Take-up guide for the Replacement of urban Diesel buses by Trolleybuses

im Auftrag der

Leipziger Verkehrsbetriebe GmbH (LVB)

Rail&Bus Consultants GmbH
Fritz-Vomfelde-Straße 6
40547 Düsseldorf

Verkehrs-Consult Leipzig
Martin-Luther-Ring 13
04109 Leipzig

This publication has been prepared by the authors in the framework of the TROLLEY project.

The TROLLEY project is implemented through the CENTRAL

EUROPE Program co financed by the ERDF

Trolley

Promoting electric public transport

INTRODUCTION

The INTERREG Central Europe project TROLLEY – Promoting electric public transport - contributes to an improved accessibility of, and within, Central European cities, focusing on urban transport. By taking an integrated approach the project has one main aim: the promotion of trolleybuses as the cleanest and most economical transport mode for sustainable cities and regions in Central Europe.

The Central Europe project TROLLEY (www.trolley-project.eu) is one consortium of 7 European cities: Salzburg in Austria, Gdynia in Poland, Leipzig and Eberswalde in Germany, Brno in Czech Republic, Szeged in Hungary and Parma in Italy. Horizontal support for research and communication tasks is given by the University of Gdansk, Poland, and the international action group to promote ebus systems with zero emission: trolley: motion.

The project TROLLEY promotes trolleybus systems as ready-to-use, electric urban transport solution for European cities, because trolleybuses are efficient, sustainable, safe, and – taking into account external costs – much more competitive than diesel buses. The project directly responds to the fact that congestion and climate change come hand in hand with rising costs and that air and noise pollution will finally result in growing health costs. Trolleybus systems are assisting with the on-going transition from our current reliance on diesel-powered buses to highly efficient, green means of transportation.

Trolleybuses long were out of fashion, but the TROLLEY project is helping to show how these existing transit networks can play an integral role in providing green transport for well-planned cities of the future. Therefore, the TROLLEY project seeks to capitalise on existing trolleybus knowledge, which is truly rich in central Europe, where trolleybus systems are more widespread.

This following Trolleybus Take-up Guide presents how trolleybus systems, as a well working sustainable public transport system, can face the challenges like growing car ownership in Central Europe city areas, strong separation of transport modes, but growing mobility demands (in quantity and quality), environmental pollution through increasing congestion of

roads traffic. Trolleybus transport is a key element of sustainable mobility and provides a real alternative to personal motorized mobility. And trolleybus systems can provide the backbone of an integrated and seamless intermodal passenger transport in urban areas.

As the energy costs, especially for fossil fuels like diesel, petrol and gas, increase and as the operating costs have to be reduced, the operators increasingly focus on alternative drive concepts. Obvious there is a change from combustion engine to electric power. The implementation of a trolleybus system is a more sustainable alternative to car transport or diesel-driven public transport. However, there are preconditions that have to be fulfilled to offer a seamless intermodal passenger transport with trolleybuses.

How to take up a trolleybus system is described in chapter 1 of this guide (management summary). Chapter 2 describes the trolleybus development and potential role of trolleybus systems in passenger transport solutions. Chapter 3 talks about the technical principles of trolleybus systems. In Chapter 4 a case study is given in which the feasibility of a trolleybus system is analyzed for the city of Leipzig. Following this, chapter 5 deals with the associated costs of trolleybus systems. Communication and marketing play an integral part in the process of implementation of trolleybus systems. Chapter 6 elaborates on this topic. Then, chapter 7 talks about different approaches, assuming the perspective of different actors in the process of implementation. One of the most important aspects of trolley busses is their economic edge over diesel-powered buses. Chapter 8 will talk about this in depth, using a case study from Poland. In chapter 9 some marketing experiences will be shared. The guide will therefore offer some best practice examples. The last chapter then offers some experiences from the cities Leeds, Eberswalde, Szeged and Salzburg. These can serve as insightful case studies in the implementation process of trolleybus systems.

Management summary – short version

I-1 Context

The trolleybus is a proven public transit system being operated in over 310 cities worldwide (56 countries); there are more than 40 000 trolleybuses in operation in the world. Far from being a «has been» mode of public transportation, 45 trolleybus systems have emerged worldwide since 1990, of which 27 are in Europe. Currently, cities such as Leeds (United Kingdom), Riyadh (Saudi Arabia), Osnabruck (Germany), Verona (Italy) and Montreal (Canada) are either introducing a trolleybus system or are studying the feasibility of its implementation. The trolleybus is the most reliable and most common electric on-road urban public transit vehicle in the world. Furthermore, it is a readily available solution to help cities achieve environmental objectives such as the European community's emission reduction target of 60 %, by 2050, as laid down in the European Transport White Paper. Results of a study in Osnabrück (Germany) show that the implementation of a trolleybus system is the fastest way to reduce CO2 emissions in the city – better than the implementation of a tram system or the use of the most recent diesel buses technology (euro 6).

This pamphlet will be of interest to those who wish to familiarize themselves with trolleybus networks and the requirements to build and operate one. Subjects addressed are: «**THE TROLLEYBUS: THE MOST EFFICIENT ELECTRIC HEAVY DUTY PUBLIC TRANSIT VEHICLE AVAILABLE TODAY**», «**the vehicles**», «**the electrical network**», « **capital and operational budget planning**», «**the business case**», «**the pre-tender**» and «**marketing and communications issues and challenges**».

Figure 1.1: New trolleybuses for Riyadh, Saudi Arabia (photo by Vossloh Kiepe GmbH)

I-2 The trolleybus: the most efficient electric heavy duty public transit vehicle available today

The trolleybus is the only electric heavy duty public transit vehicle, available in versions of 12 meters, 18 meters and 24 meters, which can not only equal the operational performances of diesel propelled buses, but also exceed them. For example, while a diesel bus can remain in customer service for periods of approximately 24 hours before it must return to the depot for fuelling, a trolleybus can remain in customer operations indefinitely. As for diesel buses that remain in customer service for extended periods of time, trolleybus operations can be planned to allow driver rotation on customer routes, hence minimizing non-productive travel back to the depot. The electric battery buses commercially available today have not yet attained, for major bus routes with heavy ridership, a level of operational efficiency and economic performance akin to those of today's diesel buses.

The trolleybus is a dynamically charged électrobus (electric bus). The dynamic charge is provided through direct contact between the trolleybus' poles and the overhead contact line; direct contact is the most efficient method to transfer electrical energy from one electrical circuit to another. It can remain in customer service as long as operationally required and can travel autonomously over short distances up to approximately 10 kilometres, without contact with the overhead contact line, relying solely on the electrical energy stored in on-board batteries. As the capacity and performance of on-board energy charging, storage and management systems improve and as the energy requirement of sub-systems decreases thru improvements resulting from R&D efforts, the off overhead contact line autonomy of the trolleybuses will increase.

The major challenge of battery bus designers is to determine the most efficient ratio of bus autonomy to battery pack weight. In other words, the autonomy of a bus is directly proportional to the energy storage capacity of the on board energy storage unit. The interaction between size, weight, thermal behaviour, life cycle and capacity has to be optimised. Ultimately, given that the vehicle must not exceed a maximum axle load, the importance of the weight of the battery pack must be weighed against the number of passengers the vehicle is intended to carry.

Figure 1.2: Hybrid electric bus from Ebers-walde, Germany
(photo by Barnim Bus Company mbH)

Today's trolleybuses can be regarded as «hybrid electric buses», hence a cross between a traditional trolleybus and a battery bus. The hybrid electric buses (today's trolleybus) can charge its energy storage units under the overhead contact line of a trolleybus during the journey and thus drive both on line sections with an overhead contact line and on line sections without an overhead contact line. In that way the disadvantages of the trolleybus (i.e. overhead contact line needed) and of the battery bus (i.e. low range) can be overcome by the hybrid electric bus. Hence, the implementation of an electric urban bus system with overhead contact lines over only about 30 to 50 % of the line becomes possible. It is thus possible to avoid line sections with overhead contact lines in:

- Sensitive urban areas where the overhead contact line itself, but also its suspension poles or outside walls, is regarded as extremely disturbing;
- Areas in which very complicated and cost-intensive crossings and switches would be needed for the overhead contact line;
- Areas with less intensive cycles due to a lower demand. In other words, in areas where an overhead contact line system would not amortize itself within a foreseeable future;
- Areas where an overhead contact line system would have to be cut off in case of an emergency because space is very restricted;
- Areas only needed for turning or in case of service interruptions.
- Areas where the overhead contact line conflicts with heavy loads transport routes.

The development of off-line electric buses is intimately linked to the R&D efforts to develop less energy consuming on-board auxiliary systems such as AC and heating systems.

I-3 The vehicles

The trolleybus was introduced more than a century[1] after the automobile yet, is thought of by some people as an outdated mode of transportation while the automobile is viewed as modern. Like the automobile, modern trolleybuses are nothing like their ancestors; they are high tech electric vehicles equipped with the latest technologies, that can be operated on or off the grid, independently of overhead wires by means of dual power (electrical or diesel auxiliary power unit). Driving comfort is better than that of internal combustion engine vehicles; the electric drive motor generates far less vibration and noise than internal combustion engines and their inherent transmission. The passenger compartment is more spacious and ergonomically better designed; the propulsion system of the trolleybus is much smaller, hence the additional available space for a given vehicle length is used for passenger comfort. The use of state of the art electronic control systems enable optimization of energy consumption; further, the “at wheel” higher energy efficiency of the electric motor (40-45 %) against any mechanical transmission of internal combustion engine (25 %) makes the trolleybus the most efficient and most environmentally friendly high capacity road vehicle.

Trolleybuses are available as standard 12 meters trolleybuses, 18 meters articulated trolleybuses or 24-25 meters double articulated trolleybuses.

Figure 1.3: 25-meter-long double-articulated trolleybus (photo by Hess AG)

Several futuristic trolleybus designs have been produced in recent years. These aim at giving trolleybuses a distinct signature so that they are easily distinguished from diesel or gas powered buses. The first such design was the Cristalis, in Lyon, prior to 2005, while in 2012, streamlined trolleybus models by Solaris/Cegelec, the «MetroStyle», and by VanHool/Kiepe, the «ExquiCity», were introduced in Salzburg and Parma/Geneva. These latter trolleybuses

[1] The first buggy powered by an electric motor connected directly to the electric power grid via a pole was introduced by Herr Werner von Siemens near Berlin (Germany) in 1884. By the early 1900, the concept had evolved to what was called the rail less tramway. In the early 1920, it was referred to as the Electric Trolley Omnibus.

have an appearance closely resembling that of modern trams. The new Hess Swisstrolley4 deliveries to Limoges in 2013 are also of a revised, more streamlined design. These trolley-buses are often operated as Bus Rapid transit vehicles. For example, in Zurich, Switzerland, line # 31, is a high-capacity trolleybus line using double articulated low floor modern vehicles (25 m vehicle) carrying more passengers than some of Zurich's tramlines. It is a radial line which serves four S-Bahn stations, as well as the main train station. It is operated on central dedicated lanes, it makes use of various traffic signal priority systems at all intersections and, dynamic and static in-vehicle information is made available throughout the route. The city centre of Zürich is fully operated by electric public transportation vehicles (trolleybuses and trams).

The trolleybus does not produce emissions while running as it consumes only electricity; if, in addition, the electricity used is produced using renewable energy, the trolleybus system is a true «zero-emission» public transport system. The trolleybus systems in Salzburg and Landskrona are, for example, true «zero emission» systems as the source of their electricity is «hydro».

The electric power system of a trolleybus comprises four (4) major sub-systems: the Propulsion system, the Energy management system, the Pole system and the Auxiliary power system.

Propulsion system: A trolleybus has the same driving characteristics as a diesel bus. However, it can be equipped with several electric motors, usually mounted under the floor rather than at the rear of the bus as for diesel buses. Because of the inherent high torque capacity of the electric motor, a gear box, unlike the diesel bus, is not required. Further, significant space can be gained if electric wheel hub motors are used instead of a conventional electric motors, allowing for the design of a more spacious and comfortable trolleybus interior design;

Energy management systems: A trolleybus is operated electrically which is the most efficient way to get power to an engine. As long as a trolleybus is operated under the overhead contact line, its range is more or less "infinite" as its fuel source, electricity from the overhead contact line, is continuous.

Poles systems: Typically, trolleybuses are equipped with two trolley poles, which are fitted in parallel on the top of the trolleybus, at the rear. They draw the traction current from the two wires of the overhead contact line one pole per wire. One wire, referred to as the negative wire, is usually the 0V-potential wire and is usually installed on the outside, while the other wire, referred to as the positive wire is the 600 V or 750 V wire and is installed on the inside. Pole systems for automatically uplifting and connecting to the contact wires, even if the overhead contact line is not situated right above the vehicle, are in development.There are exceptions such as in Geneva in Switzerland where the 0V-wire is the positive contact wire and installed on the outside. The –600V – wire is the negative one and installed on the inside.

Auxiliary power unit: Modern trolleybuses are usually equipped with an onboard auxiliary power unit that takes over as the energy source when the trolleybus must disconnect from the overhead contact line. There exist two major types of auxiliary power units, notably the diesel auxiliary power unit and the electric auxiliary power unit. One of the characteristics of a trolleybus equipped with an auxiliary power unit is its ability to temporarily disconnect from the overhead contact line and continue his journey in standalone mode. The Termini line in Rome (Italy) is operated over 3.4 kilometres without contact with the overhead contact line. Over that distance, it is the battery auxiliary power unit that provides the required energy. The electric auxiliary power unit does not generate energy; it stores the required energy in energy stockage units such as batteries or/and ultracapacitors. Batteries can be charged dynamically through energy recuperation during deceleration, through the poles during regular overhead contact line operation or through plug-in to the electrical grid when parked.

I-4 The electrical infrastructure

Today's trolleybuses are dependent on a suitable infrastructure in the form of an Overhead Contact Line system and power supply installations (substations, cabling). Clean electric power is flexible and can be produced in a number of different ways such as hydro, atomic, wind, sun, etc.

While the overhead contact line is essential to feed electricity to trolleybuses, it is also a clear indication to the Public Transport customer that a public transport route is active and will remain active many years – this assurance of a public transport service will encourage ridership and urban development and revitalisation. In Salzburg (Austria), public transport customers use the slogan “the tracks in the air”, as it indicates to them that there is a regular public transport service where they see the overhead contact line.

Figure 1.4: Trolleybus in Salzburg guided by “the tracks in the air” (photo by TROLLEY project)

To plan and build an efficient trolleybus electrical infrastructure, it is important to understand the environment within which the trolleybus network will be operated. The various factors that must be identified are:

- Regarding **trolleybuses**:
  - The number of trolleybuses required for customer service at peak periods;
  - The timeline and routing of the lines and the traffic environment of the other vehicles sharing the same routes;
  - The type and performance characteristics of the trolleybuses’ on-board electrical energy charging, storage and management systems;
  - The performance characteristics of the powertrain;
  - The performance characteristics of the auxiliary systems;

- Regarding the **electrical power network**:
  - Identification of the different routes to be connected;
  - Identification of the various operational, technical and urban factors that may influence the location of switches and crossings ;
  - A preliminary assessment of the required electrical energy supply system;
  - The architecture of the overhead contact line network. For today’s urban planners, it is essential that the overhead contact line blends in naturally into the urban landscape;

- Regarding **socio-political policies**:
  - The introduction of a trolleybus system can be a very powerful sustainable development tool and urban development tool. It is a structured network around which existing communities can be revitalised and new communities developed.

The overhead contact line network is a very flexible system. It consists of a number of different parts. At first the overhead line has to be held in position. For that, two main possibilities are available: wall anchors and poles.

- **Wall anchors**: the use of anchors on buildings walls is the least expensive solution; of course, the walls must be strong enough to sustain the forces.
- **Poles**: the use of poles is a universal solution when the use of wall anchors is not feasible; however, it will require some civil engineering work for their implementation. Several requirements can be mutualised on a single pole, such as street lighting, urban technical units and overhead contact line. Furthermore, poles can be designed to blend into the local architecture and landscape.

It is possible to leave, enter or cross an overhead contact line. Electrical switches will separate two lines, mechanical switches will link two lines, while crossings will enable a trolleybus to cross two lines *at* different angles. It is also possible to cross a tramline's overhead contact line if necessary, without power loss for the trolleybus, at angles with less than 60^0. To reduce costs, plan your system with as few crossings and switches as possible. Note that it is also possible to design the system so that the trolleybus infrastructure crosses a tramline overhead contact line if necessary.

There are two main overhead contact line system designs for switches and crossings, the «pipe» and the «tense» systems. Both systems have a common feature, they have two contact wires. These wires are connected to a direct current energy supply network; one wire is the positive line, while the other is the negative line. Overhead contact line wires are available in different sizes, expressed as «square root» values. The most common sizes for trolleybus overhead contact line wires are expressed as square root 80, 100, 107 and 120, the square root 80 wire being the smallest (and lightest) and the square root 120 wire being the largest (and heaviest). The simplest construction is the straight contact wire which connects the start and the end of a line. If there is no need to connect another line it is not necessary to implement crossings and switches.

The pipe system, also called tube system, is designed such that switches and crossings are suspended under the two continuous uninterrupted contact wires (positive and negative) and are interconnected by copper tubes. This system is simple to implement and is very simple to repair in case of a failure (e.g. derailing) because only the pipe gets damaged, the contact

wire keeps in place. Furthermore, in the event of changing operational requirements and/or changes in the assignment of public transport routes, it is easy to move switches and crossings.

The tense system implies that the overhead contact line wires are connected directly to electrical switches. The switches are under mechanical tension, so when a contact wire breaks the whole switch / crossing loses tension on each side. In such a situation the whole crossing system becomes non-functional. It is also not possible to move the crossing because it will be held in position through the connected contact wires.

A power supply (power sub-station) is required; it will supply a high voltage alternating current that is rectified into direct current. The overhead contact line is separated into different segments, each getting its electrical power from switchgears. As a key element of the substation, the transformer must be dimensioned judiciously; if it is sized to small, the overhead contact line will lack power, while if it is sized to big, it will be uselessly expensive to acquire and will generate significant no-load losses. The number of required substations is established as a function of the expected load on the overhead contact line; it is also a function of the electrical losses of the overhead contact line, the dimension and performance of the power sub-stations and the level of redundancy acceptable to trolleybus operations. Normal distance between substations is 2-3 kilometres.

I-5 Capital and operational budget planning

Many cities would like to make their public transportation both noise and emission-free and therefore switch to the operation of electric vehicles. Regardless of the type of project one wishes to sponsor or undertake, the bottom line will always rest with these key questions: how much will it cost to build? And how much will it cost to operate year after year? The actual cost of the individual project is usually difficult to estimate. While the prices for electric buses, trolley lines and maintenance facilities are generally known and planning work can be calculated, the difficulties are mainly found in the social, economic and regulatory environments, and in accounting practices, as they vary from one country to another. However, we can provide a list of «elements» which must be considered to build a capital expenditure budget and an operating budget. Each of the elements can be weighed as a function of local specifics. Accordingly, trolleybus implementation costs can be as low as 1 M € per kilometre or as high as 20 M € per kilometre.

The budgeted total investment costs should include the acquisition and construction costs, an appraisal contingency, a risk contingency, a project contingency, cost of inflation throughout the building period, taxes and financial costs.

The budgeted recurring operational costs should include the cost of customer service delivery, the cost of vehicle and infrastructure maintenance and an appraisal contingency. Of course, if the trolleybus network is to replace an existing public transit line or network, the recurring operational costs become differential costs.

Typically investment costs include:

- The cost of preparatory studies;
- The cost to adapt or construct the bus depot: electrical infrastructure within the trolleybus depot, general adaptation of the depot, a workshop for the team responsible for the maintenance of the electrical network, including space for the required vehicles, replacement parts, tools and office space, professional services for studies and construction;
- The cost to adapt the bus operations center: the transmission network for the centralized energy management center, power sub-stations control equipment, the energy control station equipment and professional services;
- The cost to acquire the trolleybuses and specialized overhead contact line maintenance vehicles can include costs for: the actual vehicle acquisition, the required spare parts, special tooling as well as equipment and professional services;
- The electric power network construction costs: the acquisition of land for the construction of power sub-stations, the acquisition of equipment and material, construction work and associated professional services;
- The cost to adapt the urban infrastructure and urban technical network: dismantling urban infrastructure, digging up and relaying cables and other equipment, the construction of the new network and the implementation of mitigation measures, including professional costs; and finally
- The cost of operational integration: personnel training (drivers, operations control, trolleybus maintenance, electrical infrastructure maintenance, human resources…), engineering and technical support, trolleybus maintenance support, supply chain support, customer service delivery support, electrical network maintenance support, urban infrastructure maintenance support, etc.

Figure 1.5: New trolleybus for Parma (photo by trolley:motion)

Typical recurring operational costs include:

- Service delivery: administrative support personnel, drivers and operations managers, electrical energy and diesel savings (when applicable);
- Maintenance: bus operations center equipment, electrical power network equipment and infrastructure, trolleybus maintenance, trolleybus depot maintenance, spare parts and consumables, tree maintenance along the overhead contact lines, etc.

I-6 A cost calculation model

An experienced German transport planner developed a calculation model, using an innovative formula, to calculate what could be the cost of a planned trolleybus project. Such valuable insight into the cost of a planned project enables an operator to accurately plan capital expenditures as well as borrowing requirements. This financial data additionally provides the necessary insight for establishing the right kind of ticket prices for passengers on the network.

This model was applied, with success, to appraise the infrastructure costs of the urban trolleybus system for the City of Esslingen (Germany). Esslingen has a population of 90 000 inhabitants, a population density of 2000 inhabitants per square kilometer, a purchasing power of 48 000 Euros per resident and an unemployment rate of 3 %. Urban public transport planning studies indicated that an ideal trolleybus network size for Esslingen would

be 20.5 kilometers. Results obtained using the model indicated that the cost to build the trolleybus system would be 23.9 million Euros, 16 million Euros of which would be for the network and infrastructure costs. Hence, city planners can anticipate that the price of network and infrastructures, per kilometer, to be approximately 800 000 Euros.

Figure 1.6: Photomontage of planned trolleybus scheme for Leeds, UK (photo by Leeds New Generation Transport (NGT))

The model applies to small rural networks as well as large public transportation systems in major urban areas. The use of the model requires the use of local public transportation parameters and demographic data such as the regional population size, population density, unemployment statistics, age structure and purchasing power, etc.

The “Esslingen example” describes general cost structures based on pre-defined parameters. The model assumes that the required power sources and urban electric grid for a new trolleybus network are already in place. If not, any new system will obviously increase the project cost. Often other factors also influence final construction and development costs such as the desired use of dedicated bus lanes. Further, local specificities must be considered such as varying topography, the degree of infrastructure development and the type of soil upon which infrastructures must be built. All of these aspects must therefore be considered when drawing up final calculations and drafting realistic project budgets.

I-7 The business case

There are probably as many reasons to explore the feasibility of building a trolleybus network as there are cities; a number of factors will likely contribute such as the desire to reduce the environmental footprint of the urban bus fleet, political platforms that include sustainable development objectives and the will to decrease the trade deficit caused by massive foreign fossil fuel imports.

Undoubtedly the idea of implementing a trolleybus system will raise questions and be challenged with objections and facts often based on urban legends. These will need to be documented and addressed appropriately.

Also from the onset, significant funding will be required, notwithstanding that the long term benefits could outweigh the capital expenditures required to implement the trolleybus network. The process to obtain the required funding may vary from one city to another, and it is likely that a full business case study be required. The business case should include the results of a feasibility study which itself should include an appraisal of social, economic and environmental impacts, and an analysis of capital expenditures and life cycle costs. Its preparation is likely to be very time consuming and demanding on local expertise. It must be rigorously prepared and planned, and while certain activities can be carried out simultaneously, the business case should be prepared sequentially and include one or more validation of milestone.

Figure 1.7: Trolleybus poles (photo by TROLLEY project)

Cities such as Leeds (England) and Montreal (Canada) which were recently successful in preparing such studies used a similar approach. They identified a 'Champion' from amongst their senior staff to lead the initiative and see it through to completion. They also built a multidisciplinary project study team and obtained the required financial resources to carry out the feasibility study and submitted the business case report to public authorities for approval.

In essence, to enable authorities to select the most optimal trolleybus scenario, their feasibility studies presented various trolleybus network scenarios. Results of implementation and integration analysis for each scenarios was presented that included drafted implementation principles such as the identification of recommended electrical power network configurations, urban hardware (i.e. mast types), trolleybus types and onboard energy management and storage systems. Further, a class D financial analysis (± 30 %) was prepared for each scenario. This analysis included an assessment of the capital investment costs to design, build and commission the electrical power network, the trolleybus depot and the trolleybus control center, an assessment of the capital investments costs for the acquisition of the trolleybuses and required maintenance systems, tools equipment and vehicles and an assessment of potential savings and expenses on recurring operational budgets.

Once authorities selected the optimal scenario, the financial analysis of that scenario was refined to a class C (± 20 %) and a very detailed description of the physical, operational and financial characteristics of that scenario was prepared.

Figure 1.8: Trolleybus scenario "glide a cloud" - European Trolleybus Marketing award winner (design by Electric Tbus Group)

I-8 Detailed development up to the pre-tender

Once a trolleybus network scenario / scheme has been selected, it is essential to set out a dedicated Procurement Process. It is recommended to prepare a clearly defined Procurement Brief and establish the Procurement Process. The procurement process itself is very exhaustive and, to ensure that it is deployed and carried out efficiently, it will be necessary to develop an Organisational Structure (team/resources and allocated budget) specific to the trolleybus project.

To proceed to the tender phase, the trolleybus network scenario / scheme must have been defined and thoroughly documented, that is to say that all technical, engineering, social, economical, political, environmental and sustainability considerations have been documented, assessed and factored into the design of the scheme. Also, network expansion opportunities have been identified and assessed and, if pertinent, have been factored into the design of the network. Usually, the budget requirement to build the trolleybus network scenario / scheme, once all these factors have been factored in, has been appraised to (± 20 %). including a risk allocation

The following is a non-exhaustive list of key elements of an effective procurement process that should be addressed:

- Identify the Project / Procurement Governance and responsibilities and define the overall Governance processes;
- Define the procurement management programme, procurement stages and inherent procedures;
- Define primary and secondary procurement and commercial objectives;
- Define the market engagement & consultation programme and strategy;
- Define the benefits realisation strategy and delivery plan;
- Prepare and implement a procurement process evaluation strategy.

Before engaging the bid process, it is essential to know what the market can offer, identify potential bidders and prepare high level cost appraisals for all the bids that will be tendered. A cost benchmarking with other trolleybus operators is important as different solutions and manufactures will have different costs. Given the very high concentration of trolleybus systems and their rich history of trolleybus operations, Eastern European Union countries can provide valuable information and data; further, this situation has led to the establishment of several trolleybus and electrical system manufacturers and a healthier competition.

I-9 Marketing and communications issues and challenges

The promotion and marketing activities of a trolleybus scheme are as important as the technical, engineering and operational planning activities. Recent experiences, notably Landskrona (Sweden), Leeds (United Kingdom) and Montreal (Canada) indicate that a proactive communications and stakeholder engagement is a must.

Communications with **internal stakeholders** must be proactive and structured. This is often overlooked but is vital to avoid the spread of inaccurate information. Indeed, internal stakeholders require a common understanding of the project to work towards the delivery of a shared goal in a structured way. Hence, regular and accurate updates on progress should be provided to internal staff. Briefings are particularly important ahead of major public announcements.

External stakeholders who don't have enough information about the project are not able to make informed choices about whether they support the project or not. Engaging with external stakeholders includes providing information, consulting on detailed issues, involving local communities in the development process and empowering them to make informed choices. It is important to try to communicate with 'hard to reach' groups (e.g. the elderly). External messages must be factually correct and consistent.

A lack of public information about the project can lead to the creation of **urban legends**. These may be created by opponents to the scheme to influence public opinion. When this occurs, there must be a quick response as it is difficult to correct inaccurate information once in the public arena. Social media can be a useful tool for responding to urban legends.

A planned, targeted, effective and consistent programme of communications will be required in terms of **mobilizing the population in favour of trolleybuses, the only state-of-the-art proven electric bus available** for full scale operation**.** A Communications Management Strategy must be developed to set out how the Project Team will establish, develop and maintain active support for the project. There are a number of key groups who have scope to influence the success of the project. These groups must be identified at the outset. Key influencers include: politicians, business leaders, transport organisations, the general public, interest groups and the media.

Figure 1.9: Trolleybus image campaign “ebus – the smart way!” (design by TROLLEY project)

The following **key steps** are fundamental in ensuring effective communications:

- Step 1: Identify the aims and objectives;
- Step 2: Identify the Communications Principles;
- Step 3: Identify the stakeholders;
- Step 4: Undertake stakeholder analysis;
- Step 5: Develop an action plan for each stakeholder;
- Step 6: Develop an overarching communications action plan;
- Step 7: Record, Monitor and Report.

A range of **tools and techniques** can be used to communicate and consult with stakeholders. Different tools will be appropriate for different groups, however common tools include: meetings, presentations, workshops, focus groups, exhibitions, drop-in sessions, direct mail, questionnaires and surveys.

I-10 Conclusion

The migration of trolleybuses to autonomous electric buses, when technology will allow should be straight forward; replace the trolleybuses' electric energy management and storage systems with state of the art systems, remove the overhead contact wires and adapt trolleybus power substations to feed quick charge stations that will be installed along the bus route corridor.

Until recently, the major drawback of a trolleybus system was that it could not be implemented in areas where it was not possible to install an aerial contact line for either urban or physical reasons. Fortunately, today's technologies enables trolleybuses to be operated over significant distances greater than 10 kilometres while disconnected from the grid. The trolleybus is, hence, today's public transit electric mobility solution adapted to the future, as the only state-of-the-art heavy duty electric bus available today.

For those who wish to act immediately and reduce their ecological footprint, while responsively preparing for tomorrow's technological public transit solutions, the implementation of a trolley-bus network provides several advantages, amongst them, the reduction of the environmental footprint of a fossil fuelled bus fleet – to '0' emissions, energy efficiency in that electric motorisation systems are more efficient than fossil fuel systems; and energy flexibility in that electricity can be produced in many ways.

II Trolley operation

II-1 Worldwide trolleybus operations

All over the world, a 'pro trolleybus' movement is gaining momentum – which is not too surprising when considering the economic and environmental advantages of trolleybus systems. Cities such as Leeds, Riyadh, Osnabruck, Verona and Montreal are either introducing a trolleybus system or are studying the feasibility of its implementation. Approximately 310 cities worldwide, of which close to 150 European cities, operate trolleybuses. A list of trolleybus cities, as of July 2013, is presented at annex 2.1. For an updated list, refer to the Trolley:motion web site[2].

Trolleybus systems receive an additional boost due to new strategies and future orientation for the European transport area, such as for example the emissions reduction target of 60 % by 2050, laid down in the Transport White Paper[3]. The emissions reduction target and the limited oil reserves currently put electric public transport on the political agenda and technical innovations in electric bus systems experience a new dynamic. When considered from the point of view of the trolleybus, it is more a "back to the future!", as the trolleybus has already presented itself as fully developed, technically secure and economical electro mobility system over the past decades.

Figure 2.1: World map presenting the locations where trolleybus systems are in operation.

[2] http://www.trolleymotion.ch/index.php?id=111&L=3.

[3] WHITE PAPER Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system, http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0144:FIN:EN:PDF.

Because trolleybus systems have been around for more than a century, there are many people who believe that such systems are 'passé'. Yet, just like other modes of transportation, trolleybus system technologies have significantly evolved. Today, trolleybus systems are equipped with advanced technologies which, for example enable the trolleybus to operate, over short distances without being connected to an overhead contact line. Another example is the use of an optical guidance system by trolleybuses in Castellon in Spain. For these and other reasons, trolleybus lines continue to be extended, new trolleybus lines continue to be commissioned and trolleybus systems are being implemented or seriously considered. A partial list of cities, as of summer of 2013, where trolleybus operations were recently augmented, improved, implemented or where new systems are being considered is presented at annex 2.2. The cities of La Chaux-de-Fonds, in Switzerland, and Seattle in the USA, have recently (2012) decided to retain their trolleybus systems in the face of some pressure to discontinue them.

II-2 Trolleybus operations

Modern trolleybuses are high tech vehicles, equipped with the latest reliable technologies. Most new trolleybuses are capable of being driven independently of overhead wires by means of dual power (electrical or diesel auxiliary power unit) or hybrid power (surplus electrical energy generated during braking is stored in batteries or supercapacitors). Driving comfort is better than that of internal combustion engine driven vehicles; the electric drive motor generates far less vibration and noise than internal combustion engines and their inherent transmission. The passenger compartment is more spacious and ergonomically better designed than that of an internal combustion engine propelled bus; the propulsion system of the trolleybus is much smaller, hence the additional available space for a given vehicle length is used for passenger comfort. The use of state of the art electronic control systems enable optimization of energy consumption; further, the "at wheel" higher energy efficiency of the electric motor (35 %) against any mechanical transmission of internal combustion engine (25 %) make the trolleybus the most efficient and most environmentally- friendly high capacity road vehicle. A trolleybus system can carry almost as many passengers as a tram system if double articulated vehicles are used, as seen in several Swiss cities. The length of such vehicles (which are produced by several manufacturers in trolley-, diesel- and CNG-bus versions) is approximately 24 m; while the maximum vehicle length authorized for circulation in EU is of 18.75 m, it is possible to obtain an exemption for use on a specified route from the proper transportation authority.

Figure 2.2: A 25m bi-articulated Zurich Hess 'Lightram' trolleybus. (Photo – Hess)

Several futuristic trolleybus designs have been produced in recent years. These aim at giving trolleybuses a distinct signature so that they are easily distinguished from diesel or gas powered buses. Further, these attractive designs attract the attention and interest of all citizens, not only PT users. The first such design was the Cristalis, in Lyon, prior to 2005 while in 2012, streamlined trolleybuses models by Solaris/Cegelec, the «MetroStyle», and by VanHool/Kiepe, the «EquiCity», were introduced in Salzburg and Parma. These latter trolleybuses have an appearance closely resembling that of modern trams. The new Hess Swisstrolley4 deliveries to Limoges in 2013 are also of a revised, more streamlined design.

Figure 2.3: An 18m articulated Solaris Trollino 18 «MetroStyle». (Photo from the Solarisbus Web Site)

Figure 2.4: An 18m articulated Van Hool «ExquiCity 18». (Photo from the Van Hool Web Site)

II-2-1 Bus Rapid Transit (BRT)

A BRT is a type of bus/trolleybus service which, as the name implies, provides rapid and efficient public transit over long urban distances. The vehicles are designed for customer comfort. Typically, the BRT operates on a dedicated lane, has full traffic light priority and makes very few stops, if any, along the way.

Figure 2.5: The Lyon C1 line is operated as BRT on dedicated lanes. (Photo PG Andersson)

The trolleybus system in Quito, Ecuador, is an excellent example of a BRT system. It opened in 1995 and, in 2002, it was carrying approximately 220,000 passengers per day.

Figures 2.6 and 2.7: Illustrations of the Quito trolleybus BRT system (Photos from Wikipedia)

Lausanne (CH) is planning a t-network. This network will be a high level of service (BRT) network serviced by trams and trolleybuses. The trolleybus line will be operated on a dedicated lane with priority at intersections. It will be operated like a tram line[4].

Figure 2.8 bis: Planned BRT system in Lausanne (CH). Artist view from http://www.lausanne-morges.ch/index.php?aid=25

II-2-2 Priority at intersections:

Trolleybuses, as is the case for diesel buses, can be equipped with traffic light priority systems. These systems can operate in different modes. In essence, when operating in traffic, these systems can be programmed so that the trolleybus is given priority over other vehicles; when operating on dedicated lanes, these systems can be programmed to secure an intersection at the approach of a trolleybus, enabling the trolleybus to safely cross the intersection without stopping - Castellón (ES) uses such a system.

II-2-3 Reserved lanes:

A trolleybus reserved lane is a lane dedicated to the trolleybus. As required by the ridership needs, the reserved lanes can be dedicated to the trolleybuses 24 hours per day, 7 days per week, or only during specific hours such as rush hours. When lanes are reserved during specific hours, they can be made accessible to traffic and parking during the other hours. In Castellón, ES, to ensure that the reserved lanes were clearly marked and distinctive, they were paved with

[4] A trolleybus line operated like a tram line will have fewer stops, a higher commercial speed, traffic priority at controlled intersections. Hence, compared to a regular trolleybus line, it will have an improved headway and an increased frequency of service.

red asphalt; to add to the attractiveness of their trolleybus system, they also introduced fashionable bus stop areas.

Figure 2.9: The distinctive red asphalt of the Castellón, ES trolleybus system's reserved lane[5].

In Zurich, CH, line # 31, is a high-capacity trolleybus line using double articulated low floor modern vehicles (25 m vehicle) carrying more passengers than some of Zurich's tramlines. It is a radial line which serves four S-Bahn stations, as well as the main train station. It is operated on central dedicated lanes along parts of the line, it makes use of various traffic signal priority systems at all intersections and, dynamic and static in-vehicle information is made available throughout the route.

Figure 2.10: Trolleybus on a reserved lane in Zurich, CH; source: trolley:motion

[5] The source of the picture is: BHLS – Final Report: Buses with High Level of Service - Fundamental characteristics and recommendations for decision-making and research results from 35 European cities; COST action TU0603.

II-3 Advantages of the trolleybus

Millions of travellers enjoy the benefits of electric urban transport every day. They travel either by rail, light rail, metro, tramway or/and trolleybuses[6]. Of the foregoing modes, the trolleybus is the mode that requires the least amount of, and less intrusive, infrastructures. Hence, the trolleybus is a clean and economical public transit mode of choice and it is operated in approximately 310 cities worldwide. The following is a no exhaustive list of trolleybus advantages:

- Trolleybuses do not produce emissions; when regenerative energy is used, trolleybuses are the most energy-efficient and climate-friendly form of transport available today (from a well-to-wheel perspective).
- Trolleybuses have the lowest possible consumption of non-renewable resources -50 % less compared to diesel buses[7]; and are 100 % environmentally friendly when using electricity from renewable sources.
- Trolleybuses are very energy efficient; state-of-the-art energy recovery systems can save up to 25 % of the consumed energy through recuperation (during braking/ due to zero consumption during idling).
- Trolleybuses are the most silent and low-vibration form of on road motorised urban public transport.
- The total cost of ownership of trolleybuses is comparable to hybrid buses and will soon be lower than for diesel buses due to rising oil prices. Some trolleybus systems such as the one in Salzburg, AT have a lower total cost of ownership compared to diesel buses; above approximately 40.000 operational kilometres per vehicle, the cost-effectiveness of the trolleybus is better than the cost-effectiveness of the diesel bus. Statistics also show that trolleybuses are the most cost efficient mode at headways from 7,5 minutes and below.
- In comparison to tram systems, similar service levels can be obtained at much lower cost (up to 50% less); implementation time is much shorter with less interruption (under one year from design to operation).
- Innovative trolleybuses are designed like trams (up to double-articulated) and can be operated over short distances without the use of overhead wires in hybrid mode (diesel, batteries and/ or supercapacitors). This type of operation can be planned, as for the Termini line in Rome, or can be used only for emergencies when there are obstacles on the regular route.
- Trolleybus systems can be an important element of the smart electro mobility infrastructure of the future (synergies between charging infrastructures for various vehicle modes, use of local production peaks, bridging technology).
- Community budgets benefit from inherent advantages of Trolleybuses such as long lifecycles and highly efficient power-technology.
- High potential for synergies: it is possible to combine tram networks with Trolleybus networks, allowing synergies by using already existing power supply facilities and knowledge about electric vehicles;
- Trolleybuses generate the least amount of noise and vibration amongst on-road public transit vehicles.

[6] Some travellers travel by electric bus, but this mode is in its infancy stage and very few electric buses are in operation. Their reliability and cost effectiveness in the 12 m or better categories has not been demonstrated.
[7] Source: http://www.trolleymotion.com/de/ 2011.

- Trolleybuses make cities more liveable by running smoothly and producing no exhaust fumes.
- Trolleybuses' strong but smooth acceleration and grade-climbing ability are highly appreciated by passengers.
- Whereas a diesel bus must stop it's engine when stopped for more than a few minutes to prevent GHG and pollutants emissions[8], a trolleybus, when connected to the OCL, can maintain it's air conditioning system (summer) or heating system (winter) in operation when stopped;
- Due to the visibility of the overhead wires the Trolleybus systems are safer as trolleybuses are less involved in road accidents than other means of public transport. Moreover, the "tracks in the air" make it easy for passengers to locate the service.

II-4 Sources of energy to produce electricity for trolleybus systems

The transport sector is the fastest growing source of greenhouse gas and pollutant emissions world-wide. (UITP VEI[9]). These emissions are not only limited to those emissions produced by the propulsion system of the end user, but also those emissions produced throughout the production cycle of the fuel, from the initial extraction process, through the transformation processes and the transportation processes from the point of production to the point of sale to the end user.

A fossil fuel, for example, from well-to-wheel requires the use of heavy machinery and transportation vehicles that use one form or another of fuel to run. To gain a just appreciation for the emissions produced when using a fossil fuel, the emissions produced at each step of the well-to-wheel process must be computed. The same approach must also be applied to electrical vehicles. While electric vehicles do not produce emissions when operated, it is essential to compute the emissions produced during the «well-to-wheel» process for electricity.

There are numerous methods used to produce electricity; the type of fuel used by the electricity production plant (power station) has a direct impact on the cleanliness of the electricity. For example, electricity produced by coal firing plant generates significant amounts of emissions, while hydro-electricity produces no emission. The type of fuel used to produce electricity is often of political-economic-social consideration. Notwithstanding, it is possible to produce electricity exclusively from regenerative primary sources of energy, not emitting emissions, and thus to have the best possible emission balance globally.

