only one lane has a left turn over the tracks and they have the same generous spacing as in the case of figure 40 and figure 41.

8. *Mid-block station*

Most of the arrangements presented for stations in intersections may also be applied at mid-block locations. A mid-block station may be located where a major trip generator or pedestrian route lies between intersections. A mid-block station also avoids the congestion and competition for limited space found at intersections.

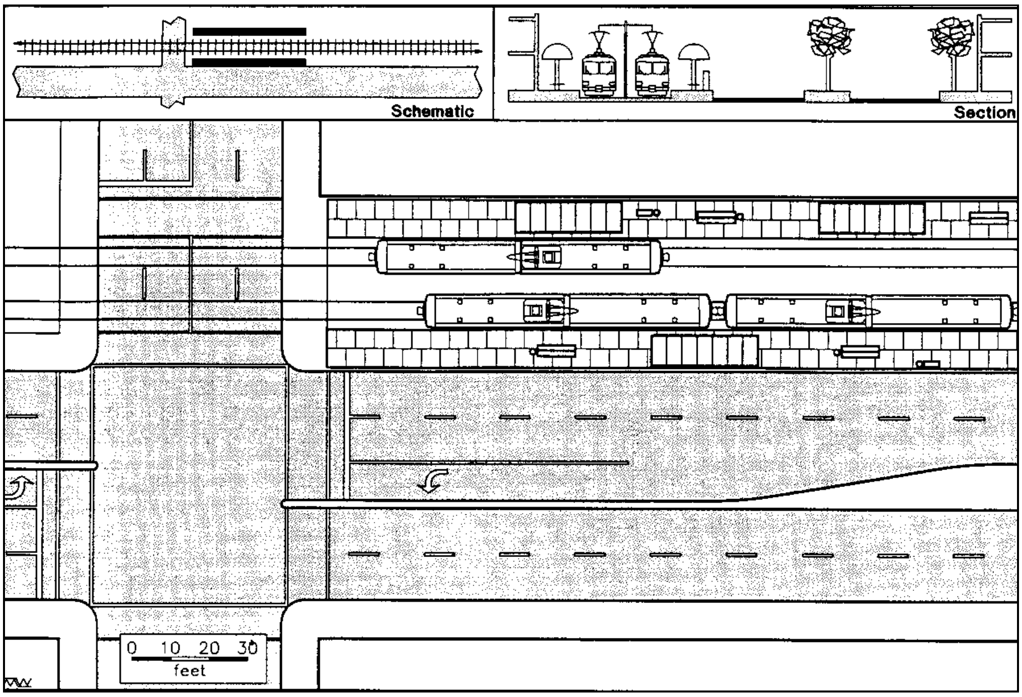


*Figure 44. Mid-block station. (*Walmsley D.A, (1992).

This kind of stop has the same advantage as in the case of figure 42.

9. *Stations in pedestrian area/malls*
   Closing a street to general traffic and developing a transit/pedestrian mall is the ultimate way to minimizing pedestrian-automobile and tram/LRV-automobile conflicts. This option is useful where traffic can be diverted, where pedestrian volumes are heavy, or where available space is limited. A transit mall may be limited to LRVs, or may allow buses to share the same roadway and station facilities.

   It is important for the safety that the track area is covered or in some way different from the surroundings, so the pedestrians is well aware that there is a track and there will come a LRV. To use lights and bell is certainly an effective way to catch the pedestrian awareness but it can also ruin the atmosphere in the mall or pedestrian area.

According to the operators in our case study cities, there is no bigger problem with the conflict between pedestrians and LRVs, neither between pedestrians and cars. The accident statistics they have given us shows this to be correct. The number of accidents between LRV and cars are at least four times higher than the accident with pedestrians, (Zurich). In the case of Saarbrucken the quota is 15, according to the information we received from them. The city of Mannheim haven't left enough precise statistic for this comparison, but the officials from MVV, (Mannheimer Versongungs- und Verkehrsgesellschaft), claims that the most number of accidents occurs between cars and LRVs/trams. (Mr. Rabe)
The largest problem is the conflict between LRVs and cars.

5.1.2 Stretching (in pedestrian zones and busy corridors)

Pedestrian zones in the centres of German cities have a long tradition. In many cases the main routes of trams or buses go through these pedestrian zones. Pedestrians and public transport is in good coexistence. Of course, trams and pedestrians fit better together than buses and pedestrians, because trams are easier to be perceived owing to the rails. An explanation for this good coexistent is that, whenever a person steps on the rail they feel that a tram/LRV can and will come along the rails. To have a clear marked track area, contributes to this feeling. If this is the exact reason for the better coexistent between trams/LRV and pedestrian than between buses and pedestrians is hard to prove.

In Germany the maximum speed of vehicles in pedestrian zones is generally 7 km/h. Public transport usually gets an exemption to 20 km/h (Mannheim) or 25 km/h (Freiburg, Karlsruhe). Full separated tracks, running as ordinary trains on its own track, are the most safe, they have the least accidents and none interactions with other traffic modes. (Prof. Dr.-Ing. Topp, Hartmund H)

5.1.3 Crossings (at-grade)

It is here, were the officials from the different transit companies consider having the most accidents. The statistics shows this very well, especially in those cities were the tracks are fully segregated. The biggest problem seems to be the cars. In all case study cities the most common accident is between the tram/LRV and a car. In Zurich for example, the accident with cars is 91% of all collisions, and 45% of the total number of accidents. In Saarbrucken the accidents with cars stands for almost 100% during the two and a half years of operation. Very often the car driver have missed the signal or ignored them.

When there is a crossing, there should be a special lane for cars turning and passing the tracks. This can be very well seen in the different systems in the case study cities. Those case study cities with a lot of separated tracks have fewer accidents than those case study cities with a lot of shared right-of-way. The cities with more separated tracks have their most accidents in crossing between tram and car.
When designing a LRT system you should try to achieve to get all crossing to be perpendicular to the tracks, which gives them good sight in both directions. There should be at least signals in the crossings, maybe even some physical hindrances. The time for signals going on and off plays an important part to gain the car driver’s patronage. Because, if they don’t believe in the signals they will ignore them and drive over the tracks any way, this will result in accidents. This has been shown in Zurich where they have cut down on the time for signals with very good results. The car drivers believe in the signals and they know that when the signal is on the tram will show up in a few seconds.

5.1.4 Personal security

To keep and to gain patronage for a Light rail system it is important to have a high personal safety, and a feeling to be safe when travelling or waiting on a tram.
On board safety can be solved with surveillance cameras on board and phones for emergency situations.
It is at the stops were the most problems within personal security occur, it is here were the most crimes and assaults take place.

To create a safe stop or station it is important to have good lightning, because dark places makes people feel unsafe, at least the most people. The stops should be located in open places, it feels and it is safer to see and to be seen by other people. To have a kiosk nearby the stop is also a very good idea. The stops and stations in a Light rail system are often located on ground and this advantage should be used compared with a metro system.

The police should also play a important part in this work, to regular patrol the station and sometimes ride with the LRV if not the operator have trained staff for this kind of job.
There should also be some education of all the staff and passenger, what to do and how to react in the case of an assault or emergency.

If you are interested to read more about personal security, the author recommends a research paper, “Crime on mass transit in the U.S.”, written by Jim Nichols from University of Minnesota, USA, which deal with this matter.

5.2 Safety evaluation of tram/LRT system

5.2.1 Vehicle-kilometre

When you evaluate the safety within a tram/LRT system there is a couple of issue that you have to keep in mind. From the pedestrians and other road users point of view, it is the vehicle-kilometre accident rate that is important. The risk of injury depends on the presence of the light rail vehicles. But if light rail can give the same travel service with less number of vehicle-kilometres, then the exposure will be reduced and so will the risk of an accident.

5.2.2 Passenger-kilometre

For the passenger, it is the rate of accident per passenger-kilometre that is important. Because this gives the probability of be involved in an accident as a passenger on a given journey. But the rate will not account the fact of how severe the accident is. Furthermore the rate of accident per passenger-kilometre also gives a measure of the social/community benefit per accident, i.e. how many people can travel per accident.

5.2.3 Severity

None of accident rate per vehicle-kilometre or accident rate per passenger-kilometre gives a measure about how severe the accidents are. It is a well-known fact that the accidents with a tram/LRV usually get more severe than with buses. When making a deeper and broader research and safety evaluation it is necessary to have detailed accident statistics. This is something that very few operators have, so an idea is to compare the police accident statistic with hospital statistic. Which can give you a very good apprehension on how severe the accidents are.

5.2.4 Trends

There are always trends within traffic, this will affect the safety evaluation, no matter if it is increasing or decreasing. When looking on statistics for several years you have to view the statistic against a background of the trends in traffic. There can also be shorter terms of variation in accident statistics; these are often results of economical changes or e.g. drink-driving programs. One thing that is important to keep in mind when you compare buses with trams/LRV is that the trends are affecting them very similar.

5.2.5 Corridor effects

When evaluating a tram/light rail system you have to be aware of corridor effects. Because this can give a light rail system a higher accident rate. A light rail line is in generally built along a high traffic intensive corridor to maximize its economic viability. This implies that the light rail vehicle carries more passengers per vehicle-km, and (depending on the track alignment) encounters more pedestrians and other road traffic, than would be the case on other corridors, which continue to be served by buses. Light rail therefore operates in a corridor where the risk of accident is higher than elsewhere.

5.2.6 Transient effects

Transient effects are something that can occur when you have built a new line or system. It consists of a higher number of accidents during the first year of operation. The number of accident will later on decline, after a year or two it will have reach a stabile number of annual accidents. The decline will appear not because of safety work, but of the facts of that drivers of other traffic modes have got used to the trams/LRVs, and the LRV drivers isn’t that skilful.

One important thing when looking on transient effects is that there should be no changes in the system to get as good result as possible. This is also the problem, because as soon as the operator finds out that there are some (e.g. crossings with) a high number of accidents they will try to do something about it. To get an approximate value of the transient effect you can always project the accident rate backward in time. In cities like Buffalo, the accident rate have fallen 30% per annum since 1987, this indicate that transient effects might last for several years. Transient effects have been discovered in cities like Grenoble and Portland.

5.3 Saarbrucken Safety

The system in Saarbrucken is a new build system with a lot of exclusive right-of-way and physical barrier, such as grass and fencing to prevent cars to drive on the tracks. In the inner city area there is some shared right-of-way.
Because of the fact that the system in Saarbrucken is new, the operator doesn't have any statistics over accidents in the system. They know that they had 15 accidents the first year and nowadays the accidents have decreased to about 6-7 accidents per year. (Mrs Del Savio, Saarbahn)

The first year they had 15 accidents and about 1 million vehicle kilometre, this gives a rate that is 66 666 vehicle-kilometre per accident. It have dropped to 6-7 accidents per year with the same number of vehicle kilometre, this gives the rate of 142 857 vehicle-kilometre per accident. There has been a cut down on more than 50%; the question is how this can be explained.
One explanation could be transient effects, and it has probably something to do with it, and it would have been very interesting to do a minor research about this. This is not possible because the second explanation, they have rebuild three crossings.
The three crossings they rebuild had more than half of the accidents during the first year.

