

New Concepts for Trolley Buses in Sweden

Nya koncept för trådbussar i Sverige



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Emission free public transport is a deserved strategy to reduce pollution and congestion in cities round the world. Electric traction is almost emission free if 95 % of electricity is produced by nuclear- or hydro power, as in Sweden and Norway.

Light rail transport system is having a renaissance, but they need an expensive infrastructure and is inflexible. Modern trolleybuses offer the same degree of zero-emission in cities, to less investment cost and somewhat more flexibility. Modern Duo-concepts (combined electric and diesel power) offer even greater flexibility.

This report contains a survey of new concepts for trolleybuses developed by various manufacturers in Germany, France, Italy and Czech Republic.

As there is no trolleybus system in operation at present in Sweden, this report present the experience from various operators of Trolleybus systems in Holland, Germany, Norway and Greece.

A comparison of external effects of trolley bus system versus other traffic system is made. This shows that even in countries with a power generating system based on fossil fuels, trolleybuses have an environmental advantage compared with the best commercially available diesel fuel powered buses.

In Sweden and Norway the greenhouse gases emissions from trolley buses would be factor 10 lower than in the Netherlands due to different sources of electric power.

An analysis of the social economic cost for trolleybuses in Sweden indicates that it would be feasible to make rather substantial investments in infrastructure for trolleybuses, and still have a social economical gain.

Trolleybus systems would be most interesting for densely populated cities, from 100.000 citizens upwards, but not big enough for Light rail systems.

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Front picture: A duo bus in Ghent, picture ScanTech Development AB.

1. Introduction

Zero emission engines for public transport

Increased use of public transport is the preferred strategy today in many countries to reduce congestion and pollution from road traffic. Buses are considered as the least expensive and most flexible mode in most transport relations. Today almost all buses and coaches have diesel propulsion. The automotive industry have invested vast amount of money to make the diesel engine as powerful, silent, fuel efficient and environmentally acceptable as possible.

A major concern about the modern diesel engine is health effects from its emissions of particulates and nitrogen oxides. Exposure to those emissions can induce cancer. There is still a long process to go before the diesel engine turns into a zero emission engine.

Many operators of public transport have tested alternative fuels for combustion engines in order to reduce the level of emissions. In many cases the change of fuel gives different kind of pollution such as formaldehyde, a well known carcinogenic substance.

Electricity for propulsion can reduce the local emission to air to zero level. If electricity is being generated by combustion of fuels in a power station the emissions will be elsewhere.

Electrical propulsion is certainly not a new technology. It is now 100 years since electrically powered trains replaced the coal fired steam locomotives in the London underground Bakerloo Line.

In the 1920s trolley buses were introduced in many large cities as an alternative to trams. In the 1930s there were more than 2300 trolley buses in London. The main reason for this was more flexibility and reduced cost compared with trams. At this time the internal combustion engine was less powerful and reliable than electrical engines.

In the late 1950s diesel performance and reliability of engines was much improved and the gasoil fuel got less expensive for every year. The economy of scale from production of diesel engines and transmission for lorries, buses and coaches made the trolley bus less competitive. Environment was not an issue at this time. Emissions from diesel engines were considered as less harmful compared with petrol engines without catalytic converters.

As a result the development of trolley bus technology came to a standstill in the west. In socialist countries as Soviet Union and China the expansion of trolley bus systems progressed. But the technology did not make much progress. The buses produced in the 1980s was much the same as in the 1960s.

Environment issues have made electrical propulsion as the only solution to get close to zero emission on transport.

The most exciting technology is fuel cells powered by hydrogen to produce electricity for vehicles without any harmful emissions. Before fuel cells can be commercialized

much more development is needed to improve safety of storage and production of hydrogen. The traction of vehicles will be by electric motors.

Fuel Cells using liquid fuels as LNG or methanol and a reformer to produce hydrogen on site is also being developed. But this technology will not give true zero emission vehicles. Carbon dioxide emissions can not be avoided.

Chemical storage in batteries to produce electricity have been tested in buses for many years, but the draw-back is high weight, high cost and low performance. The energy storage capacity per weight in batteries is in the order of magnitude 1:100 compared with conventional fuels.

A great advantage with electrical propulsion is that electric motors can be fitted in wheel hubs. This is a way to make buses with very low floors and convenient to passengers. Some bus manufacturers has developed buses with diesel engines driving a generator just in order to get the desired low floor.

As almost all the new environmental friendly technologies are based on electric propulsion it has also given the traditional trolley bus a chance to a renaissance.

In the US and Canada large cities as San Francisco, Philadelphia, Dayton, Seattle and Vancouver have decided to expand or introduce trolley buses for reducing emissions and noise.

In order to get the flexibility of the diesel bus in suburbs and the zero emission from electric traction in city center dual mode buses have been introduced.

2. Future concepts for trolley buses

Traditional trolley buses were first preferred because of their reliability, energy efficiency and their power to climb hilly streets with good acceleration. It lost ground in 1950 because of improved efficiency in diesel engines and falling prices of gasoil fuel. The cities that have continued to use trolley buses do it because of the obvious environmental benefits.

Environmental considerations in the beginning of 1980s led to renewed interest in electric propulsion. But still operators wanted the flexibility of a diesel bus. This was the origin of the duo bus. The big dedicated producers of trolley buses is all located in China and former Soviet Union and have not yet presented any duobuses. Skoda of Czech republic and the newly merged AnsaldoBreda in Italy are the only ones in the western world where trolley buses manufacturers are of any significance.

Today the trolley bus is a full scale alternative for cities with high demands on air quality and efficient public transport systems. Some of the biggest trolley bus systems can be found in San Francisco and Seattle, the heartland of American high technology. New large investments in trolley bus systems are also made in the US.

In the US the trolley bus have been used as a strategic vehicle to introduce emission free public transport. When the use of trolley bus have reached a certain level it is been replaced by light rail with even higher mass transit capacity.

To be competitive with the diesel bus the trolley bus needs high volumes of passengers and strict enforcement of environmental standards.

In Europe we can now see two different types of investments in trolley bus systems. In some places like Athens, Arnhem and Sarajevo traditional trolley bus nets are expanded and vehicles are upgraded. These investments competes with conventional diesel buses.

In France and Italy they now introduce new concepts for trolley buses. These concepts are introduced as equivalents to trams and light rail but they offer higher flexibility and lower investment costs. These new systems are developed by Matra/Renault (CIVIS), Bombardier (GLT) and AnsaldoBreda (Stream). As the new systems are just in the process to be introduced on the markets, we do not yet know the true operational costs. Most interesting is that these new systems are made by companies with experience from rail systems.

2.1 Customer viewpoint

From the customer perspective the duo bus has an advantage. The duo bus can go all the way from suburbs in to the city and even into shopping malls or underground stations. This have been full-scale demonstrated in Essen. It is of high value for customers of public transport to avoid changes and waiting time.