[8] Actual allowed idle time depends on local regulations.
[9] UITP VEI - Vehicles and Equipment Industry Committee of UITP

Thus, as the trolleybus is a local zero-emission transport mode, the emissions associated to the trolleybus system depend on the method and fuel used to produce the electricity it uses. Energy resources used are of either the non-renewable or of the renewable type:

II-4-1 Non-renewable Energy resources

A non-renewable resource is a resource that, once it is consumed, it is no longer available; such resources are fossil fuels. Once they are extracted, transformed and consumed, they are gone. These resources include coal, oil and natural gas. Many power plants use fossil fuels to produce electricity. Some power plants run on nuclear power, which is another non-renewable resource and relies on uranium, a type of metal that is mined from the ground and specially processed.

II-4-2 Renewable Energy resources

Renewable energy resources are energy streams, wind power, solar energy, biomass, hydro and geothermal energy. They are found in nature and renewed in whole or in part. The name renewable comes from the fact that the energy is consumed in an amount not to exceed the speed at which they are produced by nature.

At the UN meeting on Climate Change, held in May 2011 in Abu Dhabi, it was concluded that in 2050 renewable energy could meet as much as 80% of the demand for energy in the world, which would significantly help combat against climate change (UITP TWG, Busarcevic, Stankovic, Krstic 2013). A pie chart showing the various renewable energy sources is presented at figure 2.11.

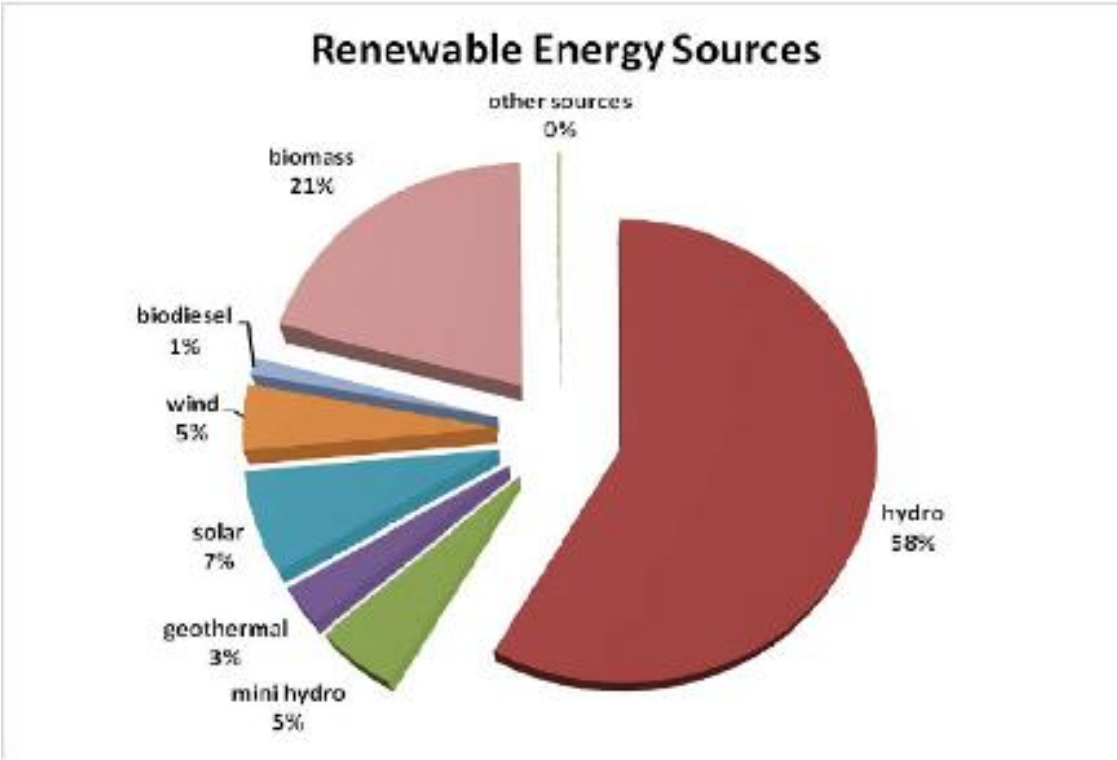


Figure 2.11: Renewable Energy Sources of the world (Source ?; UITP TWG)

Thus, a trolleybus system can be labelled a true «zero-emission» public transport system when a renewable energy source is used to produce the required electricity. The trolleybus systems in Salzburg and Landskrona are, for example, true «zero emission» systems as the source of their electricity is «hydro».

However, a comparative study[10] of the Barnim Bus Company from the German trolleybus city Eberswalde shows that the trolleybus can reduces CO2-Emission from 1600 g/km to 80 g/km according to the type of fuel used to generate electricity. For example, using electricity produced by non-fossil energy sources, CO2 emissions can be reduced by 97 %.

II-5 Relative capacities of public transit modes?

The trolleybus, as mentioned earlier, is a full electric bus which acquires its electricity via an overhead contact line. Given that it requires a significant electrical power distribution system to operate, modern trolleybuses are manufactured primarily as 18 meter and 24 meter vehicles to

[10] Trolley – Promoting Electric Public Transport, Part A: Feasibility study PBV, Berlin http://www.bbg-eberswalde.de/downloads/trolley/TROLLEY-TEIL-A.pdf

optimize and rationalize the investments. These trolleybuses have the same passenger capacity as diesel buses of same dimensions.

It is not unusual that, given the costs and extent of the civil works required to implement a trolleybus network – in comparison to the implementation of a regular bus line -, some groups will lobby for the implementation of a tram system, erroneously thinking that the price tag will be similar. The passenger capacities of various public transit modes are presented at figure 2.12. The data presented was calculated for Stockholm (Sweden, based on a ridership load of 2 passengers per square meter. The red lines indicate the passenger capacities per hour given headway of 5 minutes per lane and per direction. The blue shaded areas represent the passenger capacities for headways ranging from 2 to 10 minutes.

As can be appreciated, the passenger capacity of the various modes overlap as we move from buses to tram, to light rail and finally to the metro. Hence the first selection criterion for the selection of a public transit mode should be the required capacity of the public transit system for the medium to long terms. The second criterion is the cost of implementation; it is generally accepted that the implementation of a tram system will cost approximately five times more than the implementation of a trolleybus system.

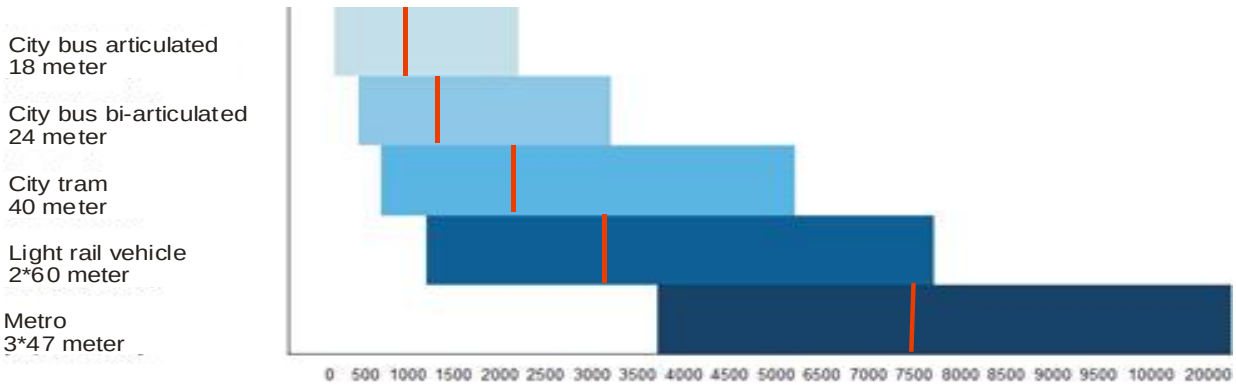


Figure 2.12: Passenger capacities/per hour of various public transit modes in Stockholm (Sweden) Source: Kol-TRAST, 2013, SKL, Sweden.

II-6 Trolleybus technologies

Trolleybuses were first introduced in the late 1800. While the principles of operation remain the same: an on-road vehicle propelled by an electrical motor which receives its energy from an overhead contact line, on-board trolleybus technologies have significantly evolved over the past

century. The following sections will describe the various on-board trolleybus systems available in 2013:

- Propulsion systems;
- Energy management systems;
- Pole systems;
- Auxiliary power systems (APU).

II-6-1 Propulsion systems

A trolleybus has the same driving characteristics as a diesel bus. It is also propelled, as a diesel bus from the rear axle, with the advantage that, if equipped with more than one electric motor, it can be propelled from more than one axle. Electric motors are usually mounted under the floor rather than at the rear of the bus as for diesel buses.

Originally, several types of series-winding, direct current motors were used in trolleybus. Those series-winding DC motors included: compensated single-collector motors, tandem (back-to-back) motors, and double-collector motors. Later on came the compound and shunt DC motors, which have nowadays been replaced by asynchronous three-phase, squirrel cage AC induction motors.

Because of the inherent high torque capacity of the electric motor, a gear box, unlike the diesel bus, is not required. However the drive axles need to be more robust and coupled to a reduction unit between the electric motor and the axle.

II-6-2 Energy management systems

A trolleybus is operated electrically. As long as a trolleybus is operated under the overhead contact line, its range is more or less “infinite” as its fuel source, electricity from the overhead contact line (OCL), is continuous. The electricity supply via the OCL does not only suffice for the propulsion system, but also for the operation of all other on-board electrical and electronic equipments such as: lighting, heating, air conditioning, ventilation, actuators, Wi-Fi, and passenger information systems to name but only a few. Hence, the degree of use of these auxiliary systems, such as heaters in winter and air conditioning in the summer can significantly affect the total energy consumption of a trolleybus.

Electrical energy distribution systems are dimensioned for continuous operation. The design requirements are function of:

- safety standards;
- power requirements;
- the topography of the routes (radii, gradients);
- maximum speed;
- climatic conditions.

Key technical elements of an electrical energy distribution system are:

- A distance, not to exceed 3 kilometres between substations, is important to ensure efficient power distribution;
- Adequate cross section of the overhead contact line so that continuous power transfer is possible in areas where the demand is higher, e.g. when the vehicle starts moving, when it accelerates or when it drives in gradients or in line sections with short distances between vehicles (> 100 mm²);
- Resistance to mechanical loads (pressure of trolley pole, wind, rain and ice);
- High availability, also in case of climatic influence like temperature and humidity, which can lead to variations of the length of the overhead contact line and of its current-carrying capacity;
- Even contact with the trolleys and constant pressure of the trolleys irrespective of the speed to avoid uncontrolled wire disengagement or fire damage on the contact wire;
- Insulation to ensure safety and avoid leakage current and its corroding effect on the environment, often combined with sound absorption and vibration damping (especially in case of suspension on outside walls);
- No restrictions for other road users as the overhead contact lines hang sufficiently high (5.5 – 6.0 m).

Key operational elements of an electrical energy distribution system are:

- Possible to operate the trolleybus at the maximum speed permitted irrespective of the thermal influence;
- No restrictions when points or crossings (trolleybus/trolleybus and trolleybus/ tramway) and section insulators are passed;
- More or less automated wire engagement with only little crew activity, with possibility of reliable automatic wire engagement (at standstill) at the beginning of a line section with overhead contact line (and at regular intervals for re-engagement after deviations from the route due to operational disorder);
- Minimisation of incidents caused by defects on sliding contacts and the overhead contact line.

In the past crossings and points in the overhead contact line usually had to be passed at reduced speed to avoid uncontrolled wire disengagement. Modern systems allow speeds of 50 to 70 km/h so that the permissible speeds in towns and cities can be maintained.

Experience from cities with active trolleybus systems (Salzburg (AT), Solingen (DE)) has shown that the contact wire reaches a life of approximately 35 years.

II-6-3 Poles systems

Typically, trolleybuses are equipped with two trolley poles, which are fitted in parallel on the top of the trolleybus, at the rear. They draw the traction current from the two overhead contact lines one pole per line. State-of-the-art systems allow automatic lowering of the trolley poles at any position. The wire engagement can also be automated, but in this case the vehicle has to be at a certain position and there has to be a wiring guide on the contact line above the trolleybus. Usually, this procedure is used when the trolleybus stands still at a stop. Other systems exist, but are at the developmental stages.

Trolley pole systems can be lowered while the trolleybus is in operation, if the trolleybus is equipped with an Auxiliary Power Unit (APU). However, it is recommended to lower and raise the poles while the trolleybus is stopped.

II-6-4 Auxiliary power unit (APU)

Modern trolleybuses are usually equipped with an auxiliary power unit (APU) that takes over as the energy source when the trolleybus must disconnect from the OCL. There exist two major types of APUs, notably the diesel APU and the electric APU.

One of the characteristics of a trolleybus equipped with an APU is its ability to temporarily disconnect from the OCL and continue his journey in standalone mode.

This feature can be used, as a planned operational feature, to cross sensitive areas such as tourism or heritage sites where the installation of an OCL, from an urban perspective, would not be acceptable, or in any area where the technical challenges are such that it is not feasible to install an OCL, or as a mitigation measure to cross areas where the OCL is temporarily not accessible (course deviation because of a traffic accident…).

The Termini line in Rome (Italy) is operated over 3.4 kilometres without OCL. Over that distance, it is the battery APU that generates the required energy. In Salzburg, diesel APU operations are regularly used for route deviations, when the regular route is obstructed. In Landskrona, the Solaris/Skoda trolleybus is operated, in continuous service, on one line that is equipped

with OCL, line 3 (3 km), and on battery APU (NanoLithiumTitanate battery by Altair Nano) for lines 4 and 5 that do not have OCL (10 km).

The APU system must be designed as a function of operational and technical criteria:

- Both the diesel and electric APUs must provide sufficient off wire autonomy to enable the trolleybus to complete its full assignment, with an energy reserve in case of unplanned off line operation. In the case of the electrical APU, it can be recharged from the OCL, but the recharge time/distance must be included in the planning of the operational journey of the trolleybus;
- Some of the key factors in the calculation of the energy that will be required from the APU are the commercial speed of the trolleybus, the topography of the route, the weight of the trolleybus, weather conditions, the weight and capacity of the APU components, the maximum passenger load and weight, the number of stop and cycles, the capability of storing regenerative energy.

II.6.4.1 Diesel APU

The diesel APU is a combustion engine that operates as a diesel-electric power generator, to power the regular electric motor. They are generally operated with diesel fuel and, unlike a regular diesel bus, the diesel engine is smaller and the diesel reservoir is smaller. The power of the diesel engine/generator is a function of the energy required to operate the trolleybus in the worst planned operational conditions. The size of the fuel reservoir is a function of the distance that need to be travelled «off-wire» and of the fuel consumption of the generator.

In the 1990s, the return loop of line 5 at François Perrin in Limoges (France) was operated without OCL, using a diesel APU. The OCL was extended to that section of line 5 in 2001.

In Central Europe, there are several examples of the use of the diesel APU in regular customer service: Hradec (CZ), Králové (CZ), Plzeň (CZ), Opava (CZ), Marienbad (CZ), and Zlín (CZ), Bratislava (SK), Riga (LV) and Solingen (DE). The average power of the diesel APU used is 100 kilowatts. However this size of APU allows only for short distances travelled.

II.6.4.2 Electric APU

The electric APU does not generate energy; it stores the required energy in energy stockage units such as batteries or/and ultracapacitors. A major concern of this type of APU is its weight. Both batteries and ultracapacitors are heavy and voluminous components with limited energy storage capacity (compared to diesel). Hence, when designing an electrical APU, it is essential

to determine the optimal ratio between the total weight of the APU and its maximum energy storage capacity.

Fortunately, unlike the diesel APU, the electrical APU can be recharge through the recuperation of regenerative energy and also through the OCL. However, provisions must be included into the operational planning of the bus route to ensure that after usage of the energy stored in the APU, the trolleybus remains connected to the OCL for a sufficient time period to recharge the APU. The recharge time of the APU is a function of the chemical characteristics of the energy storage unit, its volume and weight, of the efficiency of the regenerative system and of the available electrical power from the OCL. In Rome (It), on the 23 km return route 90 Termini line, the trolleybus travels an off-wire distance of 3.4 km (15% of the distance). The batteries used are NiMH.

II.6.4.2.1 Battery electric APU

Battery electric APUs are operated regularly in Rome (IT) on line 90 or in test mode in Eberwsalde (DE) and Szeged (HU). Moreover, Zurich (CH) is now procuring “lighTrams”[11] with additional battery drives instead of the usual diesel generator sets.

In the German trolleybus city of Eberswalde, a trolleybus was equipped with a Lithium-Ion-Battery APU and supercapacitors. The average energy consumption of the trolleybuses, per kilometre, is approximately 2.5 kWh. The lithium-ion battery pack has a capacity of 70.4 kWh. In practice, the total capacity is expected to arrive in normal operation was 42.2 kWh, which corresponds to a charge of 85%. The lithium-ion battery in Oberleitungshybridbus has already been tested extensively in Ostrava (CZ) in May 2012 before delivery to Eberswalde.

The lithium-ion battery pack was tested in Ostrava where the topography is similar to that in Eberswalde, before it was installed on the trolleybuses for Eberswalde. In Ostrava, an off-wire distance of approximately 18 km has been covered in test mode.

In practice (in Eberswalde), however, a maximum off-wire distance of 5 kilometers is planned. The charging time, to replenish the battery pack is approximately 20 minutes. The battery is charged via the trolley poles.

Skoda, a leader in the trolley poles system technology market has recently commissioned a trolley having an electric APU able to propel the vehicle over a distance of 8 at 10 km. The

[11] In Zurich the *lighTram* is a bi-articulated trolleybus manufactured by Hess.

chemistries used were Li-ion and Li-polymer. The company expects to be able to produce an electric APU that would provide a range of 20 km. However, it considers that achieving such autonomy would probably be done at the expense of the number of passengers that could be transported.

Vossloh, another leader in the trolley poles system technology market, is involved in the design of battery electrical APUs. The off-wire autonomy they are aiming at achieving is between 10 and 20 km, using Li-ion chemistry with a capacity of 50 to 100 kWh.

II.6.4.2.2 Supercaps

Supercaps are high capacity condensers. A special feature of supercaps is their efficiency in transferring input and output energy. This ensures that a large part of the energy (up to 90 %) generated during braking is stored with very little losses and in a similar way, a large amount of energy is made readily available, in a short space of time, for the next acceleration.

As well as providing energy savings, the use of supercapacitors make it possible to avoid dissipating energy on brake resistance with obvious benefits for the environment, it reduces the possibility of generating electric arcs when the vehicle transits under switches and neutral wire sections, thus increasing life-expectancy, it reduces overloads in substations and significantly reduces failures affecting on-board components powered by electric motors (air compressors, air-conditioning systems, etc.).

The system may be used to power the auxiliary equipment when the supply from the overhead wires is momentarily interrupted due to separators, switches and crossings. Amongst other things, this could lead to a reduction in failures caused by frequent ON-OFF cycles in the network power supply; in fact all the on-board power users would remain permanently powered thanks to the supercaps' batteries.

The supercap system is suitable above all for use in systems which have a low in-line recovery capacity or where it is not possible to increase the mains voltage to reduce absorption and hence voltage drops, especially in sections of line which are a long way from electric supply substations. With Supercaps current peaks are eliminated or drastically reduced.

The distinctive aspects of double-layer capacitors, or SUPERCAPS, are their particularly high level of stability and at the same time their resistance to overcurrents. It is therefore possible to use the supercaps system for a long time, even along the most arduous routes through urban

traffic. Given the reliability over time, the reduced maintenance requirements and the modular structure of the system (which facilitates servicing operations) the SUPERCAPS system appears to be a profitable investment for the vehicle's life-cycle.

For example in Parma, the trolleybus equipped with supercaps saves approx. 27% of energy consumption compared to a trolleybus running without supercap.

III Technical Principles of Trolleybus Systems

III-1 AP1: Principles of Power Supply for Urban Bus Systems

As regards the development of urban bus systems with components for electric energy supply and electric vehicle drives distinction can be made between the following basic types at present:

1. Hybrid bus
2. Battery bus or supercap bus . . .
    a. . . . being recharged when parked (plug-in)
    b. . . . being recharged inductively in the non-operating time
    c. . . . being recharged conductively when staying at stops
    d. . . . with exchange of batteries in the non-operating time
3. Trolleybus . . .
    a. . . . with a continuous overhead contact line
    b. . . . with an overhead contact line in some sections (hybrid electric)
4. Fuel cell bus
5. Inductive current transfer during the operation
6. Flywheel

Nearly all vehicle types have to be able to store energy on board, either by way of a battery, which can provide much energy for quite a long time, but has a long charging time, or by way of ultracaps (= supercaps), which can be charged extremely fast, but have to supply the stored energy as fast as possible. Therefore, it is important by the introduction of electric urban buses to harmonise the energy storage unit (size, weight, capacity) to the basic technology and the intended operating schedule. For optimisation an energy storage management system is needed, which controls the charging and discharging of the energy storage unit as well as the supply of the consumers so far that it even switches off selected secondary consumers to ensure that the next charging point is reached (incident management).

III-1-1 Hybridbus

Hybrid buses are designed as parallel or serial hybrids. Nearly each and every manufacturer of urban buses now sells vehicles with hybrid drive concepts and in several sizes (midi, solo, articulated and partly even double-articulated). The internal combustion engine can be either a diesel engine or a gas engine. Besides the electric motor the hybrid bus has an energy storage unit so that it can store the braking energy.

Volvo has announced a plug-in hybrid bus with a fuel consumption that is as much as 60 to 65 % lower than that of the diesel bus. The idea of plug-in is that the bus can go onto the line with a charged battery, which is recharged during the journey by way of recuperation and for several minutes at the terminal stops.

Volvo states that this plug-in hybrid bus can be operated fully electrically for 10 – 20 km as the capacity of the batteries has also been increased to about 40 – 45 kWh. The diesel engine then only performs subsidiary activities within the power train. In November 2012 a field test with three vehicles is to begin in Gothenburg. Volvo intends to build the plug-in hybrid bus in a modular design and even to equip it with double battery capacity, if desired by the customer. An articulated hybrid bus is also being planned on this basis.

The operation of hybrid buses does not differ fundamentally from the operation of standard diesel buses. The workshops have to be adapted to the maintenance of electric components and the staffs have to be trained for this kind of maintenance. Meanwhile, hybrid buses are often the introduction to bus technologies with electric components, but most often the expected fuel economy is not achieved. They are probably a bridging technology on the way to the electric urban bus and will be replaced as soon as useful drive technologies without diesel engines are ready for series production. Hybrid buses are not of further relevance to this study.

III-1-2 Battery Buses

As regards **battery buses** distinction has to be made between several types of operation:

- Battery buses without interim charging (only charging in the depot in the non-operating time)
- Battery buses with interim charging at terminal stops and perhaps also at some stops along the line
- Battery buses with interim charging at every second/third stop

- Battery buses with exchange of the batteries

The main problem of all battery buses is the capacity of the energy storage unit. The interaction between size, weight, thermal behaviour and capacity has to be optimised. According to the state of the art a battery bus can only drive up to 250 km without being recharged. This range is much shorter that of diesel buses. Therefore, this technology is no good for heavy urban bus transport, and at present nothing indicates that the battery technology can be improved decisively.

This problem can only be overcome by interim charging of the battery. There are various technologies ranging from plug-in (plug/cable) to inductive charging (e.g. Turin) via trolley poles (e.g. Vienna). Usually, there is enough time and space for the interim charging at a terminal stop. At a new installation in Brunswick inductive interim charging is provided at some stops with relatively long halts for the boarding and alighting.

In China (Shanghai) electric urban buses are operated that are being charged at every second or third stop. However, in most cases such a procedure would prolong the journey times in Europe as the buses would have to stay longer at many stops than necessary for the ordinary boarding and alighting.

The more often interim charging is possible, the smaller the energy storage unit can be dimensioned. However, it also has to be considered that the life of the energy storage unit depends on the frequency of the charging cycles and the degree of charging and discharging. If an energy storage unit is operated constantly between 100 % and nearly 0 %, its capacity is going decrease considerably after approx. 3,000 charging cycles. If the charging condition mainly ranges between e.g. 70 % and 90 %, the life and the number of partial charging cycles increase significantly.

At present, mini/midi buses (less than 9 m long) and urban buses of standard sizes are operated as battery buses.

Whereas mini/midi buses are being manufactured in small series by several manufacturers for inner city areas, urban buses with a length of 12 metres are still seldom and are mainly being operated for test purposes. Articulated buses with battery-electric drives are not available yet.

At present, the following manufacturers offer minibuses:

Allied Vehicles	Reconstruction on the basis of Peugeot
Breda Menarini	"Zeus" minibus
EcoPower Technology	Minibus with inductive recharging (Turin, Genoa, Lörrach)
Group Gruau	Microbus Electrique
Spijkstaal	Electric bus
Tecnobus	"Gulliver", also as a fuel cell bus
Véhixel	Aptinéo Electric (reconstruction of Iveco Daily)
Xenova	"Terryman"
ZEV	Reconstruction of Mercedes "Sprinter" and Renault "Master"

Vehicles with the character of urban buses are offered by:

BYD	eBUS12 – the only real urban bus with battery operation on the busworld 2011 in Kortrijk
Contrac Cobus	e2500 – test vehicle for Porto / Offenbach / Wiesbaden
Dongfeng Motor Co	Tianyin All Electric Bus
Krystal	EVolution KK38 – test vehicle for the US market
Opbrid	"Arctic Whisperer" – electric bus on the basis of Volvo with a trolley pole for interim charging (Umea, Sweden)
Optare PLC	Solo EV
Sinautec	Ultracap bus with 42 seats for Shanghai
Solaris	Urbino Electric – 12 m long test vehicle
SOR	EBN 10.5 – test vehicle for Ostrava
Viseon	12 m long bus for Brunswick (Primove)

Yutong	PURE Electric Bus – In Kortrijk a coach with this technology was shown, but it can probably also be operated as an urban bus

At present, it applies to all battery bus systems that the battery increases the weight to be carried by the bus relatively much. Moreover, it is problematic that the secondary consumers (e.g. door drives, passenger information systems, lighting and especially ventilation/heating/air conditioning) reduce the capacity of the battery for the traction considerably as they also consume power. Moreover, it is still an open question whether it will be possible to supply sufficient chemical-mineral components of the energy storage units for relatively big bus fleets and, in return, whether they can be disposed of or recycled in an environment-friendly way.

III-1-3 Trolleybuses

The above mentioned problems can be reduced by way of a continuous external power supply. **Trolleybuses** are the most conventional kind of buses operated electrically for the most part. However, they need a suitable infrastructure in the form of overhead contact line systems and power supply installations (substations, cabling), which also have to be maintained. Usually, they are equipped with diesel engines as supplementary drives for the bridging of sections without current.

Classic trolleybuses with diesel engines as the supplementary/auxiliary drives are not discussed below. However, vehicles with electric supplementary drive systems allowing driving in sections without overhead contact line, but nevertheless electric are considered to be interesting in the sense of this study.

At present, such trolleybuses are being operated regularly in Rome on line 90. Moreover, Zurich is now procuring lighTrams with additional battery drives instead of the usual diesel generator sets.

The necessary overhead contact line infrastructure puts off many potentially interested transport companies from the restructuring to trolleybus operation. However, it can be proved that the investments amortize within 20 to 25 years. The optical spoiling is usually a subjective feeling, and alternative power supplies are expensive both in respect of investment and in respect of operating and maintenance costs.

In Europe 27 new trolleybus systems have emerged since 1990 (worldwide 45 systems). Leeds (United Kingdom) and Montreal (Canada) have published plans recently. Up to 14 lines are to be electrified in the Canadian metropolis in the next few years.

III-1-4 Hybrid Electric Buses

Hybrid electric buses can be regarded as a cross between trolleybuses with an additional generator set and battery buses with interim charging as they can charge their energy storage units under the overhead contact line during the journey and thus drive both on line sections with an overhead contact line and on line sections without an overhead contact line. In that way the disadvantages of the trolleybus (i.e. overhead contact line needed) and of the battery bus (i.e. low range) can be overcome by the hybrid electric bus, and an electric urban bus system with overhead contact lines over only about 30 to 50 % of the line emerges. Thus, it is particularly possible to avoid line sections with overhead contact lines …

- in sensitive urban areas in which the overhead contact line itself, but also its suspension at poles or outside walls is regarded as extremely disturbing.
- in areas in which very complicated and cost-intensive crossings and switches would be needed for the overhead contact line.
- in areas with less intensive cycles due to a lower demand, i.e. in areas in which an overhead contact line system would not amortize itself within a foreseeable future.
- in areas in which an overhead contact line system would have to be cut off in case of an emergency because space is very restricted.
- in areas only needed for turning or in case of service interruptions. If necessary, wire engagement devices also have to be provided along the overhead contact lines and not only at the beginning of the overhead contact lines.

It is important to optimise the overhead contact line share to operate the energy storage unit in the optimum range as far as at all possible and to be able to “skip” a charging section now and again.

The following trolleybus manufacturers offer trolleybuses that can be further developed as described above:

Hess	Trolleybus “Swisstrolley” with an additional battery drive for Zurich (test)
	“lighTram” as a platform for a modular electric bus system
Solaris	Trolleybus with an additional battery drive (Trollino 18 for Rome, as test for Eberswalde)
	Urbino Metro Style as a platform for a modular electric bus system
Van Hool	“ExquiCity 12 / 18” as a platform for a modular electric bus system
VDL	“Phileas” as a platform for a modular electric bus system
Viseon	“Elektroliner” - trolleybus with an additional diesel drive, which can be developed to a platform for a modular electric bus system

Some manufacturers are already open to platform solutions that are based on an electric drive concept, i.e. to modular solutions with an internal combustion engine (= hybrid), a trolley pole (= trolleybus), an energy storage unit (= battery bus) or fuel cells.

Furthermore, Siemens announced in May/June 2012 that it is going to develop an overhead contact line system for trucks. The automatic wire engagement during the journey is particularly interesting.

III-1-5 Fuel Cell Buses

At present, **fuel cell buses** are peripheral phenomena as drive concepts. Particularly the FuelCELL Citaro manufactured by EvoBus is well-known. This fuel cell bus has been tested in several European cities and is now mainly being operated in Hamburg and Luxembourg. The Hamburger Hochbahn already tests the third generation of fuel cell buses within the scope of its “SauberBus” (clean bus) project. Further tests, e.g. by the Rheinbahn, Düsseldorf, or the “Ves-

tische Straßenbahn", Herne, with the minibus "Gulliver" from Tecnobus have been stopped by now.

Fuel cell buses on the basis of the "Phileas" from VDL are now being tested in Cologne and Amsterdam.

On the one hand, these vehicles do not need a special infrastructure along the line. On the other hand, the special facilities for filling up the buses with hydrogen and for storage of hydrogen in the depot are relatively complicated. Moreover, these vehicles can also only cover a much shorter range than state-of-the-art diesel buses.

The "AutoTram" project of the Fraunhofer Institute for Transportation and Infrastructure Systems is a special case in this category as the fuel cell drive is combined with guidance and interim charging at stops.

The data of the systems of particular interest to this study are listed in the annex.

Vehicles with hydrogen internal combustion engines are not being operated any more. It does not seem that this technology will be revived in the foreseeable future. However, the electric bus platforms described below under "Trolleybus" are also open to the fitting of this kind of components.

III-1-6 Inductive Current Transfer

In the middle of the 1980s the renaissance of the tramway began in France and several new networks have emerged and are emerging worldwide as a consequence. This development was combined with the wish to be able to do without the overhead contact line at least in some sections. This wish is not as much a technical necessity as a subjective and politically motivated wish. The dislike of "cabling the heaven" is often reasoned by impairment of the townscape, especially in case of historical buildings. In return, technically complicated solutions with much higher investment and maintenance costs are often accepted.

Whereas the current was transferred mechanically in the first systems (Bordeaux, APS), energy storage units are now also being used to bridge sections without overhead contact lines (Nice). At present, Bombardier tests a system with inductive, i.e. contact-free, transfer of energy, both at standstill and during the journey. Unfortunately, it has not yet been possible to present sound statements on the reliability of the system in the long term.

As rail vehicles are guided, it is relatively easy for them to pick up the current with small tolerances between the overhead contact line and the pantograph. In case of bus-based systems the buses would either have to be guided or their batteries would primarily have to be recharged at standstill. As from 2013 the latter alternative will be tested in continuous operation on a line in Brunswick. There are test facilities for the operation with buses in Lommel (Belgium) and Augsburg.

According to the manufacturers (source: stadtverkehr 7-8/2012) these test operations have shown that

- the efficiency is only slightly below the efficiency achieved with overhead contact lines (91% instead of 93%) despite multiple conversion of direct current into alternating current and vice versa and despite inductive transfer,
- the system is insensitive to climatic influences (temperature, snow, sand),
- the load of the passengers with electromagnetic waves etc. is far below the permissible limit values.

Nevertheless, questions still remain:

- Would it be possible to install an inverter (DC -> AC) in normal roads every 8 to 9 metres to supply the induction coils?
- Does a 6 cm thick cover of the induction coils suffice to permanently bear the load of trucks and buses?

Bombardier also tends to only equip some sections with “Primove” and to overcome the sections in between with batteries.

Up to now, other methods of supplying the vehicles continuously with external power via infrastructure fitted in the road instead of supplying them via the overhead contact line have not got beyond the experimental stage.

Example: “Stream” (Ansaldo) in Trieste, the rail fitted in the road should guide buses and supply them with power.

Fig.: Conductor rail for the "Stream" system in Trieste (source: wikipedia)

III-1-7 Flywheel

The idea of storing electrical energy in the form of a rotating disc (**flywheel**) dates from the 1950s, but so far this technology has not really been able to catch on. Two application cases are possible: The flywheel is fitted either in the vehicle or in the substation. It is operated by way of the recuperated current. However, in any case a rotating mass, which has a weight of at least one ton and which moves at speeds up to 900 km/h at the outer edge, has to be controlled.

The technology was revived in stationary applications for the tramways in Zwickau, Dessau, Bremen and Fribourg with systems from Rosseta Technik GmbH. The light rail and metro systems in Hanover and Hamburg also use the flywheel as the energy storage unit in substations. Here the devices are from Piller.

IV Feasibility Study for Leipzig

The Leipzig Transport Company (LVB) has initiated a thorough examination of the (re-) introduction of trolleybuses in Leipzig. In this connection it has applied successfully for participation in the “TROLLEY” project of the EU.

Meanwhile, the LVB have procured serial hybrid buses as part of a special promotion program. This design is already a first form of electrically powered vehicles and provides the basis for the development of a purely electrically powered one.

Therefore in Leipzig on line no. 70 as an example shall be examined how this line can be operated as a future electric city bus line and what requirements must be imposed on the vehicles, road infrastructure and power plants.It is the objective of this EU project to compile a “compendium”, in which all possible synergies between an electric urban bus system and a tramway system are examined, assessed and documented – with reference to the actual situation in Leipzig, but also to other transport companies in a generalising way.

These various electrical bus systems with consideration of the current state of the art are compared to a modern diesel hybrid bus system. There is particular to examine how starting from a hybride basis a linearly furnished system can be developed with a link to the power source of the tram. For technical and economic evaluation comparisons of the investigated solutions in other projects with selective injections are carried out. The study is complemented by a consideration of the planning, approval and implementation phase.

In Leipzig there are good conditions for retrofitting the present bus lines to the operation of electric urban buses. As the present public transport network is a combination of bus and tram lines, the Leipziger Verkehrsbetriebe GmbH (LVB) has extensive knowledge with the procurement, operation, servicing and maintenance of electric components (of the vehicles, power supply installations, overhead contact lines, workshop equipment etc.). There will probably be additional synergetic effects with the present tramway network because it will be possible to combine the power supply systems of the bus system and the tramway system. The keyword is recuperation.

This study project is divided into three activity packages (AP):

AP1: Permission of Trolleybus-System

Construction and operation of electrical bus systems take place in the framework of national laws, regulations and guidelines. Case studies will be used to show how different the approach in each country can be.

The regulations are specially related to:

- Construction of infrastructure (Catenary system, Charging stations)
- Permission of vehicles
- Operation
- Safety related aspects (electrics)

AP2 Economic Efficiency

In this activity package the relationship between the necessary investments and the expected benefit is examined. This benefit mainly results from the energy and operating costs, which are lower for electric urban bus systems than for the bus systems operated at present.

It will be carried out while both business and economic considerations.

AP3 Practical Application Exemplified by Leipzig (Line 70); see page 98 et seq.

On the basis of the ascertained theoretical requirements the existing infrastructure for the supply of an electrically operated urban bus line (line 70) with power is examined in this work package in respect of the possibilities of adaptation and the necessity of expansion as well as in respect of the possible synergies with the tramway operation.

For this purpose the requirements for an electric urban bus system are drawn up using the example of line 70 in Leipzig. Moreover, the feasibility is assessed and the costs and savings of energy costs are estimated.

Finally, the possibilities of financial support for the procurement of vehicles and for erection of the infrastructure are assessed.

- Operational requirements
  - Demand

- o Cycle
- o Operation of vehicles

- Scenarios for comparisons
- Analysis of status quo
  - o Existing infrastructure
- Need for adaptation
  - o Reconstruction of substations / construction of new substations
  - o Line routes
  - o Stops
  - o Workshop equipment
  - o Power Supply
- Urban Integration
  - o Stops = Charging Stations,
  - o Overhead catenary System,
  - o Right-of-Way

- Investment / Depreciations
- Operation and maintenance cost
- Synergy effects with tram
  - o Recuperation
  - o Common power supply
  - o Maintenance
- Permission procedure
  - o Vehicle (technical, ability for passenger transport, Tauglichkeit für Personenbeförderung)
  - o route concession
  - o Planning permission
- Eligibility / Network of national and european promotion programs
  - o Infrastructure
  - o Vehicles

IV-1 AP1: Basic permission regulations

IV-1-1 Permission Procedure

Construction and operation of electrical bus systems take place in the framework of national laws, regulations and guidelines. Case studies will be used to show how different the approach in each country can be.

The regulations are specially related to:

- Construction of infrastructure (Catenary system, Charging stations)
- Permission of vehicles
- Operation
- Safety related aspects (electrics)

The Public Transport Act (Personenbeförderungsgesetz PBefG) provides a clearly defined framework for trolleybus systems. The prerequisite for the permission of a bus operation is the completion of the planning approval procedure. This also applies to a partially catenary-free operation.

“Two aspects must be considered prior to construction and operation of a trolleybus system. The first is the permission for construction and line operation in compliance with article 9 paragraph 1 section 2 of the Public Transport Act; the second is the planning approval procedure for the construction of the trolleybus system in compliance with article 28 paragraph 1 of the Public Transportation Act.

The relationship of these two legal acts is ruled by article 28 paragraph 4 of the Public Transport Act. According to it the permission in accordance with article 9 paragraph 1 seciton 1 of the Public Transport Act may be issued only subject to the prior planning approval procedure or issued planning permission in accordance with article 28 paragraphs 1 to 3 of the Public Transport Act or subject to the consent in accordance with article 28 paragraph 2 seciton 2 of the Public Transport Act.” (Source: Feasibility study on introduction of an electrical urban bus system in Leipzig, Rail&Bus Consultants, 2009)

The regulative framework for construction approvals of sub-floor systems with inductive energy transmission and systems with charging stations is lagging behind the actual state of the technological development.

This is reflected by the question which legislative act is to be applied for the permission procedures for charging stations. The respective State Construction Ordinance (Landesbauordnung) is not applicable since it is not valid for public transport systems including associated infrastructure, equipment and auxiliary systems excluding buildings. Neither the Directive EG 42/2006 on machinery can be applied here.

Considering the requirement of a comprehensive consideration of all technical systems which are required for the line operation the charging stations at stations and turn-arounds should also be subject for approval within the planning approval procedure.

Charging stations within service areas such as tram or bus depots do not need a planning approval procedure or planning permission in terms of Public Transport Act. These may be panned and constructed in compliance with general construction and technology rules.

These include especially the relevant electrotechnical safety regulations to prevent accidental contact with live electrical equipment.

IV-1-2 Situation in Germany on the example of Leipzig

IV.1.2.1 Establishment of a trolleybus system under the Public Transport Act

Two aspects must be considered prior to construction and operation of a trolleybus system. The first is the permission for construction and line operation in compliance with article 9 paragraph 1 section 2 of the Public Transport Act; the second is the planning approval procedure for the construction of the trolleybus system in compliance with article 28 paragraph 1 of the Public Transportation Act. The relationship of these two legal acts is ruled by article 28 paragraph 4 of the Public Transport Act. According to it the permission in accordance with article 9 paragraph 1 section 1 of the Public Transport Act may be issued only subject to the prior planning approval procedure / issued planning permission in accordance with article 28 paragraphs 1 to 3 of the Public Transport Act or subject to the consent in accordance with article 28 paragraph 2 section 2 of the Public Transport Act. Hereby the planning approval procedure can be carried out in parallel to the construction permission process.

IV.1.2.2 Permission according to article 9 paragraph 1 section 2 of the Public Transport Act

The permission in terms of article 9 paragraph 1 section 2 of the Public Transport Act regulates the essential part of transport-related parameters of the trolleybus system by defining the requirements for its construction, line layout and operation. The permission defines herewith the business object as well as the rights and duties of the permission holder.

The preconditions for issue of the permission according to article 9 paragraph 1 section 1 of the Public Transport Act are provided in article 13 of the Public Transport Act. While it can be assumed that the subjective preconditions on the part of the applying party (here: Leipziger Verkehrsbetriebe LVB) are fulfilled, the objective preconditions are also to be considered. It is especially to be checked whether the applied trolleybus operation impairs transportation-related public interests.

The scope of application and the documents to be submitted for examination by the permission authority are defined in article 12 of the Public Transport Act. The following required submissions should be noted:

- Overview map of the area with line layout and station locations including all existing railway lines, vehicle routes etc.;
- Fares and timetable;
- Upon request of the permission authority: a construction plan with cost estimates as well as a system description, data on the highest and the lowest points of the catenary line etc.

The permission in accordance with article 9 paragraph 1 section 2 of the Public Transport Act determines the general legitimacy of the trolleybus operation and provides the transportation company the general right to start further necessary steps, while the planning approval procedure regulates technical parameters of the system.