In one of these crossings, there was a major signalling error and intersection design error. The intersection is located just along the tracks. When coming from west and driving to east you will drive through the intersection and after just a couple of meter comes the crossing over the tracks. The problem was that drivers got a green light for the intersection and missed that they had red light for the crossing over the tracks. This is not all; to this there is also a house that deteriorates your sight when coming from west.
The other two crossings were without signals and left-turns over the tracks, they have nowadays signals and left-turn lanes.

5.4 Mannheim Safety

According to officials from the Transit Company in Mannheim they have about 3-4 mortal accidents in the system every year, but they don't consider this to be a problem, or having a safety problem anyway. (Dipl-Ing. Werner Rabe)
The total number of accident in 1997 was 158, but there is a decrease in accidents. Looking back in time you will see that there were more accidents.
In 1997 there was 158 accidents and there was 4 744 575 vehicles-kilometres giving a rate on 30 029 vehicle-kilometre/accident. In 1965 there was 669 accidents and 6 770 064 vehicle-kilometres giving a rate on 10 119 vehicle-kilometres/accident.

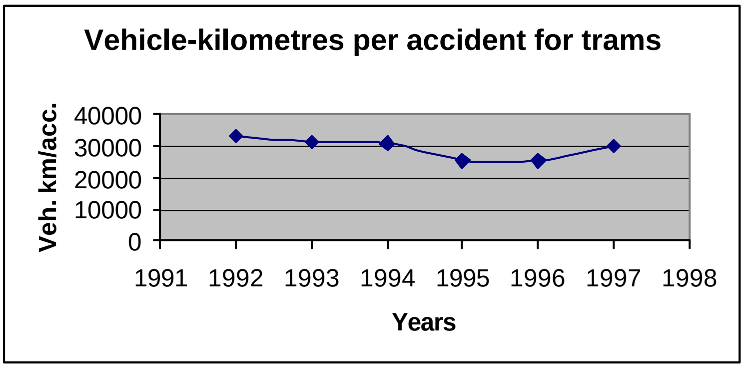


Figure 45. Vehicle-kilometres per accidents for trams in Mannheim

When you compare accident statistics from Mannheim with statistics from other German cities with new systems you will find that they have very higher number of accidents. The explanation for this is to find in the type of separation. The system in Mannheim has many stretching with shared right-of-way. This lead to many conflicts between cars and trams fortunately the accidents are not so severe, this because of the relative low speed, especially for trams. Many of the accidents would be mortal if it had been a heavy train in full speed.

The accident statistic for trams can be compared with buses; they have gone from 180 accidents in 1965 to 52 accidents in 1997. During the same time the vehicle-kilometres have decreased from 5 101 099 km to 3 273 000, this gives that the vehicle-km/ accident have increased from 33 340 to 62 896. The quota for buses is twice as high as for trams.

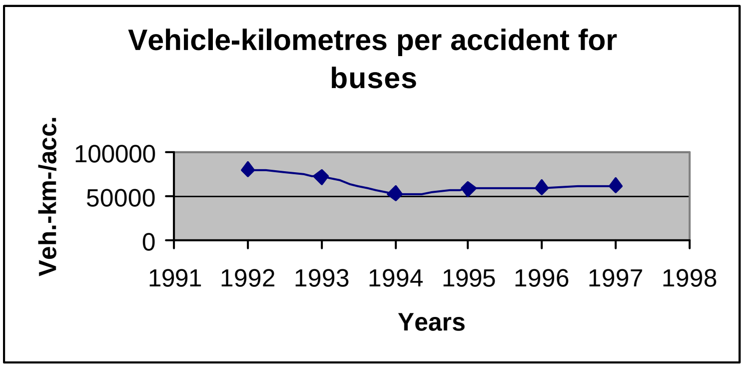


Figure 46. Vehicle-kilometres per accident for buses in Mannheim.

The diagram shows that buses have a better safety calculated on vehicle-kilometres, and in Mannheim's case the rate of vehicle-kilometres/accident is twice as high as for trams. But is not really fair, we have to take the number of passenger in the calculation. Than will find that tram have a better rate than for buses. The explanation for this is of course that trams take more passengers per ride, approximately four times more passenger. This has to be more reasonably, because we have to look on which use/benefit the operation gives to the city.
In this case it have to be defined through the number of passenger it will serve.

The exact figures for Mannheim's trams is 220,1 million passenger-kilometres in 1997, and for buses it is 49.3 million passenger-kilometres in 1997. Approximately this is a bit more than 4 times higher. If we divide the number of passenger-kilometres for each transit mode with the accident number for each transit mode we will get a measure of safety for the passenger. For trams that will be 220 100 000/158 = 1 393 038 passenger-kilometres/accident.

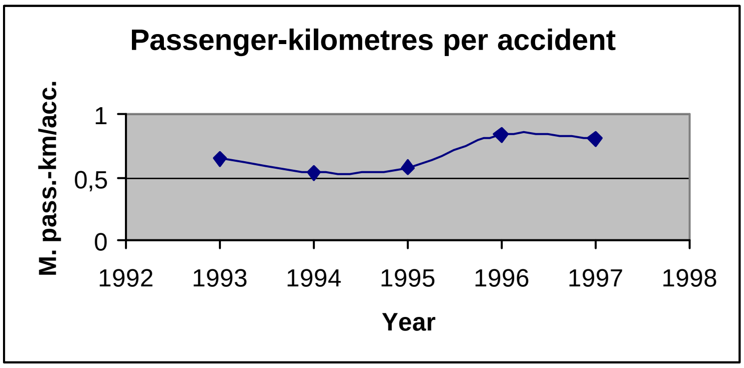


Figure 47. Million passenger-kilometres per accident for trams in Mannheim.

And for buses if becomes 49 300 000/52 = 948 077 passenger-kilometres/accident.

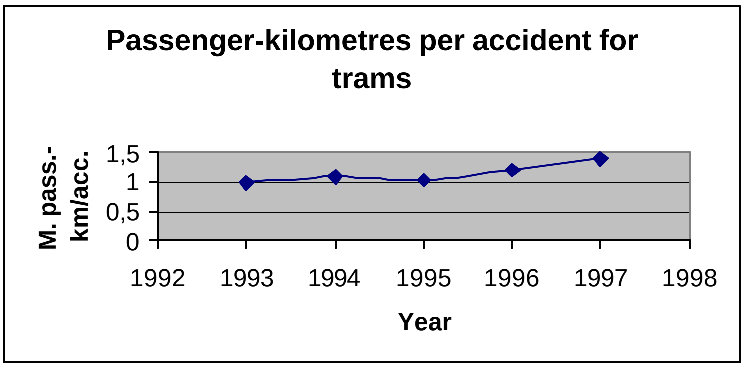


Figure 48. Million passenger-kilometres per accident for buses in Mannheim.

The quota for trams is almost 1.5 times higher than for buses, or so to speak 50% safer. So when looking to the number of passenger-kilometres the trams is safer.

It have been hard to evaluate if there is any corridor effects, it's most certain are, when the inner city area is served by trams and the periphery is served with buses. Any transient effects are not likely to be present in Mannheim, there are no new lines and it is an old system.
We haven't got any information about the general trends within traffic safety in Mannheim so any discussion about trends would be speculations.

5.5 Zurich Safety

The tram system in Zurich is an old system, with a lot of shared right-of-way. Buses are operating in the periphery and also trolley buses are operating in the surroundings. Both buses and trolley buses have some routes into the city centre area.
The information was received from, VBZ, the Transit Company in Zurich, is the accident statistics from 1993 to 1998. The number of accidents is the total number of accident divided into different types of transit mode. Unfortunately only vehicle- and passenger-kilometres for 1998 were received. Out of this we can still make a comparison between the different types of transit mode, but just for 1998. A general look on how the total number of accidents has developed was made.

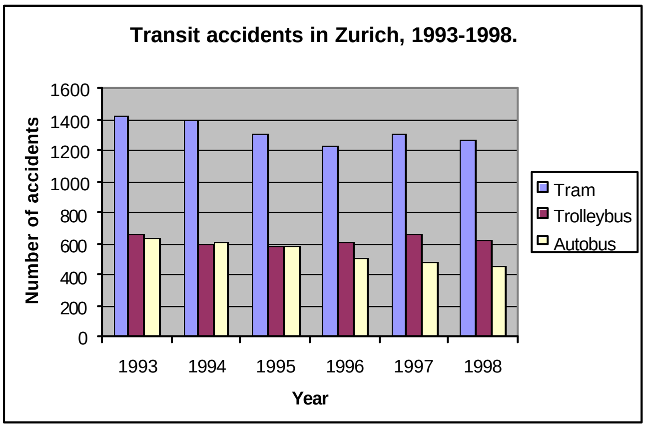


Figure 49. Accident statistics for transit modes in Zurich, 1993 to 1998.

During these years accidents for trams have decreased with about 10%, for the trolley bus it is about 6% and for the autobus it is 30%. The decrease for trams and trolley buses seems to be quite normal. In the case for autobus, it must exist some other explanation than it just follows the common traffic trend. The VBZ have probably made some changes within the autobus system, most likely drawn one or two auto bus routes to the outside of the city.

Let's make the comparison between the different types of transit modes according to vehicle- and passenger-kilometres during 1998. Here we have to put trolley bus and auto bus together, this because VBZ have put the statistics for them together.
The tram had 18,228 million vehicle-kilometres, 331 million passenger-kilometres and totally 1269 accidents. This gives a rate on 14 364 vehicle-kilometres per accident and 260 835 passenger-kilometres per accident.

The buses had 10,375 million vehicle-kilometres, 159 million passenger-kilometres and 1076 accidents. This gives a rate at 9642 vehicle-kilometres per accident and 147 770 passenger-kilometres per accident.

According to this the tram is safer than the buses in both vehicle-kilometres per accident and passenger-kilometres per accident. The quota in passenger-kilometres is 1,77, or 77% safer. As mentioned earlier, this is just for 1998.
In the case of Zurich we can have a look at the severity differences between buses, autobuses and trams. A comparison between the numbers of fatal accidents with the total numbers of accidents shows that, with statistics from 1993 to 1999, during this year's trams have totally had 10646 accidents, trolley buses have totally had 5117 accidents and autobus have totally had 4465 accidents.
Of 5117 accidents trolley buses haven't had a single fatal accident, the auto bus have killed 3 people on 4465 accidents which gives a fatal quota on 0,067%.
Trams have killed 25 people on 10646 accidents; this gives a fatal quota on 0,23%.
In a smaller severity test in Zurich for the three different types of transit, it seems that it is the tram that gives the most severe injuries, which was not so unexpected.

