Modern Light Rail as a transport solution for large cities

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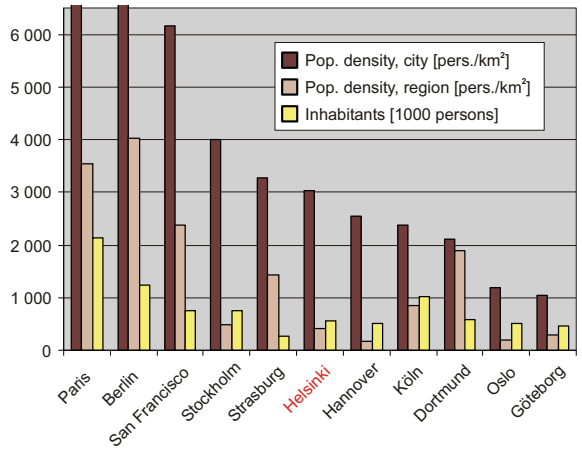
Introduction

Large cities are typically very tightly built in the city centres, which are surrounded with a large circle of suburban having much less buildings an population per area. This causes a problem for choosing a transport system. What is suitable in city centres – like underground metro systems – is too massive and expensive outside the city centre.

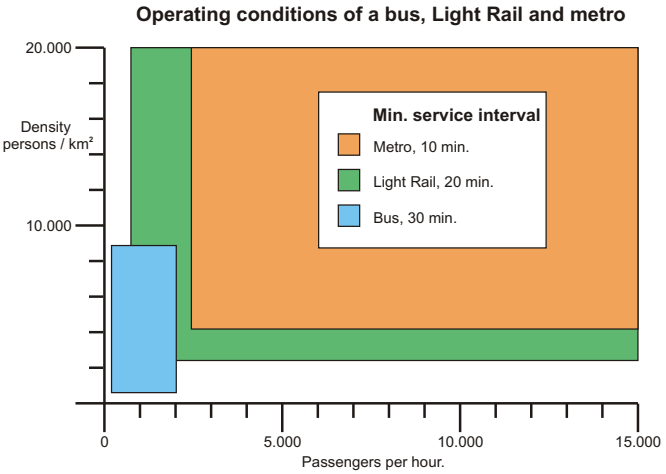


Population density in city centre and in urban area and total population in some cities.

This phenomenon was found in Europe and USA in 1960's, when private car traffic from suburban started to fill the cities. Very soon it was found, that the capacity of the street network is not enough for cars, trams and buses. Existing metro networks were able to manage the city transport where metros were already built, but were not suitable to extend outside the central city area.

As population density is the key factor for choosing a public transport system, the problem was, that the operation capacity of the traditional tramways (street cars) and buses does not overlap the metro's operation capacity. A bus systems capacity on one street is 2000 passengers per hour max, when a metro line is already uneconomical to operate at 2500 passengers per hour.

The solution was found in Germany, which did not destroy the tramway systems as had happened especially in USA and UK. Existing tramway systems were developed to fill higher standard than just a local bus like transport system on the streets. The benefits of a tram, metro and commuter trains was combined to one system. This kind of a tramway system was named as Light Rail in English.



Operating conditions of bus, Light Rail and metro system.

Light Rail generations

Stadtbahn – pre metro, 1970's

The first generation of new transport mode was Stadtbahn, that was designed to a form of a tramway line, that will later be converted to heavy uderground metro system. Final platform height would be the high one meter floor height of the rolling stock. Trains were able to operate on streets, but totally segregated right of way was the target.

Low floor rolling stock, 1980's

The principal of the segragated track was soon noted to become as expensive as traditional metro systems. Therefore the idea of segregated track outside the city centre was replaced with street level track using simple low platform stops instead of expensive high platform stations. To offer the speed and comfort of even level floor and platform, low floor rolling stock was generated.

Tram-Train – integration to trains, 1990's

To avoid unnecessary track building and boost up commuter trains economy, trams could be put to operate on railway track too. A wehicle to use both railways high voltage and trams

Tram-Trains in Germany. Tramcars operating on railway line from city of Karlsruhe. July 2003.

low voltage was designed. This flexibility for not requiring to change from a train to tram caused remarcable demand increase and cost decrease for commuting to cities.