IV.1.2.3 Planning approval procedure in terms of article 28 paragraph 1 of the Public Transport Act

Article 41 of the Public Transport Act stipulates that the planning approval procedure regulations for tramways should also be applied for the construction of trolleybus systems. Article 28 paragraph 1 sentence 1 specifies that tram (and here also trolleybus) systems may be constructed

only after the plan has been approved. For this purpose the affected public and private interests including environmental compatibility must undergo a consideration procedure.

The general prerequisite for the permission of a project that requires a planning approval procedure – in this case a trolleybus system – is that the planning approval has been issued. A planning approval may only be issued if the project is objectively necessary or reasonably required for the reasons of common good. In this respect various aspects can be mentioned that would justify the planning approval such as for example the establishment of a safe, efficient and particularly environmental-friendly transport system.

According to provisions of article 28 paragraph 1 sentence 2 of the Public Transport Act the public and private interests, affected by the project, including the environmental compatibility must undergo a consideration procedure. According to the ruling passed by the Federal Administrative Court this regulation requires that the consideration generally takes place; all concerns that must be considered are included in the consideration and neither their significance is misjudged nor these concerns are offset in any way that does not correspond to their objective weighting. Therefore all respective public and private interests must be identified and carefully examined.

Of special importance here are the transportation-related public concerns in terms of article 13 paragraph 2 section 3 of the Public Transport Act that must be considered during the permission procedure. These concerns constitute an important part of consideration process during the planning approval procedure for a public transport project. Therefore these transport-related public concerns should be examined with special attention to provide well-weighted arguments in favor of the project.

Beyond those further public concerns must be considered such as nature protection and protection of historical buildings and monuments. In addition to that the relevant private interests are also to be considered.

As a result of the consideration the planning approval can be issued or rejected. However the applying party cannot claim that the approval is issued if certain preconditions are met. The applying party has only a legal right for an accurate judgment that would consider all aspects of the project. At the same time the Permission Authority cannot reject the Planning Approval if no legal obstacles have been identified during the consideration.

IV.1.2.4 Provisions on operation of trolleybus systems

Concerning the operation of trolleybus systems the regulation on the operation of motor carriers in passenger transport (BOKraft) must be considered, which is stated in article 1 paragraph 1 of this regulation. According to it the regulation is effective for companies that transport passengers by motor vehicles or trolleybuses as long as these transport services fall under provisions of the Public Transport Act.

For this reason the provisions on bus line operations are also applied to trolleybus operations. There are no differences in legal regulations in this respect.

IV.1.2.5 Existing bus operations

In case of re-issue of permission for bus line operations, that will be upgraded to trolleybus operation in future, such permission should expire on the starting date of the trolleybus operation. In case the transportation company holds permissions that are valid beyond such date, the permissions must be suspended respectively by this date. This procedure should not lead to any legal problems though, as long as the holder of the permissions for the existing bus line operation and the future trolleybus line operation is one and the same company (which is assumed here).

IV.1.2.6 Funding eligibility / Integration of EU and national programs

According to article 2 of the Guideline on granting of subsidies in local public transport issued by the Ministry of Economic Affairs, Employment and Transport of Saxony on 8th February 2011 (RL-ÖPNV), investments in infrastructure and vehicles are eligible to subsidy as long as they improve local public transport services. The precondition for granting a subsidy is the fulfillment of the requirements on the barrier-free accessibility (in terms of Article 4 of the Law on equal treatment of people with disabilities). A subsidized project must be registered with the permission authority (the respective Regional Government Office) for the inclusion into the State Program on local public transport. The inclusion of the project into the program is decided by the State Ministry of Economic Affairs, Employment and Transport of Saxony. Besides, the subsidies can only be granted if the applying party represents a local public transport company or a local administrative body.

The amount of subsidy depends on the respective federal or state region. Exact rates have not been further investigated.

In Germany there is presently no specific funding support for trolleybus systems or for systems with partially catenary-free operation and their infrastructure. In this respect only procurement of hybrid bus vehicles is supported by the German Federal Government.

IV-2 AP2: Economic Efficiency

IV-2-1 General

The highest obstacles for the introduction of an electric urban bus system are the high initial investments in the infrastructure for the power supply and the much higher prime cost for the vehicles. On the other hand, the operating costs and the energy costs are much lower and the asset depreciation range is much longer. From a business-economic point of view the question therefore is whether or from when an electric urban bus system is more economic than a diesel bus system.

The cost-benefit analysis is very important for projects with a high share of investment costs for infrastructure measures, not only as regards the direct effect, but also and especially as regards the enduring influence on the operator's result.

Not only the results on the business economics have to be considered, but also the effects on the national economy, particularly because electric mobility projects are significant environment-friendly measures, which always have to be included in a cost-benefit analysis.

IV-2-2 Method

For the assessment of the business economics different investment and operating costs are compared. Concretely, the continuation of the operation with diesel buses, on the one hand, and the operation with electric urban buses, on the other hand, are compared. The prices in 2012 are taken as a basis, later increases in prices are not considered.

The inputs – especially the investments required for the electric bus systems – are current and carefully identified data.

For the assessment of the business economics all the expenses and the revenue are calculated at first. For clarity a statement of changes was prepared for the various systems, which only comprises the parameters that differ in each system. Valuations which are identical in both cases, e.g. for the driver or the cleaning of the vehicle, are not included in the calculation.

In the period in which the operation is changed from diesel to electric operation the efficiency has to be as high as at all possible. Therefore, it is only suitable to examine a bus line with a very strong demand to begin with. Alternatively, it is possible to examine a route on which several lines are operated and which is therefore highly loaded. During the day the line should be operated with articulated buses at least in a 10 minute cycle, which corresponds to a demand of at least 400 to 500 passengers per hour and direction (or about 4,000 to 5,000 passengers per day and direction) in the busy traffic period.

IV-2-3 Inputs and Assumptions

For the assessment of the business economics many inputs are needed:

- Operational concept
- Necessary investments
  - Procurement of vehicles (inclusive of energy storage units)
  - Redesign of vehicles
  - Infrastructure
- Overhead contact lines / charging points
- Roads / stops
- Depot / workshop
- Control room / technical control desk
- Operating costs
  - Drivers (number / qualification)
  - Workshop staff (number / qualification)
  - Control room staff (number / qualification)
  - Energy consumption (drive + secondary consumers)
  - Maintenance
- Vehicles
- Infrastructure

- Administration
- Costs of financing
- Expected benefit
    - Revenue
- Fares
- Promotional funds
    - Benefits to the national economy
- Avoidance of environmental pollution

Not all inputs can and have to be quantified, e.g. in the sense of the statement of changes. Therefore, the above list is commented as follows:

Operational concept: In the first phase electric buses should preferably be operated on lines with a high demand. Therefore, only lines / routes on which at least six articulated buses are operated per hour (workday, during the day) are suitable. It is assumed that the total time of operation amounts to 20 hours at workdays, i.e. that the operation begins between 04:00 h and 05:00 h and ends between 24:00 h and 01:00 h, and that the transport offer is about halved after 19:00 h or 20:00 h. The line is served each day. On Saturdays, Sundays and holidays the transport offer is modified, i.e. reduced as against the offer on workdays.

Procurement of vehicles: In the first phase electric buses should preferably be operated on lines with a high demand. Therefore, only lines on which at least six articulated buses are operated per hour (workday, during the day) are suitable, and therefore only the prices for articulated buses are considered or forecast, if no articulated vehicle has actually been realised up to now.

The prices for electric vehicles will probably fall as soon as a series production is started:

Diesel bus (Euro 5):	330,000 EUR
Battery bus:	660,000 EUR

Trolleybus:	700,000 EUR (with auxiliary diesel drive)[12]
	750,000 EUR (with auxiliary electric drive)
Hybrid-electric:	850,000 EUR (trolleybus + energy storage unit)
Fuel cell-hybrid:	> 1,000,000 EUR[13]
Induction-hybrid:	> 750,000 EUR

Basically, it is assumed that the number of necessary vehicles is identical irrespective of the system. As, however, the range of battery buses and fuel cell buses is limited to about 200 km at present without recharging / refilling and as a daily kilometric performance of 350 km can be assumed for some of the vehicles, it is assumed that 20 – 25 % more battery buses and fuel cell buses will be needed.

Redesign of vehicles: Particularly electric urban buses with lives of at least 15 years will probably be redesigned. The redesign mainly consists of "cosmetic repairs" (new seats, interior lining etc.). These costs are assessed to 200,000 EUR per vehicle for all electric urban bus systems once after about eight years.

Redesign of electrical components: The component with the shortest life in the electric vehicle is the energy storage unit. Its life is measured in charging cycles. Although the charging condition is optimised to a large extent, it has to be assumed that its maximum life amounts to about three years. These costs are assessed to 100,000 – 200,000 EUR.[14]

Infrastructure – overhead contact lines / charging points: As there are no market prices for many systems and their components, the investments have to be assessed plausibly:

Overhead contact line: 925,000 EUR per km two-lane bus line

[12] Source: Public transport company of Solingen (SWS)
[13] Recently, the public transport company of Stuttgart (SSB) purchased fuel cell solo buses at a price of 1.5 million euros per bus. It is unlikely that this price will be the market price when the series production has started.
[14] Source: HOPPECKE Batterien GmbH & Co. KG, Brilon

Charging point: 250,000 EUR per charging point; on average two charging points are needed per line kilometre (one for each direction of travel)

Primove: It is not possible to assess the costs seriously as too many factors are still unknown.

Rectifier substations are not considered → synergetic effect with existing DC traction system

Infrastructure – roads / stops: It is assumed that it is not necessary to modify an existing system, i.e. that no reconstructions or new constructions have to be carried out.

Depot / workshop: It is assumed that the vehicles are parked in an existing depot and can be maintained in an existing workshop. Therefore, only reconstruction / adaptation measures (e.g. charging points, roof access platforms and diagnostic devices) are considered.

Furthermore, power supply has to be provided for all vehicles in the depot, either via overhead contact lines or via charging points.

Control room / technical control desk: Here, too, it is basically assumed that there is already appropriate monitoring equipment in the control room – especially if light rail or tramway systems are already operated – and that it is possible to supplement or adapt this equipment at low cost.

Drivers: As it is assumed that the operational concept (journey times / number of cycles) is not changed, the number of drivers remains constant. Therefore, only the initial training of the drivers is considered.

Workshop staff: Due to the new vehicle technology it might be necessary to vary the number of staff. Moreover, other / new qualifications are needed. Synergies with the workshops for the light rail vehicles / tramcars have to be considered.

Control room staff: No significant changes are expected. Further technical conditions (range, charging condition) have to be considered in the event of an interruption or alternative routeing.

Energy consumption: Basically, it is assumed that articulated buses with a length of maximum 18.75 metres are operated. Moreover, it is assessed that they consume 65 l diesel or 3.3 kWh current. It is also assumed that part of the consumed current is recuperated braking energy. The values assessed for the secondary consumers in the vehicle are the maximum values that can occur e.g. due to heating in a very cold winter or due to cooling with the air conditioning system in a hot summer. The prices are based on statistical data collected everywhere in Germany. The German Federal Statistical Office in Wiesbaden mentions a price of 1.16 EUR per litre for diesel fuel to large-scale consumers for May 2012 and a price of 0.114 EUR per kWh for current, which corresponds to approx. 0.76 EUR and 0.38 EUR per km, respectively.

It is disputed how the prices are going to develop in future: Whereas increases in the price for diesel of about 5 % annually are forecast generally, the energy turnaround and the implied reconstruction and development of the infrastructure (power stations, network) make it difficult to assess the development of the price for current – at least in Germany. On average, the increase also amounted to about 5 % in the last five years.

Maintenance of vehicles: There are different opinions on the maintenance costs for vehicles: some trolleybus manufacturers say that they are comparable with or lower than the maintenance costs for diesel buses, but experience from Swiss studies (Winterthur / Schaffhausen) has shown something else: The additional expenses for the trolleybus occur due to a higher share of maintenance-intensive electronic equipment (the fault diagnosis is much more complicated for electric motors than for diesel engines), the trolleys with wear parts, the emergency generator and the checks for insulation safety. Some of the additional expenses also result from the longer life of the vehicle, i.e. eventually from its age.

Maintenance of infrastructure: Only the maintenance of installed facilities is considered. Additional cost-intensive relocations or provisional arrangements etc. can be necessary in case of building measures.

Administration: Is not considered as a variation is unlikely.

Fare revenue: Operators of traction systems or bus systems operated in a similar way often point out that an improved image or a more attractive system also increases the passenger demand and thus the fare revenue. Such effects are not considered in this study as a high-quality and environment-friendly mode of transport already exists in the form of a light rail or tramway system and as the bus lines in question therefore only partly generate additional effects for an increase in attractiveness that can be assigned directly to these lines.

Promotional funds: As it is not clear how public transport projects will be supported in future and as the regulations differ within the European Union, promotional funds are not considered.

Benefit to the national economy: Even if it is generally accepted that the operation of electric vehicles reduces the exhaust emissions (CO_2, fine dust) and the noise emissions, it is difficult to assess the monetary value of the effects. Therefore, they are only acknowledged qualitatively (cf. chapter III-3-5).

	unit	Diesel	Diesel-Hybrid	Battery without charging	Battery with charging	Trolleybus (continuous overhead wire)	Trolleybus (sectional overhead wire)	
Invest								
Vehicle purchase (articulated bus 18 m)	€/vehicle	330.000	550.000	660.000	700.000	750.000	850.000	
lifetime	years	12	12	15	15	15	15	
Redesign Interieur (1x after 12 Y)	€/vehicle	./.	./.	100.000	100.000	100.000	100.000	A)
Reinvest Electric / Electronic (every 3 years)	€/vehicle	./.	./.	200.000	150.000	100.000	150.000	B)
Infrastructure								
overhead wire	€/km	./.	./.	./.	./.	860.000	725.000	
charging stations	€/item	./.	./.	./.	100.000	./.	./.	
right-of-way, stops	€/km	./.	./.	./.	./.	./.	./.	C)
Depot / workshop (Basic)		50.000	200.000	200.000	200.000	650.000	650.000	
power supply in Depot		./.	./.	500.000	400.000	400.000	400.000	
OCC / SCADA		./.	./.	./.	./.	./.	./.	
Operation cost								
workshop staff		included in vehicle maintenance						
OCC staff		./.	./.	./.	./.	./.	./.	
Energy consumption	Liter/km; kWh/km	0,650	0,520	3,300	3,300	3,300	3,300	
Energy price	€/unit	1,160	1,160	0,114	0,114	0,114	0,114	E)
Inflation	%	4,000	4,000	4,000	4,000	4,000	4,000	
Maintenance								
vehicles	€/vehicle-km	0,520	0,650	0,650	0,700	0,650	0,700	
Infrastructure	€/year	1 % of Invest						
Administration		./.	./.	./.	./.	./.	./.	

A) within an overall lifetime of 25 years per vehicle once for the last 12 years
B) several components with different lifetimes
main component: energy storage with a lifetime of 10.000 chargings
average value: within an overall lifetime of 25 years per vehicle 7 times for 3 years each
C) Might be required with charging stations at stops and with the primove system
E) source: Statistisches Bundesamt (federal office for statistics), Wiesbaden

Table 4.1 Overview / summary of the inputs

V Cost of trolley systems

While the main focus of chapter 5 is to address questions regarding the costs of trolleybus systems infrastructures and operations, discussions amongst the UITP Trolleybus Working Group members indicate that the formulation of a unique and simple cost appraisal system is possible. The social, economic, environmental, political, legislative and regulatory environments of each country have a direct and consequent impact on the cost of infrastructures and operations. Also, the status of local urban infrastructures can have a major impact on the requirements of a trolleybus system; some cities have power line infrastructures already available underground, while others have nothing. The geographical location of a city also has a major impact on the type of infrastructures required; the climatic conditions in Brazil and South Africa are different than those in Russia and will require different types of infrastructures. Hence, the chapter is rather intended to give those organizations interested in the potential implementation of a trolleybus system general costing guidelines that can be adapted to the local specificities. The basic cost structure of a reference system is presented herein. The interested party can compare the reference system costing with his situation, and add or correct costs accordingly.

V-1 The Esslingen model

Rather than elaborating a theoretical model, it was thought more practical to document the costs to build and operate a one kilometre section of a recently built network, that of the city of Esslingen in Germany. It is a relatively small network and its specifications and operational characteristics are well known and documented. Since the Esslingen network is in operations and the costs for building and operating its individual sections are known, the risks of under or over evaluating the infrastructure and operation costs are lower than they would be for a theoretical modal that would attempt to consider an infinite number of variables. For example, in a theoretical model, how do you determine the number poles required, the number of intersections crossed and their dimensions, the number of insertion points, the number and characteristics of bends in the road, the number of substations required and the maximum number of trolleybuses that the network can support.

Before the cost to build a network can be established, it must be strategically planned, as for any major public transit project. An expedited approach to define a trolleybus network may lead to misperceptions that only become apparent in the course of construction or in the course of

daily operations. For example, is it possible that the network be expanded at some time in the future? Failure to take this possibility into account during the planning and construction stages of the network will invariably increase the costs to adapt the initial network when required.

The main advantage of using a model based on reality is that it guides the user through a real life example and limits the possibility of overlooking essential elements. While the Esslingen model is based on a relatively small network, it can also be used as a guide for the planning and costing of a large network. In any event, even in large cities with the potential for a trolleybus network of 100 km of lines or more, planning and construction will start with only one or two main lines for a total of 10 to 20 kilometres; a network expansion would likely not be done until probation time and experience. It was decided on to describe a small model network.

The physical and operational characteristics of the Esslingen model are as follows:

- Line length: 20.5 km;
- Annual customer service mileage: 500,000 kilometres;
- A stretch of about 2.5 km with a slope of more than 7%;
- Annual ridership: 3 million passengers;
- Type and number of trolleybus: 9 X articulated trolleybus (18 m);
- Service interval:
    - Peak periods: 10 minutes
    - Off-peak: 30 minutes;
- Major stops along the route: the main railway station, the Mercedes plant, the train station, schools, the old town;
- Major urban infrastructure crossing: a bridge;
- Average travel speed of 15.5 km / h;
- Commodity prices as of 23.08.2013:
    - Copper $ 7.3 USD / kg;
- Rolled steel 736 EUR / ton

The electrical power infrastructure design of the Esslingen's trolleybus network is presented in figure 5.1.

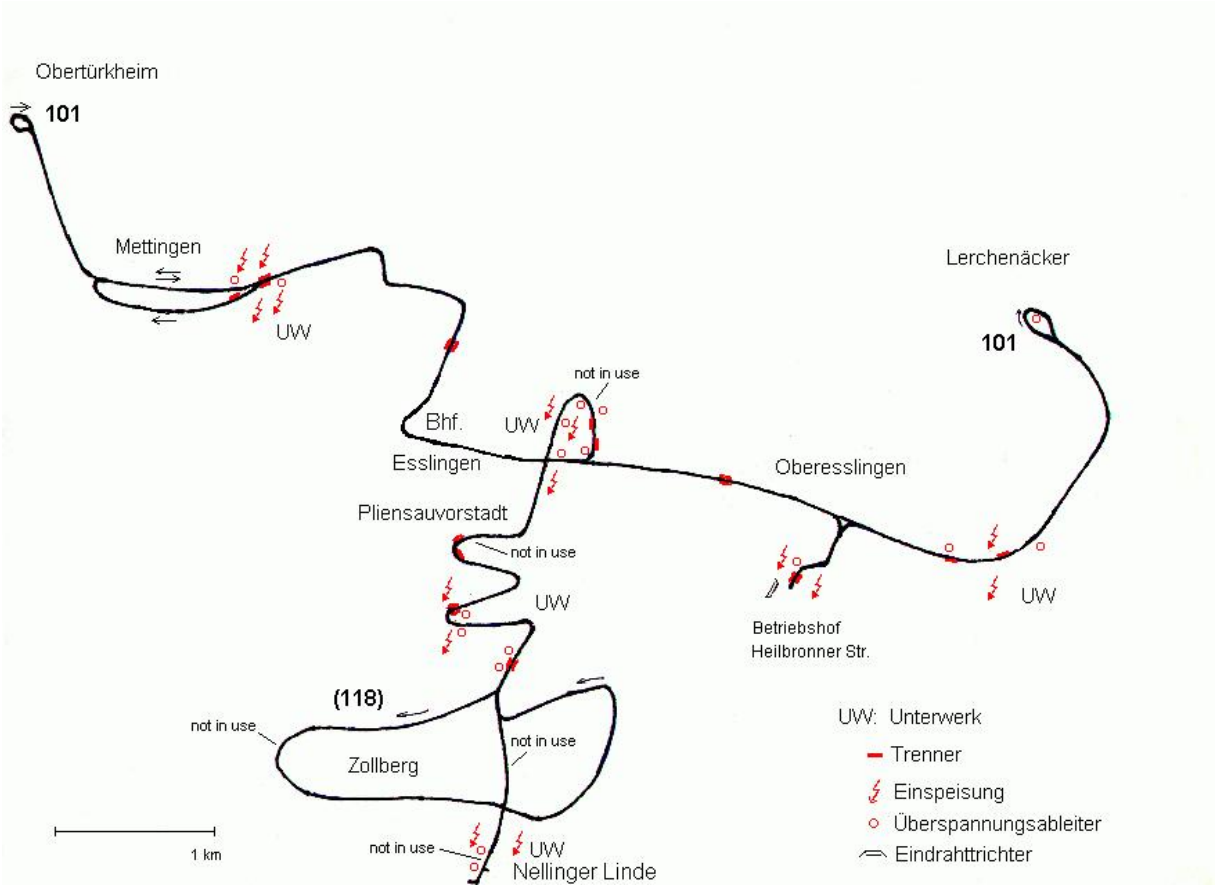


Figure 5.1: Electrical power infrastructure design of the trolleybus network in Esslingen.

V-2 Trolleybus system costs (I)

To establish the cost of a trolleybus system (I), it is essential to determine the costs of its three major sub-systems, along with the cost of the planning activity (P):

- The electrical power network (F);
- The vehicles (V);
- The Workshop (W) with their special equipment for electric mobility.
  Hence the basic formula of the trolleybus system costs (I).

  I = F + V + W + P

V-2-1 Cost of the electrical power network (F)

A trolleybus needs electrical current to run, which is provided via a dedicated electrical power network. To determine the cost of the 20.5 km Esslingen trolleybus network we will need to assess the requirements for the three major elements of the electrical network:

- The overhead contact lines system (FO) requirements;
- The overhead contact line masts (FM) requirements;
- The electric power substations (FU) requirements.

Cost of the electrical power network = F

F = FO + FM + FU

V.2.1.1 Cost of overhead contact lines system (FO)

In this section, we will assess the cost of the overhead contact lines system (FO), hence everything that hangs in the air. The three major components to be considered are:

- The overhead contact lines (FOF);
- The switches (FOW);
- The installation costs (FOP).

Cost of the overhead contact lines system = FO

FO = FOF + FOW + FOP

The cost of the overhead contact lines (FOF) is established by determining:

- The length of contact wire required (NL) multiplied by the price per meter of wire (PD). The price (PD) is dependent on the commodity prices in financial markets;
- The cost of the various components required to set-up the overhead contact lines (GET), such as section insulators, cross-clamp, push terminals, traffic signs, driving wire insulations of different categories, ropes, suspenders, curved rails, etc. The quantities of each are highly dependent on the trolleybus network structure.

Hence, the total cost **GET = ET(n,i) =** $pe_i \sum_n^i E$ where n = number of items of an element and i = number of different elements)

Cost of the overhead contact lines = FOF

FOF = PD * NL + GET

Figure 5.2: View of a stretch of the Esslingen trolleybus route.

Figure 5.3: View of the overhead contact line at the exit of the trolleybus parking bays in Esslingen

V-2-2 Synergetic Effects with the Existing Tramway System

For the introduction of electric urban bus systems the basic question is where there are synergetic potentials. To be able to answer this question, the following has to be analysed:

If the town or city already operates a tramway system, how …

- … is the present power supply being used?
- … is the workshop know-how being used (as an economic advantage)?

If the town or city operated a tramway / trolleybus system earlier, how …

- … is the power supply, if still present, being used?
- … are the exploitation rights, if still existing, being used?

Due to the example in this study, i.e. Leipzig, this study mainly considers the introduction of electric urban bus systems in cities which already operate a tramway system.

It is assumed that the existing infrastructure and the know-how from the operation and maintenance of electric traction systems provide important synergies for the change from usual bus lines to electric operation. Therefore, the combination with an already existing network can influence the calculation / cost estimate of the following cost positions:

Infrastructure – overhead contact lines / charging points: In case of overhead contact lines it can be examined whether the existing supports and contact line systems can also be used for the bus system, but synergetic effects are especially likely by the use of the rectifier substations and the cable routes.

Depot / workshop: Even if the electric vehicles of both modes of transport, i.e. the existing tramcars and the future electric buses, are parked at the same place, certain facilities can only partly be used by both modes, e.g. the roof access platforms. However, joint use of workshops (maintenance of the electrical and electronic equipment) and joint spare parts storage have to be strived for.

Usually, a tramway depot has its own substation, which can also be used for the supply of the electrical equipment of the bus system.

Workshop staff: State-of-the-art drive control systems and on-board power supply systems for traction systems and electric bus systems have many common design features. Basically, the

staff of a tramway operator has been trained for the servicing and maintenance of tramcars. It depends on the total fleet size whether more staff has to be employed.

A tramway operator has already got functioning resources for the operation and maintenance of power supply installations, e.g. tower vehicles and cherry pickers. Usually, they can still or also be used.

The size of the respective operational branches, and thus the work load, decides whether the staff is to be grouped according to the operational branches. The main difference between working on a tramcar and working on an electric bus is that the overhead contact line of a tramcar always has to be de-energised and earthed, whereas these measures need not always be taken for a trolleybus due to the two-pole contact line. To rule out serious mistakes due to different procedures, some public transport companies prefer separate maintenance areas.

Energy consumption: Usually, the energy generated by a modern tramcar or light rail vehicle during braking is recuperated and available to another tramcar or light rail vehicle drawing energy in exactly that moment. If an electric bus system is integrated into the tramway or light rail operation and combined with the existing power supply system, there are further consumers to begin with so that the chance of using the braking energy meaningfully is increased significantly. This applies mainly to systems with overhead contact lines. In these systems buses can always draw current from the system and also feed it back to the system.

However, electric buses are usually so designed that they conduct the braking energy to their own energy storage units at first and also draw current from these energy storage units, if necessary, above all because many systems are not connected continuously to a network via overhead contact lines. Therefore, bus systems with power supply in some sections or at points can only use the recuperated energy of the tramway system if it is interim stored in the substation.

V-2-3 National Economy Aspects

The decision on introduction of an electric urban bus system also has some effects on the national economy. Above all, the environmental pollution caused by CO_2 is to be mentioned. Diesel buses emit 1.7 kg CO_2 per km, i.e. if the annual performance amounts to approx. 1,000,000 km per line (as in case of the exemplary line 70), approx. 1,700 tons are emitted each year. If

the valuation rate of 231.00 euros per ton, which is usual in Germany for standardised assessment of traffic infrastructure investments, is taken as a basis, an annual effect of 393,000 euros results for the trolleybus as the saving to the national economy.

The trolleybus has further advantages from the point of view of the national economy:

- It emits less noise.
- It emits less fine dust, carbon monoxide and nitrogen.
- It increases the value of the real estate along the line as the development is stable due to the overhead contact line.
- It is covered strategically longer against competition (according to the Passenger Transport Act a contract period of up to 15 years is possible).

V-2-4 Comparison from a Business-Economic Point of View

For a basic comparison of different electric urban bus systems a comparative costing analysis was prepared on the basis of the above described assumptions and inputs.

In some cases there are no prices for vehicles and installations or the existing data are based on research and experiments. Therefore, fuel cell buses and systems with linear induction were not considered. Moreover, only costs differing significantly for the electric bus system and the diesel bus system are considered. Thus, e.g. the costs for drivers were not considered as the number of drivers is constant.

In compliance with the synergetic effects given by the operation together with the tramway costs for overhead contact lines or charging points, if relevant, are considered, whereas costs for substations are not considered as it is assumed that they already exist.

To be able to show the development of the costs (investments + operation) for a long period, the costs were considered for two life cycles of electric buses, i.e. for 50 years. It appears from Figure 5.4 that the annual costs for electric bus systems are lower than the costs for diesel bus systems after about 20 to 25 years and that they are also going to remain lower with regular maintenance investments under the assumptions mentioned above. The decisive factor is the energy costs. In this study it was assumed that the price inflation is identical. If, however, the price for diesel increases more than the price for electrical energy, the electric buses are going to amortise much earlier.

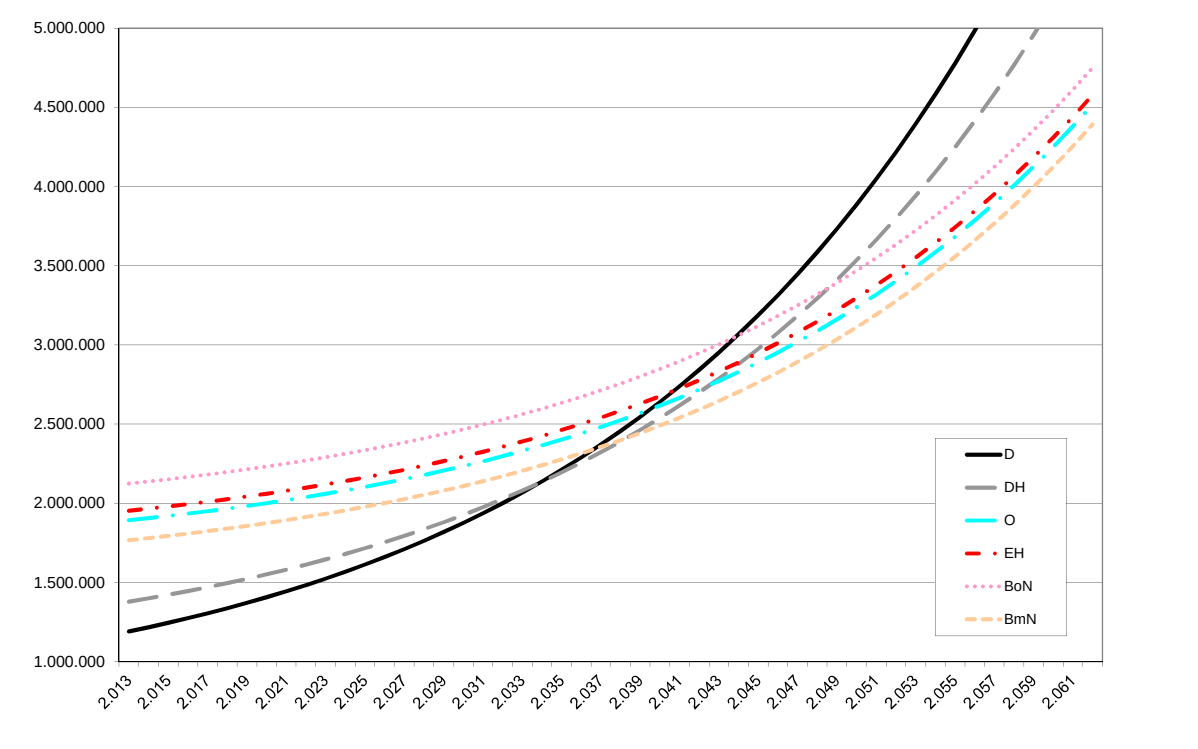


Figure. 5.4: Development of costs of various bus systems over a period of time of 50 years.

Basically, the same applies to the diesel hybrid bus as to the electric bus. Compared to the diesel bus the lower energy consumption is felt in the long term. Already after 15 years the electric hybrid bus is more favourable than the diesel hybrid bus from the cost aspect.

The jumps in the curves of the electric bus systems result from the depreciations for the redesign and for the replacement of the energy storage unit, which are not assumed to have the life of the bus, but individual lives (12 and 2 x 8 years, respectively).

For better recognisability of the curves during the first 25 years they are also shown separately in Figure 5.5

All in all, the annual costs for systems like the electric hybrid system are reduced to values under 90 % of the costs for a comparable diesel bus system.

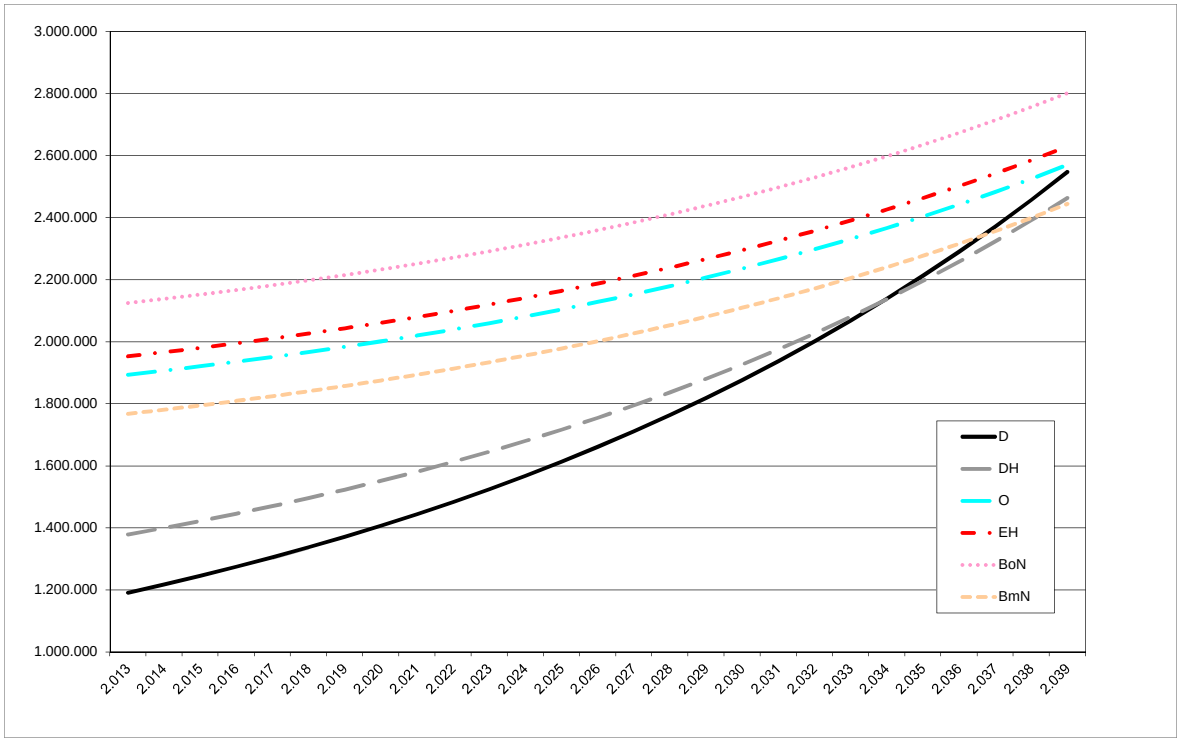


Figure. 5.5: Development of costs of various bus systems over a period of time of 25 years.

Legende:	D = Dieselbus	O = Obus (Trolley)	BmN = Batteriebus mit Nachladen
	DH = Diesel-Hybrid	EH = Elektro-Hybrid	BoN = Batteriebus ohne Nachladen

V-2-5 Promotional Funds

In Germany and other European countries measures to improve public transport are subsidized. The public authorities particularly pay part of the investment costs, e.g. for the construction of public transport ways or for procurement of vehicles, either at the municipal level or at the national level. As the rules for such involvement are managed very differently and also amended at regular intervals, such funds are not considered in this study. However, in the concrete individual case such funds can contribute decisively to the start of a project.

Most regulations on subsidies are intended for new constructions or new procurements. However, in Europe the public transport companies seem to focus less on the construction of new networks or extension of existing networks and more on improvement or development of the existing systems, e.g. by changing to more current operation management software systems or by equipping existing vehicles with new comfort features like air conditioning. Thus, in future it should also be possible to receive subsidies for qualitative improvements and not only for quantitative improvements.

V-2-6 Recommendation (Rough Choice)

A qualitative comparison of the different systems was made on the basis of the aspects discussed in chapters III-2 and III-3 (see tables III-3.4 to III-3.6). The diesel bus makes up the zero case (all fields blue). The electric bus systems are assessed as to whether they are equally good (also blue fields) or whether they are probably better (green) or a little worse (yellow) or much worse (orange) than the zero case.

First of all, the result shows that many more improvements than changes for the worse can be expected for all electric bus systems as against the diesel bus system. However, the real question is not: “diesel bus or electric bus?”, but: “which electric bus system is the best replacement for the diesel bus?”

When the electric bus systems are compared, it is seen that the trolleybus-based systems have fewer disadvantageous assessments.

The result can be summed up as follows:

As regards environment-friendliness and passenger comfort all electric bus systems seem to be better than the diesel bus system, but if the electric bus systems are compared with one another, they seem to be more or less equally good.

From an operational point of view there are hardly differences. There are nearly always technical solutions for the theoretical disadvantages of the electric bus systems. It seems to be most difficult to compensate the short range of the battery buses. Moreover, battery buses are not available as articulated buses (yet).

The most obvious disadvantage of all electric bus systems is the investment costs for the power supply and the vehicles, which have to be financed to start with and which are only balanced after 20 to 25 years by the operating and energy costs, which are much lower then.

Especially overhead contact line systems always lead to discussions. Supporters consider the “rails in the heaven” to be a visible pointer to a high-quality offer. Opponents rather believe that they spoil the street space, especially in sensitive areas, e.g. in front of historical buildings. However, it is a fact that all technologies for electric operation of bus and traction systems without overhead contact line lead to additional investments and are more expensive to maintain.

	System	Dieselbus / Dieselhybridbus	Batterybus without charging on route	Batterybus with charging at terminus	Batterybus with charging at several stops	Trolleybus with continuous overhead contact	Electro-Hybrid (partly overhead wire or energy storage)	Fuel-Cell-Hybrid	Inductive Power-Supply while moving
Advantages of electric operation									
1	locally zero emission and the opportunity to do very low emission also on a global view		Yes	Yes	Yes	Yes	Yes	Yes	Yes
2	Low noise emissions, as well inside as outside of the bus		Yes	Yes	Yes	Yes	Yes	Compressors	Yes
3	No vibrations, specially inside the bus		Yes	Yes	Yes	Yes	Yes	Yes	Yes
4	Powerfull acceleration		Yes	Yes	Yes	Yes	Yes	Yes	Yes
5	Geringer Wartungsbedarf und lange Lebensdauer der elektrischen Komponenten		Yes	Yes	Yes	Yes	Yes	Yes	Yes
6	Geringe Betriebskosten (Energieverbrauch) / höhere Unabhängigkeit von Energielieferanten		Yes	Yes	Yes	Yes	Yes	Yes	Yes
7	Sichtbarkeit eines qualitativ hochwertigen Angebotes					Yes	sectional		Yes
Compensation of disadvantages of electric operation									
8	Abweichung vom Linienweg mittels Hilfsantrieb (möglichst auch elektrisch)		Yes	Yes	Yes	Yes	Yes	Yes	Yes
9	Ausreichende Energiereserven für den Fall von Störungen bei der Stromversorgung					It is assumed that there is - independend from the basic technology - an on-board energy storage unit. The performance of this unit may vary depending on the system			
10	Geringe Beeinträchtigung des Stadtbildes durch angepasste Materialien / spezielles Design für Fahrleitung / Masten / Ladestationen etc.		no such equipment needed	Charging stations	Charging stations	Poles along the whole route	Poles in sections without sensivity only	no such equipment needed	Installations in the lane / sealing

Figure 5.6: Qualitative comparison of various bus systems, part 1 of 3.

	System	Dieselbus / Dieselhybridbus	Batterybus without charging on route	Batterybus with charging at terminus	Batterybus with charging at several stops	Trolleybus with continuous overhead contact	Electro-Hybrid (partly overhead wire or energy storage)	Fuel-Cell-Hybrid	Inductive Power-Supply while moving
Operation similar to Dieselbuses									
11	Verfügbarkeit verschiedener Gefäßgrößen entsprechend dem Einsatzzweck / der Nachfrage		currently only 12-m	currently only Midibus	currently only 12-m	Yes	Yes	Yes	currently only trial vehicle
12	Performance up to 20 h per day (duty starting early in the morning, ending about midnight)		ca. 10 h	At Turin ca. 12 to 13 h (7:00 to 20:00)	target	Yes	Yes	ca. 12 h	target
13	Range more than 400 km/day without (complete) refueling or charging		ca. 200 km	ca. 60 km without / 200 km incl. Charging	target	Yes	Yes	ca. 250 km	target
14	simple and fast procedure of refueling or charging		Yes	Yes	target	Yes	Yes	Special Infrastructure	target
15	easy going with the flow of traffic (no speed reduction or stops by technical reasons, special when using lanes mixed with other car traffic)		Yes	Yes	Yes	Yes	Yes	Yes	separated Right-of-Way needed
16	Dwell times according to passenger demand, not extended by technical needs		Yes	Minimal break time -> no rest in blocks, adjustment of delay	charging > 30 sec, dwell time < 20 sec	Yes	Yes	Yes	Yes
17	sufficient supply to all auxiliary power consumers like doors, light, heating/AC and passenger information displays		target	target	target	Yes	Yes	Yes	target
18	simple handling by the driving staff (concentration on traffic, not on the vehicle and no special know-how for electric/electronic equipment needed)		Yes	Yes	continouosly supervision of level of charge	Yes	Yes	Yes	target

Figure 5.7: Qualitative comparison of various bus systems, part 2 of 3.