In 1989 there was an analysis made on the accidents in Zurich, (Brändli and Kobe, VBZ 1989). They found that 60% of all severe accidents occur at stops, with about twice as many when the tram was stopping/arriving to the station as when it was starting/departure.

5.6 Strasbourg safety

The system in Strasbourg is the most recent build system among our case study cities.
This is also the reason why the statistics over the safety in Strasbourg is so poor.
What we know, is that there have been two fatal accidents in Strasbourg, one was suicide the other was an accident with a bicycle. This is what we been told. (Mr. Muller)
When looking on how the system in Strasbourg is constructed, you will find a lot of exclusive right-of-way with standard stops and reasonably crossings.
The only conclusions that can be made about the system in Strasbourg are that it should have a good safety.
One thing that can be mentioned is that the LRVs have a lower speed in the system in the beginning to make it easier for the inhabitants to get used to the LRVs. These of course to prevent, hold back, on the transient effects.

5.7 Karlsruhe Safety

There cannot be any deeper analysis of the safety within the system in Karlsruhe. This is because of the lack of information from the operator in Karlsruhe. The accident statistic is classified information, a decision made by the local politicians.

One can only wonder, why the statistic is classified. If you look at their system, it is like most of the other system we have looked on, i.e. within the central city area. Outside it runs according to the “Karlsruhe model”. Of course with an increasing number of vehicles running on the same tracks there will be an increase of potential accidents. But imagine a heavy train smashes a full LRV, a nightmare scenario. If it had happened, there would have been on the news, which leads to the conclusion that it hasn’t happened. There might have been safety conflicts, but this is something we know nothing about.

There have been suggestions that the accident statistics have been classified because of the business with the “Karlsruhe model” and it’s importance for TTK. This make’s no sense, because, the most accidents in every system occur in the city area, where the “Karlsruhe model” not is amplified. So this explanation doesn’t hold, the system in Karlsruhe should have the same statistic as the others cities with similar systems.

6. Conclusions

6.1 In general

The tram/LRT system play an important part in the cities where it exists. In some cities the inhabitants are very proud over “their system” and in many of these cities they identify very strong with their tram.
A Tram/LRT system takes a lot of space within a city, but not compared with the space needed if the same amount of people would travel by cars. Tram/LRT systems are not the solution for the major cities as the major transit mode; there it fits more like a complement to metros, bridging the capacity gap between buses and metros. In middle-sized cities it can work perfectly well as the major transit mode complemented with, or without, feeder buses.

6.2 Environment

Trams are good for the environment for 6 major reasons.
- The energy consumption for tram operation is much smaller than for both bus and cars calculated per personal kilometre.
- Trams run on electricity, which produce less pollution than vehicles driven on fossil fuels.
- Trams work well in an urban environment; they don’t cause barrier effects and offers a convenient and effective transports mode.
- The land use of a tramline is much smaller than a road and since land is one a cities most valuable resources this is important.
- Trams do not cause congestion.
- By replacing diesel driven buses with trams in a city one reduce the amount of pollutions that harm buildings and statues.

6.3 Safety

Tram/LRV is safer than buses in many ways. Measured in passenger-kilometre per accident the tram/LRV is safer than buses but when it comes to vehicle-kilometre per accident it is getting more equal. But if the tram/LRV can provide the same service as the bus but with fewer vehicle-kilometre than the number of potential accidents will drop. The exposure for pedestrians will be smaller and so will even the risk of being in an accident with a tram/LRV. If the tram/LRV can meet that demand, than you can say that the tram/LRV is safer than the bus in general.

How can one build and create a safe tram/LRT system?
Well, the first and most important issue is about right-of-way. An exclusive right-of-way is the safest form of right-of-way. This stands clear when comparing system with different types of right-of-way.

The second issues that have to be addressed are the crossings. They should have signal and be perpendicular to the tracks. One should try to avoid left turns over the tracks, this is of course not possible to totally avoid but try to keep it to a minimum. When there are left turns over the tracks, one should try to give them an own lane.

7. Discussion

7.1 In general

It seems, wherever there are trams, the inhabitants appreciate this transit mode and in many cities they identifies their city with it. It becomes a natural part of the urban environment, a part of the city. The authors to this thesis have been riding with trams/LRVs during the spring of 2000, and are both convinced that this transit mode is superior to, for example buses. It is more convenient to ride with a tram/LRV, one have more space and it travels more rapidly than the buses. Sure, during rush hour, this transit mode is crowded, but we never felt this to be inconvenient. But, there is one thing that should be added; it is the yearly use of a transit mode that gives the real answers to how convenient a transit mode really is. This is something that the authors not have any experience and knowledge about.

7.2 Economy

Only Strasbourg has revenue among our case study cities, it shows that there isn't any profit to be made in transit. There is revenue for the inhabitants and they are paying for it because the revenue from heat and water business covers up the losses for the transit companies. This is something that we should try in Sweden, unfortunately, it is forbidden through the "Kommunallagen"; this is something that someone should take a look at.

There is obviously something wrong with the cost-benefit analysis, when every study shows that it is not economical for the society to build LRT systems. Imdad Hussein, who is a researcher from VTI that works with cost-benefit analysis, supports this opinion. If there should be any future for LRT systems in Sweden something have to be done about the benefit side of the analysis.

7.3 Environment

The most surprising thing that we discovered was that trams use almost as much energy per passenger kilometres as for cars. Most on the energy consumption for trams came from the construction of trams and tracks (indirect energy). But still with high indirect energy consumption the amount of pollutions are low. We have not found an explanation for this, sure the work like transports and cement foundation use a lot of energy but they also produce a lot of pollution, which is not produced by the tram construction. The manufacture of rails could be the solution but since express train has lower indirect energy consumption this seems not to be the solution either. See figures for pollution in appendix 1 and energy consumption in chapter 9.3.

Trams seem to have a very low barrier effect for pedestrians, which make it an ideal transportation mode in cities. By replacing some car lanes with tram tracks one also gain space for pedestrians. This is hard to do with buses since the understanding for special lanes for buses are lower among car drivers than for tram tracks. Another thing that is advantage for trams is that it uses a small land area in comparison to how many people it can transport.
A new tramline gives a good opportunity to redesign a city and make it more beautiful.

7.4 Safety

Of course one starts to wonder about the safety in the “Karlsruhe model” when the accident statistic from Karlsruhe is classified information. But as mentioned earlier in this thesis, if there would have been a major accident, it would have been on the news. But we don’t know anything about the number of conflicts.

In general, a lot of the transit companies don’t consider the safety to be any problem, not officially any way, and sure, they have fewer accidents than other transit modes and provide a very good service to the inhabitants. One can understand that, a city like Strasbourg, which only has two lines, a lot of exclusive right-of-way and following few accidents, don’t pay so much attention to safety, but a city like Zurich should work harder with safety. They have about 1200 accidents per year; sure this is something the inhabitants accept but why not try to do it better, to improve the safety within the system.
It is hard to push for tram/LRT for its safety when the trolley buses in Zurich haven’t killed a single person during the last seven year, under the same time the tram have killed 25.
This is one of the biggest problems with trams, the severity in accidents, and this is something, fortunately, VBZ is working with. How much and how hard is not known for the authors.

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Study visits

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Mr. Kuhn, KVV Karlsruhe,
Mr. Muller, CTS Strasbourg Compagnie des Transports Strasbourgois
Mrs Del Savio, Saarbahn Gmbh Saarbrucken,
LRT Workshop 2000 March 20th-24th

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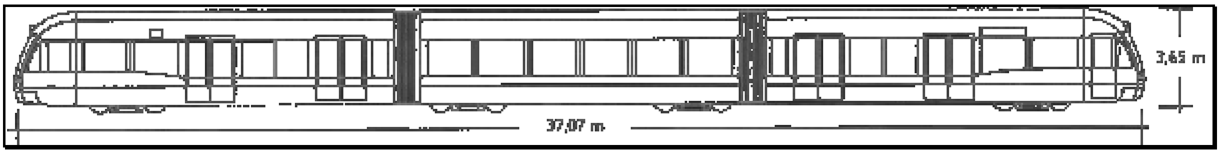
http://www.adtranz.com
http://www.bombardier.com
http://www.saarbahn.de
http://www.lrta.org
http://www.vattenfall.se