Refreshing the cities, 2000's

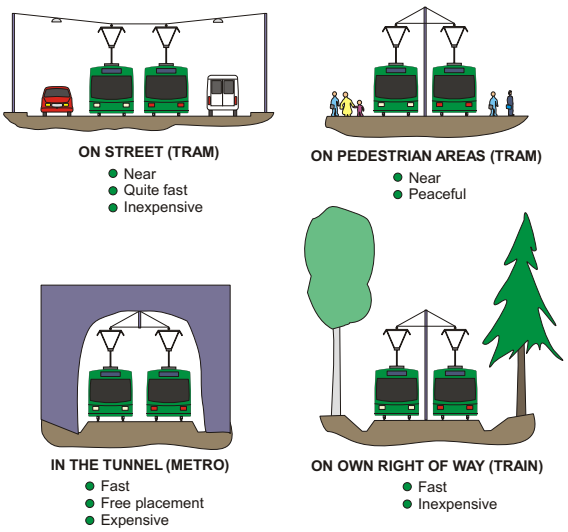
Cities with underground public transport were filled with cars the same way as the cities without well working public transport. As cars could not bring enough customers to cities, business started to leave the city with unpleasant streets filled with cars, not people. To build the track on ground reformed the city for pedestrians. Thanks to low floor and Tram-Trains, there existed a technology to bring people from large area straight to the doors of the shops and services.

In Strasbourg, France, the old city was converted to pedestrian area fed by two Light Rail lines. Business increased 30 %. July 2003.

Light Rail principals

Today the key word for high quality and economical public transport is integration. The modern tramway, Light Rail, integrates all modes of public transport into one system.

- 1) It works in the tunnels as a metro.
- 2) On the own right of ways it works like a train.
- 3) On the streets it works like a traditional tramway or a bus.
- 4) On the market squares and other pedestrian areas it works much like an old fashion slow streetcar or coaches.



Same four forms apply also for the cost of the public transport system. A Light Rail is expensive like a metro only when it is necessary to build like a metro, i.e. under ground. But also in this case, the construction is more flexible and there are many ways to save cost compared to traditional train like metro system. This kind of feature is the possibility to build the line immediately under a street. Then there is no need for the deep and large underground stations with escalators and lifts and also the on-ground station building. Elsewhere the cost of the line is similar to the cost of building a two-lane street suitable for bus traffic.

Light Rail technical specification

Specification for a modern integrated tramway system, a Light Rail:

- Overhead wire (catenary) current supply. (Metros usually have a third rail.)
- Train width max. 2,65 metres. Suitable for street traffic.
- Floor height app. 35 cm. from rail. Fast and easy access to train also from simple street stops.
- Trains capable for 20 metres curvature radius and gradients used on streets.
- Trains max. speed 80 to 100 km/h, acceleration and braking 1,2 m/s^2.
- Units capable to be coupled as trains operated by one driver.
- Rail geometry designed for smooth running using balance curves.
- Wheel geometry suitable for phoenix-rail switches on streets.

System capacity:

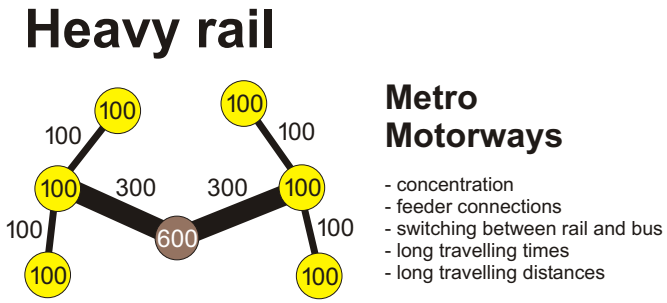
- Passengers per unit varies from 200 to 350 persons, of which seated 25 to 40 %.
- Number of units per train from 1 to 4, depending on the stop platform length.
- Train interval from 1,0 minutes upwards, depending on speed and security system.
- On high speed sections using automatic train control, train intervals may be less than 1,5 minutes.
- Minimum economical capacity usually 800 passengers per hour = one unit each 15 minutes.
- Maximum capacity per direction one dual line 30.000 passengers per hour with 4 unit trains. (Maximum capacity is limited with the length of the platform and in certain cases with the capacity of the exit ways from the platform area.)