From Arnhem the experience is that the visibility of the trolley bus net and the low noise levels have contributed to increase the market share for public transport. The

possibility to introduce low floor concepts and high capacity transport could be a winning concept for new trolley bus systems in the twenty-first century.

2.2 Industrial viewpoint

The companies who makes diesel buses have little incitement to introduce electrical drive systems. Today the conventional drive line, including engine has the best margins. The core technology to make a bus engine is the same as to make a truck engine or an industrial engine. The know how in engine production is the core competence for these companies. The first generation of duobuses have not made a big impact on the market.

There is obvious economics of scale for those bus manufacturers to introduce new better diesel engines, and get a premium price for improved characteristics from operators. On the other hand there is no obvious benefits of scale to make some buses with a lot of complicated electric systems of 600 or 750 Volt. They substitute the profitable diesel engine with electric equipment bought from outsiders.

All the big manufactures of buses have tried to make duo buses, but in most cases decided not to take them into production. Most bus manufactures is part of larger automotive groups that have spent billions in improving the diesel engine in order to reduce emissions and make it silent. The money spent on research on duo buses is futile in comparison.

In the automotive industry it is known to be a kind of mental “Berlin Wall” when it comes to electricity. There has for a long time been a resistance to rise the voltage of the electric systems in modern cars to more than 12 V, and to more than 24 V for commercial vehicles. With the amount of electric equipment in modern cars 48 V systems would be more appropriate to get more energy efficient A/C generators.

Buses also consists of a body. There are several independent companies who deliver bodies for buses. These companies can develop and deliver bodies for both diesel buses and for trolley buses.

To make new trolley bus systems more competitive there must be new constellations of companies that work together such as electromechanical-, bodywork- and independent chassis work industry. The core competence for the railway industry is electrotechnical systems. The wheel on steel track is of secondary importance for system developers.

For the railway industry the deregulation of the railway operations in many countries causes excess production capacity and resulting lower margins. The same goes for the bus manufacturers. There can be an interesting niche market for intermediaries between railway vehicles and buses.

2.3 Operational viewpoint

The deregulation of markets such as electricity, public transport and public works creates new challenges but also new business opportunities. Traditional utilities will be replaced by utility focusing on certain areas in the value added chain where they have the best competence. The foremost trend on the deregulated market is

specialization. New crossover businesses are developed utilizing core competence such as billing, customer care, maintenance, leasing and financing of equipment etc. The electrical utilities are now being divided into supply, production and distribution. And the core competence of the distribution company is to operate and maintain the electrical grid and local net. These companies spin-off new service companies specializing in certain kind of maintenance.

In the deregulated electricity market price of electricity have fallen up to 60 percent for large consumers. It is very likely that the price of electricity will be even lower within the EU because of surplus production capacity and intensified competition. The real price of coal is the lowest in history. The price of natural gas is also declining. At present the oil price is rising. If the OPEC cartel strategy is successful, the price of oil will stay high for some years. This will give an opportunity for electric driven public transport relative to petroleum based transport.

Today the real interest rate is on a high level. This makes it expensive to invest in highly capital intensive urban traffic systems. The trolley bus and its infrastructure is the least capital intensive elsewhere emission urban traffic system. Before investing in other traffic systems the trolley bus should be considered and evaluated.

The operation of public transport is now also being deregulated in European countries. The new operators are competing for contracts for public transport in many countries. They pick the best and most efficient concepts and implements these concepts where they get contracts. The operators buy their vehicles in higher volumes. The vehicles must be more standardized to be competitive. This leads to falling prizes. The new operators try to find either movable fleets or long contract time. This trend goes against both tram and trolley buses. On the other hand authorities are implementing severe environmental standards. In central urban areas the goal is zero emission vehicles. The trolley bus is the most cost efficient local zero emission vehicle. The problem for the operators is the catenary with its infrastructure.

One opportunity could be an electric distribution company owning and maintaining the catenary. In the foreseeable it will be less complicated to build and operate a catenary system in a city compared with supply a fleet with compressed hydrogen gas. With a long term contract between the electric distribution company and the city it is possible to establish a public net for vehicles. The electric distribution company can choose between providing catenaries or exchangeable batteries for electric vehicles or a combination of both. The city can introduce zero-emission areas and special submarket for elsewhere emission vehicles. This system can be used for all kinds of commercial urban transport. In Italy they are already using the catenary for refuse transport trucks.

Different operators of public transport can compete in this sub market. This increased specialization will give both lower fare prices and better urban environment.

3. Overview of trolley bus technology today

3.1 Introduction

Almost all studies concerning trolley buses that are available in Swedish are more than ten years old. Interesting research and case studies conducted at the end of the 1980s have had time to mature and is now ready for introduction at a large scale, at least from a technical perspective. Examples are a switch to AC motor technology and guidance systems. Also described are novel concepts that combine the characteristics of trolleybuses and other transportation modes, mainly trams.

3.2 Method

The level around 1990 is summarized from the referenced literature. Information on the current technology has been obtained by contacting cities that have conducted case studies of promising technologies and manufacturers of trolley buses. The information has been acquired through open sources such as folders and the Internet but most important through questionnaires. In some cases additional information has been obtained through e-mail, telephone calls and visits.

3.3 Trolleybuses ten years ago

One of the drawbacks of a trolley bus is the dependence on the electric network. Pure trolley buses are economically feasible only in densely populated areas due to the high investment costs of the overhead contact lines.

Around 1980 a new concept called the *duobus* had become reality. Duobuses can be used equally well in either of two different means of propulsion, hence the name. A given combination is a traditional trolley bus combined with a diesel engine. The engine can either be used to drive a generator (serial drive) or to drive an axle directly (parallel drive). Since the duobus can operate independently of overhead contact lines, expensive infrastructure need only to be built on high traffic routes. In order to facilitate the switch from driving autonomously in diesel mode to driving in trolley bus mode, the trolley bars find their way automatically to the contact lines. This is usually accomplished at a bus stop and takes around 10-15 seconds

Trolleybuses have long sported a auxiliary power generator driven by a small combustion engine. This contraption is used to move the bus inside bus depots or around obstacles, like construction work. Exactly where to draw the line between a trolley bus with auxiliary power and a duobus is a matter of definition. We suggest the definition, the duo bus have equal performance in either driving mode.

A second propulsion system usually means that the overall weight is increased as opposed to a vehicle with only one drive system. This means that fewer passengers can be accommodated. To increase the cost efficiency for buses with a secondary propulsion system, duo buses usually are of the articulated kind.

Trolleybuses traditionally use DC motors. The first designs used rheostatic speed regulation through electro mechanic control of the contactors. Later advances switched the electro mechanic control to control through solid-state devices. Speed regulation through a power chopper is recent technology which is now introduced in most buses. This is a more energy efficient technology.