Appendix 1- Rolling stock of Saabrucken

Technical Data

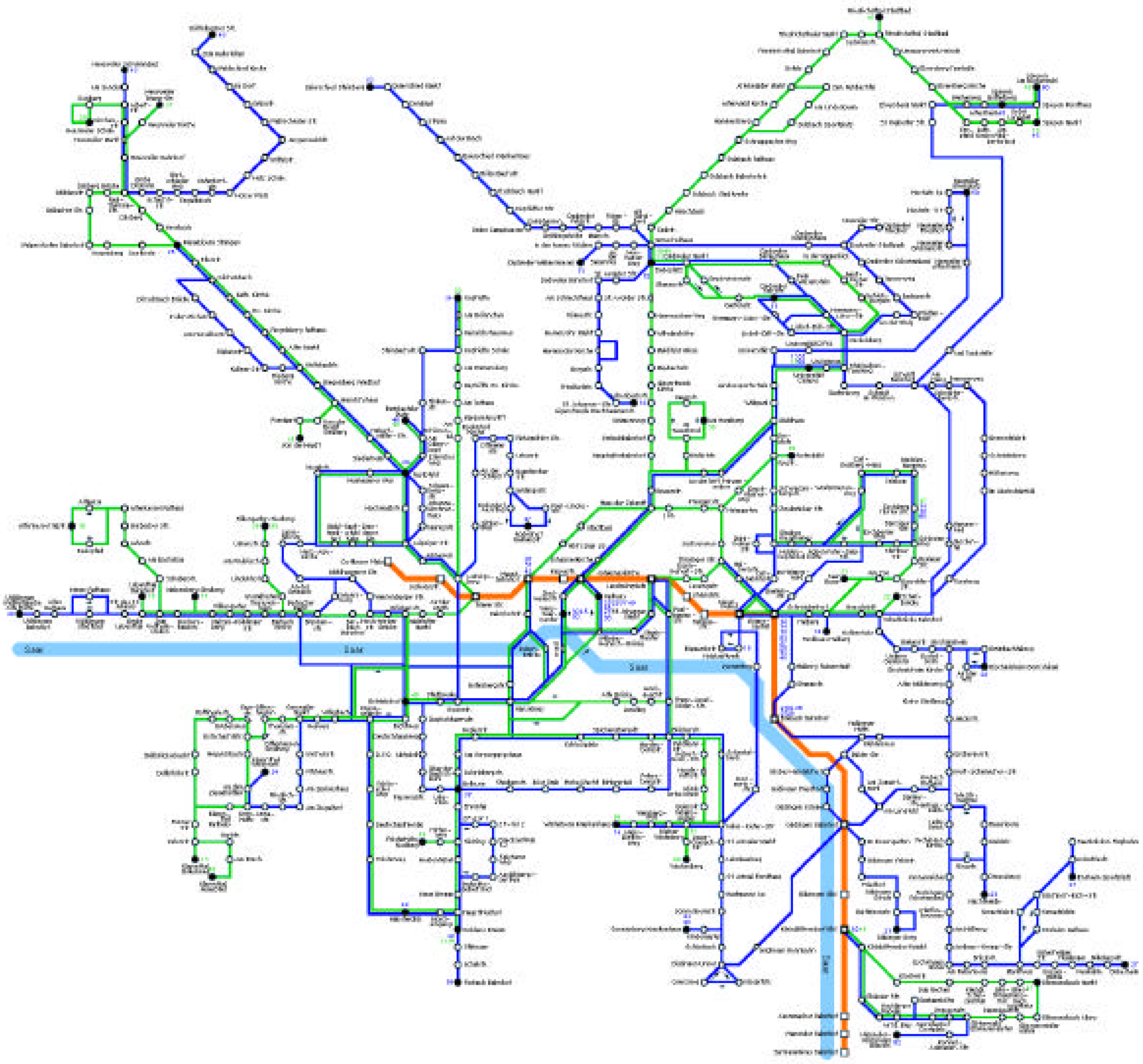
Bombardier Tram-train

Length	37 m
Width	2.65 m
Height	3.10 m
Net weight	55.4 ton
Nr of seating places	96
Rated capacity (4p/m^2)	243
Max speed	100 km/h
Average acc.	1.1 m/s^2
Max. Deceleration	1.6 m/s^2
Engines	8 x 120 kW/80 Hz
Maximum Gradient	8 %
Track Gauge	1,435 m
Duo voltage:	750 Vdc and 15 kVac



Source: www.bombardier.com

Appendix 2 - Saarbrucken's network



Source: www.saarbahn.de

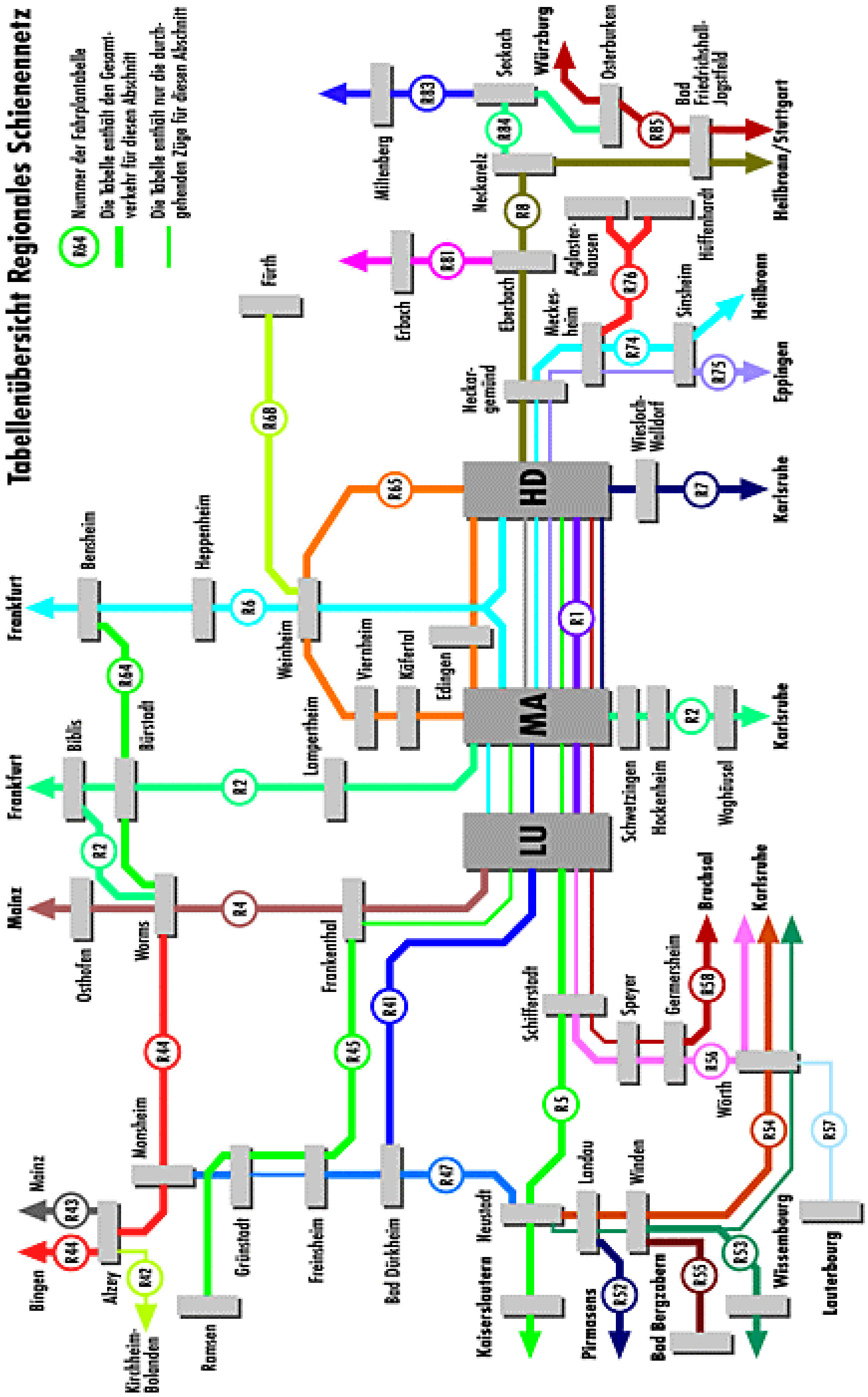
Appendix 3 - Rolling stock of Mannheim

Technical data

8MGT-LLDE by Duwag

Length	42.778 m
Width	2.40 m
Height	3.40 m
Track width	1.00 m
Net weight	48.65 ton
Nr of seating places	125
Rated capacity (4p/m2)	124
Max speed	80 km/h
Max. Deceleration	3 m/s^2
Engines	Four 95,5 kW motors

Appendix 4 - Mannheim network

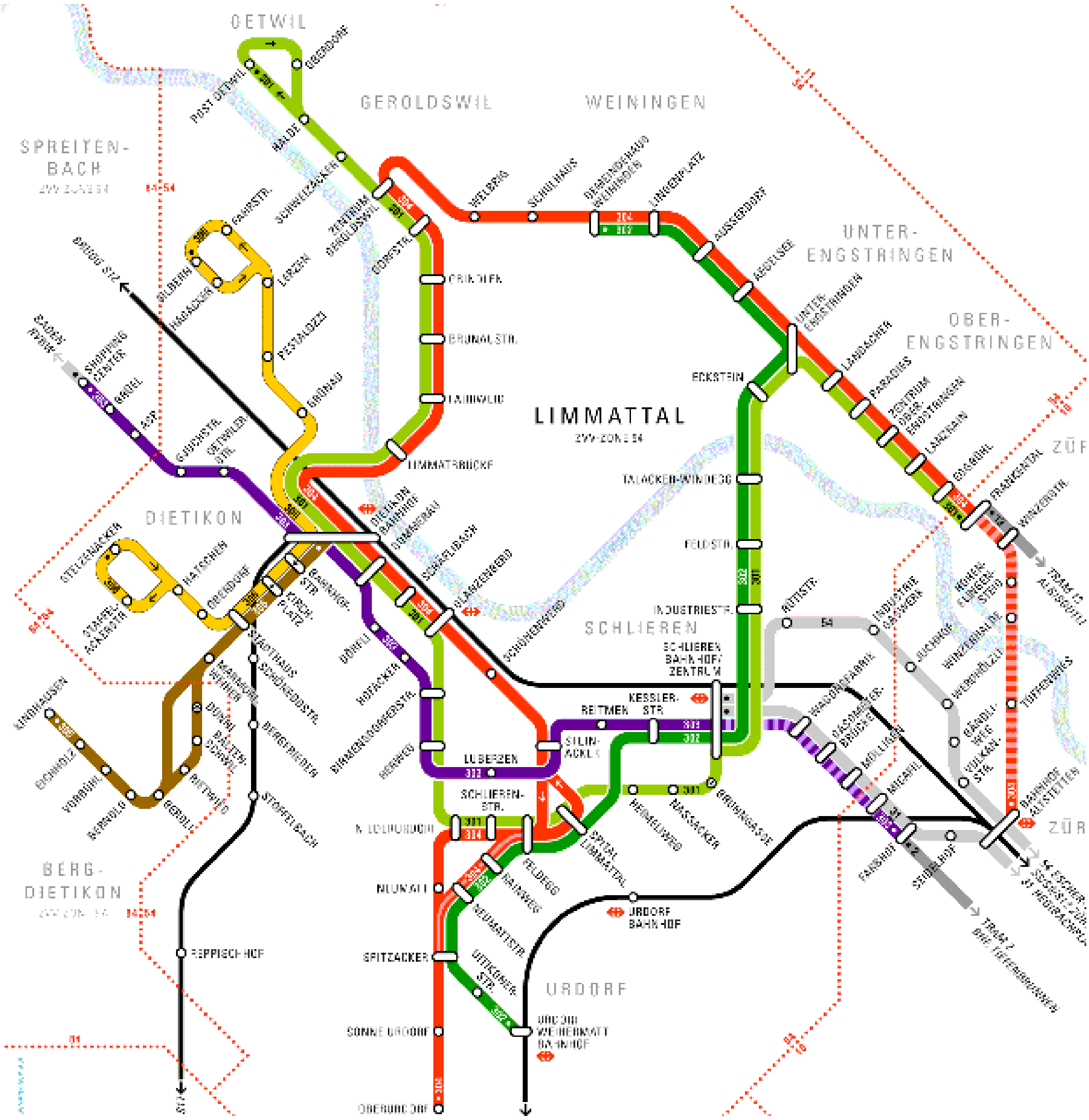


Source: www.mvv.de

Appendix 5 - Rolling stock of Zurich

Technical Data
Gelenkmotorwagen Be 4/6
Length 21.4 m
Width 2.2 m
Height 3.6 m
Net weight 26.5 ton
Nr of seating places 50
Rated capacity (6p/m^2) 157
Max speed 65 km/h
Track Gauge 1,0 m
Floor height over track, 0.83 m