	System	Dieselbus / Dieselhybridbus	Batterybus without charging on route	Batterybus with charging at terminus	Batterybus with charging at several stops	Trolleybus with continuous overhead contact	Electro-Hybrid (partly overhead wire or energy storage)	Fuel-Cell-Hybrid	Inductive Power-Supply while moving
Investment cost similar to todays systems									
19	Vehicle and components					Cost 1,5x to 2x more than EURO5-Diesel		cannot be assumed	cannot be assumed
20	Competition in market when purchasing		assumed	assumed	currently only 1 supplier	Yes	Yes	currently only 2 supplier	Monopol (Patent protection!)
21	Infrastructure on the road / along the route / at the stops		no	charging station	charging station	overhead wire	overhead wire (sectional)	no	power supply system in lane surface / separated right-of-way
22	Infrastructure in depot / workshop		Electric components	Electric components	Electric components	Electric components + on-roof working installation	Electric components + on-roof working installation	Electric components + Hydrogen	Electric components
23	future development / long-time availability of spareparts		assumed	assumed	cannot be assumed	Yes	Yes	cannot be assumed	cannot be assumed
Cost for operation and maintenance									
24	lower cost for energy consumption		expected	expected	expected	expected	expected	expected	expected
25	Independency from fluctuation of prices on the worldwide energy market		expected	expected	expected	expected	expected	expected	expected
26	Less tear and wear by electrical components		expected	expected	expected	Yes	expected	expected	expected
27	longer life cycle of vehicle / components		expected	expected	expected	Yes	expected	expected	expected
	Conclusion of evaluation (number of criteria per evaluation level)								
	improvement in comparance to dieselbus operation	0	10	10	10	11	11	9	11
	equal level like dieselbus operation	27	13	10	9	12	12	11	8
	additional effort in comparance to dieselbus operation	0	2	5	6	4	4	2	4
	Significant degradation / no clear data (degradation expected)	0	2	2	2	0	0	5	4

Figure 5.8 Qualitative comparison of various bus systems, part 3 of 3.

VI Communication and marketing

VI-1 Objective of this chapter

In cities where a trolleybus network has been operating for years, the network is taken for granted. However, in cities where it does not exist, how does it all start? Does it make sense to even consider building a trolleybus network? There are probably as many answers to these questions are there are cities.

It is not possible to point out how the idea to implement a trolleybus network germinates. A number of factors will likely contribute. For example, local authorities may wish to reduce the environmental footprint of their urban bus fleet; national authorities may include sustainable development objectives in their political platforms and they may establish policies to decrease the trade deficit caused by massive foreign fossil fuel imports. In any event, it will be important to identify and understand the factors that will militate in favour of the implementation of a trolleybus network[15].

Undoubtedly the idea of implementing a trolleybus system will raise questions and be challenged with objections and facts often based on urban legends. These issues are likely to be:

- Why build a trolleybus network when full electric battery buses are already available?
- What would the trolleybus network look like? Number of lines? Number of trolleybuses? Length of trolleybus lines? Impact on the bus depot? Impact on the rerouting of lines to optimize the trolleybus service?
- How much more, compared to a diesel fleet, will it cost to operate trolleybuses?
- How much will it cost to build the trolleybus network?
- An overhead contact line network is ugly. It will distort the urban landscape.
- Who can carry-out the feasibility study, how long will it take and how much will it cost?
- What type of special qualifications will staff require?

While the long term benefits could outweigh the capital expenditures required to implement a trolleybus network, significant funding will be required, at the onset. The process to obtain the required funding[16] may vary from one city to another, and it is likely that a full business case study be required. The business case should include the results of a feasibility study which it-

[15] It may be that cities have an aspiration for a tram system that would turn out to be unaffordable, leading them to realise that a trolleybus system may be more cost-effective.

[16] Chapter 9 deals specifically with financial support, its sources, opportunities and national and international perspectives.

self should include an appraisal of social, economic and environmental impacts, and an analysis of life cycle costs. Its preparation is likely to be very time consuming and demanding on local expertise. It must be rigorously prepared and planned, and while certain activities can be carried out simultaneously, the business case should be prepared sequentially and include one or more validation milestones.

VI-2 The business case report

The business case report must be an objectively prepared, fact based report, so that decisional authorities are equipped with factual and objective information upon which they can base their decisions. It should document the feasibility of the project, and identify, qualify and quantify all logistical, administrative, financial, environmental, social and political considerations.

While there are numerous approaches to prepare the business case, the foregoing will present a method which has the advantage of having been tried and proven. The following are key steps that most organisations will need to address:

- Identify a **champion**;
- Build a **project study team and obtain the required financial resources**;
- Carry out a feasibility study and **prepare the business case report**;
- Submit the business case report to **authorities for approval**.

VI-2-1 The champion / the promoter

The project needs a **'champion', whose** primary role is to promote the project and win over a critical mass of influential persons. Indeed, a great idea is not a great idea until it has been accepted by a critical mass of influential people. Hence, in a city where there is no trolleybus network, the idea of implementing such a network cannot progress unless a critical mass of city administrators and elected members are favourable to the idea.

The champion needs to know their subject and believe in it; it is not a responsibility that can be delegated. They must be recognized as an authority in similar subjects and be respected by his peers.

The champion's primary task is to sell an idea, not a solution. They will need to build a critical mass of supporters for his idea; the initial approach will likely be one on one with decision makers he knows share similar concerns to their own. Through these individual meetings, they will gain a better knowledge of their preoccupations and concerns and will be able to refine their arguments and be better prepared to win over those that are opposed to the implementation of a trolleybus system.

Undoubtedly they will raise a number of questions and objections, some of which will be based on urban legends. Such issues will likely evolve around the following:

- Why build a trolleybus network when full electric battery buses are already available?
- What would the trolleybus network look like? Number of lines? Number of trolleybuses? Length of trolleybus lines? Impact on the bus depot?
- How much more, compared to a diesel fleet, will it cost to operate trolleybuses?
- How much will it cost to build the trolleybus network?
- An overhead contact line network is ugly. It will distort the urban landscape.
- Who can carry-out the feasibility study, how long will it take and how much will it cost?

Paradoxically, answers to the above questions and concerns, specific to the city's situation, will be obtained through an objective and rigorous feasibility study process. It is, nonetheless quite natural that decision makers wish to obtain an objective assessment of what they could commit to. Hence, it is imperative that the champion know the subject and is able to provide a rule of thumb assessment of the parameters of the proposed trolleybus network. Their experience in the matter, along with an informal benchmarking exercise should provide the required answers[17].

Once a critical mass of decision makers are on board, the project must be presented to various committees and board meetings whose responsibilities are to validate the initiative, prioritize it amongst organizational projects.

The champion must then set up the winning conditions to carry out the feasibility study. Hence, he must:

- Define the scope, deliverables, schedule, milestones and required budget for the study;

[17] For example in Montreal, the champion, promoted a network of approximately 100 articulated trolleybuses; it was then reasonably easy, at high level, to qualify and quantify «ball park figure» the implementation of the network.

- Determine if the expertise to carry out the feasibility study is available within the organisation or if it must be contracted out (study costs will likely differ depending on the situation);
- Influence decision makers to have the feasibility study prioritized and the required budgets and resources made available;
- Appoint a study manager;
- Build the study team;
    - If the study is carried out from within the organisation, ensure that the required resources are available for the duration of the study;
    - If the study is contracted out, a mirror team will be required to assist the contractor, provide the operational data required for the study and validate the contents of the various reports;
- Identify the external partners :
    - Identify roles and responsibilities;
    - Required resources support; (expertise, financial, legislative…)

VI-2-2 The multidisciplinary team

It is likely that a city wishing to implement a new trolleybus network has no contemporary experience in the matter. It will resort to contracting to a recognized engineering firm the mandate to carry out an implementation study and preparing a business case report. The city will, nonetheless need to form a client-side team to assist, from within, the engineering team personnel. The engineering firm's study team must include, at the very least, the following personnel:

VI.2.2.1 A project team leader…

…with specific experience with the planning and implementation of a trolleybus network, who will be the key to the success of the study. They must be readily available to address concerns, with assurance and authority, which arise during the study, and must possess all the inherent qualities of an efficient project manager.

VI.2.2.2 A trolleybus network planning expert to:

- Identify and characterise the routes/corridors that are potentially apt to host a trolleybus lines;
- Identify, characterise and rank the bus lines that are potentially apt to convert to trolleybus lines;
- Establish routes/corridors and bus line combinations that are most promising for the preparation of trolleybus network scenarios;
- Establish, characterise and quantify trolleybus scenarios;

VI.2.2.3 A trolleybus operations expert to:

- Qualify and quantify all prerequisite requirements to operate trolleybuses, such as the requirements for an operational control center and the preparation of a Q&A document to demystify trolleybus operations;
- Qualify and quantify all aspects of trolleybus operations, such as personnel training, emergency procedures and daily operational procedures;

VI.2.2.4 A trolleybus vehicle expert to:

- Identify the types of trolleybuses available on the market, their characteristics and their performance;
- Develop a performance and configuration specification for the trolleybuses that will be required by the trolleybus system;
- Qualify and quantify all trolleybus maintenance requirements, such as special personnel skills and training, infrastructures, special tooling and equipment and maintenance procedures;

VI.2.2.5 An electrical and power network expert to:

- Define the system performance and infrastructures requirements;
- Define the operational requirements such as special personnel skills and training and operational center requirements, ;
- Qualify and quantify all electrical power network maintenance requirements, such as special personnel skills required, personnel training, special tooling and equipment and maintenance procedures;

VI.2.2.6 A financial analyst to carry out according to applicable regulatory requirements:

- System costing activities;
- Life cycle cost analyses;
- Other pertinent financial and economical assessments;

VI.2.2.7 The engineering firm's study team…

…should have access to other specialists such as urban planners, environmental specialists, architects, project management specialist and others as required. Also, for the credibility of the study, they must ensure the active involvement of personnel that have field experience operating and managing a trolleybus network.

VI-3 The feasibility study / pre-feasibility study

The feasibility study should be carried out in a phased approach, and the results of each phase documented in a formal phase report. These phases would typically be the identification phase, the definition phase and the recommendation phase.

VI-3-1 The Identification phase

The identification phase report should set the stage for the feasibility study. It should scope and document the current situation and identify the needs arising and objectives sought. Typical subjects addressed in this report could be:

VI-3-2 Study planning:

VI.3.2.1 Identify, scope and document the current situation;

VI.3.2.2 Clarify and document the objectives of the study;

VI.3.2.3 Establish the strategic link with the organizational strategic plan;

VI.3.2.4 Prepare the referencing plan: The identification, qualification and quantification of work hypothesis, input data required to carry out the study (sources, format, and required dates), output data (format and required dates);

VI.3.2.5 Prepare the work plan: The study's organisational chart, the role and responsibility matrix, the progressive workflow, the detailed work schedule;

VI-3-3 Benchmarking and referencing:

VI.3.3.1 A glossary of definitions and abbreviations;

VI.3.3.2 An inventory of local and national laws, rules and regulations: The objective of this activity is to prepare an inventory of all regulations pertinent to the establishment of a trolleybus network and carry out an analysis of the major standards. Typical major categories of regulations are:

VI.3.3.3 Regional and municipal planning documents;

VI.3.3.4 Regional and municipal standards and regulations;

VI.3.3.5 Development of a new trolleybus depot or adaptation of an existing depot;

VI.3.3.6 Road safety and operation in an urban milieu;

VI.3.3.7 Signals;

VI.3.3.8 Electrical equipment - General information;

VI.3.3.9 Electrical equipment - Fixed equipment;

VI.3.3.10 Electrical equipment - Vehicular technology;

VI-3-4 An inventory of similar studies and projects, with an executive summary for each:

The objective is to prepare an inventory of international trolleybus studies that can be considered pertinent to the one to be undertaken. This inventory can be supplemented by the presentation of Transit agencies that have recently invested in the establishment or extension of trolleybus lines;

VI-3-5 A glossary of current and emerging trolleybus technologies:

The objective of this glossary is to summarily describe the main components of a trolleybus as well as sketch a portrait of vehicle models available on the market:

VI.3.5.1 Provide a description of the main components of a trolleybus ;

VI.3.5.2 Perform a technology watch to identify manufacturers of trolleybuses;

VI.3.5.3 Establish a first contact with manufacturers and explore their potential interest in eventually providing trolleybuses for the project;

VI.3.5.4 Create an assessment tool, to analyze the trolleybuses offered by manufacturers who have expressed interest in an eventual call for tender.

VI.3.5.5 Describe typical safety measures inherent to trolleybuses;

VI.3.5.6 Provide a summary description of trolleybus maintenance activities;

VI-3-6 A glossary of electrical network systems and components;

VI.3.6.1 Identify and describe the infrastructure and electrical equipment required to operate a trolleybus network;

VI.3.6.2 Identify the different type of construction and where they are more efficient;

VI.3.6.3 Define the criteria to make technological choices regarding the optimal electrical feeding methodology;

VI.3.6.4 Apply a proven and safe concept for the electrification of the network;

VI.3.6.5 Minimize impacts on the environment;

VI.3.6.6 Optimize capital costs and operating life of infrastructure;

VI.3.6.7 Optimize the implementation of various facilities in urban areas;

VI.3.6.8 Facilitate the maintenance of infrastructures and equipment;

VI-3-7 Overview of trolleybus operations:

VI.3.7.1 Customer service planning, regulation and delivery operations;

VI.3.7.2 Trolleybus maintenance operations and special tooling requirements;

VI.3.7.3 Electrical network maintenance operations and special tooling requirements;

VI-3-8 Pre-screening of potential routes/corridors for trolleybus operations

VI.3.8.1 In cities where there are several tens of bus lines in operation, it may become very tedious to perform a detailed multi-criteria analysis on all routes/corridors to identify those that are most suitable for trolleybus operations. Hence, it could be advantageous to perform a pre-screening. Given the premise that implementing a trolleybus network is an expensive project, an organisation would be best advised to implement trolleybuses on lines with the greatest return on investment potential. Three pre-selection criteria can help achieve this objective:

VI.3.8.2 Select bus lines with significant ridership: investment cost per passenger will be lower;

VI.3.8.3 Select bus lines that have a constant ridership throughout the day: from a public perspective, a high investment infrastructure is used optimally all day;

VI.3.8.4 Select bus lines with rapid commercial speed: to avoid public perception that a high investment was made on buses that spend most of their time stuck in traffic.

VI-3-9 Ranking of routes/corridors and multi-criteria analysis

VI.3.9.1 This activity aims to establish which routes/corridors are most relevant to the establishment of a network of trolleybuses. Generally, these will be the routes/corridors that are easier to operate and upon which there are the least constraints regarding the implantation of the electrical infrastructure;

VI.3.9.2 The steps to achieve this goal are:

VI.3.9.3 Determine the technical feasibility of implementing trolleybuses throughout an route/corridor to potentially disqualify certain sections of a given route/corridor. This is called the GO / NO-GO principle;

VI.3.9.4 Establish the criteria to characterize and prioritize potential routes/corridors for future trolleybus operations. Typically, these criteria will be adapted to the objectives of the study. For example in Montreal, the objective of the study was to reduce the environmental footprint of the diesel bus fleet. Hence, the premise of the study was to implement trolleybuses on the busiest bus lines, using articulated trolleybuses. The 12 criterions used by Montreal are presented at annex 4.1.

VI.3.9.5 Characterize and prioritize remaining routes/corridors from the most relevant to the least relevant.

VI-4 The definition phase / feasibility study

The definition phase serves to build, and prepare class D (± 30 %) analysis and characterization of potential trolleybus network scenarios. That level of detail is usually sufficient to objectively compare scenarios and identify the winning conditions for the optimal scenario. Typical subjects addressed during this phase could be:

VI-4-1 Building trolleybus network scenarios:

This subject deals with the development of trolleybus network scenarios using routes/corridors selected as a result of the application of the selection criteria presented at the Identification phase report. The following are typical rules that can be used to develop scenarios:

VI.4.1.1 The number of vehicles comprising the trolleybus fleet of the initial network. By assumption, and in accordance with the terms of reference, the targeted number of trolleybuses for the eventual network should have been identified in Identification phase report.

Thus, assembled lines to form a scenario should require a number of trolleybuses close to the initially targeted number;

VI.4.1.2 The notion of meshed network. A network scenario must be uniform and should not contain isolated lines. This rule aims at facilitating the operation of the network by:

VI.4.1.3 Reducing non-commercial distances between trolleybus lines;

VI.4.1.4 Minimizing the area to be covered by maintenance personnel;

VI.4.1.5 Facilitating the creation of an electrical network (electrical connectivity between lines);

VI.4.1.6 Optimizing degraded modes (a power sub-station shut down can be backed up by the sub-station of another line);

VI.4.1.7 The importance of varying routes/corridors from one network scenario to another; hence, if one route/corridor is eventually eliminated, not all scenarios are affected;

VI.4.1.8 The autonomy of the auxiliary power unit (APU) (if the trolleybus is equipped with one); hence networks can be developed by taking into consideration off wire capabilities depending on the performance characteristics of the on-board APU. Further, in the event of an electrical network failure, the trolleybus must have the capability to return to the depot from any point on the network;

VI-4-2 Implementation and integration analysis of trolleybus network scenarios:

The analysis of each of the urban areas contained in the network scenarios can bring out the specific physical characteristics that may impact on the implementation of related trolleybus network equipment. Physical characteristics in the study can be divided into categories:

VI.4.2.1 Use of the route/corridor: highlight the dominant uses along the route/corridor;

VI.4.2.2 Trolleybus network: crossbreeding potential for the creation of a network;

VI.4.2.3 Island shapes and street grid: typical shape, typical length continuous sections, width of the public domain, number of circulation lanes in each direction, parking, sidewalks, bicycle lanes, projections or medians, etc...

VI.4.2.4 Built Environment: predominant architectural typology, other typologies, major architectural features of buildings, main buildings of interest, building height and homogeneous or heterogeneous nature of the built environment;

VI.4.2.5 Implementation: characterize the implementation environment along the routes/corridors, such as the clearances, street context, homogeneity of the built environment and the occupation of the private areas;

VI.4.2.6 Characterization of the landscape: public space, urban forestry, park or green municipal spaces, historic or natural district, telecom and electrical distribution equipment, urban furniture, street lamps, traffic lights, driveways, coordinating with future work;

VI-4-3 Implementation principles:

Three basic implementation principles are possible for the electrification of a network in urban areas. These principles each have specific impacts on the integration and the initial implementation costs of a trolleybus network. These are presented at annex 4.2:

VI.4.3.1 Leave the existing urban furniture as is and interpose the trolleybus infrastructure between existing infrastructures;

VI.4.3.2 4.3.3.2 Pooling of services: integration of public services (Technical Urban Network and lighting) on new Masts necessary for electrification;

VI.4.3.3 Burial of all aerial components of the urban technical network;

VI-4-4 Mast types for new implementations

The pooling principle allows the use of four types of masts. Various types of masts are used on routes/corridors consistent with existing elements. For example, on an route/corridor where there are existing lampposts on each side, these lampposts are replaced by columns of type B (contact lines and public lighting). In cases where there are also electrical distribution poles,

type C configuration (contact lines, public lighting and urban technical network) is used. They are illustrated at annex 4.3:

VI.4.4.1 Type A : Mast with contact lines only;

VI.4.4.2 Type B: Mast with contact lines and public lighting;

VI.4.4.3 Type C: Mast with contact lines, public lighting and Urban technical network;

VI.4.4.4 Type D : Mast with contact lines and Urban technical network;

VI-4-5 Types of electrical network configurations

Several configurations can be used in the construction of a trolleybus network. For example, using the pooling principle previously stated, four basic configurations are possible. These are illustrated at annex 4.4:

VI.4.5.1 Configuration 1: Simple "one way" console: it is a pole with brackets; the latter may have a length varying between 1 and 10 meters. It takes two consoles to address both travel directions of the trolley;

VI.4.5.2 Configuration 2: Double console: it is a Mast with a pole extending an equal distance on each side. It can hold the contact lines for both travel directions of the trolleybuses. The length of the pole extensions are the same as for the basic console "one way", that is 1 to 10 meters per direction (2-20 meters in total).

VI.4.5.3 Configuration 3: flexible portal (or rope cross): This is a Mast to which is attached a transverse rope. This system, often called "PARAFIL", is usually installed with two poles facing each other. However, if existing poles are staggered, it is still possible to install the flexible portal, but the contact line installation will be more complex and the visual impact will likely be greater;

VI.4.5.4 Configuration 4: Simple "two way" console: it is a Mast with a pole extending to one side sufficiently far to reach two lanes. The pole is longer than that of the Simple "one way" console, allowing it to serve two traffic lanes of traffic circulating in opposite directions. This implementation is typically used on very narrow routes/corridors.

VI-4-6 APU performances

VI.4.6.1 Modern trolleybuses can be equipped with an auxiliary power unit (APU). The APU can be all electric (batteries) or an internal combustion engine (diesel, biodiesel, gas…). The APU enables the trolleybus to travel over short distances when access to overhead wires is not available. The off wire operations can be of two types:

VI.4.6.1.1 Planned: Service planning is done by taking advantage of the off wire operation capability that the APU enables:

VI.4.6.1.2 Non commercial distances can be travelled off wire, using the most direct routes;

VI.4.6.1.3 Overhead wires are not installed on certain sections of trolleybus routes because of technical complexity or urban unacceptability;

VI.4.6.1.4 Unplanned:

VI.4.6.1.5 The trolleybus route is obstructed and the trolleybus must deviate on a route where overhead contact lines are not available;

VI.4.6.1.6 A section of the overhead contact line is unavailable for service and the trolleybus must operate off wire;

VI.4.6.2 The selection and sizing of the APU are a function of energy requirements when travelling off wire. To qualify and quantify the requirements, the following analysis will be required:

VI.4.6.2.1 Quantify energy requirements for planned off wire operation; typically for the farthest travel distance between the trolleybus depot and the bus terminal where the driver will start the customer service;

VI.4.6.2.2 Quantify energy requirements for unplanned off wire operation. The electrical network is typically configured in sections of 1.5 km to 2 km long. Each section can be turned off separately to enable, for example, maintenance workers or emergency workers to operate safely in the vicinity of overhead wires. Hence, the trolleybus must be able to operate, off wire, over a minimal distance equivalent to the length of a section;

VI.4.6.2.3 For electrical APUs, quantify the required time / distance to travel with overhead wire contact, to recharge the batteries after off wire operations and before a subsequent off wire operation;

VI.4.6.2.4 Identify APU technologies that satisfy the off wire energy consumption requirements of the various trolleybus network scenarios;

VI-4-7 Characterisation of the trolleybus network scenarios

Once trolleybus network scenarios have been formulated, the various impacts of their potential implementation must be qualified and quantified. Results of this exercise, with a class D (± 30

%) precision, will provide objective data as to the probable impacts of the implementation of a trolleybus network in light of local sensibilities and requirements such as those inherent to the political, social, geographical and urban environments. The following subjects should be assessed:

VI.4.7.1 Operational impacts: The operational impacts are those impacts on customer service operations that will be brought about with the introduction of trolleybuses. It is possible that, because of operational requirements, the travelled distances, bus driver hours and required number of vehicles differ. To quantify the potential impacts, scenarios must be simulated using the same tools normally used to plan customer service.

VI.4.7.1.1 Design, qualify and quantify the electrical power network:

VI.4.7.1.2 Identify, characterize and costs the types of power sub-stations required, and position them on the trolleybus network plans;

VI.4.7.1.3 Identify, characterize and costs the types of overhead contact line installations required, and position them on the trolleybus network plans;

VI.4.7.1.4 Identify, characterize and costs the types of power sub-station and overhead contact line maintenance equipment required;

VI.4.7.1.5 Identify and characterize the recurring operational costs inherent to the maintenance of the electrical power network;

VI.4.7.2 Design, qualify and quantify the trolleybus depot:

VI.4.7.2.1 Identify, characterize and costs the trolleybus specific infrastructure requirements;

VI.4.7.2.2 Identify, characterize and costs the trolleybus special tooling requirements;

VI.4.7.2.3 Identify, characterize and costs the requirements of the transition from a diesel bus maintenance operations to trolleybus maintenance operations;

VI.4.7.2.4 Identify and characterize the recurring operational costs inherent to the maintenance of trolleybuses;

VI.4.7.3 Design, qualify and quantify the trolleybus control center

VI.4.7.3.1 Identify, characterize and costs the trolleybus specific equipment required for the control center;

VI.4.7.3.2 Identify and characterize the recurring operational costs inherent to the operation of the control center;

VI-5 The recommendation phase

In light of the results obtained during the definition phase, an optimal trolleybus network scenario should be identified; the recommendation phase would then aim at carrying out a class C (± 20 %) analysis of that scenario. That level of detail is usually sufficient to obtain formal project approval and subsequent allocations of appropriate funding to implement the project. It is also sufficient to prepare plans and specifications should that be the decision taken. Typical subjects addressed during this phase could be:

VI-5-1 A detailed description of the physical, operational and financial characteristics of the optimal scenario;

VI-5-2 A business case report for the optimal scenario, to include:

VI.5.2.1 The results of customer service planning studies;

VI.5.2.2 The performance specifications and vehicle characteristics of the required trolleybuses;

VI.5.2.3 The characteristics of the electrical power supply network;

VI.5.2.4 The characteristics of urban and trolleybus stop furniture;

VI.5.2.5 A comprehensive plan of the pre-implementation activities that need to be carried out prior to the implementation of the trolleybus network;

VI.5.2.6 A compendium of the requirements to operate a trolleybus network;

VI.5.2.7 A class C financial evaluation of all cost centers, including the classification as operation or capital expenditure cost centers;

VI.5.2.8 A Cost / Advantages analysis;

VI.5.2.9 An appraisal of the impact of the implementation of the trolleybus network on property values;

VI.5.2.10 Master layout plans for urban furniture and trolleybus stops;

VI.5.2.11 Master layout plans for the electrical supply network;

VI.5.2.12 Master layout plans for the end of line stations, including the number of parking bays for the trolleybuses;

VI.5.2.13 Master layout plans for the trolleybus depot;

VI-5-3 A presentation folder: A comprehensive presentation folder including a PowerPoint document presenting the highlights of the recommended scenario, an executive summary, static and dynamic illustrations, fact sheets, Q&A documents;

VI-5-4 An implementation plan: A sequenced implementation plan for the progressive introduction of the trolleybus network;

VI-5-5 A sustainable development plan: A sustainable development assessment of the trolleybus network implementation scenario

AP4: Practical Application for the Retrofit of a Bus Line from Diesel Bus Operation to Electric Bus Operation Exemplified by Leipzig

VI-5-6 Introduction

On the basis of the ascertained theoretical requirements the existing infrastructure for the supply of an electrically operated urban bus line (line 70) with power is examined in this work package in respect of the possibilities of adaptation and the necessity of expansion as well as in respect of the possible synergies with the tramway operation.

For this purpose the requirements for an electric urban bus system are drawn up using the example of bus line 70 in Leipzig. Moreover, the feasibility is assessed.

The following criteria are considered for the selection of a suitable bus line in this study:

Operational concept?

- Timetable (cycle, intermediate terminals, …)
- Vehicles operated (capacity, line linking)
- Service output (vehicle kilometres per cycle)

Nearness to existing power supply installations?

- Contact line for the tramway system
- Substations

- Cable routes

VI-5-7 Operational Requirements

VI.5.7.1 Line Choice

According to the classic philosophy of the Leipziger Verkehrsbetriebe GmbH (LVB) the tramway is operated as the main mode of transport radially through the city of Leipzig. The bus lines are either urban cross connections between the tramway lines or connections into the environs (regional transport).

In Leipzig the LVB operates 61 bus lines in addition to the regional bus lines. In order to select a bus line suitable for the feasibility study the lines only operated in the periphery of the city are excluded as the first step because no synergetic effects with the traction power supply system of the tramway can be achieved with these bus lines.

Thereafter, the selection is limited to the lines on which 18 m long buses are operated according to the schedule (see chapter III-3.2). Line 60 is one of these lines, but it is also excluded from this study because it is already the focal point of another feasibility study on the retrofit to classic trolleybus operation.

Thus, there are five lines in the final round, which differ much in respect of the following criteria:

- vehicles operated
- scheduling
- passenger volume and
- nearness to existing power supply installations.

Concretely, the following lines are possible:

- Line 70 Mockau-West ➔ Connewitz (Kreuz) and vice versa
- Line 72 Main station ➔ Paunsdorf and vice versa
- Line 73 Main station ➔ Sommerfeld and vice versa
- Line 80 Thekla ➔ Lausen and vice versa

- Line 90 Wahren ➔ Paunsdorf-Center and vice versa

Line 70 fulfils all the above mentioned criteria fully. It is operated in a cycle of 10 minutes, all buses are 18 m long, and the passenger volume is high.

Lines 72 and 73 also fulfil these criteria. Both lines are now operated with serial hybrid buses, but they leave the urban area, line 73 even rather much, which restricts the possibilities of using the traction power supply infrastructure severely.

Consequently, these two lines are out of the question.

Lines 80 and 90 are also operated with 18 m long buses. Both lines offer very good possibilities of connection to the traction power supply network of the LVB, but their moderate passenger volumes are a disadvantage to this study. Both lines are mainly operated in cycles of 20 minutes.

Consequently, these two lines are out of the question.

➢ Thus, only line 70 is suitable for this study.

Line 70 has many points of connection to the tramway network along its route as stops often serve both modes of transport. Therefore, there is a good basis for the intended examination of the synergetic effects of joint power supply for the tramway and an electric bus system.

VI.5.7.2 Main Characteristics of Line 70

The examination of the requirements for an electric urban bus system in Leipzig is carried out on the basis of bus line 70 with a possible extension of this line to the Markkleeberg railway station. It is the intention that the line extension mainly follows line 9 of the tramway as from Connewitz Kreuz.

Bus line 70 runs from the north to the south between Mockau-West and Connewitz Kreuz. Its average length amounts to 16.1 km. The journey time amounts to 50 minutes for each direction of travel. 37 stops are served along the line in 12 cycles per day.

During the busy traffic period in the workdays (Monday to Friday between 06.00 h and 18.00 h) 18 m long articulated buses are operated in a 10 minute cycle. The layout of the line to the in-

dustrial estate East provides two alternative connections, i.e. either via “Abtnaundorf” or via the “Pleißenburgwerkstätten”.

In the morning hours at weekends (Saturday from 05.00 h to 08.00 h and Sunday from 05.00 h to 09.00 h) the line is only operated between Mockau West and Thekla (bus turning point) (journey time: 8 min) and in the evening (from 23:36 h to 0:06 h) between Mockau West and the Thekla station (journey time: 14 min).

From Monday to Friday 12 buses and on Saturdays 8 buses of the type Mercedes Benz O 530G are operated on line 70. On Sundays the line is served by 8 12 m long standard line-service buses. The distances between the stops vary from 198 m to 981 m, and the average distance between stops amounts to approx. 450 m. The annual kilometric performance of line 70 amounts to 1,011,800 vehicle kilometres. The average transport speed, which is calculated as an average value of both directions of travel with both line variants (inclusive of the dwell time at stops), lies at 20.39 km/h.

Within the scope of this study line 70 is examined as an electric urban bus line extended to the Markkleeberg railway station.

The layout of this extension is identical with the present tramway line 9 from Connewitz Kreuz to the stop called “Markkleeberg, Forsthaus Raschwitz”. From this stop line 70 is to provide a new connection to the terminal stop at the Markkleeberg station via a new route.

According to the line data available at present the section between Connewitz Kreuz and the Markkleeberg railway station is 5.3 km long, which means that line 70 will have a total length of approx. 21.4 km from the new terminal stop called “Markkleeberg Bahnhof” (railway station) to Mockau West and that it will have a journey time of 64 minutes. The number of daily cycles would be increased to 16.

In Annex III-4.1 the line data of the four line variants of line 70 (Mockau-West → Connewitz Kreuz) are listed. These data include data about the

- journey time (inclusive of the dwell time at stops),
- average dwell time at stops / time for turning at the terminal
- distance to the previous stop as well as the total line length
- passenger turnaround (average figure per stop without reference to the journey)

In Fig. III-4.1 the course of the line is shown graphically.

Figure 6.1 Course of line 70 (Source: Leipziger Verkehrsbetriebe (LVB) GmbH)

As no elevation data can be recalled from the digital city map, the topography of the area of line 70 was recorded by collecting the GPS coordinates and representing them graphically (Fig. III-4.2).

The evaluation of the data showed that there is a difference in elevation of about 33 metres over the entire line route as the elevation varies from 110 m to 143 m. The highest spot is between the stops called “Naundorfer Straße” and “An der Tabaksmühle”.

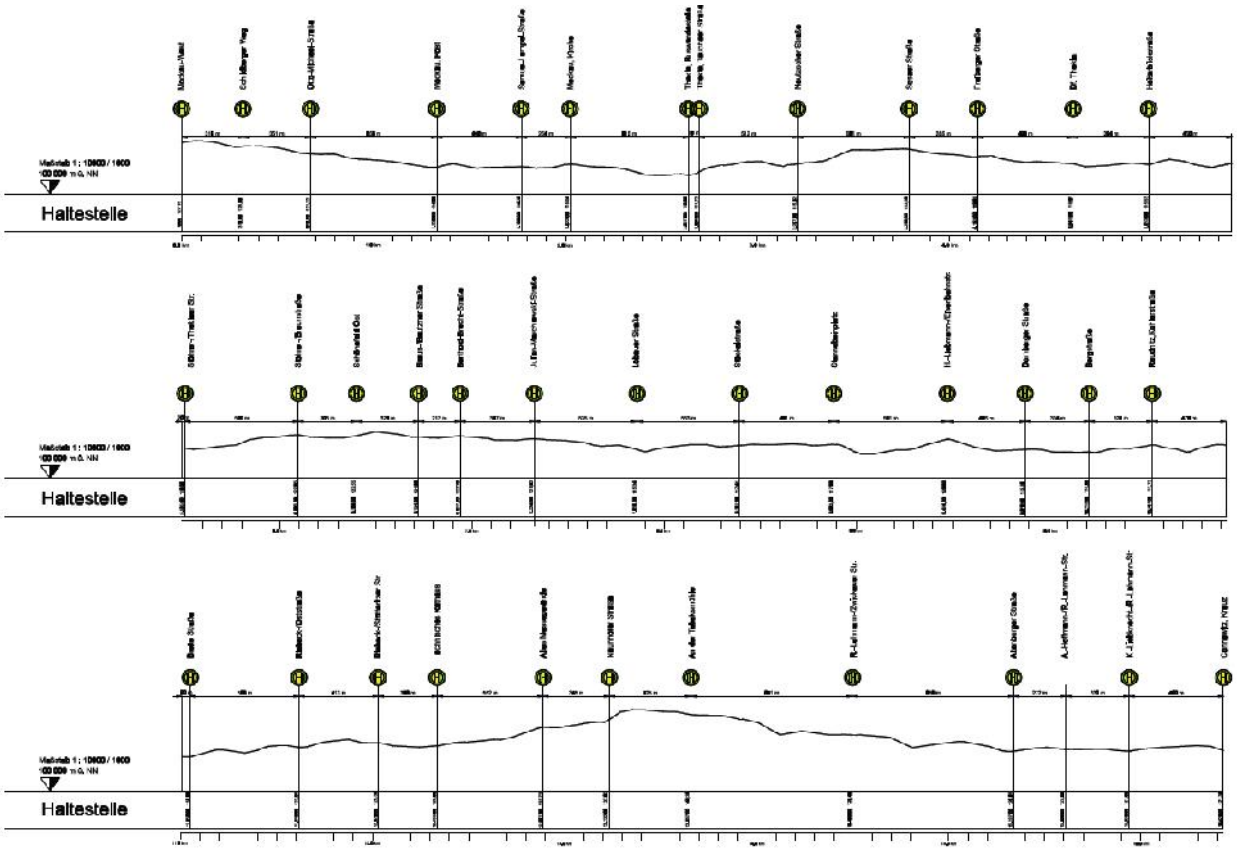


Figure 6.2. Topography of the area of line 70 (from Mockau West to Connewitz Kreuz)

VI-5-8 Comparison of Scenarios

VI.5.8.1 Choice of Scenarios

For the comparison it should not be the objective to compare as many variants as possible, but to compare as few scenarios as necessary.

This approach is not only reasoned by the understandable intention of keeping the examination effort at a reasonable level to the planning effort of a transport company, but also by the contemplation whether a higher quality of the findings can actually be achieved if the study does not only consider the realistic alternatives to the diesel bus, but as many alternatives as at all possible.

From that point of view the following scenarios are compared:

- A Operation of diesel buses
- B Operation of serial hybrid buses
- C Operation of battery buses
- D 1 Operation of electric buses needing continuous overhead contact lines (trolleybuses)
- D 2 Operation of electric buses needing overhead contact lines in some sections (“hybrid electric buses”)

It has been a deliberate choice not to include the options of “operation of fuel cell buses” and “operation of buses with linear, inductive power supply” in this study as – contrary to the above mentioned scenarios – none of the tested solutions for these modes of transport is ready for series production yet.

Scenario A “operation of diesel buses” is the point of origin of the consideration. It is the benchmark for the practical value features at least to be fulfilled by the alternative scenarios – both from the point of view of the transport company and from the point of view of the passenger.

VI.5.8.1.1 Qualitative Assessment of the Scenarios

In tables III-3.4 to III-3.6 in chapter III-3.8 a comparative qualitative assessment is made in the form of a matrix.

In accordance with the task the below comments are mainly based on the example of the Leipzig bus line 70.

In this connection the following criteria are to be mentioned:

From the point of view of the transport company:

- Transport capacity
- Driving dynamics
- Operational flexibility
- Provision of traction energy
- Energy efficiency / ecological relevance
- Cost efficiency
- Reliability
- Servicing and maintenance efficiency

From the point of view of the passenger:

- Transport quality
  - ✓ Number of seats
  - ✓ Noise level
  - ✓ Jerk-free driving
- Punctuality
- Timetable cycle
- Schedule speed
- Environment-friendliness

In accordance with the operational requirements for this bus line only 18 m long buses are considered. If there is no experience with such a vehicle in a scenario, it is mentioned expressly.

It is obvious that some criteria of the various scenarios are to be assessed nearly equally or at least only a little differentiated.

Especially the following criteria are to be assessed as absolutely equally:

- Schedule speed
- Punctuality
- Number of seats

  In this connection the transport capacity is irrelevant to the passenger. He wants to know how much room there is for prams, wheelchairs etc. and he is interested in the subjective room ambience.

There are only minor differences between the scenarios as regards the following criteria:

- Transport capacity

Generally, it may be expected from an 18 m long bus that it can transport at least approx. 140 – 150 passengers. It should have at least 40 seats. Minor differences can be ignored.

The battery bus is assessed a little poorer because the battery takes up too much space at its present stage of development.

This statement is only based on the assessment of the battery bus of the type EBN 10.5 from SOR. However, in the opinion of the authors of this study it is allowed to transfer this assessment to an 18 m long bus.

It is regarded as unfounded to differentiate the scenario “operation of battery buses” further at the present stage, especially as regards the charging technology (plug-in, via pantographs like the eBRT system from Siemens or inductively via e.g. the IPT system from Conductix-Wampfler or the Primove system from Bombardier) because this differentiation cannot be verified on the basis of an 18 m long bus.

Irrespective of the above statements, the efficiency of the energy transfer technology is commented in the discussion of the energy efficiency criterion.

Jerk-free driving

From an objective point of view all electrically powered vehicles are advantageous in this respect because the speed-torque characteristic is fully stepless.

Accelerating power

Usually, all comparable scenarios are so well motorised that this criterion is unimportant from the point of view of scheduling.

Moreover, the passenger can hardly perceive any differences in this respect.

Below the assessments of the criteria are commented for those scenarios that differ more clearly from one another:

Driving dynamics

The classic trolleybus is assessed most positively as it has got the advantage of an electric drive – and especially the possibility of operating at overload for a short time – due to the provision of the electrical energy from the overhead contact line system.

The other scenarios with electric drives (scenarios B, C and D 2) can only use this advantage to the degree that the necessary traction energy is provided by the traction generator and/or the energy storage unit (supercaps and/or battery). However, apart from that the statement on the classic trolleybus also applies to scenario D 2, i.e. operation with an overhead contact line in some sections.

The diesel bus has the lowest elastic constant as regards the speed-torque behaviour because the diesel engine cannot be loaded beyond its nominal power.

Thus, diesel buses only have power reserves for demanding operating situations if the diesel engine has been dimensioned sufficiently.

Operational flexibility

This term means the possibility of operating the vehicle on different lines of a transport company irrespective of the existence of stationary energy supply installations.

The scenarios A, i.e. diesel bus, and B, i.e. serial hybrid bus, fulfil this criterion fully. The tank volume of these vehicles always allows operation during a complete day without refuelling – also in case of heavy urban transport.

The classic trolleybus (scenario D 1) has got the lowest degree of operational flexibility as it needs the overhead contact line.

Scenario C, i.e. battery bus, has also got a comparatively low operational flexibility as it cannot perform line service without interruptions at the present state of development of the energy storage unit. Moreover, it is dependent on a stationary charging infrastructure.

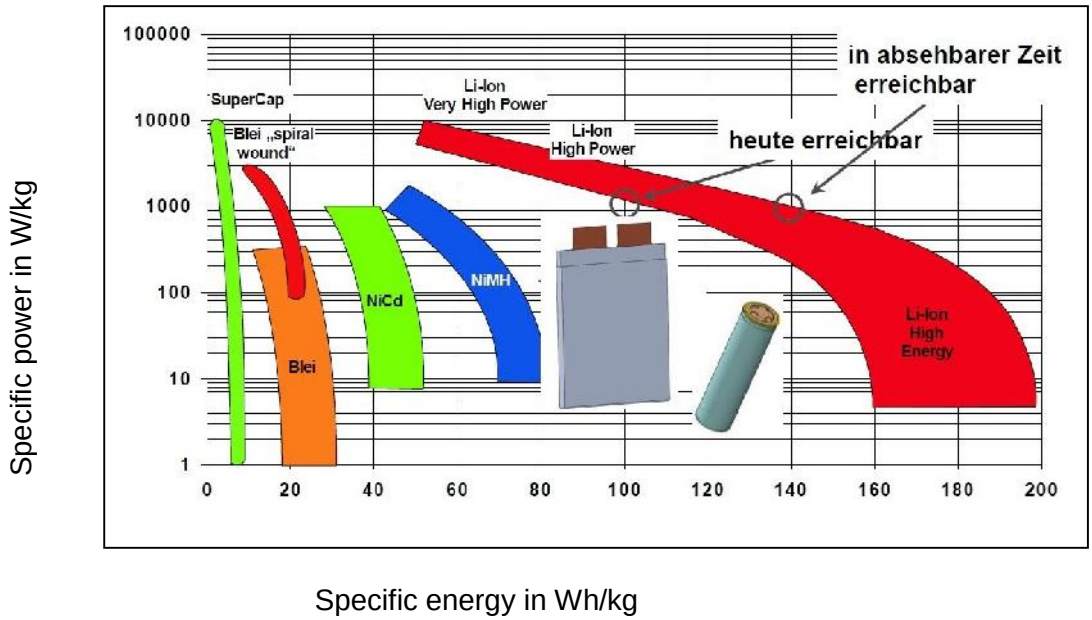


Figure 6.3.: Mass/storage capacity relationship of energy storage units (source: Prof. Sauer, RTWH Aachen)

This assessment is particularly correct if the disadvantages of a too low capacity of the energy storage unit have to be compensated by recharging it during the dwell time at stops and terminals.