Light and heavy rail networking

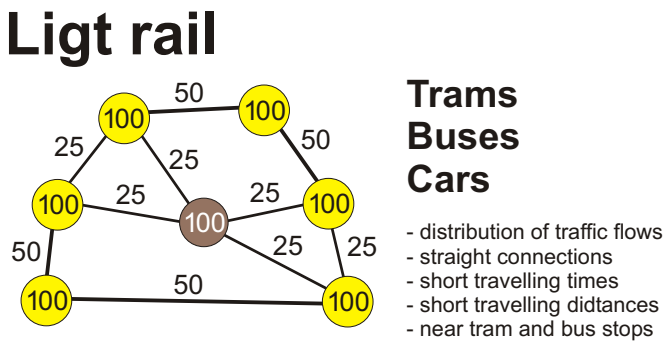
In heavy rail systems, large number of passenger capacity is concentrated into few services. This is based on the idea, that travelling cost per passenger decreases when the capacity of the system increases.

However, concentrated heavy rail network does not fit to the modern urban structure, which is not centre weighted. The travelling demand does not direct to the trips from suburbs to city centre, instead between locations all around the urban area. For the transport system this means, that there are plenty of demand for connections with relatively low capacity. Few heavy rail connections do not fit to this demand, but many light rail connections do.

The use of concentrated heavy rail connections end up to situation, where the trips do take more time than necessary and passenger kilometres are generated and paid more than actually is required.



Heavy rail network with concentrated services between locations in urban area. Passenger kilometres are generated for 10.000 units. Number in a circle describes the travelling demand of each location and number by connection describes the number of passengers on the service.



Light rail services for the same situation as in the previous figure. Light rail offers direct connection between locations for the same demand as for heavy rail solution. Required capacity per service is much less. As there is no need for extra travelling, passenger kilometres are generated only in 3500 units instead of 10.000 units.

Economical background

The total public transport cost varies along the required passenger capacity. The capacity required for a line depends on the network structure – a heavy rail rod or a Light Rail web – which is based on the city structure and population density.

Buses or heavy metro systems are suitable in very low or in very high population density. In most cases the ideal public transport capacity is between the high and low ends, where the lowest system cost is achieved with a Light Rail.

Roughly it can be estimated, that only a quarter of the network is situated in the high density city centre, where underground

Ground level Light Rail is the most economical solution when the required line capacity varies from 800 to 13.000 passengers per hour in one direction. When higher capacity is required, Light Rail wehicles can operate on a line built like a heavy metro line, but metro trains can never enter low cost Light Rail line.

lines may be necessary. At 75 % of the network heavy capacity is not required.

The integrability of the Light Rail offers flexibility that a heavy rail metro cannot offer. Light Rail trains that are suitable for street and on ground operation, are also suitable for operating in same underground or elevated lines as heavy metro trains.

Light Rail allows to build the major network length with the building cost that could be only 15 to 25 % compared to build a metro line. A Light Rail system saves in building cost when compared to a traditional metro and connecting bus solution.

The savings in building are based on several features in the line. For the first, for a Light Rail a level crossing with streets is possible and saves to construct bridges. The track does not need heavy ground modifications, because same level of curvature and up- and downhill are allowed as for streets. Light Rail does not need expensive terminals as stops, instead simple tram stop on street level works. Bus and car connections are easy and inexpensive to arrange, as both operate on same street level with the tram, and buses can share the platform with the tram. On streets with low traffic volume Light Rail

Light Rail and buses share the same platform. This is cost effective, but also offers the best passenger service where the change between rail and bus is necessary. Düsseldorf, July 2003.

can share the street bed with road traffic like ordinary trams. The only cost for a Light Rail line is the track and catenary built on existing street.

In operating cost, the basic advantage is the difference between bus and rail transport. The operating cost of a bus is roughly same as the operating cost of one rail unit. But rail units have remarkably higher capacity, which makes the cost per passenger in rail transport at least half of that in a bus transport..

Operating cost of a Light Rail is less than the operating cost of the heavy rail system. The savings are based on the bigger share of rail transport in a Light Rail system than with the metro requiring feeding with diesel buses.