Appendix 6 - Zurich's network



Source: www.vbz.ch

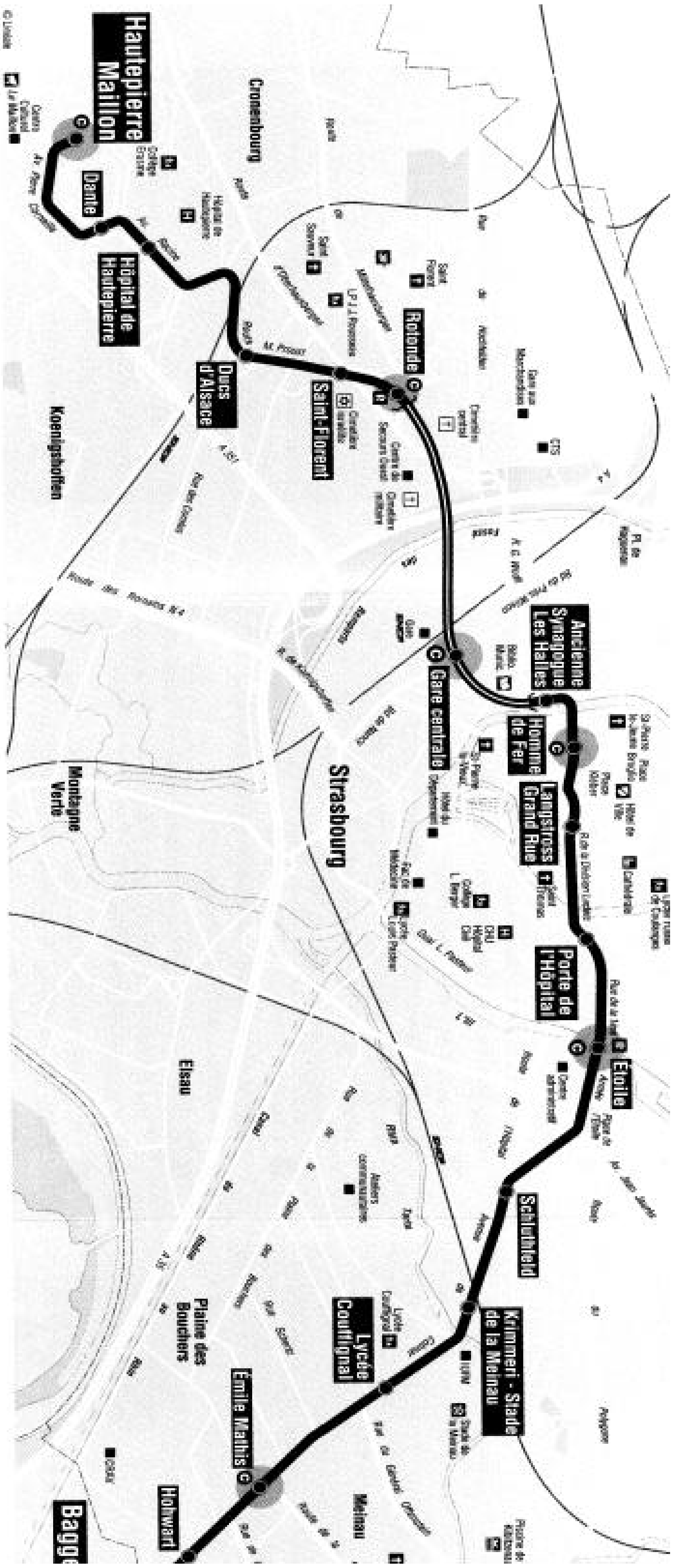
Appendix 7 - Rolling stock of Strasbourg

Technical data

Eurotram by Adtranz

Length	33.10 m
Width	2.40 m
Height	3.10 m
Net weight	29.15 ton
Nr of seating places	66
Rated capacity (4p/m2)	230
Max capacity (6p/m2)	290
Max speed	60 km/h
Average acc. >40 km/h	1 m/s^2
Average acc. >60 km/h	0.77 m/s^2
Max. Deceleration	3 m/s^2
Engines	Four 26, 5 kW (432 hp) motors

Appendix 8 - Strasbourg network



Source: www.strasbourg.fr

Appendix 9 - **Rolling stock of Karlsruhe**

Technical Data

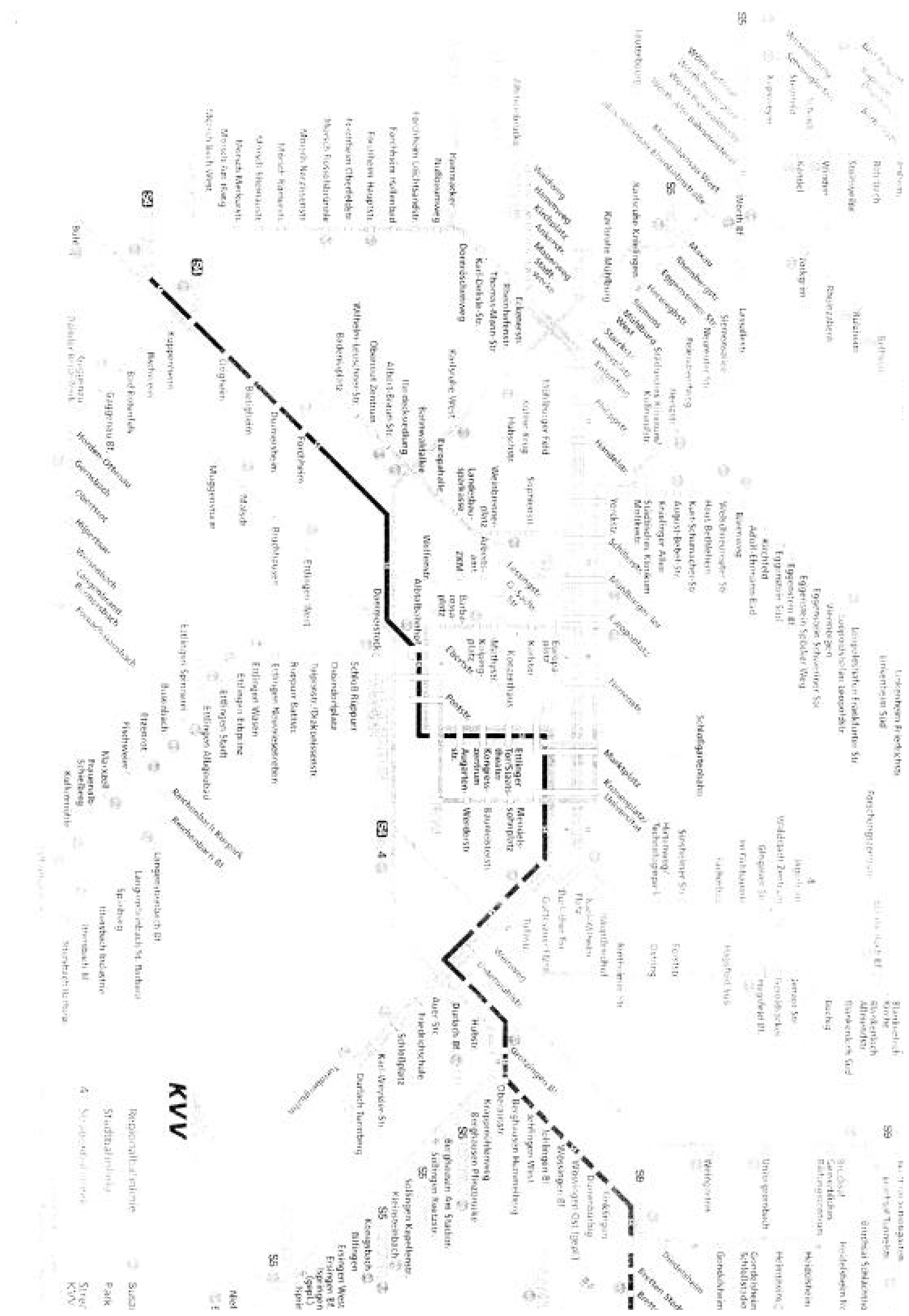
Siemens GT8-100D/2S-M

Length	36.7 m
Width	2.65 m
Height	3.3 m
Net weight	58.5 ton
Nr of seating places	100
Rated capacity (4p/m2)	223
Max speed	105 km/h
Average acc.	0.85 m/s^2
Max. Deceleration	1.6 m/s^2
Engines	4 x 127 kW/750 V
Track Gauge	1,435 m

Duo voltage: 750 V dc and 15 kV ac

Floor height over track,	0.88, 0.63, 0.89 m
Smallest turning radius	23 m

Appendix 10 **- Karlsruhes network**



Appendix 11 - Economy and Ecology are no contradictions
"Three messages from Zurich concerning the new transport policy"

The increasing significance of private motorized transport has kept our cities locked in a vicious circle for years. The blocking of roads and the lack of car parks are being counteracted by the construction of new roads and car parks and the extension of existing ones. The result is that even the new roads are blocked and the lack of car parks becomes even greater. A city becomes more unattractive, and this evil is once again dealt with by the most obvious means: with the construction of new roads and car parks! The transport policy of the City of Zurich has broken this vicious circle and transformed it into a "rainbow", a symbol of environmental protection and economic strength (Figure 1). The overflow of private motor traffic was answered not by increasing but by redistributing the existing road area in favour of local public transport and pedestrians. The result is greater urbanity, better environmental conditions, increased economic strength (!) and stabilized private transport.

The transport policy of the Council of the City of Zurich has 4 objectives:

- Promoting a change from the car to public, environment-friendly transport.
- Channelling motor traffic - creating quieter conditions in residential areas.
- Limiting the parking places for commuters.
- Reducing motor traffic in the city. This objective of generally reducing the motor traffic was first formulated with this stringency in 1987 under the impression that atmospheric pollution was increasing.

This transport policy is based on a recognition of the fact that, for physical reasons alone, it is not possible to make a city of half a million people accessible with the car. Car traffic takes up too much space, so that there is a danger that there will no longer be any city left after it has been adapted to meet the traffic needs. We are aware of similar examples from the USA.

In the interests of the economy, the quality of the environment and living and leisure standards, an above-average proportion of passenger journeys was assigned to public transport. An essential requirement for this is the provision of an attractive local public transport system and good conditions for pedestrians. Furthermore, because the individual citizen is not willing voluntarily to dispense with the use of his car despite a clear knowledge of the relationships, at the same time neither additional streets nor car parks were constructed. The objectives have been substantially achieved. A comparison of the distribution of journeys made over the various forms of transport shows that about twice as many journeys are made by public transport in Zurich than in comparative German cities; the proportion of journeys made by car is correspondingly smaller (Figure 2). The number of journeys per inhabitant per year still shows marked differences compared with other European cities (Figure 3).