Figure 6.3 describes the present dilemma of the commercially available energy storage units for traction purposes and the resulting necessity of recharging them along suitable route sections or at stops at which the buses dwell sufficiently long.

From Figure 6.3 it appears that a quantity of energy of approx. 100 Wh/kg storage mass (of the cells) can be stored today, but it is assumed that it will be possible to store up to 140 Wh/kg in future – without statement of the period of time.

At present, a battery pack has an energy density of 50 Wh/kg to 95 Wh/kg (source: Prof. Sauer, RTWH Aachen). If the degree of discharge amounts to 50 %, a mass of 2.2 t has to be assumed for a battery of an 18 m long bus (scenario C) if it has to store the energy for a complete day of operation.

Such a weight cannot be realised practically and this approach is therefore turned down.

Thus, it is the objective to find an optimum between the following parameters:

- Energy demand of the bus
- Size (dimensions, mass, capacity) of the energy storage unit on board the vehicle
- Number and positions of the charging points at stops

The trolleybus operated without overhead contact line in some sections (scenario D 2) comes off a little better than the classic trolleybus (scenario D 1) because it cannot only be operated without overhead contact line according to schedule by way of the energy storage unit, but can also more flexibly in the event of interruptions of the operation (accidents, alternative routeing).

The criteria of optimisation mentioned above for the battery bus also apply to the hybrid electric bus (scenario D 2) as the line sections with overhead contact line are to be considered as charging sections in addition to the charging points at stops and terminals.

Energy efficiency

The above mentioned scenarios differ clearly in respect of their energy efficiency. At first, it has to be mentioned that the assessment of the energy efficiency is made exclusively on the basis of the energy conversion in the vehicle. There is expressly no assessment of upstream processes, e.g. the way in which electrical energy is generated.

When the scenarios are compared, it is seen that the assessment on the basis of the energy efficiency criterion turns out in the same way as the assessment on the basis of the driving dy-

namics criterion. If the power installed in the vehicles is comparable, this fact is fully logical because the vehicle with the highest energy efficiency has most energy at its disposal for the actual traction.

The diesel bus (A) comes off worst in this comparison because the thermal engine is its only drive system.

Scenario B, i.e. the serial hybrid bus, is assessed to be only a little better. Although the recuperated energy is used for traction purposes so that up to 20 % fuel is saved, the basic disadvantages of the thermal engine cannot be compensated.

First of all, the scenarios with completely electric drives differ in the way in which they draw their traction energy, i.e. either from an overhead contact line or from a traction energy storage unit or from a combination of both systems.

Moreover, they differ in the way in which energy is led to the vehicle.

In consideration of these aspects the order of the scenarios C, D 1 and D 2 is seen as follows:

1. Scenario D 1: Classic trolleybus

   The classic trolleybus profits from the high transmission efficiency of the overhead contact line – current collection system of at least 98 %. It is independent of the storage efficiency in line-service operation.

2. Scenario D 2: Trolleybus operated in some sections without overhead contact line

   This kind of trolleybus is not quite as energy efficient as the classic trolleybus because the efficiency of the energy storage unit (which amounts to approx. 95 % for a lithium ion battery) has to be included in the assessment.

   Scenario C: Battery bus

The battery bus is only considered for the sake of completeness of the weighting. Basically, this scenario has to be rejected for the Leipzig line 70 as there are no 18 m long battery buses on the market at present.

As it was mentioned in the comments on the operational flexibility criterion, a battery with a weight of approx. 2.2 t would have to be provided for an 18 m long battery bus if it cannot be recharged during a day of operation.

Therefore, all manufacturers aim at making recharging of the batteries possible at several points of the route so that smaller battery packs suffice.

The efficiency of the energy storage unit itself as well as the efficiency of the charging technology influence the energy efficiency of the battery bus considerably.

By approximation, multiplication of the efficiency from the scenarios D 1 and D 2 can be assumed, which is only precise if the battery is recharged via a docking station (galvanic connection).

If the energy is transferred inductively to the vehicle (e.g. via the IPT system from Conductix-Wampfler or via the Primove system from Bombardier), it has to be assumed that the efficiency is about 3 % lower than in case of recharging via a docking station.

The local energy costs per vehicle kilometre (table 6.4) reflect the above comparison of the single scenarios.

Energiekosten

	Einheit	A Dieselbus	B Serieller Hybridbus	C Batteriebus	D 1 Klassischer O-Bus	D 2 Elektro-Hybrid
durchschnittlicher Kraftstoffverbrauch	l/100km	53,46	48,95			
durchschnittlicher Energieverbrauch	kWh/km	5,30	4,80	3,40	3,30	3,40
Energiepreis	€/kWh	0,14	0,14	0,11	0,11	0,11
Energiekosten pro km	**€/km**	**0,74**	**0,67**	**0,37**	**0,36**	**0,37**

Table 6.4.: Local energy costs per vehicle kilometre

Cost efficiency of the vehicle

The cost efficiency of the vehicle is a very complex criterion as it includes all factors influencing the vehicle-related costs. Thus, in the sense of this study the following factors are included:

- Investments / capital cost
- Energy costs
- Staff costs

If it is assumed that the single scenarios do not give rise to different staff costs due to the specific types of vehicles, the capital cost and the energy costs remain as the factors deciding on the order and ranking of the scenarios from the point of view of cost efficiency of the vehicle.

From table 6.5 it appears that the classic trolleybus has the lowest vehicle-specific costs.

It is pointed out that the efficiency of the maintenance is not considered here, but examined as a separate criterion.

	Einheit	A Dieselbus	B Serieller Hybridbus	C Batteriebus	D 1 Klassischer O-Bus	D 2 Elektro-Hybrid
Kapitalkosten pro km	€/km	0,40	0,70	0,51	0,49	0,53
Energiekosten pro km	€/km	0,74	0,67	0,37	0,36	0,37
Kosten pro km	**€/km**	**1,14**	**1,38**	**0,89**	**0,86**	**0,90**

Table 6.5. Cost efficiency of the vehicle

Efficiency of the infrastructure

This criterion is only relevant to scenario D 2 as infrastructure along the line is not needed for the scenarios A, B and C. Scenario D 1 requires erection of an overhead contact line along the entire line, i.e. variations are not possible here either. On the other hand, scenario D 2 requires that the overhead contact line system and/or the charging points are optimised in respect of the need for recharging.

Mainly the investment costs for the contact line sections and charging points to be erected are included in the assessment of the efficiency of the infrastructure. Moreover, the criterion of expected prolongation of the journey times caused by charging at stops or wire engagement at the stops at the beginning of contact line sections is considered.

The (non-scale) overview of the possible design variants of the infrastructure in the below table III-4.3 makes it easy to compare the possible infrastructure design variants.

After an initial examination of many technical solutions as far as the length and geographical position of the contact line sections and the arrangement of charging points at the terminals are concerned, two variants can be realised advantageously in compliance with the technical, urban and operational points of view.

An average expenditure of net 860.00 €/m is assessed as the cost for erection of the overhead contact line sections (in the sum both directions of travel are included).

Streckenabschnitte mit Fahrleitung	Variante 1	Variante 2
Haltestelle		
Mockau West		
Rosenowstraße		
Schildberger Weg		
Otto-Michael-Straße		
Essener- / Friedrichsh. Straße		
Mockau, Post		
Samuel-Lampel-Straße		
Mockau, Kirche		
Thekla, Tauchaer Straße		
Neutzscher Straße		
Sosaer Straße		
Freiberger Straße		
Bahnhof Thekla		
heiterblickstraße		
Stöhrer- / Theklaer Straße		
Stöhrer- / Braunstraße		
Schönefeld Ost / VNG AG		
Braun- / Bautzner Straße		
Bethold-Brecht-Straße		
Julian-Marchlewski-Straße		
Löbauer Straße		
Stöckelstraße		
Stannebeinplatz		
H.-Liebmann- / Eisenbahnstraße		
Dornberger Straße		
Bergstraße		
Reudnitz, Köhlerstraße		
Breite Straße		
Riebeck- / Oststraße		
Riebeck- / Stötteritzer Straße		
Technisches Rathaus		
Altes Messegelände		
Naunhofer Straße		
An der Tabaksmühle		
R.-Lehmann- / Zwickauer Straße		
Altenburger Straße		
A.-Hoffmann- / R.-Lehmannstraße		
Liebknecht- / R.-Lehmannstraße		
Connewitz, Kreuz		
Mathildenstraße		
Koburger Brücke		
Wildpark		
Forsthaus Raschwitz		
M'berg, Sonnensiedlung		
M'berg, Gautzscher Platz		
Markkleeberg West		
Markkleeberg, Ring		
S-Bf. Markkleeberg		
Anzahl Fahrleitungsabschnitte	4 / 5	4 / 4
Länge (gesamt) [m]	13.205 / 12.934	13.172 / 13.147

Figure 6.6. Overview of the design variants of the infrastructure

The variants only differ a little in respect of the investment costs (see below) and thus inevitably in respect of the costs for servicing and maintenance.

- **Variant 1**
  - Markkleeberg - Mockau-West net 5,561,620 €
  - Mockau-West - Markkleeberg net 5,678,150 €
- **Variant 2**
  - Markkleeberg - Mockau-West net 5,653,210 €
  - Mockau-West - Markkleeberg net 5,663,960 €

Both variants can be realised without additional charging points at the terminals. Here variant 2 especially benefits from the fact that the overhead contact line section fitted in the town is closer to the terminal.

In that way it is possible to keep the charging condition of the traction battery entirely above the value of 80 %, which increases the life of the battery.

In our opinion this criterion is so decisive that it is the crucial factor for choosing variant 2 as the solution.

In the annex the charging condition is shown as a function of the position and length of the contact line sections for both variants and both directions of travel.

Therefore, it is technically absolutely justified to do without charging points at both terminals and thus to save costs. Not only investment costs are saved, i.e. for the actual charging points and their integration into the terminal stop, but also expenses

- for the necessary expansion of a control panel in the rectifier substation and
- for the cable route between the rectifier substation and the charging point.

Due to the much longer cable route it would be much more expensive to erect a charging point at the Mockau West terminal than to erect one at Markkleeberg-West (railway station). Thus, the charging point at Mockau West would cost approx. 300,000 € net, whereas the charging point at Markkleeberg-West would cost approx.180,000 € net.

This means that investment costs of approx. 480,000 € are inapplicable without these two charging points.

Comments on the assessment of the infrastructure design variants

In both directions of travel **variant 1** has an additional contact line section approximately in the middle of the line. Nevertheless, the costs for the stationary infrastructure are only slightly higher than in case of variant 2.

Variant 2 only needs four contact line sections in each direction of travel.

The decisive advantage of variant 2 as against variant 1 is the optimised energetic operation of the line at the Mockau West terminal.

Variant 2 is the preferential solution.

Efficiency of the maintenance

Of course, all technical installations – and especially all electrical installations – have to be serviced and maintained at regular intervals, no matter which maintenance philosophy the operator of the installations prefers.

In this case

- approx. 26,000 m overhead contact line and
- 7 switchgear cubicles in existing rectifier substations

would have to be serviced and maintained for both directions of travel.

The servicing and maintenance of the overhead contact line, which is calculated to approx. 2 €/m per year (i.e. approx. 52,000 €/year), only profits from a synergetic effect with the servicing and maintenance of the overhead contact line of the tramway in so far as technical resources and qualified staff are already at disposal and can take over the work on the additional installations.

This also applies to the servicing and maintenance of the rectifier substations, but in this case there is the additional positive effect that the present concept can be realised without having to

build new rectifier substations. Instead an additional switchgear cubicle is fitted in each existing rectifier substation.

These switchgear cubicles are serviced and maintained together with the other traction power supply system components fitted in these rectifier substations.

According to a conservative estimate the maximum annual costs for the switchgear cubicles needed for the power supply of the electrically operated bus line amount to 1,400 € (200 €/year per cubicle).

The costs for the servicing and maintenance of the switchgear cubicles are estimated to be so low because they are part of the maintenance costs for the traction power supply system of the rectifier substations and are maintained within the scope of maintenance of these rectifier substations.

Reliability

For the assessment of the reliability a simple breakdown was examined for both directions of travel.

As a precaution the failure of the power supply for a complete overhead contact line section – and not only for a feeding section – was examined as the simple breakdown.

Thus, a breakdown with a very low probability of occurrence was examined.

The calculations of the resulting charging condition of the traction battery appear from Annex III-4.3 in WP4 – AP4.

Such a consideration should always be carried out to examine or prove the reliability of the operation if part of the charging infrastructure fails. Just as in case of the traction power supply the following applies: It has to be possible to overcome the simple breakdown (failure of an incoming feeder) without impairment of the transport performance.

The results of these examinations are encouraging. In the most unfavourable case the vehicle would reach the next overhead contact line section with a charging condition of the traction battery of approx. 40 %.

Therefore, it is not uncertain whether the scheduled operation of the electric bus line can be kept up.

It is possible to cope with the simple breakdown without having to interrupt the operation.

Noise level in the bus

The noise level is higher in the diesel bus and the hybrid bus than in the electric bus because they have diesel engines as the drive units, which are perceived acoustically by the passenger during the journey. The noise is louder in the rear part of the bus because the diesel engine has been fitted here.

The hybrid bus has a clear advantage within the stop zone because it can drive electrically, i.e. hardly audibly for the passenger, into this area. It can also leave the stop zone fully electrically as the diesel engine is only switched on when the energy management system of the vehicle initiates switching on due to the decreasing charging condition of the vehicle. The driver cannot influence this behaviour of the hybrid bus.

The scenarios with fully electric drives (C, D 1, D 2) are assessed to be equally good because these buses are only powered electrically.

Visible transport offer

The scenarios D 1, i.e. the classic trolleybus, and D 2, i.e. the trolleybus operated in some sections without overhead contact line, fulfil this criterion fully as a visible line layout, i.e. the overhead contact line needed for the operation, is seen by the passenger and as this overhead contact line clearly shows that public transport is within reach.

Neither the diesel bus nor the hybrid bus nor the battery bus has such a visible symbol as these types of buses do not need an overhead contact line and fit into the road traffic.

Environment-friendliness

The scenarios C (battery bus), D 1 (classic trolleybus) and D 2 (trolleybus operated in some sections without overhead contact line) are assessed most positively, both as regards the noise pollution and as regards the pollutant emission, as they are operated fully without emissions.

As both hybrid buses and diesel buses are powered with diesel fuel, they are assessed to be less good than the above mentioned scenarios.

The pollutant emission of internal combustion engines has been thoroughly discussed, and this subject is not commented anew in this study.

The hybrid bus is assessed to be better than the diesel bus because it can store and recuperate the braking energy, whereas a diesel bus is only powered by diesel fuel.

VI.5.8.1.2 Result of the Qualitative Assessment of the Scenarios

In the concrete case, i.e. line 70 in Leipzig, the tendency of the qualitative assessment corresponds to the general assessment: electric urban bus systems have many advantages and only few disadvantages as against the operation with diesel buses. Moreover, systems with batteries are inferior to systems with overhead contact lines at the present state of the art. The apparently higher degree of freedom without overhead contact lines is paid expensively with a much shorter range, i.e. operating time, or with an additional load due to the high weight of the battery.

A system with an overhead contact line only at positions at which it is really needed is the ideal combination, also for Leipzig, as it overcomes the disadvantages of a short range (battery bus) and of the restriction of an overhead contact line (trolleybus).

VI.5.8.1.3 Determination of the Power Required per Scenario

The power required for each scenario is determined in three steps:

- **Step 1: Approximate determination by way of the graphical timetable**
  - Basis: a constant average traction power of 20 % of the nominal power per cycle => 2.5 kWh/km
  - Additionally: power required by the secondary consumers as summer/winter scenario

- **Step 2: Vehicle simulation of the scenarios**

- Basis: test runs with a serial hybrid bus → Recording of the power from the intermediate circuit
- Computer-based modelling of the data acquired

- **Step 3: Examination of the various cases of operation**
  - Basis: maximum demand for traction energy per km determined during the test runs
  - Calculation of the development of the charging condition of the traction battery, especially in the event of a simple breakdown as well as for the journeys from the parking facilities to the line and vice versa

The basis for step 1, i.e. for determination of an average traction power per cycle at a set schedule speed of 20 km/h, is the nominal power of the decisive secondary consumers given in the manuals on the hybrid buses operated in Leipzig.

The simultaneity factor g and the load factor a per day were applied for the calculation. The result of this calculation showed that the secondary consumers require a total power of 18 KW, which corresponds to a consumption of approx. 0.9 kWh/km. Accordingly, the specific total energy demand amounts to approx. 3.3 kWh/km. If the calculated data are compared with the data of the SWISSTROLLEY 3 project, they can be regarded as realistic for the further examination due to their accuracy.

Figure 6.7 presents the secondary consumers of the hybrid buses used for the calculation as well as the appertaining nominal powers.

Nebenverbraucher	P_{nenn} in W	a	g	P_{max} in W	Kommentar
Fahrer-Assistenzsysteme	100	0,66	1,00	66	
Fahrzeugbeleuchtung gemäß StVZ	250	0,50	1,00	125	
Belüftung/Kühlung Energiespeicher	600	1,00	0,75	450	
Kühlsystem Fahrgastraum	36000	0,40	0,27	3.888	an 100 Tagen im Jahr
Heizsystem Fahrgastraum	76.000	0,40	0,27	8.208	an 100 Tagen im Jahr
Kühlsystem Fahrerarbeitsplatz	8.000	0,40	0,27	864	an 100 Tagen im Jahr
Heizsystem Fahrerarbeitsplatz	22.000	0,40	0,27	2.376	an 100 Tagen im Jahr
Defrosteranlage	22.000	1,00	0,05	1.100	an 100 Tagen im Jahr für 4 h
Innenraumbeleuchtung	360	1,00	0,33	119	2.920 Jahresbenutzungsstd.
Fahrgast-TV	50	1,00	1,00	50	
Entwerter	300	0,75	0,01	2	vernachlässigbar
Zielanzeigen	50	1,00	1,00	50	
Sonstige: z. B. E-Kompressor etc.	15.000	0,25	0,10	375	
Leistung Nebenverbraucher	**180.710**			**17.673**	entspricht ca. 0,9 kWh/km

Figure 6.7. Decisive secondary consumers in the hybrid bus

It appears from the graphical timetable of line 70 (see Fig. III-4.5) that 12 cycles are operated in the morning between 6 h and 9 h from Mockau West to Connewitz Kreuz and from the “Arno-Nitzsche-Straße” to Mockau West, respectively.

16 cycles are required for the entire line 70 when it has been extended to Markkleeberg.

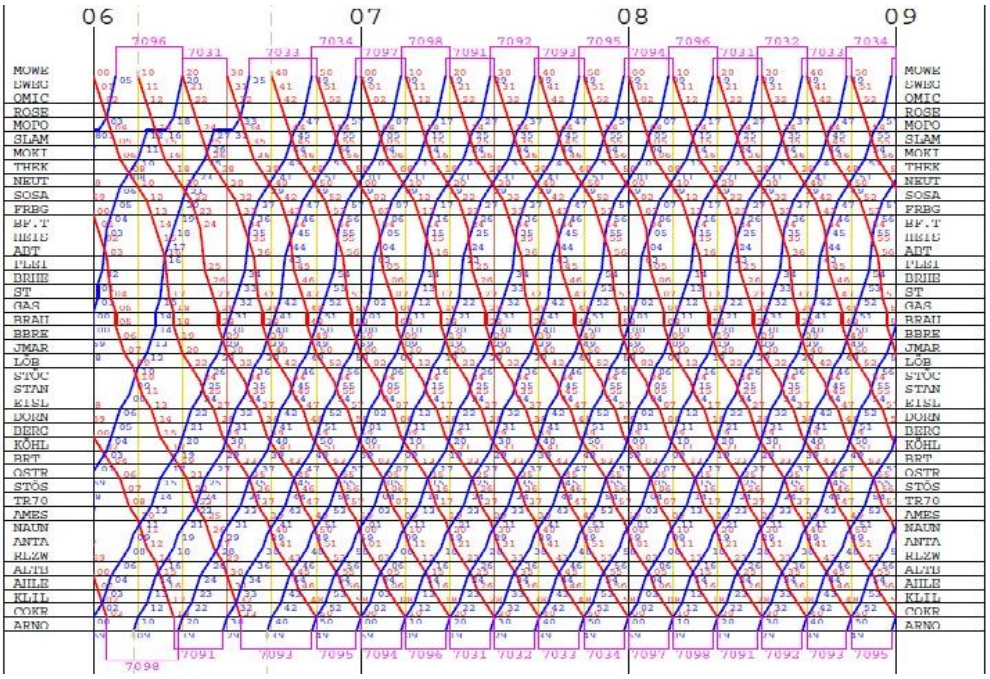


Figure. 6.8 Graphical timetable of line 70

The Fraunhofer Institute for Transportation and Infrastructure Systems IVI in Dresden performed the vehicle simulation of the power demand and calculated the necessary charging power (step 2).

The power is recorded on the basis of test runs with a serial hybrid bus on line 70 in Leipzig. Thereafter, the acquired data are used for a computer-based modelling of the scenarios:

- Simulation of a classic trolleybus (scenario D 1)
- Simulation of a trolleybus operated without overhead contact line in some sections (scenario D 2)
- Simulation of a battery bus with interim charging at certain points (scenario C)

  + determination of the charging power

It was only possible to continue the calculations and examinations (step 3) in this simplified way due to the flat country character of the topographical line profile.

On an average, the bus consumes approx. 3.7 kWh per km from its energy storage unit when it is operated in sections without overhead contact line. When it is operated by way of the overhead contact line, its energy storage unit is recharged with approx. 3 kWh.

VI.5.8.2 Interfaces between the Bus and the Tramway

The existing infrastructure along line 70 and possible interfaces to the tramway lines have to be analysed. It has to be examined whether it will be possible for the bus and the tramcar to use the same power supply system in future.

As regards the existing infrastructure any parallels concerning the

a) availability of the traction power supply installations (cable distributors, rectifier substations),
b) need for adaptation,
c) reconstruction of substations / construction of new substations,
d) arrangement of stops and/or charging points

have to be examined.

a) Availability of traction power supply installations (cable distributors / rectifier substations)

The below Figure 6.9 shows at which stops of line 70 (from Mockau West to Connewitz Kreuz) inclusive of the extension to the Markkleeberg railway station there are interfaces or parallels between the bus line and the tramway.

The graph of the line shows that many stops of the bus line are served in parallel by both modes of transport in the following sections:

- Mockau, Post - Thekla, Tauchaer Straße,
- Löbauer Straße - H.-Liebmann-/ Eisenbahnstraße,
- Reudnitz, Koehlerstraße - Naunhofer Straße,
- at the stop R.-Lehmann-/ Zwickauer Straße and between
- A.-Hoffmann-/ R.-Lehmann-Str. - Connewitz Kreuz

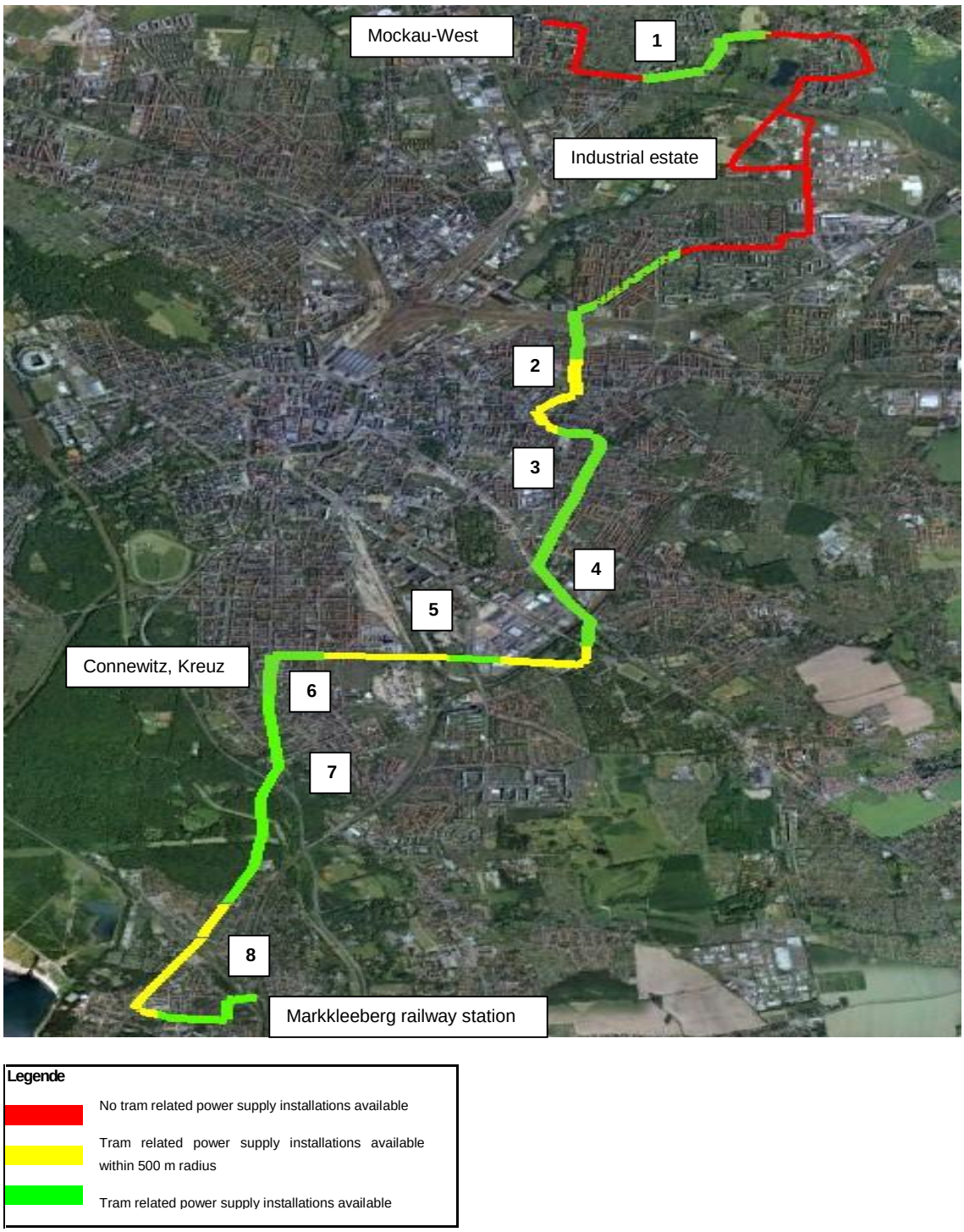


Figure 6.9: Line 70 – interfaces to the tramway lines and rectifier substation locations (Source: google earth)

According to the key the line sections with traction power supply installations are shown in green. Due to the alternating line routes through the industrial estate Leipzig East line 70 is operated alternately via “Abtnaundorf” and the “Pleißenburgwerkstätten” on workdays. Just in this line section there is no connection to the tramway lines at present. The same applies to the Mockau West terminal. The line sections without traction power supply installations are shown in red. The yellow line sections are the sections with traction power supply installations within a radius < 500 m.

There are eight substations within the zone of line 70 (inclusive of the extension to the Markkleeberg railway station):

1. Mockau
2. Neuschönefeld
3. Reudnitz
4. Dauthestraße
5. Zwickauer Straße
6. Arthur-Hoffmann-Straße
7. Connewitz
8. Markkleeberg Mitte

The locations of the rectifier stations along line 70 (from Mockau West to the Markkleeberg railway station) are shown in Figure 6.10 in accordance with the above numbering.

The year of construction of the single substations is listed in the below table 6.10.

Substation	Year of construction	New substation planned	Nominal power in MVA
Mockau	1977		2
Neuschönefeld	1973		4 (3.2 after reconstruction)
Reudnitz	1973	2013	4 (3.2 after reconstruction)
Dauthestraße	1978		3
Zwickauer Straße	1999	new	3.2
Arthur-Hoffmann-Straße	1988		4
Connewitz	1973	to be given up	3
Markkleeberg-Mitte	1993	new	3.2

Table 6.10. Substations – Year of construction and nominal power

The examination of the condition of the overhead contact line system for the extended line section between “Connewitz Kreuz” and “Markkleeberg West” (which corresponds to the present tramway line 9) revealed that the poles of the overhead contact line system are in a critical condition. This line section can only be used for a trolleybus line if all poles are exchanged. As regards the entire extended line section this applies particularly to the section between “Connewitz Kreuz” and “Markkleeberg, Forsthaus Raschwitz” as well as to the section between “Markkleeberg West” and the Markkleeberg railway station.

The existing overhead contact line system is not suited for operation of electric buses in the classic sense of a trolley variant. It would be absolutely advisable to modernise the infrastructure or erect new infrastructure on the above mentioned line sections.

b) Need for adaptation

The following questions have to be answered:

1. Where are feeding points along the bus line needed according to the result of the simulation of the power required?

   Note: The exact positions of the feeding points are determined at a later planning stage. For this purpose the overhead contact line sections set out in the study have to be divided into feeding sections.

2. Are all traction power supply installations found within an economically reasonable distance?

   Note: Distances of 500 m (in justified cases up to 800 m) are considered to be economically reasonable.

3. Can the existing traction power supply installations (rectifier substations or at least cable distributors) provide the additional power needed for the operation of electric buses?

   Note: Basically, it is always possible to ensure the supply of an electric bus line in all new substations or all reconstructed substations.

4. Is it possible to fit additional cable outlet fields in the existing rectifier substations?

   Note: The necessary space for the expansion of the switching device is available.

5. If necessary: Which locations are suited for the construction of new additional rectifier substations?

   Note: Up to now, it is only intended to build new rectifier substations or expand existing rectifier substations at their present locations.

c) Reconstruction of substations / construction of new substations

Since 2008 the LVB has been changing the nominal voltage of the contact wire from 600 V to 750 V within the scope of an extensive modernisation concept. The electrical installations and their equipment are examined and, if necessary, exchanged in this connection.

Although the rectifier substations are rather old (on average 30 – 35 years), it is preferred to reconstruct the substations instead of building new ones because the buildings are in a relatively good condition. The reconstruction programme of the LVB will probably end in 2015.

The following effects are achieved with the change to a nominal voltage of the contact wire of 750 V and with the building measures to be taken for this reason:

- better utilisation of the braking energy,
- less total demand for power,
- less conduction loss in the traction power cables and the overhead contact lines
- increase in the capacity of the power supply system – improvement of the security of supply
- less wear on the overhead contact lines and the trolleys for current reasons.

The modernisation of the substations is a good initial position for implementation of modern transport concepts and modes of transport, e.g. new electric bus systems or retrofit to an electric bus system.

The substations *Mockau* and *Arthur-Hoffmann-Straße* are to be (re-)constructed within the scope of the 750 V programme of the LVB sometime after 2013. It has not been finally decided yet whether the Mockau substation is to be reconstructed or replaced by a new substation at another place. Both substations have enough space for an extension.

It is the intention to reconstruct the substations *Neuschönefeld* und *Dauthestraße* next to the "Härtelstraße" within the scope of the 750 V programme when the existing Reudnitz substation has been replaced by a new substation. The exact schedule for this building activity depends on the available funds.

Here, too, space has been reserved for the extension in the form of an additional switchgear cubicle for another line.

The substations *Markkleeberg-West* and *Zwickauer Straße* are still new as they were built after 1990. At present, all the existing routes are used for the tramway operation. As the buildings of these substations were dimensioned for this purpose, there is no room for an extension of the substations.

Next year the *Reudnitz* substation is to be replaced by a new substation in the same place.

The *Connewitz* substation is to be given up as this real estate is not owned by the LVB. One or several small substations next to the "Bornaische Straße" are to supply the areas of Connewitz and Lößnig in future. The exact positions have not been fixed yet.

If the tramway line 9 is extended from the Thekla terminal to the Thekla station, a new substation would have to be erected in this area. As line 70 also serves these two stops, this line should also be considered for the future.

Moreover, the *Volbedingtstraße* substation, which does not lie directly next to line 70, should also be examined as this substation has room for an extension after the reconstruction realised already.

d) Arrangement of stops and/or charging points

A basic requirement for the erection and operation of charging points along the line is that the dwell time at stops amounts to at least 15 – 20 seconds. This requirement is always fulfilled at the terminals as the average time for turning amounts to 9 – 10 minutes.

The below table III-4.5 shows at which stops the average dwell time at stops is ≥ 15s.

This restriction is necessary to be able to examine the variant of supplying the bus with power at points (charging). However, it is not enough that the dwell time is sufficiently long. In fact, it is decisive whether it is possible to supply the charging points with power.

Line 70 **Mockau-West --> Connewitz Kreuz**		**Line 70** **Connewitz Kreuz --> Mockau-West**	
Name of stop	Ø dwell time [s]	Name of stop	Ø dwell time [s]
Mockau-West	600	Arno-Nitzsche-Straße	543
Mockau, Post	18	Connewitz, Kreuz	15
Thekla, Taucher Straße	17	Naunhofer Straße	21
Julian-Marchlewski-Straße	16	Altes Messegelände	16
Stöckelstraße	20	Riebeck-/Oststraße	15
Stannebeinplatz	16	Breite Straße	17
H.-Liebmann-/Eisenbahnstraße	19	Reudnitz, Koehlerstraße	24
Reudnitz, Koehlerstraße	24	H.-Liebmann-/Eisenbahnstraße	23
Breite Straße	20	Stannebeinplatz	16
Riebeck-/Oststraße	17	Löbauer Straße	18
Naunhofer Straße	17	Thekla, Tauchaer Straße	15
Connewitz, Kreuz	554	Mockau, Post	20
		Mockau-West	600

Table 6.11.: Line 70 – stops with an average dwell time > 15 s

It does not matter for this analysis which alternating route is followed through the industrial estate East as the dwell time at the stops in this estate are all under the set limit.

It is a premise for the possible operation in Leipzig that the mobile energy storage unit of the vehicle is exclusively charged at the charging points from the overhead contact line of the trolleybus by way of the standard trolley of the trolleybus. It is a deliberate choice within the scope of this study that no other technical solution is accepted for the charging than the one that has already proved its worth and is standard for the operation of buses in sections with overhead contact lines.

As another design solution for the power supply in the sections without overhead contact line charging points designed as a firmly installed contact line was considered as the trolleybus contact line within the area of the charging point.

A recommended design solution is the integration of the firmly installed contact line into a complete stop shelter construction, which is applied by Siemens within the scope of its e-BRT project (see Fig.6.12).

Fig. 6.12.: Charging point at a stop taking the e-BRT system from Siemens as an example

This solution is based exclusively on components that have already proved their worth in practice. The continuous current-carrying capacity of the system consisting of a contact wire or a firmly installed contact line and a trolley allows a charging current of approx. 150 A for several minutes without any problems. In that way the charging condition of the mobile energy storage unit can e.g. be improved by at least 15 kWh if the bus stays 9 minutes at the terminal.

Moreover, the system consisting of a contact wire or a firmly installed contact line and a trolley has a high degree of transmission efficiency. It should lie at 97 % under the usual contact conditions (no icing, not too much dirt).

An interesting alternative in the form of inductive transfer of energy is the PRIMOVE concept developed by Bombardier (see Figure 6.13). Due to the inductive transfer of energy the vehicle has to be modified technically as a so-called power pick-up unit has to be fitted under the vehicle. This unit acts as the secondary coil of a transformer.

According to information from Bombardier the costs for a PRIMOVE charging point amounts to approx. 125,000 €, but it is unlikely that this sum includes the costs for the installation or the costs for the feeding cables.

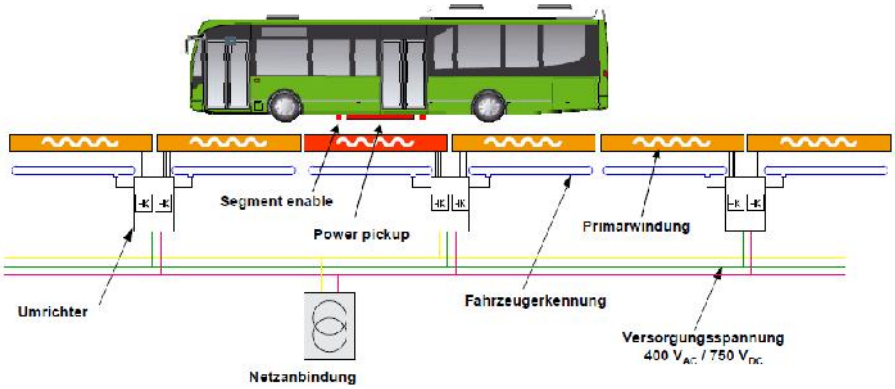


Figure. 6.13: Charging point according to the PRIMOVE principle of Bombardier

On the basis of the available information it is assessed that the costs for a complete charging point amounts to approx. 150,000 €. Thus, the inductive charging point would be about 50,000 € more expensive than the conventional charging point (no consideration at all of the feeding cables from the next rectifier substation to the charging point and no consideration of the costs for expansion of the rectifier substation itself).

The transmission efficiency of about 95 %, which is mentioned by Bombardier, is also lower than that of the conventional charging point.

At the deadline of this study it was not possible to finally assess the two alternatives as the information about the PRIMOVE concept was incomplete.

VI.5.8.3 Urban Integration

The integration of overhead contact lines into the city is a very emotional subject. Often the town planners do not approve of the overhead contact lines and often the citizens find that they spoil the townscape.

It is admitted that optically suboptimal structures emerge at complicated crossings with the overhead contact line system of the tramway from straight and branching line sections and that it is also expensive to install and maintain such crossings.

Alternatives, like operation without overhead contact line in some sections, make it possible to avoid such conflicts in urban surroundings of high quality (e.g. in historical town or city centres) and to reduce the costs for the overhead contact line systems. However, it is a condition that the trolleybus is technically able to drive fully electrically or by way of an auxiliary generator set in some sections.

So far, the subject of urban integration of charging points into the townscape has not been discussed broadly. It is essential that the charging installations are integrated fully into the design of the stop.

Fig. III-4.7 presents a stop design into which the e-BRT system from Siemens is integrated. Here the bus is interim charged during its dwell time at the stop via the overhead contact line fitted in this section.

Generally, this aspect will be weighed differently by each municipality. It is hardly possible to generalise. The instincts of the experts involved in such a project are in demand.

VI.5.8.4 Costs and Investments

Many inputs have to be considered when the economic effects of the scenarios mentioned in chapter III.4.3.1 are to be compared.

As regards scenarios A (operation of diesel buses) and B (operation of serial hybrid buses) the data gained from the operation of the fleet of the LVB are taken as a basis. Relevant cost elements concerning scenario D 1 (operation of electric buses needing continuous overhead contact lines (trolleybuses)) are found in the specialist literature and taken from practical examples in German cities with trolleybus operation.

However, as regards scenarios C (operation of battery buses) and D 2 (operation of electric buses needing overhead contact lines in some sections (“hybrid electric buses”)) it has turned out to be difficult at the present stage of the study to mention typical values and reference val-

ues for the operation of 18 m long buses. At present, only 12 m long battery buses are operated by transport companies.

The following cost elements and criteria are to be analysed and assessed for an 18 m long articulated bus:

- Vehicle costs
- Workshop
- Charging points
- Overhead contact line
- Further costs

Vehicle costs

The costs for the procurement of one vehicle make up the basis for the further cost analysis. In table III-4.6 these costs are mentioned for each scenario.

	Procurement costs and service life of an 18 m long articulated bus				
	Diesel bus	Serial hybrid bus	Battery bus	Electric bus with continuous overhead contact line	Electric bus w. overhead contact line in sections
Purchase price	330,000 €	700,000 €	660,000 €	750,000 €	850,000 €
Service life	12 years	12 years	20 years	20 years	20 years

Table 6.14 Procurement costs and service life of an 18 m long articulated bus

The comparison of the purchase prices shows that the diesel bus is the most inexpensive kind of bus, but also that it has got a shorter service life than a trolleybus, which has an average service life of 20 years.

There were no practical reference values for the battery bus. On the basis of the costs for procurement of a 12 m long battery bus (approx. 440,000 €) it was assessed that an 18 m long battery bus would cost approx. 660,000 €.

The high purchase price for an electric bus needing overhead contact line in some sections mainly arises due to the costs for procurement of the system components needed in the vehicle.

Moreover, the life of its energy storage unit is limited by the expected high number of charging cycles per bus and per year. Thus, the energy storage unit probably has to be replaced after maximum 60,000 charging cycles, i.e. after about 3.2 years in a bus operated on the exemplary line 70 (cf. variant 2). Therefore, these replacement investments in batteries to the amount of approx. 150,000 € per bus are an important cost factor in the cost-benefit analysis. This aspect will be discussed in detail further below in this chapter.

Workshop

The costs for servicing and maintenance of the various kinds of buses differ. All scenarios lead to costs for the provision of a necessary spare parts centre for material and tools. Moreover, costs emerge for the qualification of the workshop staff in the form of training if the staff is not already suitably qualified. The LVB has a cost advantage in this respect due to its experience with the hybrid bus fleet and the training already realised.