3.4 Recent Advances

Transportation technology has advanced since the introduction of trolley buses. Today a high degree of integration of different transportation modes is possible through the use of sophisticated information systems. Information can be collected about the traffic and presented to those who need it most. For example, positioning systems such as GPS can be used to keep track of individual vehicles and used in conjunction with computers, stops can be announced automatically to the passengers. Available resources can be used more efficiently.

Some advances are of particular importance to trolleybuses and are discussed below.

3.4.1 Low floors

All modern trolleybuses for European market have low floors and/or kneeling that facilitate entering and leaving the vehicle. This is obvious an advantage for elderly people, parents with prams, people in wheelchairs. Apart from customer satisfaction, low floors also contribute to higher efficiency since the time waiting for people to board or alight is diminished.

3.4.2 Guidance Systems

Guidance systems are used to assist the driver in steering the vehicle. In most futuristic scenarios there will be no need for a driver. Today, guidance systems are used to increase the average speed of trolleybuses, to allow exact positioning at elevated bus stops and increase safety.

Information technology has paved the way for advanced solutions to self-guided trolleybuses. But not all systems are state-of-the-art computer systems; some rely on simpler and possibly more reliable solutions.

Mechanical track guide systems rely on a physical structure on the road to mechanically guide the vehicle. For example small guide wheels mounted on the sides can be used to directly control the steering mechanism through laterally mounted guidance strips.



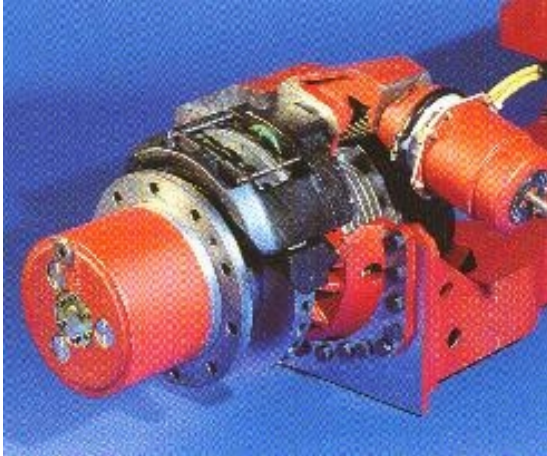
Mechanical track guide systems, picture ScanTech Development

Another solution consists of small wheels that runs on a single rail in the road and affect the steering of the vehicle.

Electronic guidance systems depend on some sort of electronic sensor instead of mechanical principles to follow markings on the road. The markings can be on the form

of a magnetic strip or mere paint. In the case of the magnetic strip the sensor depends on induction. If paint is utilized, an optical sensor system of some sort is required. More advanced optical guidance systems include the interpretation of road signs, but these are still at an experimental stage.

3.4.3 Wheel Hub Drive



The wheel hub drive, picture DaimlerChrysler

The wheel hub drive consists of an engine for each wheel. Power is conveyed directly, without gears or intervening transmission systems. This reduces energy loss and saves space.

The wheel hub drive is ideal to be integrated as a regenerative braking system. When the electric engine is not driving the wheel, it serves as a generator supplying braking action at the same time as producing electricity. Electricity that can be used to charge batteries, propagated back to the power grid or used for heating.

Eliminating the gearbox makes and substitute it with electric traction for smoother rides.

Increased concern over passenger comfort and accessibility to people with impaired mobility has introduced the low-floor concept. This applies to buses in general, but combined with wheel hub drive it puts the trolley bus to an advantage. Eliminating the drive chain of conventional systems means that the new low-floor idea can be taken to its extreme with a completely flat floor. In other systems elevations and angled floors are impossible to avoid.

An interesting consequence of using wheel hub drives is that the traditional approach of building buses on an existing drive chain and adding a chassis can be abandoned. Instead a modular approach where the vehicle is designed as an integral structure and parts added to the frame can effectively be adopted. This means that novel designs are possible, e.g. seats hung from the high strength walls thus freeing floor space and ease cleaning of floors.

3.4.4 AC induction motors

Today most modern trolleybuses have switched from DC to AC motors. The main advantage of AC motors over DC motors is reduced weight, less expensive components

and better speed regulation. AC engines can be exactly controlled by modern power electronics. DC engine power is controlled by rheostatic systems. AC engines is more efficient at partial load.

3.4.5 Catenary

One of the arguments against trolleybuses is the visual impact of the overhead wiring. However, the development of new materials and suspension techniques has paved the way for lighter and better wiring.



Overhead catenaries in Bergen, picture ScanTech Development.

Today bright stainless steel is used as overhead wiring as a mean to reduce the visual impact from wires. Also switches are today made of stainless steel for the same reason.



A modern switchgear for trolley buses in an Arnhem bus station, picture ScanTech Development

3.5 Concepts

An insight in the particular strengths and weaknesses of trams, buses and trolleybuses respectively has resulted in attempts to combine the best from the all worlds. From trams is desired the punctuality if operated in segregated track. From trolleybuses is desired the flexibility and low noise-levels. From buses is desired the rapid insertion and independence of contact lines. Trams and trolley buses both share the characteristic of being practically emission free.

Several large manufacturers have such products in their portfolio: Bombardier with the tram-on-tires, Renault-Matra with CiViS and Mercedes-Benz talks about an electrically driven, 200 passenger double-articulated bus. Somewhat on the same track is Ansaldo with Stream, though this seems to be more of a traditional trolleybus with an innovative power collector.

Škoda makes affordable and reliable trolley buses of traditional type. This have had a very good market penetration in the US in recent years. Škoda is the largest producer of trolley buses in western Europe. Škoda is an totally integrated and specialized manufacturer of trolley buses.

3.5.1 Renault-Matra CiViS

CiViS is guided trolley bus that shares many characteristics with a tram. It is designed to operate in a segregated lane, though this is not an absolute requirement.

Its optical guidance system relies on pattern recognition to follow the route painted on the street. The switch between guided and unguided mode occurs seamlessly, without the need for slowing down.

Electricity is collected from overhead contact lines. When desired CiViS can run short distances off-line using batteries. This is useful inside depots, to avoid temporary obstacles where contact lines are unwanted. For longer distances off-line, a diesel- or natural gas-powered generator can be used. Reconnecting to the contact lines after independent operation is accomplished automatically.

Due to wheel hub motors CiViS features a level floor that facilitates boarding and alighting. Since the vehicle shares many of its components with the new generation of Renault buses, maintenance is facilitated.