First message from Zurich
If you ask the inhabitants of a town, which transport policy, should be followed, the citizens will not choose the car. They are much more intelligent, than politicians and other opinion leaders believe and have higher values than merely standing still in a traffic jam.

The answer to the question as to how it was possible in Zurich to convince the citizens of the advantages of a transport policy which gives preference to public transport in the existing road system over private motor transport is as follows: Politicians and experts did not have to persuade the citizens. On the contrary, the citizens themselves initiated this transport policy through several referendums and a public campaign, in opposition to the will of politicians and experts. In Zurich, the public must vote every public construction project that costs more than SFr. 10 million on. As long as 20 years ago a phenomenon emerged which has been very clearly developed by Brög Sozialdata Munchen, in the publication "Estimates of mobility in Europe" for the countries of the European Community:

- The citizens are very well aware of what has to be done in terms of transport policy: 84% would like to promote local public transport at the expense of private motor transport, 85% want preferential treatment for pedestrians and 73% want this for cyclists at the expense of private motor transport.

- The decision-makers (politicians, experts, etc.) do not believe the citizens to be capable of this insight. They believe that only 49% are in favour of promoting local public transport at the expense of private motor transport, only 43% want to give preference to pedestrians and only 30% favour cyclists.

- The citizens are also prepared to accept restrictions in the use of a car: 75% favour enlarging the pedestrian zones, 71% would like to see restrictions on car traffic and 53% are in agreement with parking restrictions.

- The decision-makers very considerably underestimate this willingness. They believe that only 51% are prepared to agree to enlarging the pedestrian zones, only 48% are prepared to accept restrictions on car traffic and only 36% are willing to see parking restrictions.

The question of course does arise as to why the citizens of these countries do not behave in a corresponding manner. The difference between collective reason and individual reason is evident here:
in a group, at a strategic level, the citizens are quite able to recognize the superior interest as their own interest and to decide accordingly - in questionnaires or in referendums. As an individual, when leaving the house early in the morning, only individual reason applies: a saving of 10 minutes or the greater convenience of using the car results in a decision in favour of this form of transport. Only when this has no immediate advantages (no available parking spaces, travelling time longer than with local public transport, more stress, etc.) owing to superior (individual decisions) does the attitude change, giving way to greater insight. No one would then seriously suggest replacing taxes with voluntary donations. We know very well that the fundamental (collective) view that taxes must be paid is not sufficient to overcome the short-term individual advantage of using the money for something "more intelligent".

The misjudgement of the citizens opinion and the underestimation of the citizens' collective reason by politicians and experts was corrected in Zurich by the necessary referendum: the citizens rejected projects for new roads and multi-store car parks and they refused investment credit for underground local public transport systems (underground tram, metro). On the other hand - contrary to the recommendation of the town council - they agreed with the public campaign which demanded giving priority to trams and buses in the existing road system and, by constructional and operational measures, ensuring that they are able to travel from stop to stop without delays, without interference from the car traffic and at the technically feasible speed.

The instrument of the referendum is very clearly responsible for the fact that transport policy in Zurich differs from that in towns where elected representatives of the public determine what happens. Brög (kleine Fibel) has an explanation for this phenomenon too: representatives of the citizens, politicians, are generally men aged between 20 and 60 and hence belong to that quarter of the population which uses the car to an above-average extent of 66% (average for all citizens 40%) and makes only 30% of journeys by public transport or bicycle or on foot (average for all citizens 49%). Expressed more simply, the quarter of citizens who travel by car at above-average frequency also make the decisions and, because they use their own needs as a measure of the needs of all citizens, they decide in favour of car traffic.

Second massage from Zurich

The future of urban transport policy lies not in expansion but in the intelligent use of the existing traffic areas. The objective of ensuring mobility for people when travelling to work and shopping and during leisure time requires imaginative urban traffic management based on modern information technology.

In a city, there will always be a shortage of space for traffic owing to the apparently unstoppable growth of private motor traffic with its enormous need for space. The expansion of these traffic areas through the extension of roads and car parks or the construction of new ones is extremely expensive and takes place at the expense of economically useful areas or of open spaces and is therefore in competition with other basic values of the citizen. If the traffic areas cannot be expanded, the popular request is not fully met. Coming to terms with this problem without economic and ecological losses means urban traffic management. Figure 8 impressively shows the different space requirements of 240 people who travel to work or to the shops by various means of transport. A tram transports about 8000 people per hour on one track, and a bus about 4000. Ten and five tracks, respectively, are required for transporting the same number of people in cars. Trams or buses do not occupy parking spaces in the inner city. An employee who travels to work by car occupies twice the useful area there compared with someone who uses public transport: like himself, his car requires about 25 m^2.

These physical facts explain why the growth in road systems and the construction of car parks cannot solve the traffic problem in the city. Accessibility for employees and visitors can be ensured only when a decisive proportion uses space-saving public transport.
If, as decided by referendum in Zurich, the citizens as taxpayers do not find it reasonable to replace the trams with expensive underground railways or find it more attractive if trams and buses travel through the urban streets in daylight in the interests of short walking distances, the high density of stops and high frequency in the timetables, the first requirement in the

management of the valuable traffic area is the priority for public transport in the existing road network.

Numerous analyses of the hindrance of trams and buses indicate three technical/operational instruments of urban traffic management, which permit this priority:

- Free travel, unhindered by private traffic, between the junctions with the creation of individual routes and separate bus lanes.

- Maximum preference for public transport at the junctions controlled by traffic lights through real-time detection of trams and buses with the aim of ensuring "Waiting Time Zero" for public transport.

- Introduction of the tram- and bus-operation control system so that, on the one hand, the drivers are continuously informed about their timetable situation and can therefore adhere exactly to the timetable, and so that, on the other hand, the operations control centre is always informed about deviations from the timetable and faults and can intervene in a corrective and helpful manner with prepared measures.

Travel unhindered by private traffic between junctions
The measures under this heading must ensure that trams and buses can overtake slow-moving or stationary lines of cars and quickly reach the next junction, so that the priorities provided there are effective. Furthermore, it is necessary to avoid the situation where cars turning left in the free sections or cars pulling out to avoid parked vehicles force trams and buses to brake or to stop. In Zurich, these measures have to be realized without extending the road area, either by converting an entire road section into a pedestrian public transport only area, or by eliminating the parking spaces along the edge of the road or by structural redesign of the road cross section with a separate track, etc. With this objective in mind, the following measures are among those implemented over the past twenty years: parking and stopping prohibited in 17 road sections. 41 bans on left turn in roads with tram routes. 72 "Give way" signs at intersections in roads carrying bus and tram traffic. 21 kilometres of bus lanes. About 40 building projects, such as islands for bus and tram stops, separate tracks, pedestrian zones with trams and buses, multi-track systems, bus lanes, etc. 2 newly constructed sections for extending a tram line by 2 and 6.4 km, respectively, with a separate track throughout.

Maximum preference for public transport at traffic lights
Modem urban traffic management requires not only clear priorities in the allocation of the available traffic areas but also modern operating systems which manage these areas and always maintain them in a state which permits maximum movement. A novel traffic light operating system is of key importance.

A very special traffic light operating system designed for active management of the limited traffic area was developed and set up in Zurich over the past twenty years. Typically, the work is carried out not by transport engineers but by electrical engineers that work according to the principles of operations research. The Zurich traffic light operating system requires about five times more hardware and five times more software than system usually installed in comparable European cities. 14 process computers, 2 central coordination computers and over 3000 SESAM detectors in the road surfacing permit completely dynamic signal program switching. The controllers do not contain any fixed signal plans but merely conditions relating to safety and priority. The signal sequence will be calculated at each point in time - on-line - on the basis of the many pieces of information from the detectors. All traffic lights are controlled centrally: the computers control 7 areas, each in a duplex system and with about 60 traffic lights. The traffic lights are combined in small groups of varying size and shape, depending on the traffic situation and are internally coordinated in terms of time.

Between these intersection groups are back-up spaces (intermediate storage areas) which make the groups independent of one another with regard to time. Coordination in terms of quantity is always guaranteed, to such an extent that the flow towards an overloaded group is restricted whereas the flow towards a poorly used intersection group is promoted. A central master computer coordinates the 14 area computers and serves in particular for storage of operational data, detection of system faults and continuous counting of the traffic volumes. Furthermore, the master computer serves to revise continuously the control programs, which can then be loaded into the traffic computers via the cable network connecting all traffic lights.

Conventional traffic light controllers serve two purposes: traffic safety and optimisation of the efficiency of an individual junction or of a group of junctions combined to form a green zone. If the traffic light operating system is to fulfil the objectives of urban traffic management, the following requirements also apply:

- Prevention of "overcrowding" of the road network by continuous counting of traffic area by area and metering of access to maintain the mobility of cars at a stabilized level. Every housewife knows that a washing machine must not be completely filled if a good result is to be achieved. The same applies to the urban road network.

- Preferential treatment of trams and buses through constant readiness to give them priority without delay when they arrive.

- Taking into account the importance of pedestrians by keeping pedestrian waiting times short.

- Continuous possibility of observing program sequences centrally and making program changes centrally and without great effort, so that it is possible to react rapidly and expediently to roadworks, diversions or traffic conditions altered in some other way.

Unfortunately, such an operating system cannot be simply bought, set up and left to function by itself. Industry offers no such controls at this time. They have to be developed afresh for every city; set up step-by-step and then operated. A very decisive factor is that one body in the city should be responsible for the entire operating system, including the fixed road signals and signs: planning, design, construction and operation are so closely intertwined that a permanent group - in Zurich there are 22 people, including 6 programmers - must be employed. The traffic light operating system set up in Zurich meets the requirements described to a high degree. It is very clearly superior to traffic light operating systems conventionally installed. Although the same traffic lights are present in the roads, they switch on the basis of more wide-ranging objectives and more complex, refined technology and with a result, which is evidently different.

The tram- and bus-operation control system

The second modem operating system is a high-quality management instrument with which the Traffic Manager can talk to every driver and to the passengers in every tram and every bus. The master computer of this system knows where these are located to an accuracy of 10 m. However, all the timetables are stored in the system, so that it is always clear whether a vehicle is travelling according to the timetable or, if not, how great the difference in the timetable is. The comparison of the actual and ideal situations is communicated continuously to every driver in his vehicle. He is therefore able to monitor himself. Conformity to the timetable and hence regularity can thus be considerably improved.