Another source of savings is the better correspondence between the travelling demand and offered capacity as what is the case with a metro system. The feeding bus lines also usually operate with higher offered capacity than what is required.

Metro stations also require cost for maintenance and security, which tram stops do not need at all.

Light Rail and investment flexibility

The drawback of any rail based transport system including Ligh Rail is said to be the extra price of the rails compared to street building suitable for buses. Actually this is false, and it is the result of planning the environment primarily for car use.

The cost of a Light Rail line is only app. 5 % of the cost of the total traffic network. If rail transport is considered as an alterntative for road transport, total cost of the traffic network is lower using rail transport than only road transport.

Buses and cars do not require rails, instead they require lanes. A price for a lane is nearly equal wheather it is built for a car, bus or Light Rail. But the capacity of a Light Rail lane is the highest of all.

The cost of the bus “track” is usually hidden. The expenses are taken from street building moment in the city’s economy, not from the budget of the transport authority.

The investment for the Light Rail rolling stock is higher than that for buses. But the life cycle of a bus is app. 1/4 of the life cycle of a Light Rail unit and the operating cost is higher, which means, that in long term the tram is cheaper.

Usually the investment resources are limited. The benefit of a Light Rail is that it can be built in several steps. Another benefit is, that the building of the system is not bound to other large investments that must be done at the same time, like business and shopping centres in which the station is a part. This kind of centres can be made with the Light Rail, but they are not the term to make the public transport system economically possible.

Covering the investment

Usually it is hard to cover Light Rail investment from ticket sales. But the Light Rail has an economical impact for the area it is built in. A Light Rail line increases the value of housing where the service is available. The latest experience is, that values of housing and rent is 5 to 15 % higher by a Light Rail line than elsewhere in similar circumstances.

In Europe and USA, the increase in housing value is many times as highs as the Light Rail investment. This means, that to invest for a Light Rail line adds value for the city more than the cost of the line. So the question is, how to make this value to pay the investment. One way is to include the Light Rail line to the prices of the sites or to the agreements of building new areas. Another way is to set a development fee for a certain area the same way as building companies must pay for other infrastructure that is necessary in the city. In both cases the benefit is shared for both the city and builders, and building a Light Rail is benefical for both.

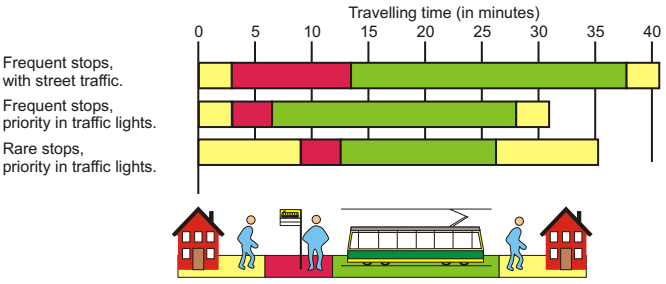
Another economical impact is that Light Rail makes possible to use land more effective than with a car or bus based transport system. This causes savings in the total infrastructure cost what for the city is responsible. The value of these savings is also higher than the cost of the line. Where there is possible to make more effective land use by building a Light Rail, the city can expand with less cost than having to build totally new areas and infrastructure for them.

Anyhow, each city must have a traffic system. If it is not a Light Rail, in worse case it is pure car based system, which requires the most space and limits the development of the city. When compared to the other possible solutions, Light Rail is in most cases the chapest and best working.