Renault Matra CiViS, picture Renault Matra

Model:	Natural gas	Trolley/batteries
Capacity:	120	140
Empty Weight:	18.4 tons	18.4 tons
Power:		
Lengths:	18	19.5
Top speed:	70 km/h	70 km/h

3.5.2 Mercedes-Benz

Mercedes-Benz takes a system-wide view of bus transport solutions. Each city is considered unique, requiring a unique solution with special attention being paid to geographical, historical and other factors. To meet this demand Mercedes-Benz has developed a resource-kit from which individual elements can be selected and adapted. This resource kit has four key areas, vehicles, infrastructure, guidance systems and information systems.

Vehicles come in the lengths of 8, 9.5, 12, 15, 18 meters. Future development focuses on a 24-meter double articulated vehicle carrying around 200 passengers. This vehicle is low-floored with electric wheel hub drives, designed to operate on dedicated tracks or

on normal roads. All vehicles can be delivered with customized design in order to give each city its own special public transportation profile.

Propulsion systems range from trolleybus to diesel to fuels cells. Fuel cells produce electricity by combining hydrogen and oxygen in a catalyst. This process is almost emission free. Fuel cells under development and not yet commercial but they are thought to dominant in the future if the technology can prove its reliability and cost efficiency. It will take another ten years until we know if the fuel cells are commercial competitive.

Guidance systems are either mechanical or electronic. Advanced imaging systems that identify and interpret road signs are under development. These systems are meant to assist the driver.

3.5.3 Bombardier GLT and Bombardier Tram-on-Tyres

The GLT and Tram-on-Tyres have adopted many features from different public transportation modes. They run on rubber tires like a bus, have a bogey system resembling a train and is double articulated. They both have a serial hybrid drive where electric power is obtained from overhead contact lines or through a diesel engine running a generator.

They can run in guided mode using a single rail with a steering wheel. When used this way it can operate as a tram with single contact line and pantograph, as a trolleybus with contact lines and trolleys or as diesel bus. When unguided it can operate either as a trolleybus or as a diesel bus.

The French town Nancy has ordered 25 Tram-on-Tyres vehicles that will operate on trolley bus contact lines by the end of 2000. In Caen 24 vehicles using a single contact line and tram pantograph will be in service by 2002.



Bomardier GLT/TVR, picture Bomardier

Model:	GLT/TVR	Tram on Tyres
Capacity:	200	143
Empty Weight:	25,0 t	25.5 t
Power:	300 kW	300 kW
(autonomous)	(200 kW)	(200kW)
Lengths:	24,5 m	24.5 m
Top speed:	70 km/h	70 km/h
Acceleration:		1.2 m/s ²
Braking rate:	5,5 m/s ²	5,5 m/s ²



Bombardier Tram-on-Tyres for Nancy, picture Bombardier.

The difference between the GLT and the Tram-on-Tyres is that the GLT when guided by a central rail can be fed by a single wire catenary. The GLT also have a higher capacity, it can take 200 passengers compared with maximum 143 for the Tram-on-Tyres.

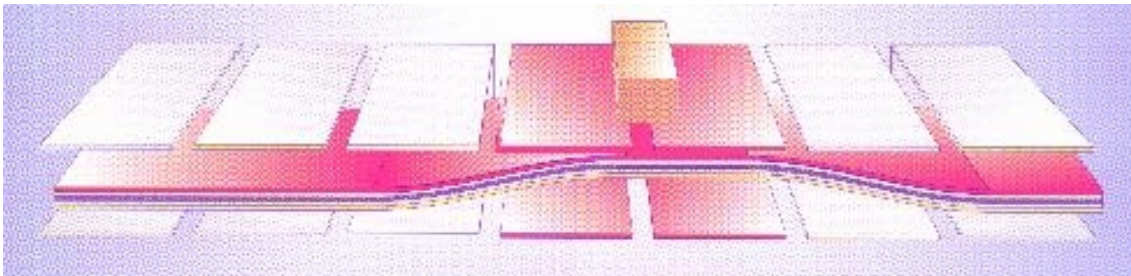
3.5.4 AnsaldoBreda STREAM

Stream is a new public transportation concept from AnsaldoBreda, part of the Finmeccanica Group. Stream operates on a network embedded in the ground. From this network it obtains traction power and exchanges control signals and messages. Thus Stream shares many operating characteristics with a trolley bus.



The AnsaldoBreda Stream, picture AnsaldoBreda

Stream does not require segregated lanes and can be driven anywhere the network is installed. It can be driven short distances off the contact line using batteries.



Contact line for the AnsaldoBreda Stream, picture AnsaldoBreda

The embedded network consists of modular units put in a trench. On the top there is a contact line and inside the units a conducting wire. As the bus passes over a segment on a unit, a special collector arm with a strong magnet at the end lifts the wire so that electrical contact is established. When bus and collector advances to the next segment, the wire falls to the bottom and electrical contact is lost. Thus only a spot directly beneath the collector is electrified at any given time.

The collector can be raised or lowered at any point. It is automatically centered on the contact line independently of vehicle movement and it can be used to steer the front wheels. Since signals and messages can be exchanged through the embedded network and the segments of the contact line can be used to determine the position of a vehicle, a high degree of automation and integration in traffic control systems can be accomplished.

The operating characteristics of Stream in Northern countries are unknown. The operating reliability in snow and ice is unknown. Further studies of this concept must be done in colder climate.

AnsaldoBreda also produces traditional trolleybuses.

Model:	Stream 24m	Breda F321	Breda F19
Capacity:	160-180	154	90
Empty Weight:		18.9 t	12.8 t
Power:		185 kW	145 kW
(autonomous)		(80 kW)	(80 kW)
Lengths:		18 m	12 m
Top speed:	60-70 km/h	60 km/h	60km/h (55 km/h)
Acceleration:			
Control		IGBT Inverter	
System:			



The articulated trolley bus BredaMenaribus F321, picture AnsaldoBreda

3.5.5 Škoda

Škoda is still the leading manufacturer of trolleybuses, regarding the number of vehicles produced annually. It is probably the only manufacturer that has series-production of its models, which accounts for durable and affordable vehicles.

New models have low-floors and DC motors with chopper control. Research on AC motors is being conducted.

Vehicles

Model:	14 Tr M	15 Tr M	21 Tr	22 Tr
Capacity:	100	176	86	140
Empty Weight:	10 t	15.9 t	11 t	17 t
Power:	100-170 kW	200-340 kW	132-167 kW	240-280 kW
(autonomous)	(-)	(-)	(-)	(-)
Lengths:	11.34 m	17.72 m	11.56 m	17.87 m
Top speed:	65 km/h	65 km/h	70 km/h	70 km/h
Acceleration:			1.3 m/s ²	1.2 m/s ²
Control System:	GTO thyristors	GTO thyristors	GTO thyristors	GTO thyristors



The new Škoda articulated trolley bus 22 Tr, Picture Škoda

4. Experience by operators of trolley-bus systems

4.1 Introduction

The experience from operators of trolleybus systems in our survey shows that duo/trolleysystems are more expensive and complex to run than pure dieselbus operations. On the other hand, trolleys are less expensive and complicated to maintain compared with trams and light rail. Today most new trolleybuses is articulated type of 18 m. Trolley buses are in first hand a less expensive and more flexible alternative to trams or light rail.