The tram- and bus-operation control system permits efficient fault management. The control centre has two manned, central positioned trams and five buses distributed over the network and can use these to replace a late or missing vehicle in the correct position in the timetable. Where accidents, processions, demonstrations, etc- block sections, the control centre orders diversions and - if required - organizes operation with extra buses as a replacement. In addition, the police, ambulances and technical assistants can be summoned very quickly when required. The aim of all measures is to eliminate faults rapidly and to limit their effects so that as few uninvolved people as possible have to suffer from them. The information provided for the passengers in the vehicles and at the most important stops of the Zuri-Line over loudspeakers connected to the control centre should not be forgotten.

In order to be able to maintain continuous operation of the tram network when sections are blocked or during authorized processions in the inner cities, some additional set-vice tracks, i.e. branching facilities, diversion sections and turning loops, were constructed. Thus, operations control is flexible and can also order diversions for the tram network.

With the tram- and bus-operation control system, the journeys by the vehicles can be stored and can be described in terms of certain evaluation criteria. These serve, for example, as a basis for the timetable or for evaluating trouble spots. Investigations of the situations before and afterwards show the effectiveness of improvement measures of a constructional or organizational type. The line and travel time files are also used for the timetable generation program, the results of which in turn forms the basis of the service plan generation program and the service plan disposition and salary bonus program.

Third massage from Zurich

With regard to urban transport policy, economy and ecology are by no means contradictory. Zurich is living proof of the fact that a transport policy, which promotes public transport at the expense of private motor transport, results in considerable economic development of the city.

The urban transport policy must provide optimal conditions for the development of the economy. It is vital to ensure accessibility for employees and visitors in sufficient numbers and under attractive conditions and to enable freight transport to be conducted economically. Whether the visitors come by car or by public transport is unimportant for the economic development of the city; a decisive factor is that they come and are restricted as little as possible in their freedom of movement. Unfortunately, it has been found again and again that private motor traffic bas a tendency to stifle itself. If its volume is not stabilised at a level, which corresponds to the efficiency of the urban road network (cf. washing machine), the result is congestion, and accessibility is no longer guaranteed.

The transport policy must also ensure that, when providing mobility, the negative effects on the environment do not exceed a tolerance level. Ecology in its widest sense means an environment worth living in, an environment that brings joy to the majority of those affected and in particular does not make them ill. Unfortunately, private motor transport is rapidly reaching the limit of tolerability from this point of view too. Although certain adverse side effects can be suppressed by technical measures, for example NO_x emission by means of catalysts, however atmospheric pollution, noise, the danger of accidents, etc. are unacceptable for the environment in the case of a major proportion of private motor traffic. The transport policy chosen in Zurich by the citizens themselves is clearly more advantageous from the points of view of ecology, quality of life and leisure time value. The greater the number of passenger journeys combined into large vehicles of the local public transport system the lower the risk of accidents, the less space required and the lower the level of emissions, and the higher the quality of the environment and the quality of life and of leisure time in the city. Less private motor traffic with the same or better accessibility means:

- Greater safety in traffic, less danger for children and the elderly,
- Less noise in residential areas and along important street sections,
- Roads and squares are used to a greater extent for social activity and play and are not so cluttered with cars from other districts,
- Better air quality and less danger to the health.

From economic points of view, it is first necessary to consider the benefit of mobility. There is no doubt that benefits can be obtained from an increase in mobility. It is just as clear that this increase gives rise to costs. Figure 1 shows how benefits and expenditure change with an increase in mobility: the benefits initially increase sharply and subsequently level off.

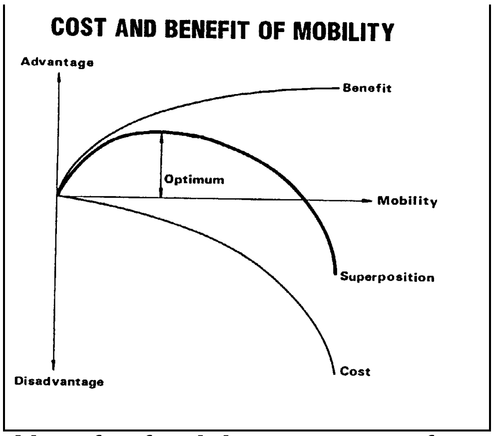


Figure 1. Cost and benefit of mobility. Source Prof. Rotach, ETH Zurich.

The expenditure shows the opposite behaviour: the initial increase in mobility costs little whereas further increases require higher and higher expenditure. If the two curves are superposed, it is evident that there is a region in which the cost/benefit ratio is optimal. To illustrate the cost/benefit ratio, three different approaches are shown Figure 2 in which initially the benefits in terms of the number of people transported are compared with the costs in money. Figure 2 shows that the cost/benefit ratio - expressed in francs per person per hour - is about six times more advantageous for an underground railway and almost ten times more favourable for a tram system on a separate route than the corresponding ratio for an urban motorway.

Cost: Transport corridor of 1 km length in mio £ Benefit: Capacity in persons per hour in one direction			
	Cost in mio £	Benefit in pers./h	Cost/Benefit
Expressway, 6-lanes	30	5'600	5'300
Metro (heavy rail)	28	30'000	900
Tramway, exclusive right of way	4,5	8'000	600

Figure 2. Cost and benefit ratio expressed in £/person per hour.

Figure 3 shows that the cost-benefit ratio for the development measures is eight times more advantageous for trams and buses and four to five times more favourable for the suburban railway than for the urban motorway network.

Cost: Expressway-network (not yet completed), S-Bahn (heavy-rail) system, and speed-up programmes for tram and bus, all realised in Zürich in mio £ Benefit: Capacity in persons per hour in one direction			
	Cost in mio £	Benefit in pers./h	Cost/Benefit
Expressway-network, without ring-expressway	750	15'000	50'000
S-Bahn Zürich	550	50'000	11'000
Speed-up programmes for tram and bus in Zürich	100	40'000	2'500

Figure 3.Cost and benefit ratio expressed in £/person per hour.

In Figure 4, it is assumed that all eight cities compared had the same conditions about 20 years ago: historic city centre, increasing concentration of jobs in the city centre and private traffic reaching the limits. All eight cities had a well developed tram network and had the same aim, which they have since achieved: the creation of an attractive reliable local public transport system. The three largest cities, Munich, Stockholm and Vienna, constructed underground railways, which was unavoidable in view of the large numbers of passengers to be transported. Four cities constructed light rail systems, which are comparable to tram systems in their transportation capacity but travel in tunnels in the city centres and leave the traffic space in the inner city road free for private motor traffic. The existing tram networks were removed. Zurich remained loyal to the tram and gave it priority in the allocation of the road area and in the operation of the traffic lights (and did the same for buses).

Cost:	Investments in transit-systems since 1960 in mio £				
Benefit:	Fast, regular, reliable transit				
Cost/benefit:	In £ per trip and £ per inhabitant				
	Investments in mio £	Trips per annum in million	Inhabitants in transport area in million	£/Trip	£/Inhabitants
Metro					
München	1'100	379	1,4	2,9	790
Stockholm	1'500	432	1,5	3,5	1'000
Wien	1'000	612	1,5	1,6	670
LR Rapid Transit					
Düsseldorf	700	170	1,1	4,1	640
Hannover	600	124	0,54	4,8	1'110
Köln	500	179	1,1	2,8	450
Stuttgart	500	139	0,56	3,6	890
Tram and Bus Zürich	100	306	0,55	0,3	180

Figure 4. Cost/benefit ratio comparison between different cities.

Even with all the problems of this comparison, it is quite clear that the investments in local public transport in Zurich have resulted in an excellent cost/benefit ratio with comparable quality of service: 4 - 11 times better, based on the passengers, and 2 - 6 times better, based on the residents, than in the case of the cities compared.

Economic data provide a valid answer to the question as to whether the transport policy is successful. And – surprisingly (?) - this answer is extremely positive for the City of Zurich. The economic strength of this city is unaffected.

- The Zurich land prices - which are a reliable yardstick for the profitability per unit area - are among the highest in the world.
- Switzerland has one of the highest gross national products; Zurich can be shown to be responsible for a significant part of this.
- The people of Zurich pay the state 30% of the gross national product in taxes and social security contributions. The inhabitants in neighbouring states on the other hand pay over 40%. Note: Transport policy is paid for from taxes.

Final considerations

The transport policy of the City of Zurich may be regarded as a model of an economic, environment friendly transport policy for a city with a population of half a million. The requirements of the Environment Protection Law and clean air regulations need no revision but consistent further development. The policy is based on management of the existing road system with clear preference for tram and buses, for which "unhindered travel without delays between the stops" is ensured and preferential treatment of pedestrians. It is the result of a long political process and is based on a freely chosen restriction of the requirements of private motor traffic in the interests of superior political objectives.

The fact that it is necessary to set limits to the free market economy in urban traffic and that the "free" car traffic destroys not only one's own freedom but also the quality of the environment and the economy are not new discoveries. Not so well known was the fact that, when backed up by the necessary political will and modern technology, the good old tram is a very up-to-date means of public transport which is very particularly valued by the passengers.

The Zurich model of an economic, environment-friendly transport policy proves that the redistribution of road areas and of green time at traffic lights in favour of trams, buses and pedestrians is not only an aesthetic idealistic aim but also a well-founded materialistic objective of a modern urban transport policy.

Appendix 12 - Karlsruhe Model attracts world-wide interest

The successful Karlsruhe track-sharing experience -- with light rail vehicles sharing DB (Deutsche Bahn) tracks with heavy rail traffic -- has attracted interest from far beyond Germany.
During 1984/1985 "track-sharing" by light rail and heavy rail vehicles in the Karlsruhe region was investigated in an initial study sponsored by the German Ministry for Research (Bundesforschungsministerium). This triggered the development of the so-called Karlsruhe Model.

This consists of three components
- A vehicle equally able to use regional DB tracks and light rail tracks in the city centre
- Connecting DB tracks to a tramway system, in the case of Karlsruhe, an existing network
- Building new stops on existing heavy rail lines which can be served without extending journey times, thanks to the improved acceleration of light rail vehicles.

The ultimate aim is to create direct connections without passengers having to change vehicles, as every interchange causes modal split losses making the public transport system less attractive. Converting this idea to reality did not prove easy during the years, which followed the initial studies, especially where the suitability of light rail vehicles -- in particular their safety -- on DB lines had to be proved.

These problems have been solved in the last years. Light rail services using DB tracks between Karlsruhe and Bretten commenced in September 1992 and the scheme has been a huge success, with a 500 % increase in passengers. Since the establishment of the Karlsruhe Verkehrsverbund (KVV) in 1994, light rail vehicles are now operating in a preliminary phase on DB's Karlsruhe-Bruchsal, Bruchsal-Bretten, Karlsruhe via Rastatt to Baden-Baden, and Karlsruhe-Wörth routes. And DB AG has made its own rolling stock investment in the project, acquiring four dual-mode GT8/2S vehicles, which it operates alongside those of Karlsruhe public transport operators VBK and AVG.