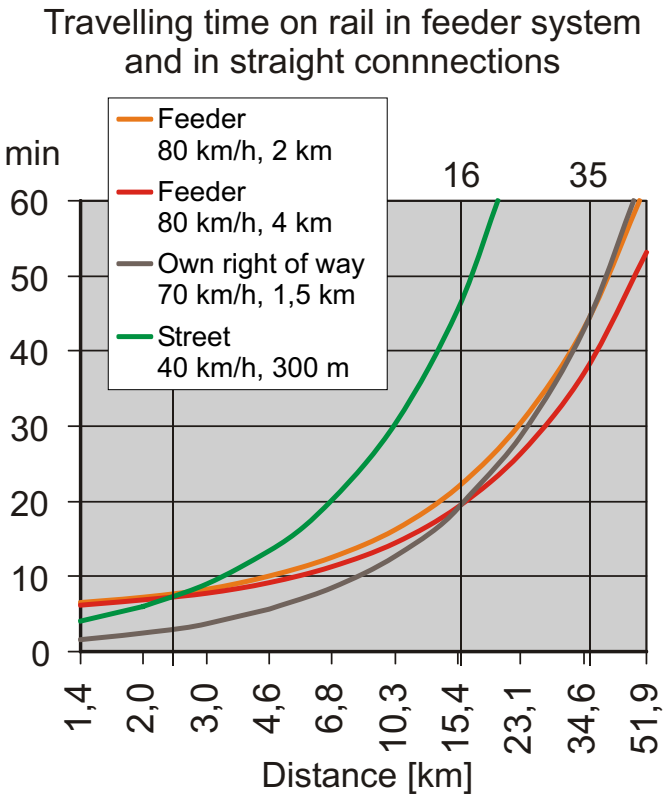
Competitivity as a transport system

One major benefit other than the economy, is the competitivity of a Light Rail as a transport system. This is a very important factor in Europe and USA, where people like to use their own cars.

When properly organised, travelling time from door to door is shorter with a Light Rail than with a metro system. The long stop distance of a metro increases the speed of a metro train, but requires more time for walking or in a feeder bus. In the best solutions, the travelling time with a Light Rail can be



Total travelling time is not only the time in the coach. It includes also the walking time, so increasing the speed of a train with longer stop distance decreases the total travelling time.



A Heavy Rail feeder system competes with straight bus or Light Rail connections. It is competitive only in city centres, but not in the connections between city centre and suburbs. A bus on a motorway or a Light Rail on it's own right of way is faster below 35 km distances.

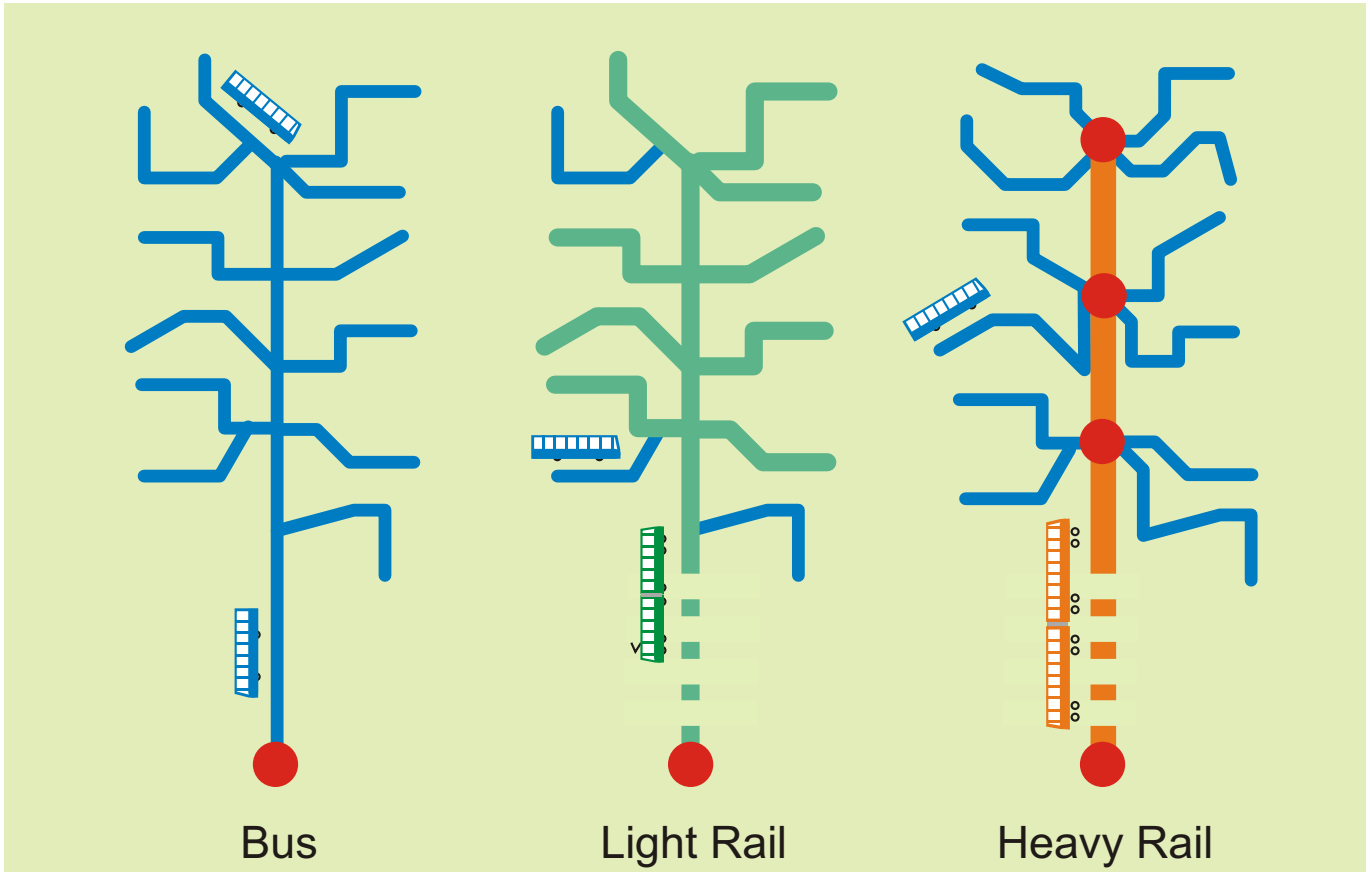
shorter than with a car in large cities, where parking is not possible as near as a Light Rail stop can be.