Newer trolleybuses have some kind of APU (auxiliary power units) ex. batteries or a small generator to be able to drive short and infrequent movements free from wires. Duobuses with full sized diesel engines, that are capable to operate with normal loads and speed, are not very much in use. The reason for this is the high cost and complex maintenance.

We have sent our questionnaire to 10 operators of trolleybuses and made short visits to Bergen, Essen and Arnhem. Essen and Copenhagen have had tried duobus systems in 1990s, but decided to discontinue the operations. In Essen the duobuses are still in daily use, but operates only with diesel engines.

Detailed figures about operating cost for individual routes have not been available for us, for obvious commercial reasons. But some operators have presented us with useful relative figures.

4.2 Arnhem

The city of Arnhem is situated in north east Holland. The area round Arnhem is a flatland, as most of Holland. In this country almost all electricity is generated by fossil fuels, equal parts come from coal and gas fired power stations.



Arnhem will stay trolley bus another 50 years! A trolley bus in Arnhem, picture ScanTech Development

The tram system in Arnhem was destroyed in the war. Trolleybuses replaced it and Arnhem is the only city with trolley buses. The route length is 50 km. When other cities in Holland have had a declining market share for public transport, Arnhem have a positive trend. From 1986-92 the trolleybuses increased the number of customers with 13 % and still keep its market share. Today Arnhem has five different trolley bus routes with a total coverage of 50 km. Trolleybuses is the preferred mode of public transport in the city. Minor routes in the city and regional traffic is by dieselbuses. The council have recently decided to invest more money to upgrade the system - Trolley 2000. This investment is a essential part in a grander scheme, the KAN-masterplan, for improving public transport in Arnhem - Nijmegen region. The government will subsidy the trolley net by 4.1 M NLG (2 M Euro)/year. In Holland the environment benefits of trolleybuses is considered to reduce harmful emissions.

Operator of the system is Connexion Arnhem, a subsidiary to Connexion Personenvervoer NV. They operate public transport and taxis all over Holland. They have got a concession for 15 years to operate trolleybuses to be able to invest in buses, as well as in overhead lines. Connexion have made market research, it indicates that by implementing Trolley 2000 they will get 16 % more customer next five years. If the trolleys had been discontinued and substituted by best type of dieselbuses market research suggest they will get 5 % less passengers.

Trolley 2000 will consist of 32 new articulated trolleybuses with low floor. The investment will be 30 M NGL(14 MEuro), twice the investment compared with articulated dieselbuses. Part of the present fleet of trolleys will be modernized, the total fleet of trolleys will be more than 40, all of the articulated type. A new route will be built added to the five present lines. The extension and rewiring is estimated to cost 6M NLG. A further 20 new 12 m dieselbuses with low emission engines will run on feeder routes.

Much effort have been taken in preparing buslines separate from other traffic and to arrange signal systems to give trolleys priority in intersections. Each bus have three large doors to ease access for passengers. By increasing average speed and capacity of each bus, they will cope with increasing customer volume. In peak hours there will pass 8 buses an hour on each route and in off peak hours 4 buses an hour. The revenues of each bus will be higher than in the old system.



This trolley bus in Arnhem will be replaced by an articulated trolley bus with a capacity of 135 customers, picture Scantech Development

Trolley buses in Arnhem are considered very reliable and durable and they don't require more maintenance than dieselbuses. Maintenance of overhead power lines is provided by the same organization that provides the service of public streets lighting. Duobuses have been tested, but is not at present considered as competitive because of high cost and questionable reliability.

Environmental benefits are much appreciated. Calculated on primary energy in Holland, trolleybuses use 22 % less energy than best diesel buses. Emissions to air of particulates, NO_x, SO_x and HC is 1:20 compared with diesel busses.

4.2 Bergen

The city of Bergen is situated on the west coast of Norway. In this country almost all electricity is generated from hydropower. Electricity in Norway can be regarded as free from any emissions to air and renewable.



A Mercedes trolley bus in Bergen, picture ScanTech Development

Bergen city is situated in a hilly landscape and have many streets along steep hills. Trolleybuses was introduced in 1950 to replace trams and at this time they were, faster and more reliable and silent than trams and buses with initial combustion engine.

Operator of the system is Gaia Trafik A/S. They operate diesel- and trolley buses in Bergen area. They have today 11 articulated trolleybuses that serves one route of 11 km. The average age of buses is 15 years. Total production is 2.700.000 customers /year. The continued operations of trolleybuses is conditional of an annual subvention of 4 M NOK = Euro 500.000 from Bergen city council. Purchase of new trolleybuses will be made in cooperation with other trolley operators in order to get economy of scale.

Gaia have bought 3 duo buses but decided to not invest more in this concept due to high maintenance cost and lack of reliability. Recently Gaia decided to invest in 80 new LPG buses to replace most dieselbuses. The experiences from use of gas buses will in future decide if the trolley system will be in operation after 2005.

Advantage of conventional trolleybuses in Bergen is

- Low noise
- Quick acceleration up hills
- Reliability
- Emission free

Problems

- Lack of flexibility
- High cost
- Icing of overhead lines in winter
- Unreliability of duobuses

4.3 Essen

City of Essen is situated in Rein-Ruhr area in West of Germany. Rein-Ruhr has more than 7 million inhabitants and a comprehensive public transport system with trains, S-

bahn (light rapid transit), tramways and buses. In Essen most of public transport in the center is provided by trams. To avoid congested streets part of the tram lines in the city center is underground and connects with S-bahn under ground.

1979 the city got funding from the federal ministry for Science, Research and Technology (BMBF) to develop and test a new concept of guided buses. The concept was called "Guided Bus Essen."

This would enable joint operation of buses and trains in tunnels. The joint use of railway lines by bus presupposes that the latter is able to run in the existing clearance gauge. The aim of the project was to develop and test all the components of a mechanically guided bus that are necessary for joint operation and test this in passenger service. This should be achieved without interrupting the train and tram traffic. The most important components were:

1. Track guidance of the buses.
2. Guided bus trackway
3. Guided bus switch
4. Route protection system (location, identification and influencing)
5. Emission free drive system for tunnel operation

Each part of the complex system was developed and tested gradually. Development was divided into three phases. All the components needed for tunnel operations should first be tested above ground.

The original selection of the testing and demonstration lines was made in such a way that continuous new lines were created, connecting to existing lines. As many customers as possible were to benefit from the advantages of the demonstration line. In order to ensure that the advantages of joint use of tunnel facilities were noticeable over the entire lines, also these lines outside the tunnel were to include as long route sections as possible in guideways separated from rest of the traffic.