The following main items have to be procured for the servicing and maintenance of buses of all scenarios in a workshop, provided they are not already part of the workshop equipment:

- Working pit
- Roof access platform
- Test bay
- Feeding and charging installations
- Overhead contact line within the depot area (for scenarios D 1 und D 2)

It is not possible to do without a roof access platform because work has to be carried out on the roof of the buses, e.g. corrective and preventive maintenance of the air conditioning installations, the supercaps and the ancillary units, as well as on the trolleys and the electrical traction equipment.

The investment costs for an 18 m long roof access platform, which is equipped with swivelling railings and accessible from two sides and which is so high that articulated buses can pass unter it, amount to approx. 130,000 € nowadays.

The average maintenance costs per kilometre for the diesel buses of the LVB amount to 0.50 €/km at an annual average kilometric performance of approx. 61,000 km per bus.

This cost rate consists of 40 % labour expense and 60 % material costs.

At present, it is difficult to exactly state the reference values for the maintenance of the hybrid buses of the LVB. As these vehicles are still very young, the vehicle manufacturers are obliged to repair any damage occurring during the guarantee period and to maintain the special components. Therefore, the exact maintenance costs per kilometre cannot be mentioned before the guarantee period has expired.

As the operation of trolleybuses was stopped already in 1975, no current local price can be mentioned for this operating system.

The analysis of an electric bus system has to consider that new electrical components have to be serviced and maintained, whereas some other components like the diesel engine and the gear box fall away.

Consequently, it is assumed that there will only be minor differences as regards the servicing and maintenance of the various types of vehicles, which can be neglected for the further analysis.

However, the costs for the vehicle reserves needed to ensure reliable operation may not be neglected. They amount to approx. 21,500 € per bus annually.

Charging points

The scenarios D 2 (operation of electric buses needing overhead contact lines in some sections) and C (operation of battery buses) require that charging points are erected

- at the terminals and at the stops for the (fast) interim charging necessary during the line service (only relevant to scenario C) and

- within the depot for the normal recharging of the battery overnight or out of the line service period.

Further costs in addition to the pure investment costs for the charging points incur for the provision of the necessary infrastructure, e.g. for the connection to the power supply system. Moreover, the costs for the integration of a facility for interim charging into already existing stops and the reconstruction measures to be taken in this connection as well as the costs for the operation of the system have to be examined.

The analysis of the two line variants examined (cf. variant 1 and variant 2 mentioned in chapter III.4.3.1.1 under the point “Efficiency of the infrastructure”) showed that it is not meaningful to erect and operate charging points along the line due to the short dwell time at stops (< 15 s).

It was originally considered to erect charging points at the terminals to increase the charging condition of the energy storage units, but within the scope of the analysis and due to the positions of the line sections with overhead contact lines it has become clear that the energy storage units do not have to be charged at the terminals. As the batteries are recharged during the journey, such a high charging condition of the batteries can be ensured that charging points at the line terminals become superfluous.

However, this does not mean that it is possible to do completely without stationary charging points. The batteries of the vehicles always have to be recharged overnight, e.g. at the Lindenau bus station or in the “Technisches Zentrum Heiterblick”, so that the vehicles are ready for operation at the beginning of the daily service.

It is assessed that the costs for all parking facilities amount to approx. 400,000 €.

The configuration of the charging points in the parking facilities is not specified within the scope of this project because a reasonable decision can only be made on the basis of a specification of the vehicles to be procured. A plug-in solution seems to be meaningful as it has proved its worth for the pure battery buses.

Overhead contact line

In connection with the erection of an overhead contact line system for trolleybuses costs incur for the:

- contact wire,
- poles,
- section insulators,
- points and
- crossings.

If the overhead contact line is only needed in some sections, the latter two items become superfluous or are at least reduced considerably, but the vehicle costs are increased. Moreover, costs arise for the servicing and maintenance of the overhead contact line system.

An average expenditure of net 860.00 €/m is assessed as the cost for erection of the overhead contact line sections (in this sum both directions of travel are included).

A comparison of the costs is found in the next chapter, in which the figures of the line variants are compared.

Further costs

Further costs are e.g. the consequential costs for the integration of the charging points into the townscape and the costs for adaptation of the road network, if any. This cost aspect is included in the costs for the power supply system.

VI.5.8.5 Economic Comparison of the Line Variants

The economic efficiency of the line variants is explained by means of bus line 70.

In the below figure, which shows an economic comparison of the variants of line 70, the examined variants 1 and 2, i.e. operation of electric buses needing overhead contact lines in some sections, and the classic trolleybus variant with continuous overhead contact lines are compared.

The economic analysis is performed for a period of 20 years.

Due to the different lengths of the sections with overhead contact line the highest construction costs for the overhead contact line and the traction power supply arise for the classic trolleybus

variant as its overhead contact line share amounts to 100 % along the line. Consequently, it is also expected that the highest costs for the servicing as well as the preventive and corrective maintenance of the overhead contact line system incur for this variant within the period under consideration.

The servicing and maintenance of the overhead contact line, which is calculated to approx. 2 €/m per year, only profits from a synergetic effect with the servicing and maintenance of the overhead contact line of the tramway in so far as technical resources and qualified staff are already at disposal and can take over the work on the additional installations.

This also applies to the servicing and maintenance of the rectifier substations, but in this case there is the additional positive effect that the present concept can be realised without having to build new rectifier substations. Instead an additional switchgear cubicle is fitted in each existing rectifier substation.

According to a conservative estimate the maximum annual costs for the switchgear cubicles needed for the power supply of the electrically operated bus line amount to 1,400 € (200 €/year per cubicle).

The costs for the servicing and maintenance of the switchgear cubicles are estimated to be so low because they are part of the maintenance costs for the traction power supply system of the rectifier substations and are maintained within the scope of maintenance of these rectifier substations.

These switchgear cubicles are serviced and maintained together with the other traction power supply system components fitted in these rectifier substations.

Position / Kriterium	I Variante 1 O-Bus partielle Fahrleitung	II Variante 2 O-Bus partielle Fahrleitung	III O-Bus mit durchgängiger Fahrleitung
Streckenlänge in m	43.874	43.874	43.874
Anzahl der Ladestationen	0	0	0
Anzahl der Fahrleitungsabschnitte	9	8	2
Länge der Fahrleitungsabschnitte in m	26.139	26.319	43.874
Anteil der Fahrleitungsstrecke in %	60	60	100
Baukosten Fahrleitung + Bahnstrom in €	11.239.770	11.317.170	18.865.820
Wartung/Instandhaltung/Reparatur Fahrleitung für 20 a (mit 2 € / m * a)	1.045.560	1.052.760	1.754.960
Ausbau von 7 GUW in €	420.000	420.000	420.000
anteilige Wartung/Instandhaltung/Reparatur GUW mit 200 €/GUW * a	28.000	28.000	28.000
Anzahl Ladezyklen je Bus p-a. (bei 330 Einsatztagen)	20.790	18.480	1.320
Lebensdauer der Batterie in Jahren (bei max. 60.000 Ladezyklen)	2,9	3,2	10,0
Fahrzeugbeschaffungskosten (I, II: 18* á 850.000€; III: 18* á 750.000€)	15.300.000	15.300.000	13.500.000
Ersatzinvestitionen für Batterie (I, II á 150.000€; III á 50.000 €) bei Nutzungsdauer der Busse von 20 Jahren	16.200.000	16.200.000	900.000
2 Ladestationen in den Abstellanlagen mit 200.000 € / Station	400.000	400.000	400.000
anteilige Wartung/Instandhaltung/Reparatur Ladestation mit 200 €/Station* a	8.000	8.000	8.000
Gesamtkosten über 20 Jahre in €	**44.641.330,00**	**44.725.930,00**	**35.876.780,00**
Kosten / a in €	**2.232.066,50**	**2.236.296,50**	**1.793.839,00**

Figure 6.15 Economic comparison of the variants of line 70

As already mentioned in chapter III.4.3.4, the costs for erection of two charging points in the parking facilities probably amount to altogether approx. 400,000 €.

If it is assumed that a bus is operated 330 days a year, the life of the battery will probably only amount to 2.9 or 3.2 years, respectively, due to the many charging cycles per bus according to the state of the art. To realise a conservative cost-benefit analysis, the possibility of a longer life is deliberately not considered. A longer life would be possible if the charging condition of the energy storage unit would amount to at least 80 % as calculated or only falls below 80 % in exceptional cases. Moreover, there is no long history of use as regards the increase in life in that way.

Therefore, the necessary replacement investments in batteries are a cost factor, which decisively explains the big differences in the overall cost analysis of the variants.

To avoid that other public transport companies get a wrong idea of the expenditure - revenue image, the revenues situation of bus line 70 is deliberately not included in the analysis.

Too many local factors, like

- line loading
- fares
- local politics decisions,

do not allow a general assessment of the revenue.

That variant 2 is favoured shows that the decision-making may not follow exclusively on the basis of the investment and life cycle costs. The technical reliability is extremely important.

One technical reliability parameter is the charging condition of the energy storage unit. In the concrete example it was regarded as very important that the charging condition does not fall below 80 % during normal operation, which naturally influences the positions of the overhead contact line sections along the line.

Moreover, the decision in favour of variant 2 clearly shows that the size of the investment and operation costs is an important, but not crucial decision criterion.

In the present case the charging condition of the energy storage unit during the journey is considered to be important

- because the expected life of the energy storage unit is extended when the energy storage unit is operated at a charging condition between 100 % and 80 % and
- because the positions and the lengths of the overhead contact line sections have to be able to cope with a simple breakdown.

VI.5.8.6 Servicing and Maintenance

In Leipzig a concept for efficient servicing and maintenance of electric urban buses cannot be examined without also examining the servicing and maintenance of the hybrid buses.

At present, the diesel buses and the hybrid buses are serviced and maintained in the Lindenau bus station.

There is no depot along the route of the examined line 70. Thus, it is not necessary to discuss whether another site than the Lindenau bus station should also be equipped for the servicing and maintenance of electric buses.

The buses are now being parked in the Paunsdorf and Lindenau depots. When the “Technisches Zentrum Heiterblick” has been erected and put into service as the main workshop of the LVB and when the Paunsdorf depot has been closed as a consequence of the new workshop, some of the buses are going to be parked on the site of the new workshop.

VI.5.8.7 Analysis of the Routes of Buses Coming onto or Leaving the Line

As mentioned already, buses will be parked in the Lindenau bus station as usual and in future also in the “Technisches Zentrum Heiterblick”.

The possible routes of buses coming onto or leaving the line are examined for both destinations in consideration of the recharging facilities.

Figure 6.16: Route for vehicles to park in the Lindenau bus station (Source: google earth)

It is recommended that vehicles that begin or end their journeys at the Markkleeberg railway station follow this route (see Figure 6.16):

- From the Lindenau bus station the route of line 60 is followed (direction of travel: Lindenau - Lipsiusstraße) via the “Kurt-Eisner-Straße” to “Connewitz Kreuz”.

It is not possible to recharge the energy storage unit on board the vehicle along this route, which means that it is always discharged during the journey from or to the bus station. If the batteries have been charged nearly 100 % in the bus station, e.g. overnight, it is unproblematic to pass this section, which is about 6.3 km long.

The overhead contact line can be used to recharge the energy storage unit as from the “Mathildenstraße” stop towards the Markkleeberg terminal.

In the other direction the complete overhead contact line section from “Markkleeberg, Gautzscher Platz” to “Mathildenstraße” can be used to recharge the energy storage unit to such a charging condition that it would be possible to drive the above mentioned route to Lindenau.

An examination of the route to the “Technisches Zentrum Heiterblick” as a possible parking location for the buses shows that in principle there are two possibilities of access to this site, which are differently long.

Figure 6.17: Route for vehicles to park in the “Technisches Zentrum Heiterblick” (Source: google earth)

Merely the access to the “Technisches Zentrum Heiterblick” via the “Teslastraße” is being analysed because this way is shorter. If it is favoured to lead the vehicles via the “Wodanstraße” for operational reasons, this way is also unproblematic from the aspect of the charging condition of the energy storage unit.

In the above figure the recharging section is shown by way of green squares. It is about 1.9 km long. It begins at the junction “Essener-/Friedrichshafener Straße” and follows the line route to the stop called “Thekla, Tauchaer Straße”. From this stop the journey is continued without overhead contact line to the destination, i.e. to the “Technisches Zentrum Heiterblick”.

The situation is similar in the opposite direction. The recharging section begins at the “Thekla, Tauchaer Straße” stop and continues to the “Rosenowstraße”. This section is about 2.1 km long.

VI.5.8.8 Diesel Bus and Trolleybus - Joint Servicing and Maintenance?

Diesel buses and trolleybuses can be and are being maintained in the same workshops. As many components are identical in the vehicles (e.g. axles) and as many procedures are identi-

cal (e.g. tyre management and corrective maintenance after accidents) (source: Annex to VDV Recommendation 881, 05/2006), it is not advisable to separate the maintenance of trolleybuses. Joint use of the workshop is advantageous to the public transport company not only in respect of the provision of the real estate (buildings) needed, but also in respect of the workshop staff (no additional staff needed).

It is not possible to do without a roof access platform because work has to be carried out on the roof of the buses, e.g. corrective and preventive maintenance of the air conditioning installations, the supercaps and the ancillary units, as well as on the trolleys and the electrical traction equipment.

If the workshop is used for diesel buses and trolleybuses, it is avoided to invest twice in the same equipment. If the maintenance of the diesel buses and the trolleybuses takes place on two different sites, this advantage is not given.

The more maintenance-intensive electronic equipment as well as the necessary exchange and maintenance of the carbon inserts and the trolleys of the trolleybuses lead to higher maintenance costs and a demand for higher qualification of the staff than required for diesel buses. If, however, it is taken into consideration that the LVB has been operating 14 articulated hybrid buses and 5 standard hybrid buses since 2010 and that the staff has already been trained to service and maintain hybrid buses, the workshop staff has a state of knowledge that is advantageous to the maintenance of trolleybuses in future.

Moreover, the LVB can fall back on many years of experience with tramway operation. Thus, the handling of the relevant workshop components and spare parts is no problem at all and this know how can also be used for the servicing and maintenance of trolleybuses.

The situation is more difficult in towns and cities in which neither a tramway nor a trolleybus system is operated. In this case each transport company has to examine which kind of maintenance and which real estate represent the most economic variant for the operation of such a mode of transport like the electric bus.

In such a case it should not be forgotten that staff with the necessary qualifications has to be trained or hired at first. Public transport companies already operating tramcars or trolleybuses employ persons who are skilled to handle electrical and electronic equipment and who can service and maintain electric buses. Employees who have exclusively worked on tramcars so far

already fulfil the qualification requirements for performing servicing and maintenance work on electric buses. They merely have to be made acquainted with the specific features of the electric buses within the scope of introduction.

VI-6 AP5: Summary / Result

VI-6-1 Recommendation for Leipzig

It is recommended to retrofit line 70 (Mockau <-> Connewitz <-> Markkleeberg) for the operation of electric buses. Four line sections are equipped with overhead contact lines, whereas the remaining line sections are operated by way of energy storage units on board the vehicles. Additional charging points at the terminals are not needed.

It is recommended that the overhead contact line is a two-pole overhead contact line for trolleybuses as all other technologies for the transfer of current during the journey are not fully developed yet.

VI-6-2 Transferability to Other Cities

The subject of “electric mobility” is one of the challenges of urban development in the short or medium term. Public transport can contribute considerably to meeting this challenge, also in the bus sector, as the appropriate technologies are already available. Although the present study goes into great detail with line 70 in Leipzig, this example can be transferred to any bus line

- that is operated with articulated buses in a cycle of 10 minutes at the most (at least in the busy traffic period). Other operating concepts might require other technical solutions.
- that has got several points of contact to the power supply system of a tramway or light rail system and
- that has got staff qualified to operate and maintain the infrastructure and the vehicle components.

The latter two items are especially important for the economic efficiency of the system.

Naturally, the positions and lengths of the sections with overhead contact line always have to be determined individually from town to town and from line to line, but generally about 50 % of the line have to be equipped with an overhead contact line to ensure sufficient power supply if charging points are undesirable at the terminals.

The following generally valid conclusions can reliably be drawn from the analyses carried out:

a. It is technically and economically advantageous to operate an electric urban bus line.

b. If a diesel bus line is retrofitted for the operation of electric buses, it is possible to do without the overhead contact line of the classic trolleybus in some sections if the energy storage unit of the vehicle is dimensioned sufficiently.

c. A very high degree of operational reliability is achieved with overhead contact lines only in some sections if the overhead contact line system is dimensioned correctly in respect of the positions and lengths of the contact lines. In that case a simple breakdown can be overcome without obstructing the operation.

d. The necessary vehicle and infrastructure components are available as desired from the series production of well-known manufacturers.

e. Basically, electric buses can be supplied with power from the power supply system of tramways. In practice, the same examinations and calculations as in case of an extension of the tramway network have to be carried out.

f. Public transport companies operating tramways have got sufficiently qualified staff for the servicing and maintenance of electric buses. Operators of hybrid buses are in a particular advantageous situation in this respect.

g. The assessment of the synergetic potentials mainly depends on the structure of the area and the capacity of the traction power supply system that is to supply the electric buses with power in addition to the tramcars or light rail vehicles. The topography of the area and the structure of the town or city are of minor importance.

h. The economic feasibility of such a measure cannot be described generally as not only knowledge of the expenditure, but also of the revenue is needed.

However, the expenditure described in this study in the form of investments and life cycle costs should enable companies interested in taking up the ideas of this study to complete the economic calculation on the basis of their concrete revenues.

Basically, it can be stated that public transport companies that look into the subject of “introduction of new electric bus systems or retrofit to electric bus systems” within existing tramway or light rail systems always have to analyse the operational requirements for the bus lines within their transport network, i.e. they have to analyse the actual situation to be able to make the correct decisions on the further procedure.

VI-6-3 Communications and Marketing

VI.6.3.1 Objective of this chapter

The objective of this chapter is to provide a practical guide on how to promote and market the development and delivery of a trolleybus scheme though proactive communications and stakeholder engagement. Effective communication with stakeholders will be essential to the success of a project and as such there must be adequate time and resource devoted to this area of work.

This chapter will consider the need for effective communications, how to mobilise support for a project, tools and techniques for effective communications and how to market a trolleybus scheme. Consideration will be given to communications with internal and external stakeholders, both of which require separate consideration.

VI.6.3.2 Communications internal to own organisation

It is vital to ensure that communications with internal stakeholders from within the organisation are proactive and structured. This is often overlooked as much of the focus will be on consulting with external stakeholders and the general public. However, if internal communications are not properly managed this could have a significant impact on the project as circulation of inaccurate information will lead to inefficiencies in the development process.

VI.6.3.3 Need for information

Internal stakeholders require a common understanding of the key aspects of the project in order to ensure that they are working towards the delivery of a shared goal in a structured way. The information required by internal stakeholders includes, but is not limited to:

- The strategic context for the project (why is it being developed, what problem(s) is it trying to address?)
- The key aims and objectives of the project
- A common understanding of what the project will actually deliver (key outputs)
- The key benefits of the project (key outcomes) and the evidence that these are based upon
- The impacts of the project and how these will be addressed and mitigated
- The costs of the project and how these will be funded
- The business case for the project (i.e. what are the level of benefits compared to the costs of the project)
- The overall timescales for delivery of the project and the key interim milestones
- The construction proposals for the scheme
- The operational proposals for the scheme
- Roles and responsibilities and governance structure for the project.

The timing of providing this information is also important. Regular and accurate updates about the progress on all of the key aspects of the project will be necessary. It will also be important to ensure that internal stakeholders are well briefed ahead of any major public announcements about the scheme, so that they are well prepared to respond to any enquiries from the public, the media and other external stakeholders.

VI.6.3.4 Urban legends

A proactive programme of internal communications will help to reduce the potential for the circulation of inaccurate information which could lead to the formation of ‘urban legends’. However even with the most comprehensive of communications strategies, there is still scope for urban legends to be formed. These may relate to a number of different aspects of the project.

It is particularly important that the project development team act quickly to correct any inaccurate information about the project that they become aware of and try to contain this within the organisation. This may present an issue at times where factual information is not readily available to be able to adequately rebut this information.

Communications tools such as regular e-newsletters for staff, internal staff briefings, and holding lunchtime seminars, can all help to ensure people have accurate information about the project and reduce the spread of urban legends.

VI.6.3.5 Communications external to own organisation

In addition to internal stakeholders there will also be individuals and groups who are external to the project but who will need to interact with the project or may be affected by the project in some way. These stakeholders generally fall into the following categories:

- People who directly benefit from the project;
- People who are directly negatively impacted by the project;
- People who indirectly benefit from the project;
- People who are indirectly negatively impacted by the project;
- People who are not affected either way by the project but who have an interest.

Depending on which of these groups people fall into, they will either support the project, oppose the project or have no strong view about the project. It will be necessary to categorise external stakeholders in this way in order to target resources at the priority groups.

It is however particularly important to ensure that external communications are not just directed at those stakeholders who are the most vocal about the scheme. It is important to consider how to best engage with those groups who are traditionally quite hard to reach – for example this may include the elderly and people from different ethnic origins who may have trouble understanding information which is disseminated in the parent language.

It is vital that all external communications are planned and implemented in a controlled manner in order that accurate and consistent messages are disseminated about the project. As with internal communications, the circulation of inaccurate information externally will lead to the development of ‘urban legends’ relating to the scheme (see below).

Engaging with external stakeholders includes providing information, consulting on detailed issues, involvement of local communities in the development process and empowering them to make informed choices.

VI.6.3.6 Need for information

It is important to provide external stakeholders and the wider general public with information at regular stages throughout the project. This is necessary in order to both raise awareness of the scheme generally and to ensure that the information in the public realm is both current and accurate.

In the absence of accurate information from the Project Team, external stakeholders will come to their own conclusions about the project without access to the relevant facts. External stakeholders who do not have enough official information about the project, are often not able to make informed choices about whether they support the project or not.

It is therefore important that a consistent programme of external information dissemination is adopted at the outset of the project and maintained throughout all stages. This should cover issues such as:

- The key benefits of the project (the outcomes);
- The key components that the project will deliver (the outputs);
- The overall aims and objectives of the project;
- Details of how the routes and technology have been chosen (option appraisal)
- The impacts of the project and how these will be addressed and mitigated;
- The plan for the construction of the project;
- The costs of the project and how these will be funded;
- The timescales for delivery and the key milestones;
- Information on how people can contact the project team with queries or concerns (including any formal consultation process or procedure for raising objections);
- Regular and accurate updates about the progress on developing the scheme.

VI.6.3.7 Urban legends

If there is a lack of information circulated to external stakeholders about the project, it is inevitable that urban legends will be circulated in its place. This will either happen as a result of people being genuinely mistaken about some aspects of the project, or as part of a coordinated effort by those opposed to the scheme, to influence public opinion.

Whatever the cause, the spread of urban legends can have a significant impact on the development of the project, as increased time and resource will be required to deal with issues that may be completely irrelevant. In addition once false rumours have been circulated it is very difficult to correct that inaccurate information in the public arena since it will potentially have reached a very wide audience particularly if it has been in the media.

VI-7 Mobilizing the population in favour of trolleybuses

At the outset of the Project, a Communications Management Strategy should be developed to set out how the Project Team will establish, develop and maintain active support for the project.

In order to obtain support from key stakeholders, partners and ultimately the public, a planned, targeted, effective and consistent programme of communications will be required. This will include:

- Identifying key stakeholders and influencers who can support and champion the project;
- Ensuring that accurate and timely messages about the project are disseminated to these people;
- Considering how to communicate with the general public and how that population breaks down into sub-groups, requiring specific messages;
- Establishing appropriate, accurate and relevant messages for each of these stakeholder and general public groups and the methods, or combinations of methods, by which they will be conveyed;
- Ensure that any consultation activities provide stakeholders with the opportunity for two-way dialogue;
- Ensure that consultation activities are planned and delivered in a manner that will reach the intended audience and will be accessible to all; and
- Ensure that consultation activities are monitored / evaluated and appropriate feedback is provided to people who have taken part in consultation.

VI-7-1 Identification and mobilisation of partners within the organisation

There will be a number of key partners from within the organisation that is developing the trolleybus project and these people will be vital to the successful delivery of the project. These partners include:

Project Board/Steering Group

The Project Board/Steering Group for the project should be set up at the outset of the project. This will comprise a group of senior officers who will be responsible for the overall direction and management of the project. It is vital that the Project Board contains individuals who will be able to act as champions for the project and influence internal and external stakeholders.

Where possible the Project Board should include a representative from the ultimate end-user – in the case of a trolleybus project this would be someone who could represent the needs of passengers. In addition a representative of the organisation(s) that will be a 'supplier' to the project e.g. (construction company/operator where known) should also be included.

The Project Board will provide overall leadership for the project and will have ultimate responsibility for mobilising other individuals from within the organisation.

User Representatives

It is important to identify any partners within the organisation who are able to represent the end-users of the trolleybus system i.e. passengers. There may already be people within the organisation who hold relevant data relating to passenger preferences or who already have established communication networks with passengers that can be used to disseminate information about the project.

It is also necessary to consider whether there are any internal contacts who may be able to represent particular groups of users. For example there may be an accessibility officer within the organisation who can coordinate communications with disabled passenger groups and other specific mobility groups.

Supplier Representatives

There may be people within the organisation who can represent the interests of those who will be supplying services to the trolleybus project (e.g. construction companies, bus operating companies). For example the organisation may have a procurement department who will be able to advise on the appropriate communication channels for consultation with the market on key aspects of the development and delivery of the project.

Finance and Cost Management

A lead contact in the organisation's finance department will need to be identified to provide financial advice to the project. This will be necessary to ensure that finance and funding issues are properly communicated through the organisation's financial management systems. If the organisation has employees who are cost management professionals, links with these individuals should also be made in order to ensure appropriate cost controls are employed on the project.

PR/marketing

Many organisations have their own specialist Public Relations/Marketing departments and it will be vital to involve these departments throughout the life of the project. These people will be able to assist with organising and disseminating all communications related to the project through established communications networks.

Human Resources

It will be important to establish strong links with the organisation's Human Resources/Personnel department as the structure of the Project Team is likely to require some changes as the project moves through different phases. For example there will be different skills and level of resource required at the feasibility stage in comparison to the procurement phase. Robust communications channels with the Human Resources team will be necessary to ensure any necessary changes/additions to the project team can be implemented quickly and smoothly.

VI-7-2 Identification and mobilisation of partners outside the organisation

There will be a number of individual stakeholders and groups who are external to the project, but who have scope to influence the success of the project. As such these stakeholders must be identified at the outset and a strategy must be put in place to effectively engage with these stakeholders. The key external groups can be summarised as follows:

Politicians

Key groups of politicians to engage with will include:

- Local City Politicians
- Regional Politicians
- National Politicians

It is vital to identify and involve political leaders and groups in the development of the trolleybus project from the outset. Politicians will have a significant influence on the success of the project and depending on the approvals process for the project may have the ultimate authority on whether the funding to deliver the project is provided.

It may be appropriate to establish a small political steering group involving politicians from different political parties to provide strategic advice on the development of the scheme.

As well as the initial mobilisation of politicians it will be vital to ensure regular communication to ensure that they remain supporters of the scheme. The development of a trolleybus project is inevitably a long process during which political objectives may change as may politicians themselves.

Business

The main business groups to communicate with include:

- Business federations/umbrella groups
- Businesses located along the trolleybus route
- Businesses who are interested in becoming a supplier to the scheme

The local and regional business community has a powerful voice and can have a strong influence on decision makers. As such it is important to engage with the business community fre-

quently. Business leaders are likely to be interested in the high level benefits of the scheme (particularly the economic benefits) in addition to the construction process and how disruption to local business can be minimised.

It will also be important to communicate with local businesses along the trolleybus routes about any changes to the local road layout or infrastructure that may have an impact on their operation (e.g. loss of car parking, restriction of deliveries).

There will also be a need for engagement with companies who are interested in becoming a supplier to the scheme (e.g. construction companies, vehicle suppliers, operators etc). In line with procurement law this will require a formal market consultation exercise to ensure that communications are carried out within a legal framework.

Transport organisations

Communications with a number of transport organisations will be required including:

- Bus operators
- Other transport operators (e.g. rail/tram/taxi)
- Transport Unions
- Emergency services

It will be important to ensure effective engagement with bus operators already operating services in the city in which the trolleybus system will operate. The level and nature of engagement will depend upon the regulatory framework in place and whether other bus services will be ruining in competition with the trolleybus or fully integrated with it.

Other local transport operators such as rail/taxi/tram operators will also be an important group to engage with. They will require information relating to the future operating proposals and disruption related to the construction process in addition to the general scheme information

General Public

It is essential to engage with the general public who can be divided into a number of categories including:

- General public along the route
- General public not on the route
- Residents groups
- Landowners directly affected by the project

In order to gain high levels of public support for the trolleybus scheme it will be important to ensure that a sufficient amount of information about the scheme is in the public arena and that people feel that they have some form of involvement in the process of developing the scheme. This may mean holding formal public consultation as well as general communications about progress on the development of the trolleybus project.

Whereas general levels of support for the scheme may be high, it is inevitable that those people who live directly along the route will have some concerns about the impact of the scheme on their property and their local area. It will be necessary to directly engage with these people (particularly landowners who will have a direct impact on their property) and seek to address their concerns through the design of the scheme if possible. It will however be important to ensure that the benefits of the scheme are not unacceptably reduced and therefore each concern raised by the public will need to be considered to identify the appropriate response.

Interest Groups

There will be a number of interest groups who will form a view on whether they support the trolleybus scheme. These include:

- Cycling groups
- Environmental groups
- Equality access groups
- Other voluntary groups

Some interest groups will be very well organised and will have the capability to lobby for or against schemes and influence key decision makers. Organisations such as cycling groups and access groups can be a very useful source of information and advice to the project and if communication with these groups is effective, can become powerful supporters of the project.

In some instances it may be useful to establish advice groups (e.g. cycling advice group) that meet with the project developers on a regular basis to review progress on the scheme and provide feedback on behalf of their members which can then be used to enhance the project.

Press and Media

It will be important to develop a strong relationship with the media including:

- Local/regional newspaper's
- Local/regional radio
- Local/regional TV
- Student TV/radio

A proactive approach to engaging with the media will be required to ensure that they have a balanced view of the project and are not unduly influenced by vocal opponents to the scheme. Regular briefings with local journalists will help to ensure that they are aware of the facts and should help to reduce the potential for 'urban legends' to be circulated.

It is also worth investigating the opportunities to circulate information about the scheme through student and university media. For example an article on student radio has the potential to get information to a very large pool of potential supporters for the scheme.

VI-7-3 Key steps

In order to ensure that all communications activities are effective and coordinated it is necessary to develop a Communications Strategy at the outset of the project. This strategy will cover all communications both internal to and external to the project and will need to be regularly reviewed and updated.

The steps involved in creating the Communications Strategy are as follows:

Step 1: Identify the aims and objectives

- What is the purpose of the Communications Strategy? (gain supporters, raise awareness etc.)
- Why is it needed?

Step 2: Identify the Communications Principles

- Inclusivity (how communications will take account of stakeholders and different needs)
- Accessibility - Information will be available in a variety of formats and languages
- Identify roles and responsibilities for delivering/authorising communications

Step 3: Identify the stakeholders

- Who are the internal stakeholders?
- Who are the external stakeholders?

Step 4: Undertake stakeholder analysis

- What is their current view of the project (positive, negative, unknown)
- What is the desired relationship with them (supporter, champion, information provider etc.)
- What are the interfaces for communicating with them? (meetings, exhibitions, direct mail, social media etc.)
- What are the key messages to give to them to achieve the desired relationship?

Step 5: Develop an action plan for each stakeholder

- What communications activities are planned
- Who is responsible for undertaking these activities
- What resources will be required (staff, materials, funding)
- When will they happen

Step 6: Develop an overarching communications action plan

- Brings together all the activities planned into one coordinated programme
- Used for monitoring progress and planning overall resources required

Step 7: Record, Monitor and Report

- Appropriately record all communications with stakeholders
- Monitor the success of communications activities (against budget, programme and objectives)
- Report back on the findings (internal reporting and public reports)

VI-7-4 Tools and Techniques

A range of tools and techniques can be used to communicate and consult with stakeholders and it is likely that different tools will be appropriate for different groups. The stakeholder analysis (Step 4) will determine what type of tools are most appropriate for each stakeholder. The summary below provides an indication of the types of tools that could be used:

- Face to face meetings;
- Briefing sessions and presentations;
- Workshops and seminars involving participation;
- Public exhibitions and 'drop-in' sessions;
- Information dissemination through project website and social media (e.g. Facebook and Twitter);
- Newsletters, leaflets and direct correspondence to external parties;
- Direct emails (email subscription service);
- Questionnaires and surveys;
- Focus groups;
- Media articles, campaigns and initiatives;
- Periodic bulletins and briefings to internal staff;
- Advertising;
- Merchandising.

VII The business case

The implementation of a trolleybus network will require significant funding, and while the process to obtain the required funding may vary from one city to another, it is likely that a full business case study be required. The business case should include an exhaustive feasibility study which itself should include an appraisal of social, economic and environmental impacts, and life cycle costs analysis. Its preparation is likely to be very time consuming and demanding on local expertise. It must be rigorously prepared and planned, and while certain activities can be carried out simultaneously, the business case should be prepared sequentially and include one or more validation milestones.

While there are numerous approaches to prepare the business case, the foregoing will present a method which has the advantage of having been tried and proven.

The business case planning process is, in essence, rather simple. However, as will be described later, carrying it out is an exhaustive process which can become very challenging and demanding. The following are key steps that most organisations will need to address:

- *Identify a **champion**;*
- *Build a **project study team and obtain the financial resources** required;*
- *Carry out a feasibility study and **prepare the business case report**;*
- *Submit the business case report to **city authorities for approval**.*

VII-1 The champion / the promoter

*A great idea is not a great idea until it has been accepted, as a great idea, by a critical mass of influential people. Hence, in a city where there is no trolleybus network, the idea of implementing such a network cannot progress unless a critical mass of city administrators and elected members of a city council are sold to the idea. The project needs a **«champion»** who will become its advocate and sell the project to a critical mass of decision makers.*

The champion needs to know his subject and be totally convinced that the idea he wishes to push forward is the best; he must be recognized as an authority in similar subjects and be respected by his peers. At this point, he wants to sell an idea, not a solution. Because he needs to build a critical mass of supporters for his idea, his initial approaches will likely be one on one with decision makers he knows share similar concerns to his own. Thru these individual meetings, he will gain a better knowledge of the preoccupations and concerns of decision makers

and will be able to refine his arguments and be better prepared to win over those that otherwise would not support him. Once a critical mass of decision makers are on board, the project must be presented to various committees and board meetings whose responsibilities are to validate the initiative, prioritize it amongst organizational projects, assign the leadership of the project study to a city organisation such as the city's Public Transit Agency and appoint a project study promoter from within that organisation. The assigned promoter, if he is not the champion, assumes the role of the champion. He can expect to be regularly solicited to address political and social issues that are raised by administrators, elected officials and the population.

VII-2 The viability check

In cities where a trolleybus network has been operating for years, the network is taken for granted. However, in cities where it does not exist, how does it all start? Does it make sense to even consider it? There are probably as many answers to these questions are there are cities. The recent experience of the city of Montreal in this matter can provide some answers.

It is impossible to know for sure how the idea of implementing a trolleybus network germinated Montreal[18]. A number of factors have likely contributed. For instance in Montreal, residential, commercial and industrial energy requirements are satisfied by hydro-electricity, a clean form of energy. Road vehicles, however, continue to use fossil fuels. Hence, for the city of Montreal to achieve its environmental goal of reducing its GHG emissions by 30 % by 2020, it must address the area of its operations that proportionally generates the most GHG: the fossil fuel consumption of its vehicle fleets.

The Société de transport de Montréal (Montreal Transit Agency), in support of the city's GHG emission reduction goal, adopted an electrification plan which aims, amongst other measures, at the objective that all busses purchased beyond year 2025 will be zero emission busses. A potential step towards that goal could be the implementation of a trolleybus network. However, before a decision could be taken to go ahead with a full feasibility study, the ***promoter*** *carried out a rule of thumb type appraisal to explore the viability of implementing a trolleybus network in Montreal. All Montreal bus lines were screened using three key criteria: a line must have a sig-*

[18] Montreal had a trolleybus network until the early 60s. At that time the trolleybus was vilified and all traces of the network were removed. Many of the arguments against the trolleybus that were formulated then are still conveyed.

nificant ridership, the ridership must be important in both directions and the line must be in operations all day.[19] *Subsequent to that analysis, 15 lines were identified and the service planning experts concluded that it could be viable to implement a trolleybus network. Furthermore, given the specificity of trolleybuses, it chose to plan for a network which would require approximately* ***100 articulated trolleybuses****. The rule of thumb evaluation indicated that it would be advantageous to dedicate a bus depot to trolleybus operations and maintenance, hence concentrating into a single bus depot all required expertise, tooling and special components and parts. The 100 figure represented a critical mass of trolleybuses which would facilitate the upkeep of expertise and on the job training activities.*

VII-3 The project study team and the required financial resources

The implementation of a trolleybus network implies that infrastructures will be introduced in the cityscape, that bus maintenance facilities will need to either be built or adapted or both, that new rolling stock will need to be purchased, that an incommensurable amount of logistical matter will need to be addressed and that a significant change management effort will be required. The effort to assess, qualify and quantify the trolleybus network project will likely be very long and costly. Typically, such a study will require at least one year and cost over 1 million Euros. Hence, the first task that the promoter/champion must carry out is to appraise the extent of the efforts required to build a project study case, obtain the required budget and build a multidisciplinary project study team.

The champion can assume the leadership of the team, or appoint a project manager to lead the team. In any case, the champion will be regularly be solicited to provide directions and establish policies for the team to follow

Typically, the multidisciplinary project study team will be comprised of a leader with expertise in trolleybus operations, and experts in the following fields of expertise (the following list is not exhaustive): trolleybus network design and planning, trolleybus service planning, trolleybus motorisation and construction, trolleybus maintenance, electrical infrastructure design, electrical infra-

[19] In Montreal, the bus lines are interlined which means that a bus can be assigned to several lines successively. The introduction of a trolleybus network, i.e. of buses that cannot be assigned to other bus lines unless it is to another trolleybus line, will have an impact on the efficiency of the interlining process, hence the criteria chosen.

structure maintenance, trolleybus maintenance facility design, trolleybus maintenance facility operations, rules – regulations – social prerogatives, economic and financial analysis, risk management, real-estate appraisal, communications, public affairs and project management."

VII-4 The business case report

The purpose of the business case report is to document the feasibility of the project, and identify, qualify and quantify all logistical, administrative, financial environmental, social and political considerations. At the very least, it should include:

- *A detailed description of the trolleybus network recommended;*
- *A compendium of the results of pertinent studies and analysis; and*
- *Detailed layout plans of the recommended trolleybus network, and of its components.*

VII-5 Preparing the business case report

When the Société de transport de Montréal (Montreal Transit Agency) launched its study to implement a trolleybus network on the Island of Montréal, it chose to contract out to a consulting firm a mandate to accompany its personnel. The scope of the expertise required, and the extent of the effort required were beyond the capabilities of the agency. The firm was selected following an international call for tender. The requirements specified in the tender included:

I The deposit of a detailed work plan;
II The preparation of a compendium of all prescriptive elements such as applicable laws and regulations, a benchmarking report on other trolleybus networks and those under study and trolleybus technologies, and the characterisation of the 15 lines which had been screened by the Montreal Transit Agency ;
III The development and analysis of potential trolleybus network scenarios;
IV A quantitative and qualitative analysis report of the recommended trolleybus network scenario, regarding all logistical, operational, social, political, environmental and financial elements;
V A preliminary and then final «Business case report» for the «Implementation of a trolleybus network».

VII-5-1 The detailed work plan:

- *Identification of the project team and stakeholders*
  - *Definition of roles and responsibilities;*
  - *Project work breakdown structure;*
  - *Responsibility matrix.*

- *Identification of activities and deliverables*
  - *Definition input and output data, including the required formats;*
  - *Identification of those responsible for the production of such data;*
  - *A MS Project schedule of project activities with the critical path.*
- *Definition of working hypotheses*
  - *Formulation and characterization of the working hypotheses;*
  - *Characterization of the consequences should the assumptions prove inaccurate;*
  - *Formulation of mitigation measures.*

VII-5-2 The identification of prescriptive elements, benchmarking and characterisation of the lines

- *A list of standards and regulations pertinent to the implementation of a trolleybus network;*
- *A list of trolleybus types and of their characteristics:*
  - *Relevant criteria for evaluating trolleybuses and their motorization technologies.*
- *A list of electrical power system network technologies and of their characteristics:*
  - *Relevant criteria for evaluating electrical power system network technologies for trolleybuses;*
  - *Types of electrical networks.*
- *A list of the different elements of street furniture inherent to a trolleybus network;*
  - *Relevant criteria for evaluating components of street furniture;*
- *Evaluation of the routes considered for future trolleybus operations;*
  - *An evaluation matrix to classify the various routes considered;*
  - *Results of the analysis and classification of the routes.*

VII-5-3 The development and analysis of potential trolleybus network scenarios

- *Description of several potential trolleybus network scenarios, including and a summary of their operational characteristics;*

- *An argument folder for each scenario developed. This folder should include, but not be limited to:*
  - *Urban planning studies and related studies, along with a public consultation plan ;*
  - *A quantitative and qualitative analysis of the performance features required of the trolleybus ;*
  - *A quantitative and qualitative analysis of the characteristics of the electrical power supply network;*
  - *A quantitative and qualitative analysis of the characteristics of the street furniture;*
  - *A quantitative and qualitative analysis of the requirements to build and implement the scenario ;*
  - *A quantitative and qualitative analysis of the annual requirements to operate the scenario ;*

- *A class D financial evaluation of the scenario (± 30 %);*
- *A NPV financial analysis ;*

- *General design drawings and plans for each scenario, for:*
  - *Street furniture;*
  - *The electrical power supply network;*
  - *End of line trolleybus stations, including parking bays as well as the required infrastructure;*
  - *The trolleybus depot (maintenance, parking and logistics).*

- *A recommendation for the preferred trolleybus network implementation scenario;*

VII-5-4 A quantitative and qualitative description/analysis of the recommended trolleybus network scenario

- *A detailed description of the recommended trolleybus network scenario and a detailed description of its operational characteristics;*
- *A business case folder for the recommended trolleybus network scenario. This folder should include, but not be limited to:*
  - *Urban planning and insertion studies and related studies,*
  - *A quantitative and qualitative analysis of the performance features required of the trolleybus ;*
  - *A quantitative and qualitative analysis of the characteristics of the electrical power supply network;*
  - *A quantitative and qualitative analysis of the characteristics of the street furniture;*
  - *A quantitative and qualitative analysis of the requirements to build and implement the scenario ;*
  - *A quantitative and qualitative analysis of the annual requirements to operate the scenario ;*
  - *A class C financial evaluation of capitalizable and not capitalizable costs centers of the scenario (± 20 %);*
  - *A NPV financial analysis ;*
  - *Detailed functional drawings and plans of the various elements of the recommended network such as:*
  - *The street furniture and bus stops;*
  - *The electrical power network;*
  - *End of line trolleybus stations, including parking bays as well as the required infrastructure;*
  - *The trolleybus depot (maintenance, parking and logistics).*
- *A presentation folder which should include all material that might be required by the project promoter to present the findings of the business case study to various groups of interest. As a minimum, the folder should include dynamic (videos) and static (illustrations) representations of the proposed network, PowerPoint presentations and executive summaries of the various studies.*
- *A sequenced implementation plan of the trolleybus lines, in the event that the implementation of several lines are recommended;*

- *A Sustainability assessment of the implementation of the trolleybus network;*

VII-5-5 The preliminary and then final «Business case report for the implementation of a trolleybus network»

The sum of all activities carried out to prepare the business case are compiled and structured into one report, and an executive summary written. The preliminary version affords the promoter the opportunity to validate the findings, ensure that organizational policies, requirements and standards are satisfied and that political issues are aptly addressed. The final report will stand as the business case report.