To travel in a rail transport unit is much more comfortable than in a street bus or even in a car at rush hour. Light Rail is also competitive to a metro system, as Light Rail offers much more straight connections and less changes than a metro with feeder buses. To get a metro from a suburb requires often a bus travel for the first and for the last when returning. This makes the metro trip as comfortable as the bus trip, when the Light Rail trip is a rail trip from the beginning to the end.

Comparison study of Light Rail, metro and bus systems

There are few real world examples where it is possible to compare different public transport systems. In many cities there are now experience of switching from one system to another, like from bus to Light Rail or from tram to Light Rail. Many middle European cities are good examples, like Dortmund, Duesseldorf, Köln and Strasbourg. One interesting example is Berlin, where the shared city grow with metro in west and with tram in east. After joining the city, the eastern tram system is modernised and it is growing when the metro network remains mostly as it was.

This study is based on a 20 kilometres transport corridor, and the public transport of that corridor is compared between a bus, a Light Rail and a metro and feeder bus system. The idea is, that the system has one end in the city centre and on the other end the system divers in suburb area. The rails – both

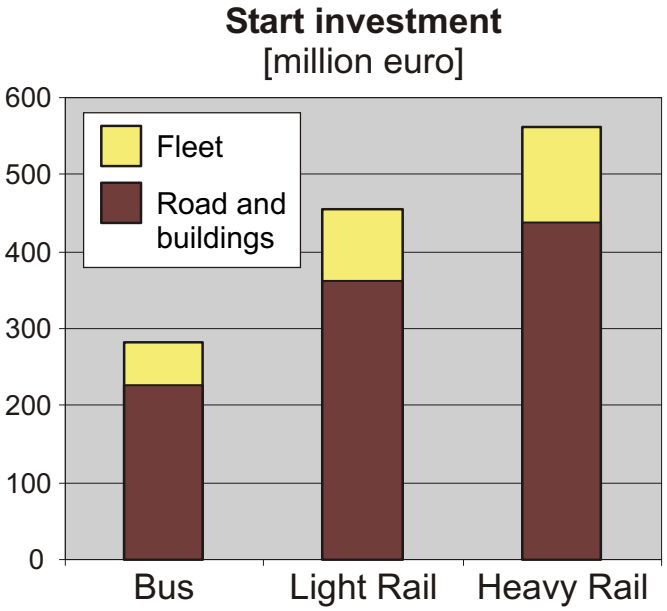


Structure of each network in the study. Each network has a main station in the city centre (red circle). A metro and feeder bus system requires also 3 more stations for connecting the feeder bus lines. A Light Rail network has only 3 feeder bus lines for the areas considered not dense enough for economical building of rail.

metro and Light Rail – are put into a tunnel in the city centre, but on outer area on ground. The buses operate on streets all the way.