A Mercedes-Benz duo bus in diesel operation in Essen, picture ScanTech Development.

With the introduction of the guided bus the public transport system could offer an attractive bus system that:

1. Serves the area flexibly on the existing road network.
2. In some sections runs on its own guideway and is able to operate independently of other traffic.
3. Runs on existing routes jointly with rail vehicles.
4. Is able to make use of existing routes for public transport service where rail or trams are no longer profitable.
5. Reduces transfer distances by joining up with the light rail rapid transport system in joint tunnel stations.

It would go too far in this report to explain all the intricate problems with guideways. But the lessons of duobus operation in tunnels is interesting:

It was decided to opt for duobuses to get emission free traffic in the tunnels. To build overhead power lines on the guideway that followed the A40 motorway was considered too expensive. Therefore the buses would use diesel engine on the motorway to the suburb Kray. In Kray town they resumed to electric drive to get emission free traction in residential areas and narrow shopping streets.

The first duobuses bought in 1980 was not of the low floor type. In 1986 18 more articulated buses of the low floor type was ordered from Mercedes. The service of buses in tunnels began 1988. In Essen the buses only serve tramway stops in the tunnels. Here the first step is almost in level with the edge of the platforms. As two of the stops are stations with a central platform. The buses were modified with additional doors on the left as well as on the right side to serve the central platforms.

For mechanical track guide only a few components need to be fitted to the vehicle. Steering signals is transmitted via guide rollers located directly in front of the front wheels. Distance rollers is located after the other wheels in order to protect the wheel axels from damages from kerbs etc.

The joint use of track by bus and tram in tunnels in Essen requires many more modifications to the buses than an exclusively guided bus operation. Driving the buses with internal combustion engines was not considered feasible, as it would be required to install a costly automatic ventilation system. The buses should therefore have two drive systems operating independently of each other. The change over from diesel engine to electric traction was made at suitable stops in the network. The driver can control the attachment and disconnection from the catenary system from his cab.



The joint use of track by both trolley bus and tram in Essen, picture ScanTech Development.

It was decided to not interfere with the existing tram catenary system. Because the buses could not fit an pantograph they built a complete separate catenary system of the normal trolleybus type. Therefore the buses was able to run at 750 V and the tram could retain the 600 V system. In the tunnels the trolleybus catenary was kept aside the trams in a low position because of lack of height. Power for the trolley system was supplied from four separate rectifier substations.

In order to integrate the guided buses in the existing tramway protection system, they were equipped with sensors for an automatic braking system and a device for reducing the typical bus braking performance to that of a tram. A modern bus can decelerate $>5 \text{ m/s}^2$ in an emergency, a tram on the other hand can brake only $1,5 \text{ m/s}^2$ under ideal circumstances. If the automatic train protection system ordered the bus to stop, it risked to be hit by a tram from behind. Still German vehicle inspection require the buses to brake at least 4 m/s^2 when in road traffic. So the braking system must know when and if it was on the road or on the track.

Operational experience shows that the system with guided buses have proved its serviceability. Passengers, particularly elderly, appreciated the quick transfer from bus to tram very much. The drivers appreciated the guided driving and separation from other traffic. The system had a lower rate of accidents than any other part of the public transport system in Essen.

In 1995 the German government cut down the funding for the experiment. At the same time it occurred several dewirings in the tunnels, that showed that part of the catenary needed rebuilding. It was therefore decided to quit operation in the tunnels and use the buses only in diesel mode over ground. The guided tracks are still in use.

Reason for this was that operational cost for duobuses was 25 % higher than for articulated dieselbuses. Due to greater complexity they needed 50% more maintenance time. Still the duobus was cheaper to run than a tram with equal passenger carrying capacity. What influenced the decision to stop operations in trolley bus mode was the slowness and inefficiency of the suppliers of the electric components. A commercial dieselbus can normally get any spare part over night when breaking down. In the case of the electrical components for trolley operation EVAG in some cases had to wait for important spares in months, as happens with spare parts for trams. This is an important factor why the duobuses still operates every day on streets in Essen, but now only powered by dieselengines. The catenary is still in place, but the trolley poles lie flat on the vehicle roof.

The experiment in Essen shows that it was technically possible to implement all this complex technique and run it successfully. It was never really a commercial project.

4.4 Athens

The City of Athens was in the 1980s in the process to be as famous for its smog as for its ancient monuments. The streets passes many steep hills. The geography is thus ideal for trolleybuses. To improve the air quality the government decided to reinvest and greatly expand the trolley bus system. Today it has EUs largest trolley bus fleet. It has 90.000.000 customers a year. In peak hours the trolleybuses operates in five minutes traffic. The routelength is 148 km.



A Russian built ZIU trolley bus in Athens, picture ScanTech Development.

The trolley bus fleet consists of more than 400 buses, mainly from Trolsa/ Dynamo (former ZIU, Engels City, Soviet Union). The last batch of Russian made buses was obtained by barter trade. Recently Athens ordered 192 new trolleybuses, equally divided between Van Hool/Alsthom and Neoplan/Kiepe. Athens have no duobuses and is not intending to buy any at present.

4.5 Nancy

City of Nancy is situated in east of France. In order to reduce emissions they The trolley bus route net is 30 km. At present the fleet consists of 48 articulated Renault per 180 duobuses that produces 40 % of all public transport. In the end of 1998 Nancy decided to invest in 25 Bombardier GLT (Guided Light Transit.). This is a revolutionary new concept, a form of light rail on rubber wheels. They can operate either in electric or diesel mode. They are scheduled to come into operation in the end of year 2000.

4.6 Copenhagen

The city of Copenhagen have made a test of a duo bus system. The authorities decided not to go further with duo buses. Instead Copenhagen invested in an automatic subway system from AnsaldoBreda.

4.7 Seattle

The City of Seattle, situated on the north west coast of USA. Its all hilly city with many road tunnels. Seattle has 14 trolley bus lines, total length of routes is 90 km. 109 conventional trolleybuses from AM General and 46 articulated from MAN. In 1990 they introduced articulated duobuses from Breda/Merani to better utilize the trolley net in city center and in the many tunnels in the city. The 234 duobuses in service have unfortunately had technical problems, making them unreliable. They will be replaced by new vehicles.

5. Comparison trolley bus systems versus other traffic systems

5.1 Introduction

In this comparison we have compared different trolley bus concepts with diesel buses and trams.

We have made a synoptic survey of external effects, costs and operating flexibility. This survey is based on literature, interviews with traffic operators and a questionnaire to trolley bus manufacturers.

5.2 External effects

5.2.1 Exhaust emissions

Trolley bus systems operating on electricity together with trams and light rail have no local emissions from combustion engines.