VII-5-6 Go/No go milestone

The call for tender identified a «go/no go» milestone upon completion of the 3rd deliverable. The nature and quality of the information, at this stage of the study project provide «class D» data about the trolleybus network project. The precision of that data, which should be within ± 30 %, is sufficient to allow the promoter and decision makers the opportunity to objectively review the trolleybus network findings and, validate that their initial hypothesis and appraisals are still valid and that their objectives are attainable. A «go» at this point implies that the recommended trolleybus network scenario will be detailed and that it will be appraised to a class C (± 20 %) precision. That precision is sufficient, if approval to proceed is given to the project, to initiate the drawings and plans stage of project management.

VII-5-7 The conduct of the study project

The expert firm retained by the Société de transport de Montréal (STM) proposed a project study structure with eight (8) areas of expertise. The STM built its own «shadow» team of experts to ensure that the both the expert firm and the STM could establish a constructive and complimentary work environment. Further, that structure ensures that communications between the expert firm and the STM, in any given field of expertise are facilitated. These fields of expertise are:

- *Trolleybus network planning;*
- *Trolleybus maintenance facility planning;*
- *Electrical network infrastructures planning;*
- *Trolleybus technologies;*

- *Trolleybus operations;*
- *Financial and cost analysis;*
- *Rules, regulations and contextual elements.*

VII-5-8 Benchmarking

The objective of the study project is to identify the streets on which the trolleybuses will run and then fully qualify and quantify the future trolleybus network project… but what step comes first? Why not study what has been done elsewhere to find answers? Hence, several benchmark efforts were launched to identify and document:

- *Trolleybus networks that had been, during the last 10 years or so, extended, built from nothing or terminated. The objective was to learn as much as possible about these networks, the difficulties they encountered and the factors that contributed to their success.*
- *The legal and regulatory articles that would apply to the local implementation of a trolleybus network and the commissioning of trolleybuses for circulation on urban streets;*
- *The characteristics of electrical network infrastructures;*
- *The characteristics of trolleybuses and their modes of motorisation;*
- *The characteristics of both onboard diesel and electrical auxiliary power units.*

VII-5-9 Characterizing potential streets

The objective of this activity is to prepare a decision matrix to evaluate the chosen streets for the ease with which electrical network infrastructures can be implemented and also according to their operational viability to operate trolleybuses. At this stage, the STM had a list of 15 streets/bus lines. It wanted to reduce their numbers to facilitate simulations for the building of trolleybus network scenarios.

Preparing the list of criteria for the matrix is no simple task. For example, the initial list prepared for the Montreal study project contained 43 criteria[20] *which fit into four categories: feasibility of implementation, operational feasibility, urban integration feasibility, and impact on fuel consumption. Upon careful analysis of these criteria and with the expert assistance of the personnel from Lausanne Transport in Switzerland, it was quickly concluded that, to achieve the objective of shortening the list of potential streets/bus lines, only 12 of them needed to be retained. These criteria and their relevant weights are presented below:*

[20] An exhaustive list is presented in annex 1.

- ***Criterion 1*** *– Aerial obstacles with contact lines*
  - *Objectives of the criterion - This criterion is intended to penalize those streets that have several aerial electrical lines crossings which would interfere with the trolleybus aerial contact lines. These lines would likely require to be buried, thus increasing network implementation costs.*
    The weight factor of this criterion is 5%.

- ***Criterion2*** *– Crossings under works of art*
  - *Objectives of the criterion - This criterion is divided into two separate criteria, to highlight the difficulty of implanting electrical equipment to permit passage of the trolleybus.*
    The penalty associated with the first case (clearance ranging from 4.95 m to 4.15 m) relates to the risk associated with atypical power equipment installation under a bridge.
    The penalty associated with the second case (clearance less than 4.15 m) refers to the additional operating costs that the lowering and raising of poles upstream and downstream of these structures would generate, in view of the inability to install aerial contact lines on these very low clearance works of art.
    The weight factor of this criterion is 10 %.

- ***Criterion 3*** *– Crossing over works of art*
  - *Objectives of the criterion - The test serves to highlight the difficulty of implanting electrical equipment on structures whose deck length exceeds 30m. Indeed, it is unlikely that new equipment be installed on these structures to avoid damaging their structural integrity.*
    The weight factor of this criterion is 5 %.

- ***Criterion 4*** *– Geometric complexity*
  - *Objectives of the criterion - This criterion highlights the impact on the landscape and the important capital costs that complex geometries such as sharp bends (45 °turns) and crossing of major intersections (intersections over 30m in length) may generate.*
    The weight factor of this criterion is 10 %.

- ***Criterion 5*** *- AREA OF THE CANOPY*
  - *Objectives of the criterion - The purpose of this criterion is to penalize the streets whose canopy cover would significantly interfere with the aerial contact lines.*
    The weight factor of this criterion is 10 %.

- ***Criterion 6*** *– Patrimonial sectors*
  - *Objectives of the criterion - This criterion assesses the risk associated with the installation of electrical power equipment in a protected area (as defined at article 47.1 of the Cultural Property Act).*
    The weight factor of this criterion is 5 %.

- ***Criterion 7*** *– Number of vacant lots for the installation of electrical sub-stations*
  - *Objectives of the criterion - This test favors streets lined by 150 m2 lots, to facilitate the installation of electrical substations.*
    The weight factor of this criterion is 10 %.

- ***Criterion 8*** *– The density of population affected by the passing of buses*
  - *Objectives of the criterion - The use of this criterion is to quantify the gains relating to atmospheric pollution and noise reduction for local communities.*
    The weight factor of this criterion is 10 %.

- ***Criterion 9*** *– Directional equilibrium ratio*
  - *Objectives of the criterion – This criterion seeks to penalize the streets on which the number of bus departures in each direction are not balanced. Bus lines on these streets are significantly interlined with bus lines on other streets; introducing trolley-buses on these lines would significantly affect the efficiency of the interlining system.*
    The weight factor of this criterion is 10 %.

- ***Criterion 10*** *– Distance to the terminus*
  - *Objectives of the criterion - The criterion relates to the distance between the bus depot and the line's terminus. The shorter is the distance, the better it is for operations.*
    The weight factor of this criterion is 10 %.

- ***Criterion 11*** *– Number of passengers per kilometer*
  - *Objectives of the criterion - Prioritise bus lines with very important ridership. Given the important cost of electrical network infrastructures it was thought advisable to transport a maximum of passengers with the new trolleybus network.*
    The weight factor of this criterion is 5 %.

- ***Criterion 12*** *– Commercial speed*
  - *Objectives of the criterion – Prioritise streets on which circulation is more fluid. Given the important cost of trolleybuses and of their electrical network infrastructure, it was thought advisable to avoid having «brand new» trolleybuses continuously stuck in traffic.*
    The weight factor of this criterion is 15 %.

The criteria listed above are specific to Montreal's environment and have been provided as examples. However, discussions with experts from Lausanne Transport indicate that some of these criteria are universal.

The identification, collection and analysis of the data required to carry out the ordering of the streets/bus lines originally selected, from best suited to worst suited represents a significant effort in coordination and communication. For example, the required data for the Montreal study project had to be obtained from over 20 municipal and public organizations. Once the data is collected and the multicriteria matrix is completed, a sensitivity analysis of the various criteria can be carried out by modifying the assigned weight factors.

VII-5-10 Building trolleybus scenarios

The objective of this activity is to prepare different trolleybus network scenarios. Clear objectives with regards to the operational characteristics and costs of implementation of the trolleybus network must be formulated.

VIII Comparison of financial and economic efficiency between bus and trolleybus systems in Poland

VIII-1 Introduction

Nowadays trolleybus systems aren't as popular in Europe, as they used to be 50 years ago, nevertheless a number of cities run and develop their trolleybus systems. Also some other cities (as for example Leeds) are considering constructing totally new trolleybus networks. On the other hand, closures of the existing lines are also considered, especially in Western Europe.

All this undertakings and decisions raise discussion about the economic efficiency of trolleybus systems. Obviously there is no easy answer what is better – bus or trolleybus. Surely trolleybuses have higher investment and fixed costs of the electricity supply system. On the other hand, trolleybuses offer lower variable costs of energy, as well as some external saving – lower noise emissions and potentially lower CO2 emissions.

We intuitionally feel, that there are some cases when trolleybuses are reasonable, and some cases when they are unfavorable. Surely trolleybuses are more efficient, when:

- there is more traffic – as the fixed costs split into the higher number of passengers;
- zero-emission or low-emission electrical energy is available;
- the electrical energy is cheap, compared with petrol; this should be considered in long term, so forecasts of energy price should be taken into account;
- there is higher willingness-to-pay for lower emissions (especially noise);
- local conditions are favourable, for example by high share of sloping routes;
- there are some sunk costs of infrastructure or vehicles.

Our aim is to provide a model that provides a framework to assess viability of a trolleybus system in given conditions. As the conditions vary by country or city, the model must be easily fitted to the local conditions, so that a user may easily change the input parameters, such as for example unitary costs of a vehicle, energy, network maintenance or capital expenditures.

On the other hand, a model must provide a clear, easy-to-understand output. In our case, we use a concept of break-even point, i.e. the point of balance between making either a profit or a loss, a point when trolleybus is exactly as efficient, as bus system.

As we already mentioned, the biggest difference between buses an trolleybuses from the economic point of view is different cost structure – higher level of fixed costs and lower level of variable costs (this will be proved later in the paper). In such cases, traffic intensity should be the best way to express break-even point.

Therefore, we aim to provide a model, that produces a break-even point for trolleybus system, expressed as minimum traffic intensity, where trolleybus system is not more expensive, than buses, at given assumptions, that are pre-defined in the model, but can be easily change by a user, in order to fit the model to local conditions.

The analysis will be made using two concepts:

- financial analysis – i.e. pure analysis of costs, including maintenance costs and costs of assets;
- economic analysis – i.e. the analysis, when we include also valuation of externalities (such as noise and emission – called also social costs), on the top of financial analysis.

In the following paper we will present:

- in the first chapter – general construction of the model, including location and units of main inputs (that may be re-defined by the user), and some of key calculation methods, that are used in the model (they cannot be easily changed by the user);
- in the second chapter we are going to present and discuss sources of pre-defined inputs of the model; please mind that this inputs may not be relevant to each city, therefore they should be carefully reviewed, before applying the model to a given city.
- in the third chapter we are going to present different outputs of the model, i.e. discuss, how does the break-even point move, when we change some of the assumptions; this will provide us some information, which conditions are favourable for trolleybuses, and which conditions aren't.

This means, that the first two chapters are somehow a ‘user manual’ to the enclosed model, and the third chapter is an attempt to demonstrate some of the possibilities, that the model offers, as well as an attempt to draw some general conclusions.

Obviously, the model itself is an important attachment to the paper, as it enables the user to change the assumptions, and draw conclusions relevant to a given city. We also strongly encourage users to change the assumptions by themselves, as we did in chapter 3.

VIII-2 Basic concept of a model

The model includes six unhidden sheets, as well as a number or hidden sheets that are for calculation purpose only.

Three sheets (1 – 3) contain input data, those are:

1. General parameters (see figure 5.3-1) – including: financial and economic discount rate (r), average speed, number of workdays equivalent per year and share of rides in peak hour;

   - share of rides in peak hour (see ❶) aims to estimate the number of vehicles needed to serve the connection; shall we have lower share of rides in peak hour, we need less vehicles to serve the line, what influences total costs; share of rides in peak hour should be expressed as a network-average quotient of departures in peak hour (understood as an hour with the highest number of departures), to the total number of departures during entire workday;

   - number of workday equivalents per year (see ❷) aims to estimate supply on non-workdays; for example if we assume, that we have 255 (X) workdays and 110 (Y) non-workdays, with 50% (n) daily supply of workdays, we should input X+Y*n = 255+50*50% = 310 workday equivalents / year;

	A	B
1	r - financial	5%
2	r - economic	8%
3	av. speed [km/h]	18
4	share of rides in peak h [%]	10%
5	workdays equiv. / year	295

Figure 8.1.: Sheet 1 - General parameters.

2. environmental costs, which include unitary values for different pollution emissions and noise ((see figure 5.3-2));

   - the model assumes, that there are two sources of energy available – a conventional source that causes emissions and a zero-emission source; we may define both – emission values for conventional energy for both buses and trolleybuses (❶), as well as share of non-emission energy(❷);

	A	B	C	D	E	F	G	H
1								
2								
3	**Emission**	**CO**	**NMHC**	**NOx**	**PM10**	**CO2**		
4	Bus Euro 5 [g/vehkm]	0,040	0,110	2,830	0,030	1400,000		
5	Trolley [g/kWh]	0,086	0,000	1,822	0,220	811,300		
6	Trolley [g/vehkm]	0,163	0,000	3,462	0,418	1541,470		
7								
8	kWh/vehkm	1,9	<- if you want to change this parameter, pls go to financial costs					
9								
10	Value [EUR/g]	0,00001	0,00100	0,00440	0,08931	0,00009		
11								TOTAL
12	Bus Euro 5 [EUR/vehkm]	0,00000	0,00011	0,01245	0,00268	0,12180		0,137042
13	Trolley [EUR/vehkm]	0,00000	0,00000	0,01523	0,03733	0,13411		0,186673
14								
15	Share of no-emission-energy	0%						
16								
17	Noise costs bus [EUR/vehkm]	0,06						
18	Noise costs trolley [EUR/vehkm]	0,012						
19								
20	Total externalities bus [EUR/vehkm]	0,20						
21	Total externalities trolley [EUR/vehkm]	0,20						
22								
23	EUR/PLN	4						
24								
25	Total externalities bus [PLN/vehkm]	0,788						
26	Total externalities trolley [PLN/vehkm]	0,795						
27								

Figure 8.2.: Sheet 2 - Environmental costs assumptions.

3. financial costs (see figure 5.3-3), which include full infrastructure costs (overhead wires construction and substations), full vehicle costs, energy consumption;
   - we also define a number of parameters, referring to the lifetime of assets, such as bus and trolleybus lifetime, as well as residual value of the network, after the 30-years analysis period (we assume, that vehicles are depreciated linearly and may be changed within the analysis period);
   - due to different lifetime of assets, they are considered in a model using linear depreciation, and not as one-off spending;
   - shall you assume, that the infrastructure is already existing and only maintenance is needed, you should input both overhead wires and substations costs (❶) equal 0;

Please mind, that the model contains two factors of energy price dynamics – bus fuel (diesel) price dynamics (❷) and trolleybus fuel (electricity) price dynamics (❸); we assume that the dynamics is equal in time, but different for both energy sources; they should be expressed as annual, real growth of both prices; the model is very sensitive to both of the values.

We assume, there is only one type of buses/trolleybuses at the network, and those are single (12-m) vehicles, as all trolleybuses in Poland. If you want to consider other types of rolling stock, you may change purchase costs for the type you selected (❹). If you consider a mix of different types, you should input weighted average prices.

Please mind, that only grey cells should be edited and contain input variables. White cells contain numbers deriving from other values.

	A	B	C	D
4	Overhead wires [PLN/km]	1 500 000		
5	Substation [PLN]	1 300 000		
6	Substations/km	0,29		
7	Substations [PLN/km]	371 429		
8	Overall construction	1 871 429		
9	Yearly network matainance [PLN/km]	100 000		
10	Network residual value (30 years)	35%		
11				
12	**Vehicles**			
13	Bus - purchase [PLN]	770 000		
14	Trolley - purchase [PLN]	980 000		
15	Bus - lifetime [years]	12		
16	Trolley - lifetime [years]	20		
17	Bus - maintainance [PLN/km]	1,05		
18	Trolley - maintainance [PLN/km]	1,35		
19				
20	**Energy**			
21	Bus - consumption [l/100km]	40		
22	Bus - price of fuel [PLN/l]	4,00	Bus - energy costs [PLN/km]	1,6
23	Bus - real dynamics of energy price [%/year]	4%		
24	Trolley - consumption [kWh/100 km]	190,00	Trolley - energy costs [PLN/km]	0,57
25	Trolley - price of fuel [PLN/kWh]	0,30		
26	Trolley - real dynamics of energy price [%/year]	2%		

Figure 8.3.: Sheet 3 - Financial costs assumptions

The three other sheets (4 – 6) contain output data, presented on graphs for easier interpretation. The graphs change automatically, every time we change our assumptions, therefore it's important to save entire Excel file for each set of assumption, under a new file name.

Before passing to the output data, please mind, that the model omits some costs, that are equal for bus and trolleybus transport, such as for example personal costs. The model basically presents the data for 1 km of two-directions trolleybus line, i.e. all costs are estimated for such section.

The first of the graphs (see figure 7.4.) contains financial analysis output. It shows total discounted costs (infrastructure and vehicle, depreciation and maintenance) of the section, expressed by the formula:

$$FNPV = \sum_{t=0}^{N} \frac{C_t}{(1+r)^t}$$

where:

- t are given time periods (years)
- C_t are costs in a given period (here only 'real', financial costs are considered);
- r is financial discount rate.

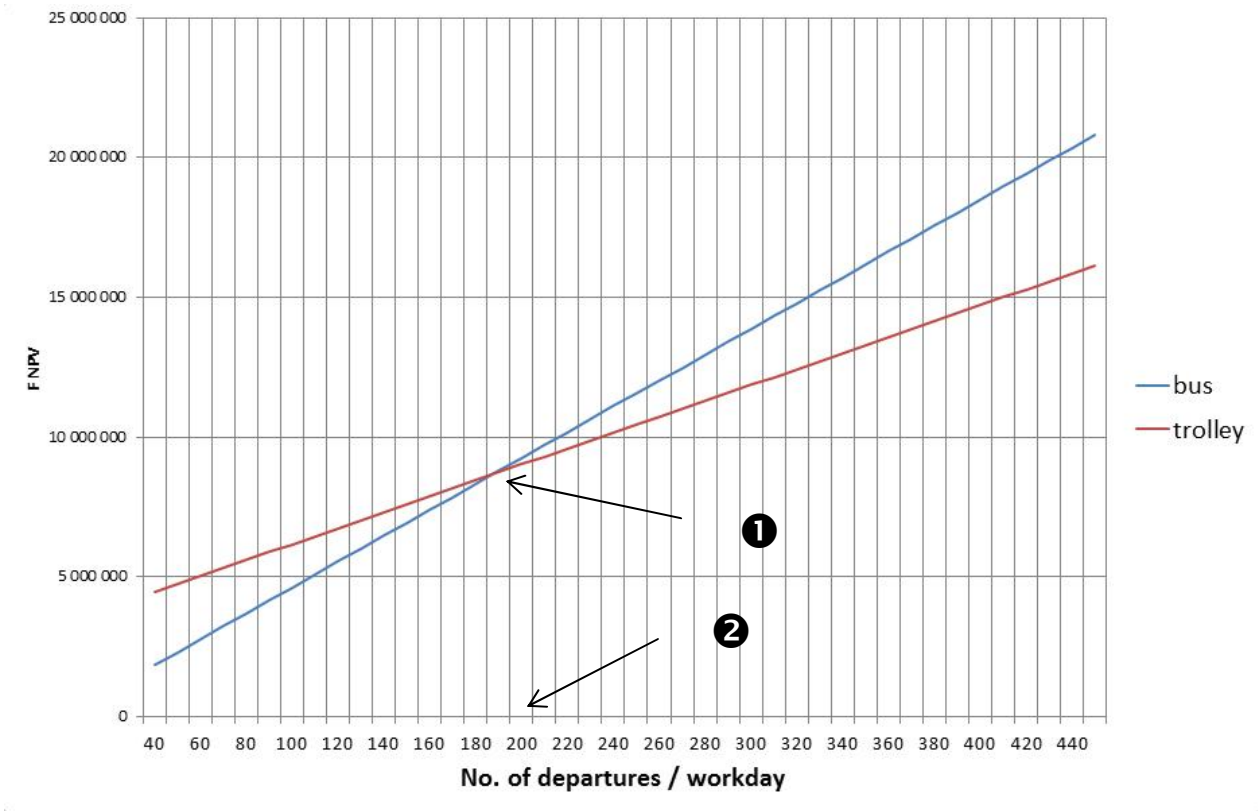


Figure 8.4.: Sheet 4 - Financial analysis output graph

The graph presents FNPV (or total discounted costs – vertical axis) for both bus and trolleybus at different traffic intensity levels (horizontal axis). The level is given as the number of departures over workday at the given section (please mind, that also weekends are considered, due to the "workday equivalent" concept, described earlier).

We can easily spot from the figure, that in case of trolleybuses initial costs (red line) are high and then they rise slower. In case of buses (blue line), they are lower, but raise quicker. The point ❶, when the blue and red lines cross, represents break-even point. The level of traffic at the break-even point can be spotted from the horizontal axis at the point ❷.

The second output graph (see figure 5.3-5) is based on the similar concept, although it takes into account – as we already wrote – not only financial ('real') costs, but also external (social) costs, namely emissions and noise. Also other (separately defined) discount rate is used, what may influence the results.

ENPV is calculated in the similar way, as FNPV, just with the higher range of costs.

Break-even point (❶) and the critical traffic level (❷) can be spotted in the same way, as before.

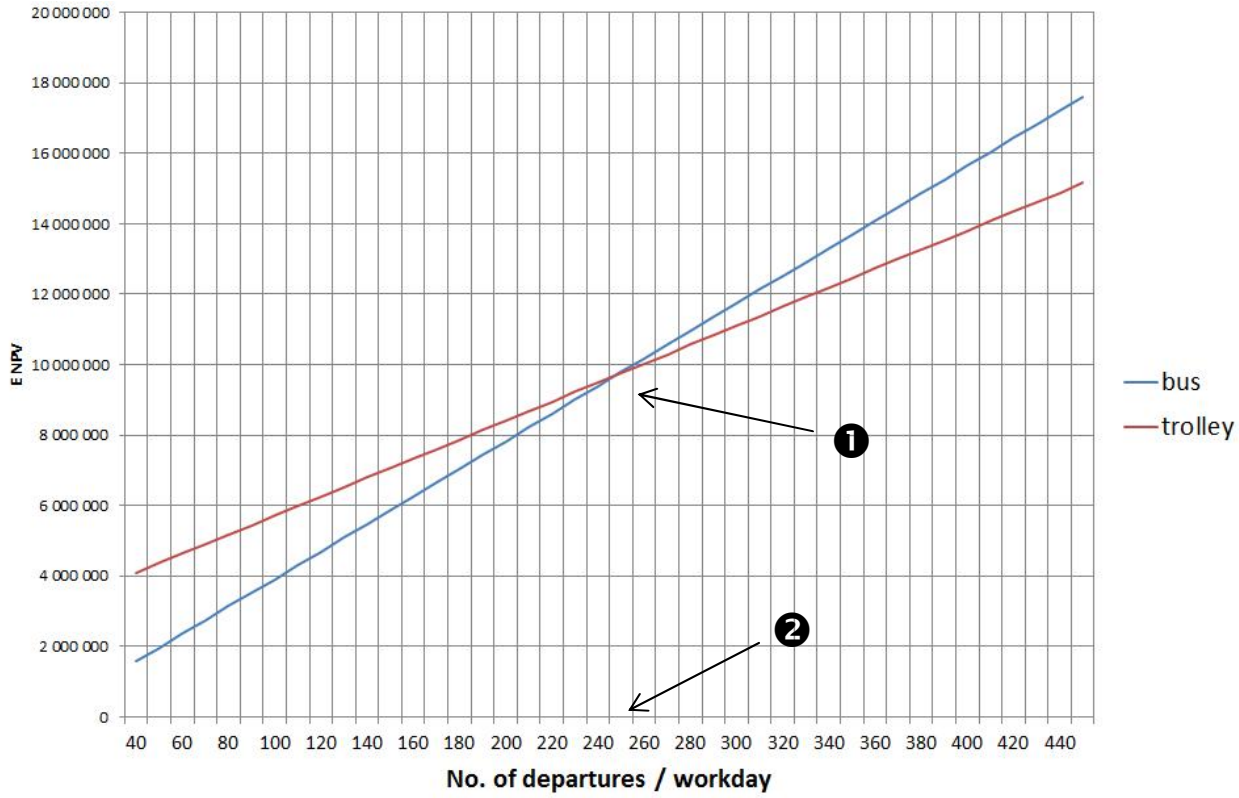


Figure 8.5.: Sheet 5 - Economic analysis output graph

Very useful information is provided by the last output graph, which presents structure of costs in economic analysis (see figure 5.3-6).

This graph shows what are exact social and financial costs of both bus and trolleybus transport at four levels of traffic intensity – 100, 200, 300 and 400 departures / workday. The costs are split into five categories:

- infrastructure (costs of construction and maintenance of electrical energy supply system – for buses it's always equal 0);

- vehicle (costs of vehicle depreciation and maintenance);
- energy (costs of diesel or electricity);
- emission (costs of emission of CO, NHMC, NOx, PM2 and CO2)
- noise.

The two latter – presented on the top of each graph – are externalities, the three other are financial ('real') costs.

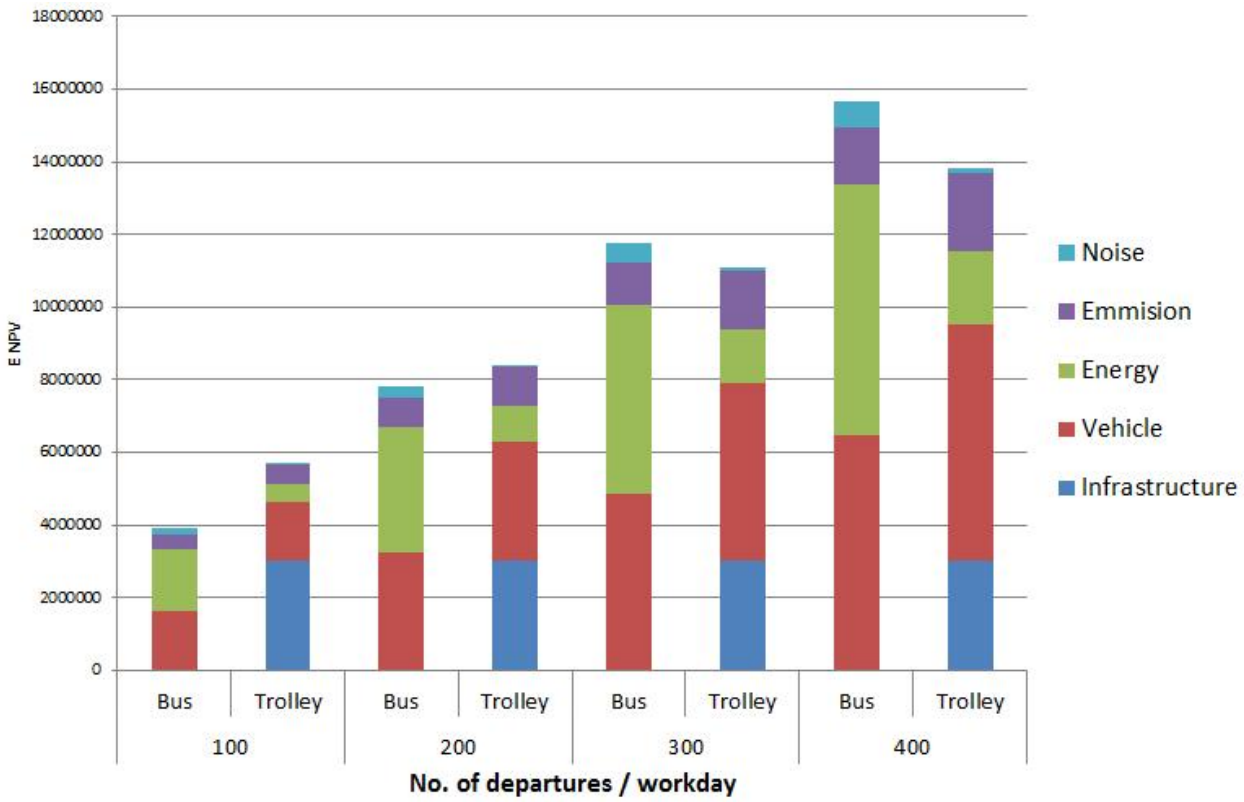


Figure 8.6.: Sheet 6 - Financial and social costs structure

VIII-3 Model assumptions

As we already mentioned, the model is pre-parameterised. We tried to find parameters, that are possibly relevant to the Polish trolleybus systems, but each time you draw conclusion for your city, you should check carefully, if you don't have other, more exactly estimated or locally specific values.

The most important assumptions are:

- assumptions on unitary costs of construction and vehicles;
- assumptions on unitary costs of energy;
- assumptions on emissions and their unitary values.

Assumptions of unitary costs of construction and vehicles are based mostly on the experience of Lublin – Polish city of 350 000 inhabitants, that currently is doubling its trolleybus network from 30 km to 60 km, as well as exchanging the fleet and therefore has good orientation in costs.

Also a feasibility study for the project was prepared.

The **assumptions referring to infrastructure** can be found in table 5.3-1. We assume, that one km of overhead wires costs 1.500.000 PLN (ca. 425.000 €)[21] and a substation costs ca. 1.300.000 PLN (ca. 325.000 €). We need 2,9 substations for each 10 km of two-directions network.

Yearly maintenance of 1 km of the network costs 100.000 PLN/year.

We also assume that after the 30-years operation period, the infrastructure will be worth 35% of its initial value.

Overhead wires [PLN/km]	1 500 000
Substation [PLN]	1 300 000
Substations/km	0,29
Yearly network maintenance [PLN/km]	100 000
Network residual value (30 years)	35%

Table 8.7 .Assumptions on infrastructure costs

[21] Unless we stated otherwise explicitly, „one km of network" means always 1 km of network in two directions. All prices are net prices (without VAT).

The **assumptions referring to vehicle purchase and maintenance costs** can be found in table 5.3-2.

We assume that a trolleybus is ca. 27% more expensive than a bus, but its lifetime is much longer – 20 years, compared with 12 years lifetime of a bus. Nevertheless maintenance of a bus is over 22% cheaper, than in case of a trolleybus, as longer lifetime requires more effort in servicing, especially at the later stage.

Assumed cost of bus purchase is 770 000 PLN (over 190 000€) and of a trolleybus – 980 000 PLN (ca. 245 000€), what is confirmed by a number of public procurement processes in Poland. We would like to remind, that the pre-defined values refer to single (12 m) vehicles.

Bus - purchase [PLN]	770 000
Trolley - purchase [PLN]	980 000
Bus - lifetime [years]	12
Trolley - lifetime [years]	20
Bus - maintenance [PLN/km]	1,05
Trolley - maintenance [PLN/km]	1,35

Table 8.8. Assumptions on vehicle costs

Assumptions on energy cost can be found in table 5.3-3. We assumed, that a bus consumes 40 l of diesel per 100 km and 1 liter of diesel costs 4,00 PLN (1,00 €). Diesel prices are going to rise 4% per annum in real terms.

A trolleybus consumes 190 kWh/100km and each kWh costs 0,30 PLN (0,075€). Electricity prices are going to rise 2% per annum in real terms.

Bus - consumption [l/100km]	40
Bus - price of fuel [PLN/l]	4,00
Bus - real dynamics of energy price [%/year]	4%
Trolley - consumption [kWh/100	190,00

km]	
Trolley - price of fuel [PLN/kWh]	0,30
Trolley - real dynamics of energy price [%/year]	2%

Table 8.9.: Assumptions on energy costs

Assumptions on emissions and noise costs were (see tables 5.3-4 and 5.3-5) were evaluated on a basis of:

- EURO 5 norm for bus emissions;
- a study on emissions of Polish coal power plants, made for the City of Lublin, in case of the trolleybus emissions (we would like to remind, that the third row in table 5.3-3 means emissions of pollutions for conventional energy sources, you may separately define a share of non-emission energy, which can be equal up to 100%);
- EU Directive 2009/33[22] for CO2, NMHC and NOx emissions;
- a study by Mayeres, Ochelen and Proost[23] - for other emissions, not valuated in the directive above (noise, PM10);
- trolleybus noise costs was valuated as 1/6 of bus noise costs, estimated by Mayeres, Ochelen and Proost.

22 Directive 2009/33/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of clean and energy-efficient road transport vehicles, Official Journal of the European Union L 120/5, 15.5.2009

23 I. Mayeres, S. Ochelen and S. Proost, The marginal external costs of urban transport, Transportation Research Part D: Transport and Environment, 1/1996, p. 111-130.

Emission	CO	NMHC	NOx	PM10	CO2
Bus Euro 5 [g/vehkm]	0,040	0,110	2,830	0,030	1400,000
Trolley [g/kWh]	0,086	0,000	1,822	0,220	811,300
Value [EUR/g]	0,00001	0,00100	0,00440	0,08931	0,00009

Table 8.10.: Assumptions on emissions and their valuation

The remaining values were assumed at the level, that is typical for Poland, but may not be relevant for other countries – for example in the United Kingdom, discount rate of 3,5% is currently recommended, as the growth perspectives are lower, and the care for future generations is increasing.

Noise costs bus [EUR/vehkm]	0,06
Noise costs trolley [EUR/vehkm]	0,012
r - financial	5%
r - economic	8%
av. speed [km/h]	18
share of rides in peak h [%]	10%
workdays equiv. / year	295

Table 8.11 Other assumptions

VIII-4 Modelling outcomes

In the following chapter, we are going to discuss modelling outcomes, basing on four different sets of assumptions:

- in section 3.1 we discuss modelling outcomes, basing on the possibly realistic assumption for Poland – i.e. we use assumptions, elaborated in chapter 2, with energy deriving from conventional sources;
- in section 3.2 we discuss a zero-emission scenario, i.e. we assume that all energy for trolleybuses origins from environmental friendly sources – all other assumptions remain unchanged;
- in section 3.3 we discuss a zero-emission scenario with higher diesel prices (5 PLN = 1,25 €/litre, instead of 4 PLN/1 €/litre) and higher diesel prices dynamics (5% p.a. in real terms instead of 4% p.a.) – this makes the model more adequate to Western European conditions;
- in section 3.4 we discuss a scenario, basing on section 3.2, but the infrastructure costs are sunk (i.e. there is an existing infrastructure, that only needs maintenance), we call it 'no-infrastructure-costs-scenario'.

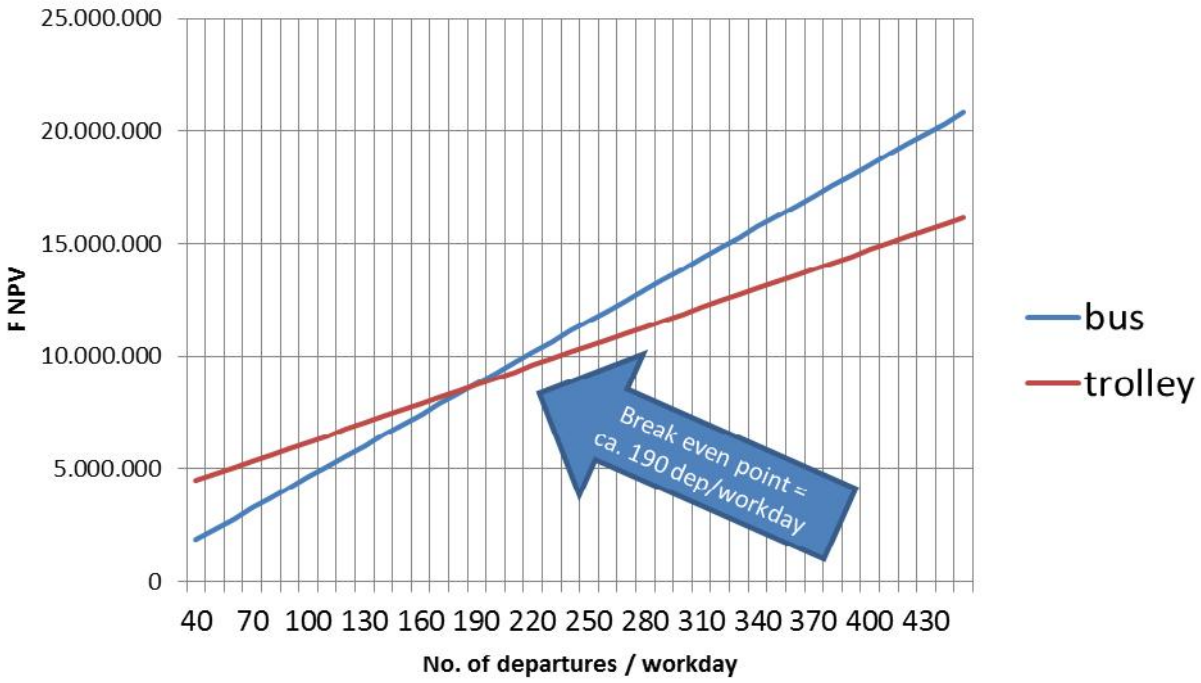
VIII-4-1 Realistic scenario for Poland

The modelling output for Poland is presented on figures 5.3-7 and 5.3-8. We can see that break-even point in financial terms is at ca. 190 departures / workday, what is equal to 5 minutes interval.[24]

This means, that from purely financial point of view, trolleybuses are more efficient then buses, if we introduce them on lines, with interval lower than 5 minutes. The same may apply for a network, when we consider average frequency, weighted by the length of different sections (i.e. some parts – 'branches' – may have 10 minutes interval and other – 'the root' – 3 minutes).

[24] We give exemplary values of intervals, assuming that trolleybuses run from 6 a.m. till 10 p.m. (i.e. 16 hours) in equal interval.

Break-even point in economic terms is surprisingly higher – it equals to 250 departures per day, i.e. ca. 4 minutes interval. This means, that including emissions and noise is – in Polish conditions – unfavorable for trolleybuses.



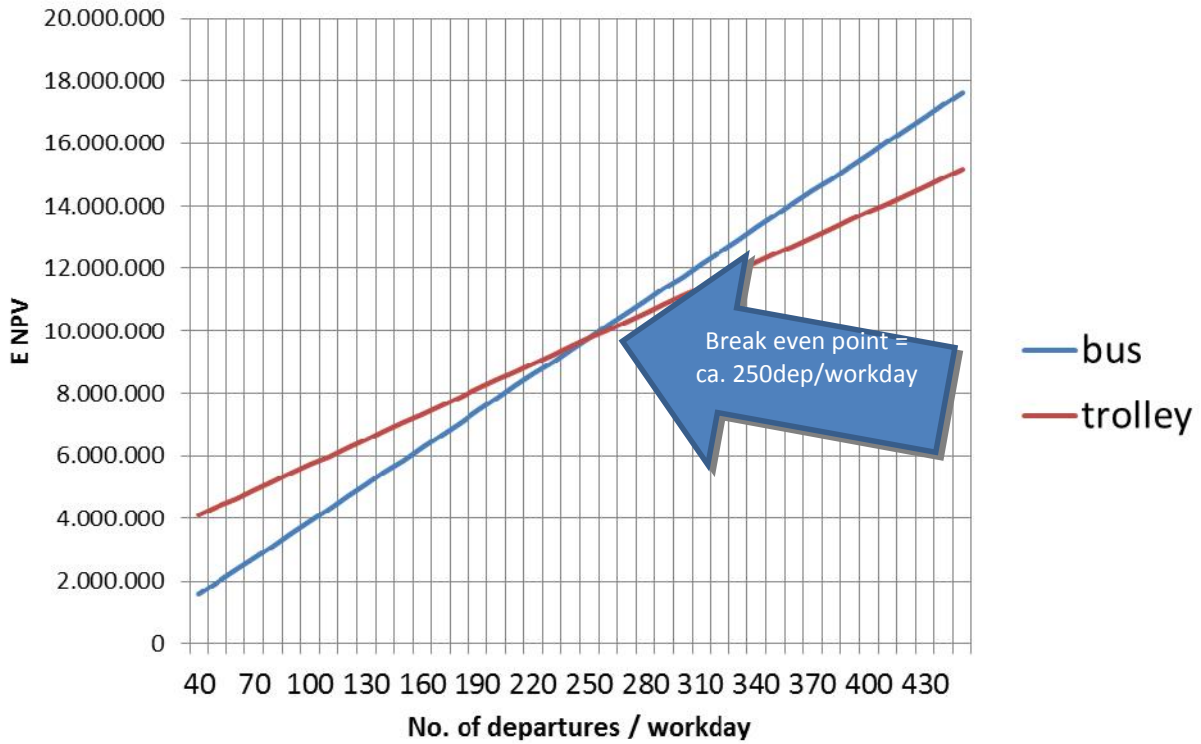


Figure 8.12 and 8.13.: Realistic scenarios for Poland – financial and economic analysis

The reasons for the above mentioned phenomenon may be found on figure 5.3-9. We can easily spot, that:

- externalities (noise and emissions) do not constitute big share of overall costs, and are not favorable for trolleybuses; although trolleybuses generate lower noise costs, in case of coal-powered electric system, emission costs are lower in case of buses and they offset noise savings; please mind, that our model doesn't include different values of emissions in different locations, although this theoretically may be evaluated and may make the results more favorable for trolleybuses;
- the biggest advantages of trolleybuses are low energy costs, and the biggest disadvantage are high infrastructure costs; the energy costs are almost 4 times lower in case of trolleybuses;
- in the long-run vehicle costs are virtually the same for buses and trolleybuses.
- Please mind that we take into account only selected costs. If we take full cost model, energy prices are usually equal to 1/4 of the vehicle kilometer price (excluding infrastructure). This means, that according to the model, when we exclude all infrastructure costs, trolleybuses should be ca. 19% cheaper, than buses in purely financial terms.