Each system has the capacity of app. 12.000 passengers per peak hour, to the city centre. So they all offer same service that is possible to manage with a metro and feeder bus system, but not taken into account the advantages of a Light Rail network to direct connections without travelling via the city centre.

The study proves, that the bus system is weighted to operating cost and the rail based systems are far less expensive to operate. The metro replaces a large part of the bus network and saves bus operating cost, but metros capacity and connecting services to buses require large investments. Light Rail replaces the major part of the bus network saving most of the bus operating cost. Still the investment is 20 % less than metro network.



Starting investment

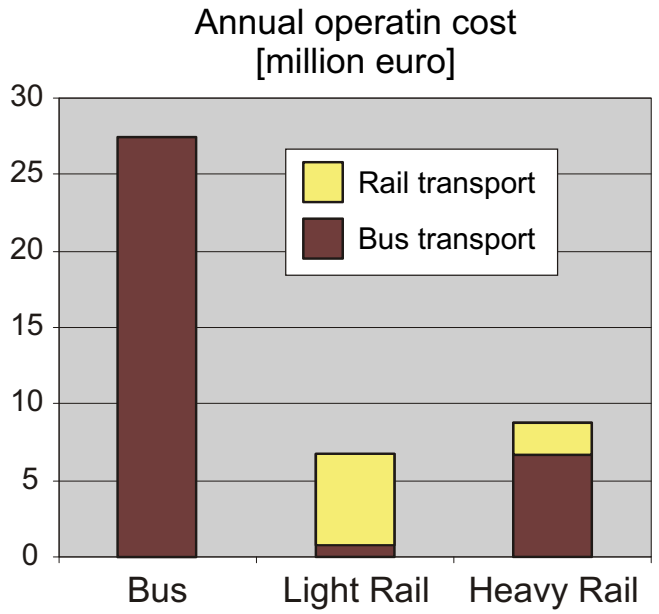
To set up each system requires the investment for the infrastructure and a set of rolling stock. As the rail rolling stock last for 40 years but the buses for only 10 years, that gives a benefit for the bus system.

Anyhow, in many cases the rolling stock is leased. In that case, the leasing fee is based on the estimated age of the units, which makes the leasing of the rail rolling stock cheaper than leasing the set of buses required.

Running cost

Running cost here includes the driver's salary and the kilometre based cost of the rolling stock, which is the energy and service. Administrative expenses are calculated separately.

The operating cost is calculated for a working day. The result is expanded to year level using factors to cover the weekend cost.



Total annual cost

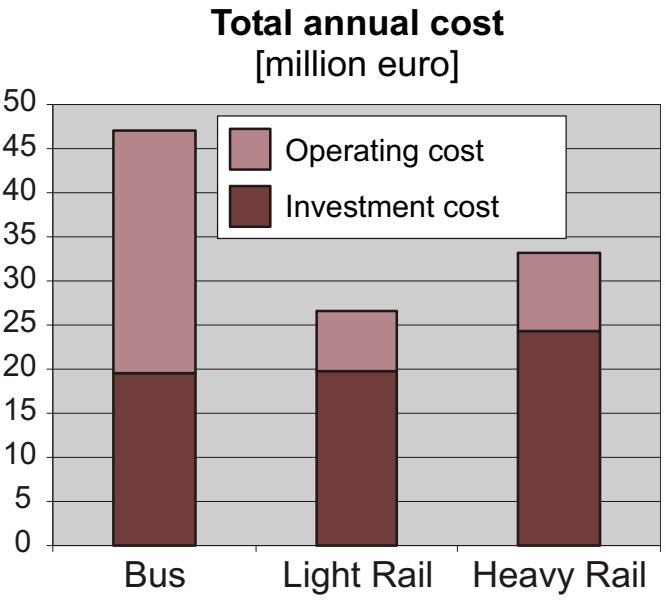
Total annual cost is calculated as a sum of operating cost and the liquidation of the investment. The liquidation is calculated here based on 3 % annual interest and 40 years period.