The diesel bus emits e.g. nitrogen oxides, particulate matters, and carbon monoxide and volatile organic compounds. Although extensive efforts to reduce the environmental impact are made by diesel engine producers the problems with emissions of nitrogen oxides and particulate matters remains. Both nitrogen oxides and particulate matters are hazardous to humans.

There are national Swedish goals for reducing emissions of both nitrogen oxide and particulate matters. About 300 000 persons are exposed for hazardous levels of emissions in Swedish cities. Emissions from urban traffic causes between 100 and 1000 cases of cancer every year. Diesel exhausts have a considerable impact on the total emissions in urban areas. The smell of diesel-exhausts is an inconvenience for bicyclists, specially uphill.

Exhaust emissions from a diesel engine for a bus are measured as g/kWh. The figures below is for modern Scania engines for the EURO 3-norm.

Emissions for three modern diesel engines.

Engine power	NOx	PM	CO	HC
300 kW	4,6	0,08	0,5	0,3
250 kW	4,8	0,1	0,6	0,3
220 kW	4,7	0,07	0,4	0,2

Source: <http://www.scania.se/environment/emissions.html>

The trolley bus together with the diesel bus uses tires. Tires contributes to the emissions of particles. Trams emits microscopic metal particles due to the friction between rail and wheel. Diesel particles are recently considered as a health hazard. Particulates from tires and asphalt are known to be bigger in size and therefore less dangerous for health. The health effects of microscopic metal particles are not yet an issue in the traffic debate although they are known to be as an health hazard in the steel industry.

The total effects on emission of greenhouse gases are due to the overall system consumption of energy and the emissions from electricity production. To compare the emissions of greenhouse gases from diesel buses with the emission trolley bus systems it is necessary to study the overall energy consumption for the trolley buss system including energy losses in the electric net.

A environmental study (Trolley 2000) on the trolley bus system in Arnhem compares the emissions from trolleys and modern diesel buses with different fuels. The study compares 18 m articulated trolley buses with 18 m articulated diesel buses.

The emissions was calculated for the whole system including energy production. In the Netherlands the power mix is about 50 percent coal and 50 percent natural gas produced in combined cycle plants with very high energy utilization. More than 90 percent of the electricity in the Netherlands is produced with fossil fuels.

**Emissions from trolley bus system compared with diesel buses,
ex. Arnhem.**

	Diesel bus g/vehicle km	Trolley bus g/vehicle km	Trolleys total emissions compared with diesel engines
NOx	18,60	1,27	7%
CO	1,90	0,06	3%
HC	1,34	<<0,1	<<1%
SO2	1,44	0,62	43%
Particulates	0,56	0,012	2%
CO2	1880	1380	73%

For countries like Sweden where hydro- and nuclear power contributes with more than 90 percent of the electricity the trolley bus will be even more favorable than in the Netherlands. For greenhouse gases the emissions will be factor 10 lower than in the Netherlands.

We have taken the best emission factors for a modern articulated diesel bus with a Euro 3 diesel engine (Scania) using best available diesel (MK I= Jet fuel) together with the energy consumption data from Arnhem and made a brief calculation for the Arnhem trolley bus system with Swedish power production data. This calculation is only made to show the order of magnitude. We also don't know what the fuel consumption of a diesel bus in Arnhem traffic pattern should be with Swedish low energy diesel fuel.

**Emissions from trolley bus system compared with diesel buses.,
ex. Arnhem with Swedish power mix.**

	Diesel bus g/vehicle km	Trolley bus g/vehicle km	Trolleys total emissions compared with diesel engines
NOx	10,4	0,1	0,1%
CO	1,5	0,01	0,6%
HC	0,85	0	-
SO2	-	-	-
Particulates	0,17	0,001	0,5%
CO2	1600	140	8%

5.2.2 Noise

Noise from urban traffic is a serious problem. Many efforts are made by local authorities to reduce noise from urban traffic. In urban traffic noise from the diesel engine is most prominent part of the noise from the diesel bus. This is particularly important when the bus accelerates. For tram and light rail the dominant part of the noise comes from the contact between rail and wheels. The trolley bus with its rubber tires and electric engine has lower noise levels than trams and light rail vehicles. Most of the noise from a trolley bus originates from the fans cooling the electrical equipment and from the wheels. When the bus is standing still it is almost silent.

In the Arnhem report (Trolley 2000) the noise emissions from diesel buses and trolley buses are measured. A trolley bus generates 72 dB (A). A diesel bus with best noise reducing equipment generates 78 dB (A) at the same speed. The difference in noise is almost factor four.

5.2.3 Energy consumption

Experiences from Arnhem (Trolley 2000) shows that for a trolley bus system with capacity of 135 passengers in each bus and a total production of 324 millions of passenger kilometers consumes 1,95 kWh/vehicle km (4,89 kWh/vehicle km as primary energy in Holland). If the trolley bus system had been substituted with state of the art diesel buses with equal capacity each of the new articulated buses would have had a energy consumption of 7,18 kWh as primary energy in Holland. The Arnhem system uses regeneration of braking power. A concentrated trolley bus system makes it possible to reuse up to 50 percent of the regenerated power.

5.2.4 Visibility of network

The network for trams and light rail have a high visibility. It is easy for commuters to find where the tram goes. Visibility is often assumed to increase the use of public transport systems.

Trolley bus systems using overhead grids have almost the same visibility. Trolley bus systems using ground connection to the grid, such as AnsaldoBreda STREAM, seems to have less visibility of network.

New concepts such as Bombardier GLT and Matra CiViS can be made with the same visibility as tram- and light rail systems.

The operating line for a diesel bus is in itself not visible. It is of course possible to use other means to increase the visibility of the line.

5.2.5 Flexibility

The conventional diesel bus is the most flexible traffic system. The diesel bus has increased its domination of urban traffic due to high flexibility.

The least flexible systems are trams and light rail. It is very expensive to make changes in the operation lines for trams and light rail.

The flexibility of a trolley bus systems is somewhere in between. New hybrid concepts make it possible to leave the operated line for shorter detours.

Indoor operations will have increased importance in the future. Trolley bus, trams and light rail systems with no local emissions can operate in tunnels and inside shopping malls. Many operators and building constructors judge indoor operations as a great advantage for the competitiveness of public transport systems.

5.2.6 Traffic safety for passengers

Trams and light rail vehicles give high passive safety for the passengers due to their heavy construction. In most collisions with other vehicles the rail bound vehicles will remain undamaged.

There is no difference between the diesel bus and the trolley bus in passive passenger safety. In most collisions with railbound passengers will remain unhurt.

5.2.7 Traffic safety for other road-users

The situation is the opposite the above when it comes to traffic safety for other road users. The heavy construction of the rail vehicles is a safety problem for other road vehicles. Vehicles with rubber tires have much better braking performance in an emergency. Diesel- and trolley buses with steering wheel can also avoid collisions with other road users by turning away. Traffic systems with buses gives higher safety for other road users.