The Karlsruhe Model has attracted much interest both within Germany and beyond, prompting other cities to explore its potential. When considering the model, a fundamental question must be asked: does the region already have direct connections to the city centre without passenger interchange?

For large conurbations such as Frankfurt, München or Stuttgart for example, where there is already a metro in the shape of S-Bahn services, the Karlsruhe Model is less suitable. However, in large urban areas such as London or Paris, the implementation of tangential lines to connect regional sub-centres can be of interest.

Transferability does not mean adopting the Karlsruhe Model in all respects: the basic idea of providing through connections should be adapted to the specific conditions of the region. Use of the regional railway infrastructure and the linking of regional and city transport is what all projects have in common. The basic concept is the key: solutions must be adapted to specific local conditions.

Adopting the model is ideal where standard gauge tracks exist in the city as well as the surrounding region, and where the regional lines are electrified. However, this position does not always apply: quite a number of cities abandoned their tramway networks in the 1969s and are building new systems.

This may not be the disadvantage it might seem, as existing infrastructure can often be more of a hindrance than help. Even where other track gauges are in use, the Karlsruhe Model can be applied, for example linking meter-gauge tram networks and local lines. If different gauges exist, as is the case in Ulm, with a small city centre network, gauge conversion can be considered. In other cases, 3-rail tracks will allow the sharing of existing lines, a solution applied in Genève. Even 4-rail tracks can be used to combine heavy rail clearance restrictions with 2.3m-wide low floor vehicles, as the Kassel-Baunatal line demonstrates.

The Karlsruhe dual-mode vehicle is the first of its kind on the market. Without doubt low-floor developments will follow. Both the dual-mode vehicles for Saarbrucken and those recently ordered for Karlsruhe are examples of this. Both will be partly low-floor, and the last-mentioned will be equipped with a bistro-restaurant in the panorama middle section. Vehicle length and width can be selected according to specific conditions in the area, and this flexibility allows a city with a medieval centre, like Graz, to consider the Karlsruhe Model.

The type of power to be used is not fixed. Initial developments for a battery/direct current vehicle were abandoned due to a lack of suitable battery technology. A hybrid diesel/direct current vehicle is a potentially attractive solution for regions with little or no electrification. In Karlsruhe, the development of such a dual-mode vehicle has just started. Differing power systems in various European countries also require suitable solutions. Lastly, a power pack as is being used in Chemnitz could also be a solution for non-electrified lines.

Since 1990/91, following the success of the Karlsruhe-Bretten project, the transferability of the Karlsruhe Model has been actively discussed not only in Germany, but also in other European countries.

In these difficult financial times for cities and regions all over Europe, the use of existing and little-used tracks is preferable to the construction of new and often parallel tram lines. This however is dependent on local transport operators not having to pay track access charges which make the use of existing infrastructure more expensive than using their own newly-built lines.

The Karlsruhe experience has certainly been positive, and there are already several follow-up schemes in Germany:
- Saarbrucken is the most advanced system. Implementation started in 1995 and the first line has gone in service in autumn 1997.
- Heilbronn, a city of only 120 000 residents, will follow during the next few years. With only 8km of newly constructed tracks through the city centre, the light rail system will gain access to some 200 km of regional DB lines.
- Aachen took the political decisions to develop a scheme in the summer of 1995.
- Kassel is to use the tracks of a private railway with low-floor vehicles and 750V-dc electrification. A special solution here is the use of 4-rail tracks at stations to allow low-floor platforms outside of heavy rail clearances.
- Chemnitz will use low-floor light rail vehicles equipped with a power-pack for use on non-electrified regional DB lines.
- Dresden, with a gauge of 1,450mm, is investigating the possibilities of track sharing with DB by widening the latter's standard gauge tracks.

Kiel, Osnabrück, Paderborn, Rostock and Ulm are other German cities where the German Model has been an issue during studies, but where no political decision has been taken so far. Meanwhile, elsewhere in Europe, the model is being discussed in several countries, Austrian projects in Graz and St-Pölten have not yet been sufficiently developed for a definite assessment, but first steps have been made. What is possible for DB should not be a problem for ÖBB.

In Great Britain, the question of track sharing is being discussed for a number of schemes, such as Cardiff, the Medway Valley in Kent, Newcastle and Nottingham. The railway authorities seem to change their attitudes to the concept. In a country which private funding is the key term for public transport projects, and where German financing methods such as the local authorities transport-financing act (GVFG) are admired, the best possible use of existing infrastructure should be the first priority.

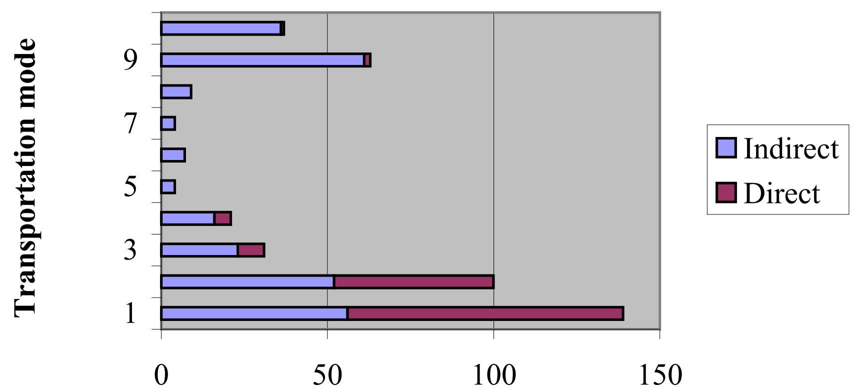
In France a few years ago SNCF discussed the use of the Karlsruhe Model in internal papers and confirmed its feasibility for certain selected lines. A number of cities and regions -- such as Ile de France, Marseille, and Valenciennes -- are beginning to think about this concept. In the Netherlands, studies into mixed tram and heavy rail use are being carried out in the Rijn and Bolenstreek region covering Alphen, Gouda, Leiden and Nordwijk. Similar work is being done in the border region around Maastricht, Heerlen and Kerkrade, which lies close to Aachen.

The state and city of Luxembourg has already decided to follow the Karlsruhe Model by introducing a new light rail system in the city centre and connecting this with the national CFL rail network. In view of frontier traffic into France, Germany and perhaps Belgium, a multi-mode vehicle will be one of the characteristics of this project.

Interest in the Karlsruhe Model has also been shown in Norway and Sweden as well. Examples where the initiative has come from national railways are more the exception than the rule, but Slovenian Railways' interest in such a scheme for Ljubljana is one instance. Soon other national railways operation is not only a matter for city transport authorities or non-national undertakings.
Compared with other solutions, the Karlsruhe Model seems to be a particularly attractive alternative for medium-sized cities and for regions of 200,000 to 500,000 inhabitants.

Appendix 13. Direct and Indirect pollution for different transportation modes

NHMC Emission



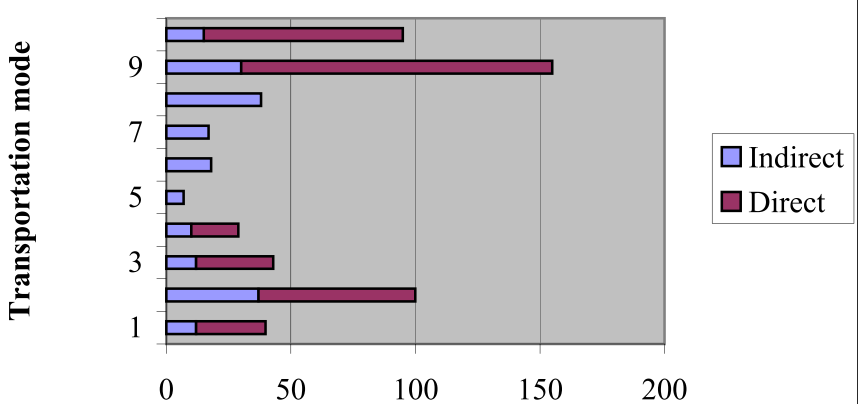
	1	2	3	4	5	6	7	8	9	10
Direct	83	48	8	5	0	0	0	0	2	1
Indirect	56	52	23	16	4	7	4	9	61	36

%

1. Motorbike
2. Car
3. Bus
4. Coach
5. Trolleybus
6. Tram
7. Express Train
8. Regional Train
9. Short distance jet plane
10. Long distance jet plane

Car = 100 % = 1.12 g/Pkm

CO2 Emission



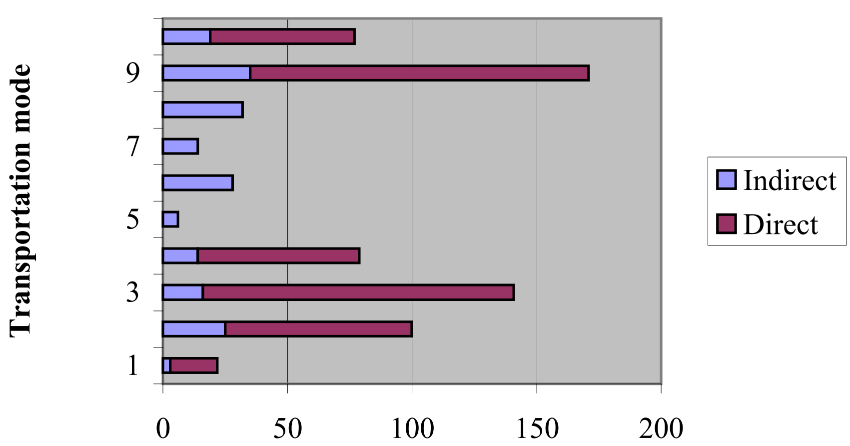
	1	2	3	4	5	6	7	8	9	10
Direct	28	63	31	19	0	0	0	0	125	80
Indirect	12	37	12	10	7	18	17	38	30	15

%

1. Motorbike
2. Car
3. Bus
4. Coach
5. Trolleybus
6. Tram
7. Express Train
8. Regional Train
9. Short distance jet plane
10. Long distance jet plane

Car = 100 % = 200 g/Pkm CO_2

NOx Emission



	1	2	3	4	5	6	7	8	9	10
Direct	19	75	125	65	0	0	0	0	136	58
Indirect	3	25	16	14	6	28	14	32	35	19

%

1. Motorbike
2. Car
3. Bus
4. Coach
5. Trolleybus
6. Tram
7. Express Train
8. Regional Train
9. Short distance jet plane
10. Long distance jet plane

Car = 100% = 0.74 g/Pkm