The investment here includes the price of the rolling stock for 40 years. The total investment for both the bus and Light Rail is near equal, therefore the annual liquidation is also equal.

Total annual cost gives a figure of the price of the public transport system. Public investments can be financed also tax based, when there is possible not to count any interest for the investment. In that case the annual investment cost may be considered as the share of tax income to be used for public transport building.

Conclusion

This comparison is calculated as a theoretical sample urban sector, in which the public transport can be organised either



with a metro line and connective bus service or with Light Rail network, that covers the most of the suburbs. The length of the sector is 20 km, which in case of metro is the length of a metro line.

The study shows, that most of the cost in the bus system is based on the operating cost. This is because the cost per passenger kilometre is high with buses.

Replacing part of the bus transport with rail transport in metro system saves operating cost, but plenty of bus operating still remain. The major drawback with the feeder bus system is, that the travelling time increases highly because of the switching between bus and train. The travelling distance in the metro train should be 30 to 35 km, until the switching delay is covered with the higher speed of the train compared to buses on a motorway or Light Rail in its own right of way.

The best savings in operating cost can be achieved with a Light Rail system, that replaces the most of the bus transport with rail transport. Light Rail is also cheaper by means of investment, as it does not require expensive bus interchange stations as the metro system needs. To build the rail is also cheaper with Light Rail than with metro, because thanks to the overhead power supply, the line can cross the streets in level crossings and bridges and two level stations are not required.

The calculation does not take into account the possibility to build circular lines, which is possible with bus and Light Rail systems, but not with a heavy rail metro system. If this had been made, the operating cost of the Light Rail systems had been even more competitive than the metro system, as the total amount of passenger kilometres had been less than with the systems compared here.

The cost of each system is different, and a pay back calculation for the Light Rail compared to a bus systems can be made. It shows, that a Light Rail covers it's investment as savings in operating cost in app. 7 years.

Income

The income of the public transport is based on the number of passengers and the average ticket price per trip. The price of the ticket is usually a political decision rather than based on the expenses of the public transport.

The number of passengers is limited with the capacity of the system. The experience in Europe and USA is, that during the peak hour 12 % of the daily trips are made.

With the daily capacity, there can be made estimates for the cost per trip:

	Bus	Light Rail	Metro
Operating	1,18 €	0,36 €	0,58 €
Operating + investment	1,75 €	0,9 €	1,55 €

For the reference, the average ticket income in Finland varies from 0,55 to 0,75 €/trip.

Unit costs used in the study

The unit cost are valid in Finland and based on the cost level in Finland in year 2004. As the labour cost varies around the world, calculation should be made with the local unit cost.

One Euro equals to 1,3 USD in the end 2004.
All the prices are given ex. VAT.

Typical investment costs

Rolling stock

- Light Rail rolling stock unit for 250 persons: 1,8 M euros
- Metro train unit for 400 persons: 2,7 M euros
- Diesel bus for 65 persons: 0,25 M euros
- Share of rolling stock units to be as spare (in service and repair) over the required capacity: 10 %

Rail structure

- Street base suitable to carry tram rail: 1,2 M euros / km
- Track and catenary on street, two ways: 1,5 M euros / km
- Track right of way in plain ground, two ways: 5 M euros / km
- Tunnel Track, two ways: 7,5 M euros / km
- Track bridge for two tracks: 9,3 M euros each

Stops and stations

- Tram or bus stop with shelter: 120.000 euros pair
- Combined tram and bus stop with large shelter: 0,7 M euros each
- Simple tunnel station with one on-ground building: 20 M euros each
- Metro type station on-ground with bus terminal: 25 M euros each

Operating cost

Operating cost is calculated from 2 components. Then there are included service, maintenance, salaries and energy of the system.

- Cost per hour: 24 euros per driver per day
- Cost per kilometre in rail unit: 0,3 euros per km
- Cost per kilometre in a bus: 0,4 euros per km

Administrative cost of the system: 4 M euros per year

The required number of rolling stock units is based on the peak hour of the day. Systems are running 16 hours per day and peak hours are 6 hours per day. Operating cost is calculated based on working day. For a year there are factors used to expand the working day cost for the whole year with weekends.