The experience from Essen is that the trolley bus has the lowest accident rate of all traffic systems. Against the trolley bus when it comes to safety is that it is so silent that it can't be heard by other road users.

5.3 Economy

5.3.1 Investment costs

5.3.1.1 Investment in fleet

The Arnhem experience from Trolley 2000 is that the investment cost for the fleet will be twice the investment compared with an equal number of articulated diesel buses. The trolley bus has an estimated economic life of 20 years and is written off in 15 years. The diesel bus has an estimated economic life of 12 years and is written off in 10 years.

A report from Denmark (Lettbaner i Storkøbenhavn? – Status marts 1996, Rambøll, København 1996) states that investment cost for a modern tram is about 2 million Euro. An articulated trolley bus with the same capacity costs about 0,6-0,8 million Euro. A diesel bus with the same capacity costs about 0,3 million Euro.

5.3.1.2 Investment in infrastructure

In Copenhagen (Lettbaner i Storkøbenhavn? – Status marts 1996, Rambøll, København 1996) they estimated the investment in the network, rails and catenary, to 4,3 million Euro per kilometer. An Italian report indicates investment costs for the catenary for a traditional trolley bus system with 50 km double track overhead wiring to 32,5 million Euro. The cost per kilometer will be 0,3 million Euro per km single track.

5.3.2 Maintenance cost

An English report (The Electric Trolleybus – its role in future transport system, P Williams, 1996) describes the total maintenance for both fleet and network costs for different traffic systems in the Netherlands. The overall yearly maintenance costs in Euro for a diesel bus, trolley bus and tram is shown below.

Yearly maintenance costs in Euro

Diesel bus	Trolley Bus	Tram
7400	9800	19000

Source: The Electric Trolleybus – its role in future transport system, P Williams, 1996

5.3.2.1 Maintenance cost fleet

We have got maintenance costs from different operators. Due to the deregulation and increasing competition we have only been allowed to publish the maintenance costs as percentage with the typical articulated diesel bus as base.

The maintenance costs for trolley buses operated in a large net is equal to the maintenance cost of diesel buses of the same capacity. In the case of duo buses the best figure is 25 percent more and the worst figure is 100 percent more.

The maintenance costs of a tram is even more expensive than the duo bus. The experience from Essen is that the maintenance costs for a tram is double that of an articulated diesel bus.

5.3.2.2 Maintenance cost infrastructure

The diesel bus don't need any special infrastructure. It uses streets.

The trolley bus system consists of several parts. It needs sub-stations for rectification of AC power to DC, normally 600 or 750V DC. It also needs cables for distributing the electricity to the overhead catenary.

The tram need both power supply systems and rails.

It has not been feasible in this project to get up to date and reliable maintenance costs for trams and trolley buses that operates under comparable circumstances.

5.4 Conclusions

Comparative analysis, trolley bus and new trolley bus systems vs tram and diesel buses

	Trolley bus	Diesel bus	Tram	Bombardier GLT Matra CiViS	DUO Bus (trolley + diesel)	Ansaldo- Breda STREAM
Noise	***	**	**	***	**(*)	***
Local emissions	***	*	***	**(*)	**(*)	***
Flexibility	*	***	*	**	**	**
Maintenance costs	**	***	*	?	*	?
Investment network	**	***	*	**	**(*)	**
Investment fleet	**	***	*	?	*(*)	?
Capacity	**	*(*)	***	**(*)	*(*)	*
Visibility of network	***	-	***	***	**	*
Energy consumption	***	**	**	?	***	?
Braking performance	***	***	*	**	***	***
Traffic safety passengers	***	**	***	***	***	***
Traffic safety – other trafficants	**	***	*	*	***	***

*** = best

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Interviews with:

EVAG, Essen

Connexxion Arnhem

Gaia Trafik a/s Bergen

Appendix 1

New concepts for trolley buses in Sweden

Socio-economic costs

Our finding shows that shows that trolleybuses from a commercial perspective have higher investment cost than comparable diesel driven buses.

It could be interesting to try to internalise external effects in the calculation.

As an example, we presume that in a Swedish city, the build and operate trolleybuses in a similar as in Arnhem.

We thus take the production figures in Vehicle km /year from Arnhem and use typical Swedish emission data from state of the art dieselbuses and best available fuel.

The production figures from Arnhem 2.400.000 km /year with trolley.

Electricity consumption 195 kWh/100 km (including heating & ventilation). Total: $1.95 * 2,400,000 = 4,680$ MWh/year.

Diesel alternative: 65 litre/100 km total: $2.400,000 * 0.65 = 1.560.000$ l
CO₂ emission is: $2.61 * 1,560,000 = 4,0716,000$ kg

In cities the trolley have no exhaust emissions. The internalised cost is = 0

The diesel bus have following social economical costs to be internalised.

	Emission factor g/vehicle km	total emission kg	Cost SEK/kg	Total cost SEK
NO _x	10,4	24,860	92	2,287,120
HC	0,85	2,400	66	237,600
Particulates	0,17	408	1084	442,272
CO ₂		4,0716,000	0,38	1,547,208
In total:				4,5 M SEK

We have used cost factors from Swedish sources (Hansson 1997). In the case of particulates the social cost might be higher today. This would not affect final result very much.

We have not credited the trolleybus with the reduction of noise, because it is difficult to calculate the benefits of noise reduction of certain vehicles in a traffic flow. More could be gained also trucks used the catenary and thus reduced the noise from all commercial transport.

The social cost from accidents is assumed to be equal.

The social cost from emissions in the Swedish electricity production incl. transition losses is assumed to be equal to emission from refineries and other up-stream losses in oil processing and transport.

The bus uses 4,680 MWh electricity /year. The price ex. tax, ex. distribution duties for this is in Sweden is today less than 150 SEK/MWh = 700.000 SEK.

A diesel alternative would use $2.400.000 \cdot 0.65 = 1.560.000$ litre

The price of diesel fuel (MK 1) (27 Nov 1999) ex.taxes is 3.30 SEK/litre. Total cost is:
 $1.560.000 \text{ l} \cdot 3.30 = 5,148,000 \text{ SEK}$

The difference in cost between electricity and oil is (M SEK/ year):

Oil	5,1
Electricity	0,7
Difference	4,4
Internalised social cost	4,5
Total cost difference	9 (1,1 M Euro)

An annuity on 15 year and 4% real interest is 0,09

It would be possible to invest $9/0,09 = 100$ M SEK in infrastructure.

If the catenary system was used as a public net for other commercial transport as refuse collection, distribution etc the social economic benefits would be greater still.

Compared with trams trolley bus solution is less capital cost intensive. As the trolley bus is much less specific weight it will use less energy.

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