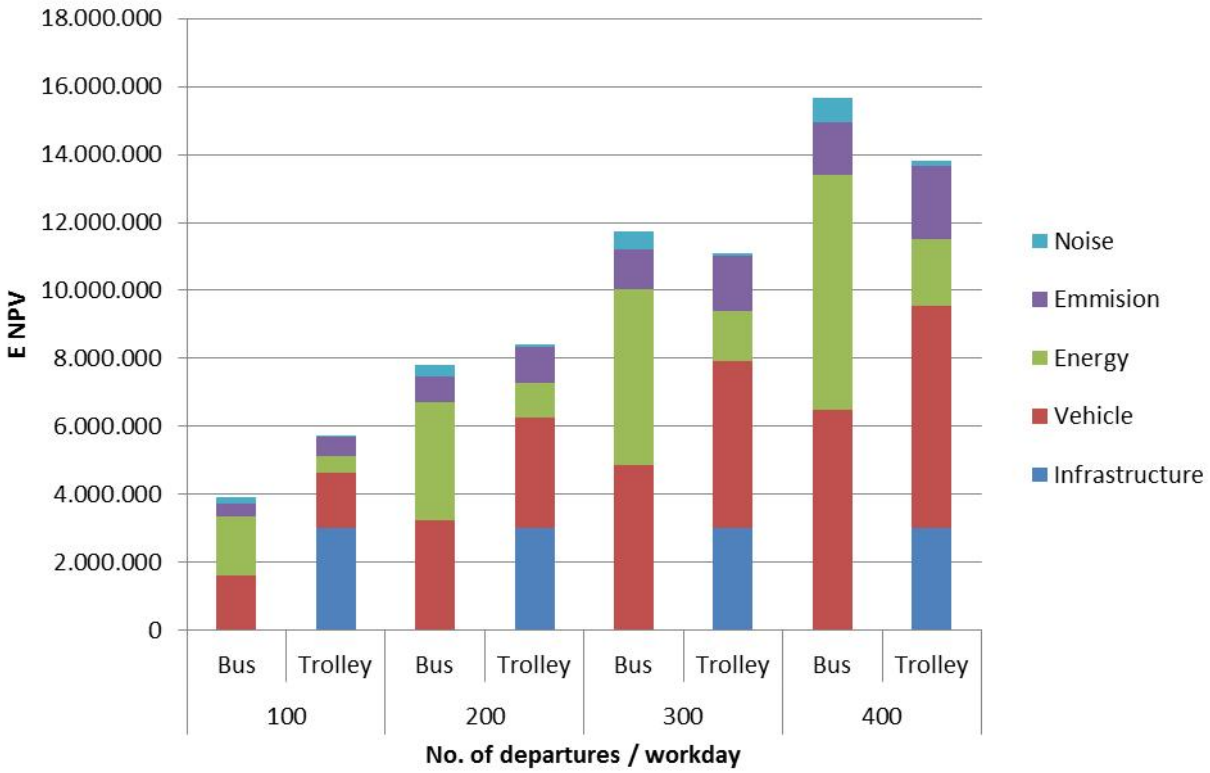


Figure 8.14.: Realistic scenario for Poland - financial and social costs structure

VIII-4-2 Zero-emission energy model for Poland

As we know, that a big disadvantage of trolleybuses is pollution, we repeated the modelling, assuming that energy origins from zero-emission sources.

In this case results of financial analysis remain unchanged (see figure 5.3-10), because emission does not influence financial costs.

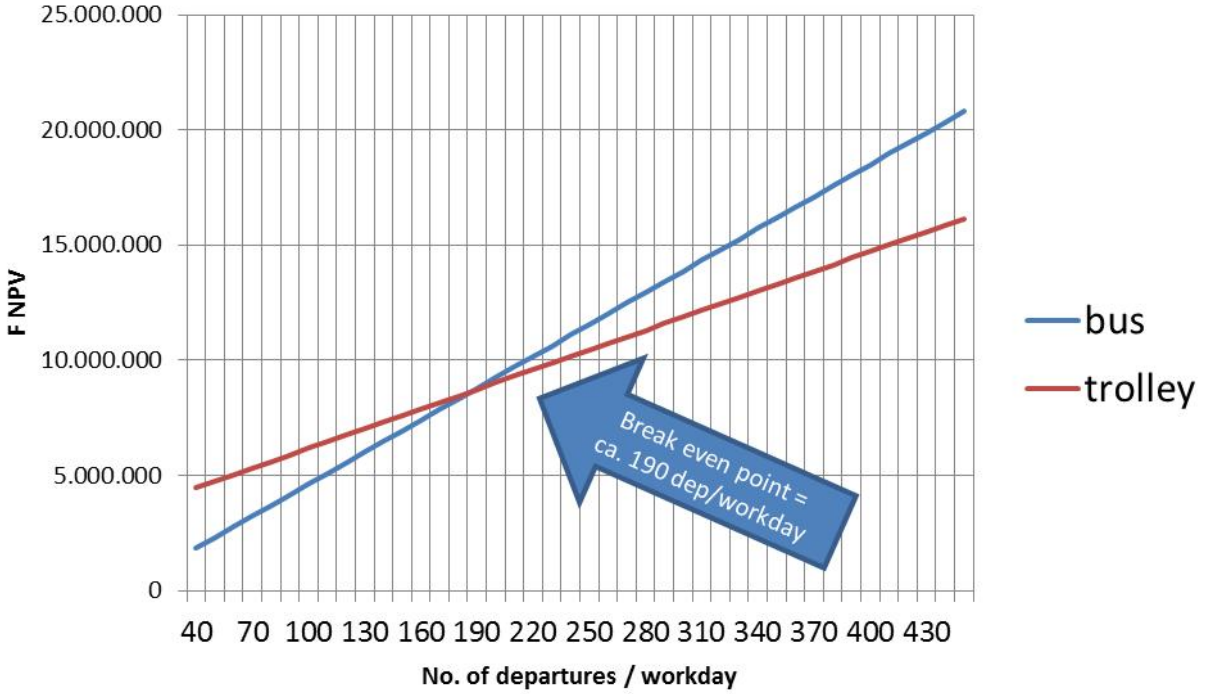


Figure 8.15 Zero-emission energy scenario for Poland - financial analysis

There are, however, substantial changes in economic analysis results. Break-even point moved substantially down and in this case is equal to ca. 170 departures/day what equals to interval of more than 5.5 minutes.

As we can spot at figure 5.3-12, this was caused by 0 emission costs for trolleybuses – in this case only higher infrastructure costs are disadvantageous for this kind of transport.

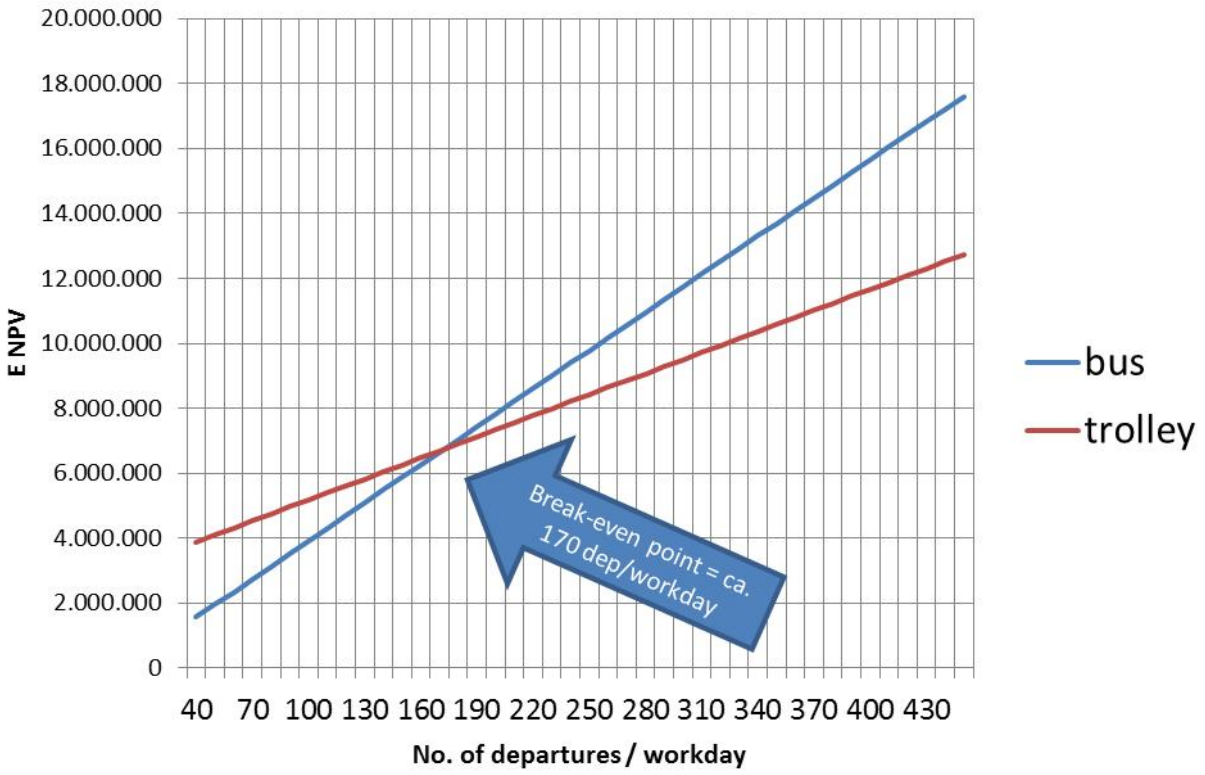


Figure 8.16.: Zero-emission energy scenario for Poland - economic analysis

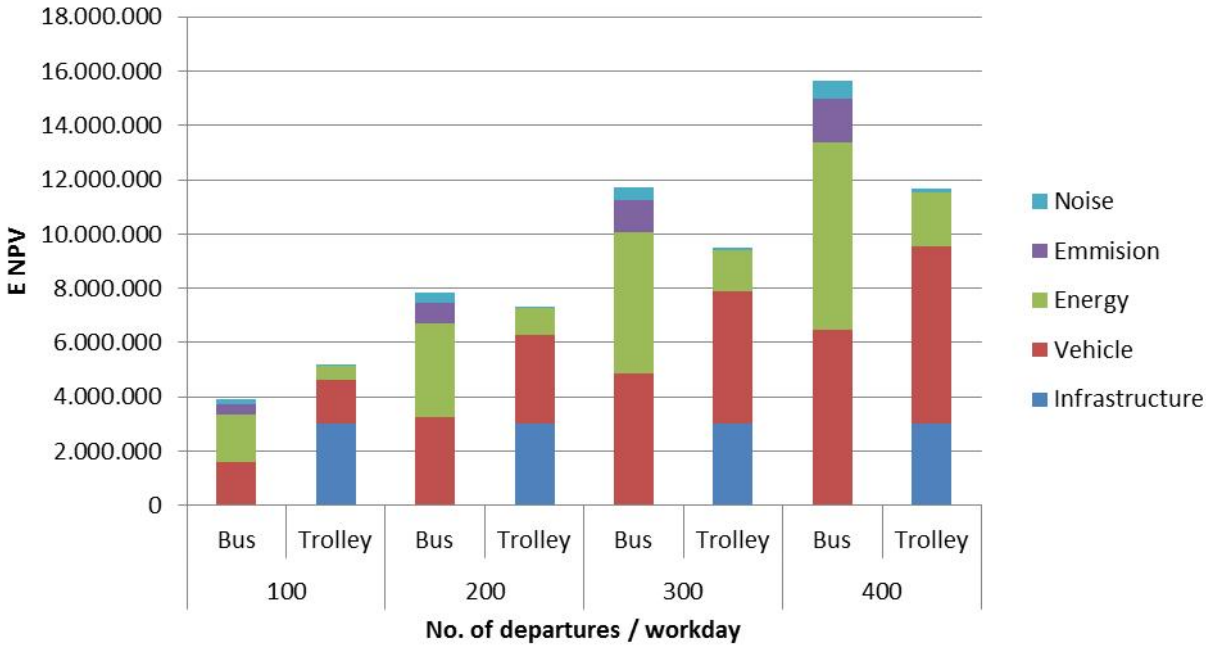


Figure 8.17.: Zero-emission energy scenario for Poland - financial and social costs structure

VIII-4-3 High-diesel prices scenario

In the above scenarios we included relatively low diesel costs of 1€/litre. In most of the Western European countries this price is however higher. In the last scenario, we assume initial net price of diesel of 1,25€ and its higher dynamics.

In this case, the results of financial analysis changed substantially – break-even point is now equal to 120 departures/workday what is equivalent to 8 minutes interval. This means, that the model is very sensitive to diesel prices and their dynamics (see figure 7.18).

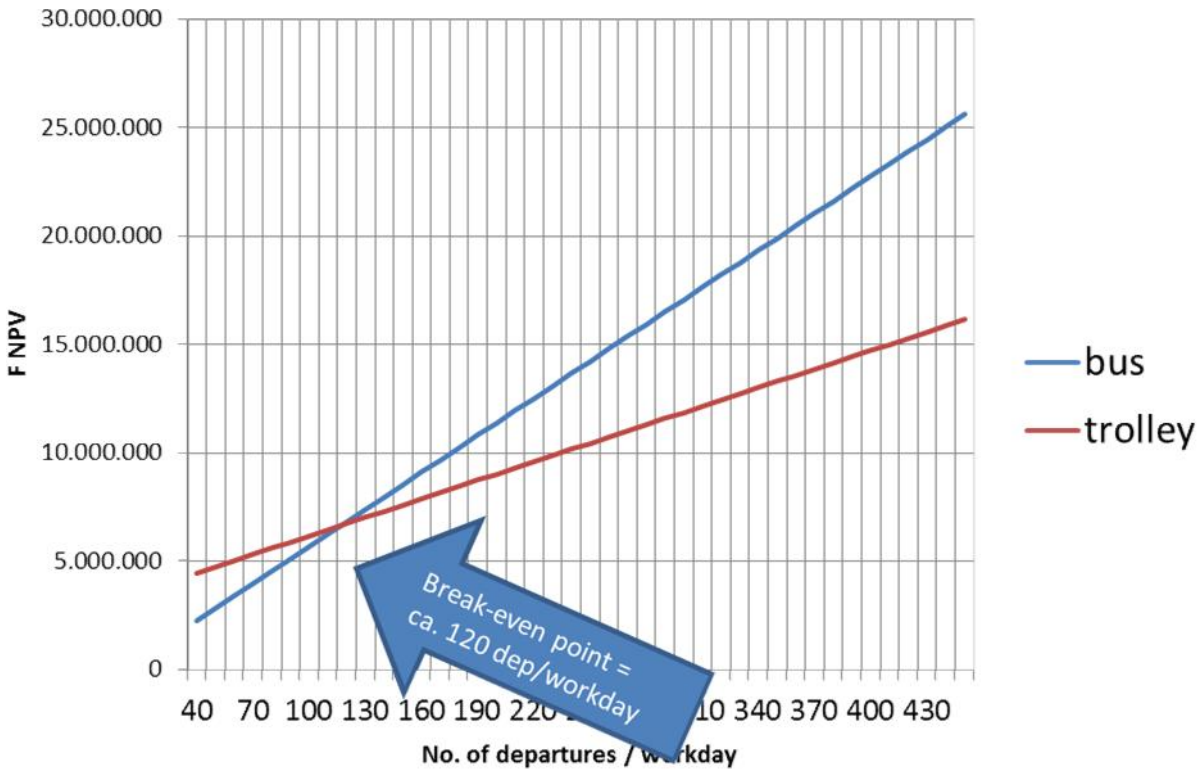


Figure 8.18.: High-diesel prices scenario - financial analysis

When we include also social costs, in this scenario break-even point is a bit lower (ca. 110 departures/workday), but still equals to ca. 8 minutes interval (see figure 7.19).

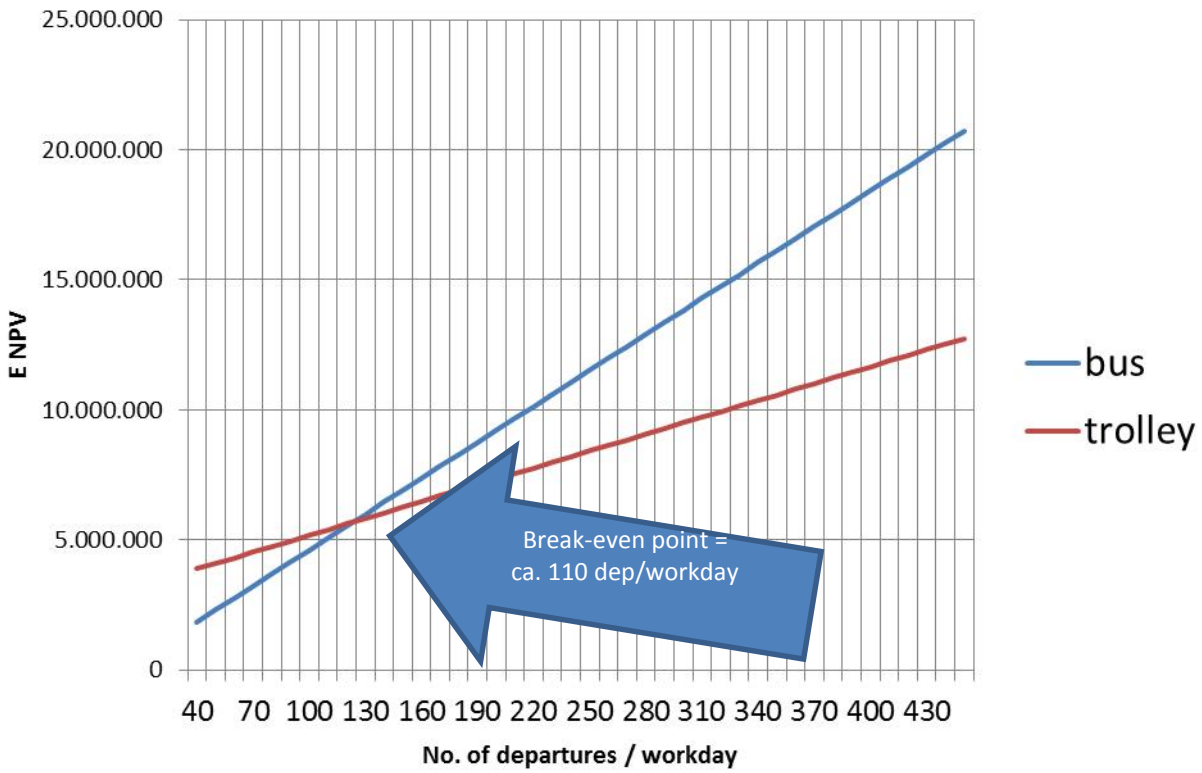


Figure 8.19.: High-diesel prices scenario- economic analysis

When we analyse the full structure of social and financial costs (see figure 5.3-15), we can see, that in this case energy costs of energy in case of buses are ca. 5 times higher, than in case of trolleybuses.

Please mind that the model is very sensitive to diesel prices, but less sensitive to electricity prices, as they have lower share in total cost structure. Electricity prices in most of the countries are also less variable, than diesel prices.

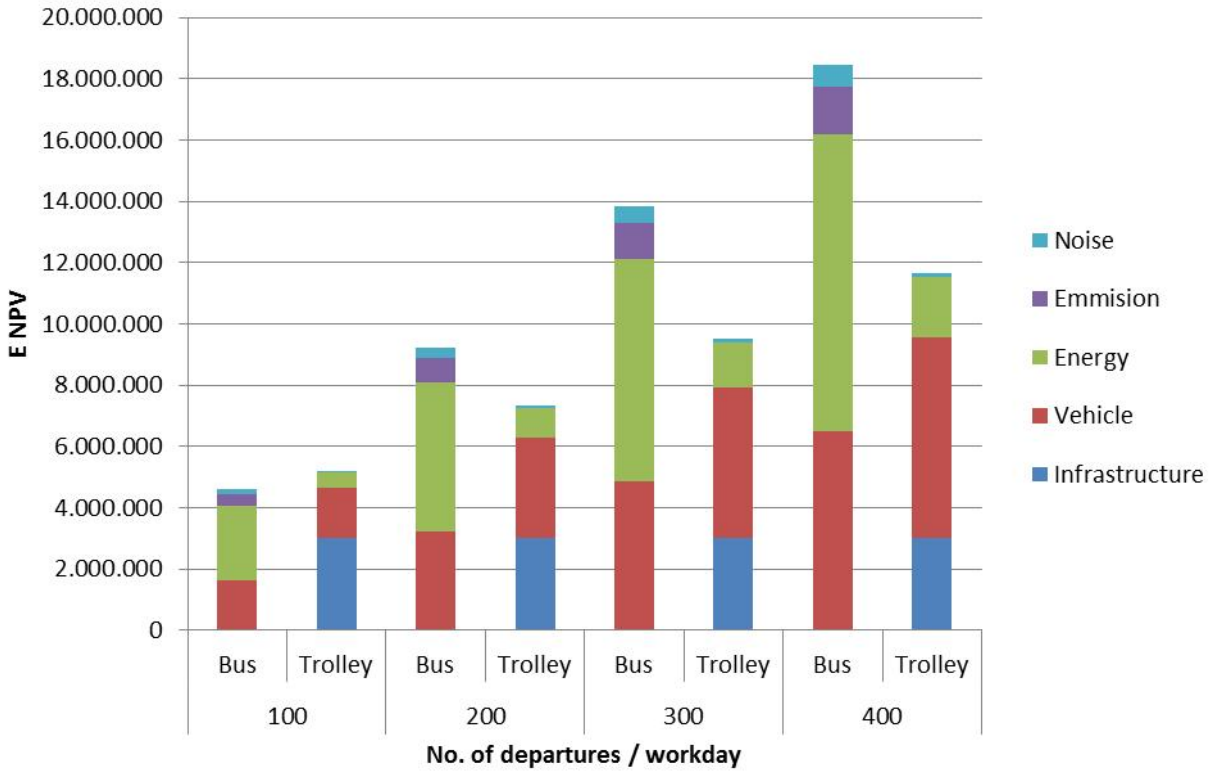


Figure 8.20.: High-diesel prices scenario - financial and social costs structure

VIII-4-4 'No-infrastructure-costs' scenario

In the last scenario, we assume that there is trolleybus infrastructure existing in a city. We return to 'low' diesel prices, but we assume that electric energy origins from zero-emission sources (exactly as in section 3.2).

This may be relevant also for a case, when the infrastructure is financed (or co-financed) from external grants, such as government or European funds.

In this scenario we still include infrastructure maintenance costs.

The results of the modelling show, that in this case break-even point falls even lower, than in section 3.2, down to ca. 95 departures/workday when we consider financial costs (see figure

13), and ca. 80 departures/workday, when we add social costs (see figure 14). This is respectively equivalent to ca. 10 and 12 minutes interval.

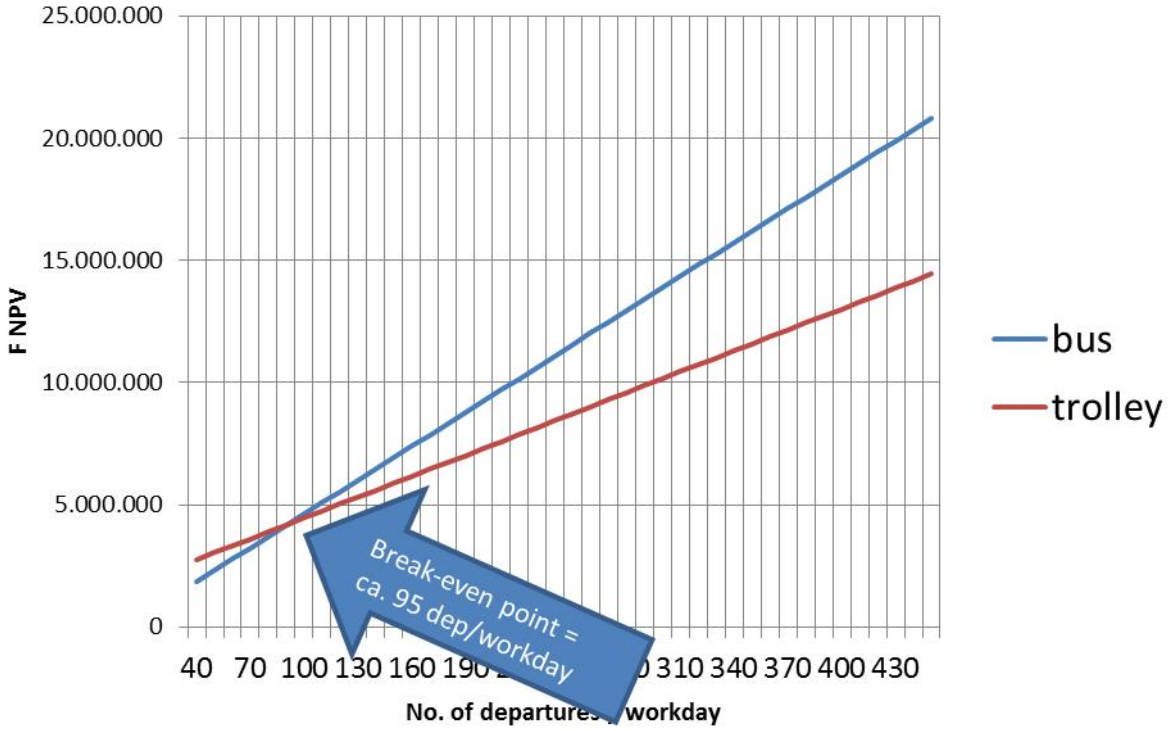


Figure 8.21.: 'No-infrastructure-costs' scenario - financial analysis

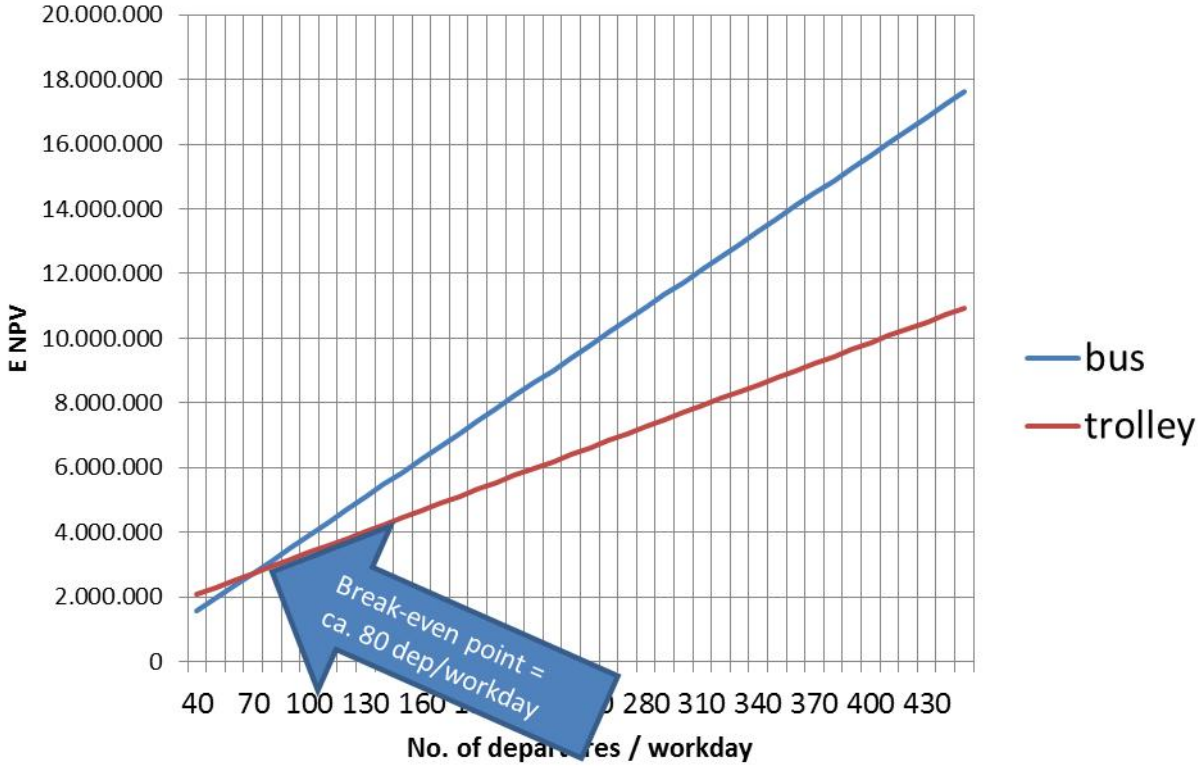


Figure 8.22.: 'No-infrastructure-costs' scenario - economic analysis

In this scenario infrastructure maintenance is still remarkable component of the total cost of trolleybus transport, but its share is smaller, than before (see figure 14). Above the break-even point, vehicle costs are the biggest part of trolleybus total cost.

In case of very strong traffic (300 departures/day), trolleybuses may provide savings over 20% in 'real' costs, and almost 25% including social costs.

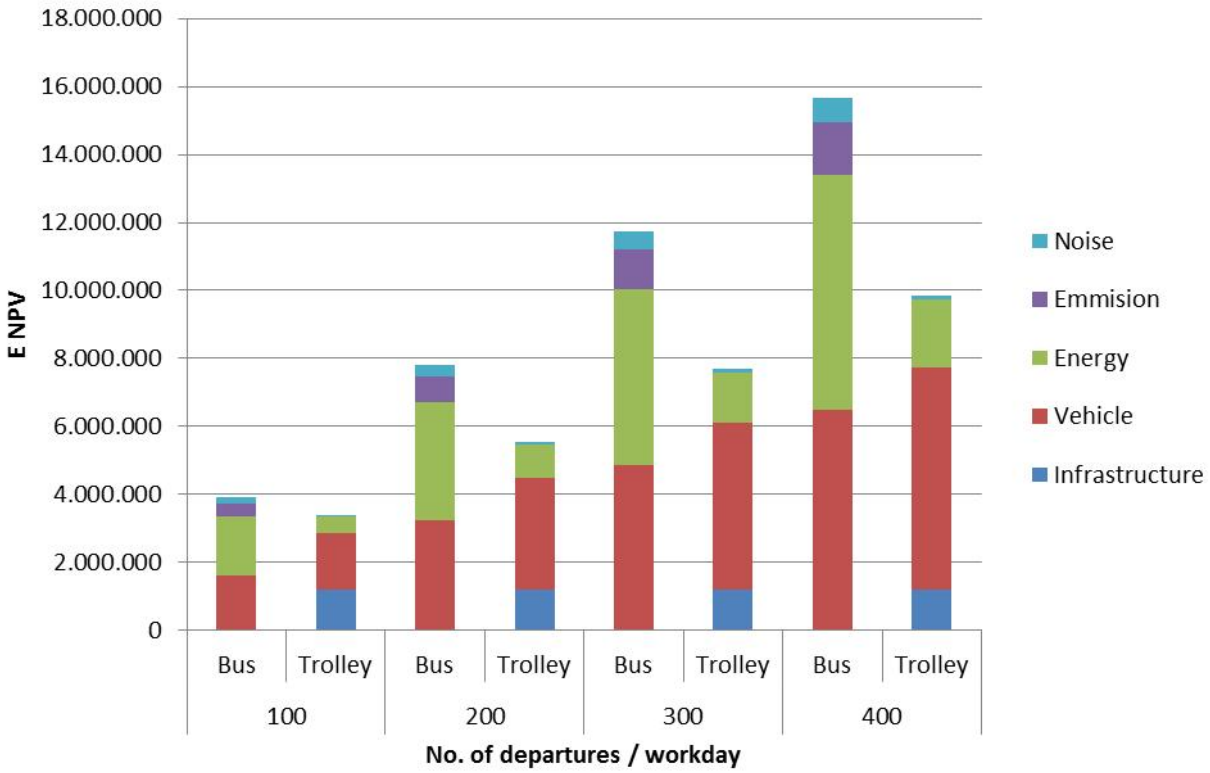


Figure 8.23.: 'No-infrastructure-costs' scenario - financial and social costs structure

VIII-5 Conclusions

Concluding we may state, that in case of newly-built networks we usually should have an average interval of 4-8 minutes during workdays, in order to provide efficiency (see table 5.3-6). If some of the infrastructure or vehicle costs may be considered as sunk or is covered from an external grant, the break-even point is obviously more favourable for trolleybuses and then critical traffic may be below 100 departures/workday (below 10 minutes interval).

	Realistic scenario for Poland	0-Emission Energy scenario	0-Emission Energy, High diesel costs scenario	0-Emission Energy, no infrastructure investment scenario
Financial Break Even [departures/workday] (average interval)	190 (5 min.)	190 (5 min.)	120 (8 min.)	95 (ca. 10 min.)
Economic Break Even [departures/workday] (average interval)	250 (4 min.)	170 (5.5 min.)	110 (8 min.)	80 (ca. 12 min.)

Table 8.24.: Modeling outcomes

The most important factor, influencing cost of trolleybuses are diesel prices, which are very difficult to forecast. According to the scenario, energy prices in case of bus transport are 4-5 times higher, than in case of trolleybuses.

On the other hand, the most important component of trolleybus total cost is infrastructure. This cost is not so variable and may be easily predicted. In many cases it can be also externally co-financed, what constitutes an additional advantage.

Finally, we must stress, that the model can be further improved by adding different values for urban and extra urban emissions. This could additionally decrease break-even point, but the change will be rather slight, as the emission cost is a small component of the total costs.

IX Marketing in developing the image of trolleybus transport

IX-1 The rationale of developing the image of trolleybus transport

In this section characteristics of the city will be presented in relation to marketing philosophy. Subsequently, the focus will be shifted to the role of public transport in the marketing aspect of developing a city's competitive advantage. After the above aspects have been taken into consideration, issues involving development of trolleybus transport's image will be presented.

The image is an element of a brand (including a brand of a city). It has an influence on its perceived value. It is also a central factor in positioning of a product on various markets25. Image management is a continuous process of forming the desired image of a location, audience segmentation and positioning its points of interest for different target groups. These actions form the basis for a wide range of marketing activities aimed at both internal and external users of a city.

In terms of the degree of aggregation, a product in city's marketing may be considered as:

- a "city mega-product";
- a partial product, forming a part of the "city mega-product", which can be considered a separate product in the exchange process.

The concept of a "city mega-product" encompasses both material ingredients, like technical and social infrastructure, residential, commercial and industrial buildings, and non material ingredients, like specific "social atmosphere" (determined by its inhabitants attitudes towards problems and the future), the openness of the city, its image among visitors and locals (related to the level of social optimism and a sense of identification with the place of residence), history and tradition, and natural conditions. The composition of these factors forms the general "image" of the city mega-product, which is a subjective category and varies depending on the type of custom-

25 Doole I., Lowe R.: International Marketing Strategy. Analysis, development and implementation. Published by South-Western Cengage Learnings 2008, 5th edition, p. 283

er, his preferences, the degree of recognition of his needs, and his purchasing power26. Individual components of the product have a relatively varied meaning for specific groups of buyers. An extreme case is that of "niche" cities, offering specialized products that are difficult to create and to imitate, which is a significant entry barrier for potential competitors. Such products are aimed at relatively narrow target groups and refer to higher-order needs and changes in the way of spending free time by rich post-industrial societies.27.

However, for its users, the city mega-product is seen through the lens of partial products, which to them have relatively the greatest importance. The dysfunction of one of them, with others remaining at a relatively high level can be a part of reducing the level of purchaser's satisfaction. An example of this process can be an inefficient transport system, which makes it difficult to access various sub-products located within a city, thus increasing the cost of their acquisition by adding the external costs of transport congestion. This may lead to substantial disparities in the development and perception of the city, expressed by disproportionate urbanization28. In addition, the same partial product can be perceived and evaluated differently depending on who the "users of the city" are. Their large variation makes developing the image of the city a complex and long-term project.

One of the key partial products of the city is public transport, which determines the spatial and temporal availability of the city. Public transport system in a city can be analyzed as:

- an element of the city's transport system (individual and mass transport);
- a significant beneficiary of budget expenditure;
- an instrument of social politics (influencing the availability of urban goods with the help of a tariff-ticketing system);
- an element of municipal services and labor markets;
- a factor in the competitiveness of a city;

26 M. Wołek: Transport publiczny w kształtowaniu wizerunku miasta. [W:] XI Symposium of the Faculty of Management and Computer Modelling. Published by Kielce University of Technology, Kielce 2013 [in print]
27 Wołek M.: Marketingowe kształtowanie przewagi konkurencyjnej miasta. Studium na przykładzie Gdyni. Faculty of Economics of the University of Gdańsk, Sopot 2005. Typescript, p. 167
28 Ibidem, p. 168

- a partial product of the city's marketing concept.

Reasons for considering public transport a partial product which has an impact on developing the image of the city include:

- its impact on the city's development;
- the fact it determines the availability of other partial products;
- its impact on the perception of the city, both by residents and visitors;
- the fact it uses innovative technological and organizational solutions;
- the growth in importance of environmental issues and the related quality of life in the city.

Basic reasons for developing the image of public transport in European cities include:

- the problem of individual automotive transport and the varied speed of its development;
- uncontrolled suburbanization processes („urban sprawl");
- rising passenger expectations for quality of services (a car being a strong alternative),
- public transport development projects, which by themselves may be considered a proof of market attractiveness;
- financial constraints associated with high levels of debt of public budgets;
- a change in passenger structure requiring to seek new forms of marketing communication.

Trolleybus transport is currently not considered a modern and efficient means of urban transport. This is particularly evident among the decision-makers affecting the development of urban transport policy, which does not consider trolleybus transport. There are many reasons

that make up this state of affairs, but they can be systematized according to the following issues:

- economic issues (the barrier of additional costs required for the construction of the overhead wire infrastructure and a higher unit cost compared to a standard bus);
- operational issues (additional costs associated with maintaining the overhead wire infrastructure, the existence of other means of urban transport with electric traction);
- architectural issues (the existence of overhead wire lowers the value of urban space, especially in the city center);
- political issues (previous decisions on developing other means of transport, such as gas or hybrid buses);
- image issues (reluctance to trolleybus transport as a non-modern means of urban transport).

The biggest barrier for exchanging positive experience and promoting development of trolleybus transport is a small number of cities with this mode of transport in relation to its heyday. A large number of cities with trolleybus transportation is outside the European Union, which is an additional difficulty in establishing cooperation and the search for sources of funding. Due to the lack of a large enough market for trolleybuses in the European Union, they are produced in small batches which is reflected by a higher unit price. In addition, trolleybus transport is usually the first victim of savings in a situation of limited resources for proper maintenance of the public transport, leading to a gradual deterioration of the quality of services. This is particularly noticeable in relation to bus transport. As a result, after a period of gradual reduction in the range of trolleybus transport services, a decision is made about its physical liquidation, which tends to be justified by rising fixed costs associated with the need to maintain additional power supply infrastructure and outdated fleet. By analogy to the negative phenomena in urban transport market one can speak of a "spiral decline in trolleybus transport", the essence of which is the reduction of the supply, which leads to the reduction of trolleybus transport attractiveness and an increase in fixed costs. This in turn is a prerequisite for further activities limiting the scope of operation of trolleybus transport and the deterioration of its market position especially in favor of the more flexible (independent of the necessary power supply infrastructure) bus transport.

An image is shaped by traits ("attributes"), whose importance is a matter of a passenger's subjective evaluation. „How a passenger perceives the reality of the situation depends not only on his personal experience of the service but also on associated services, on the information he receives about the service (not only that provided by the company, but also information coming from other sources), on his personal environment, etc.29"

Offering integrated services under a single brand associated with modernity fosters a positive image of public transport. Cain et al. (2009) found that "full bus rapid transit (BRT) is perceived by everyone as superior to regular bus services in the Los Angeles region. In contrast, although other high-quality bus services (non-BRT) also were highly regarded by their users, the general public's view was influenced by the same negative perceptions as regular buses. Hence, modal familiarity led to a higher acceptance of the respective transport mode30".

In identifying barriers to the development of trolleybus transport two main target groups should be taken into account: decision-makers responsible for the development of transport policy (politicians, administration, public transport authorities and transport unions, the management of transport operators) and residents, who are also a diverse group. Diagram showing this state of affairs and the main differences between them are shown on Fig. 1.

29 WG 3 "Market Organisation – Contracts, incentives and monitoring". Background Paper for the fourth WG Meeting in Prague, 9th and 10th October 2008SPUTNIC – Strategies for Public Transport in Cities, p. 13, http://www.sputnicproject.eu

30 M. Scherer, K. Dziekan: Bus or Rail: An Approach to Explain the Psychological Rail Factor. "Journal of Public Transportation" 2012 Vol. 15 Nr 1, p. 77

B2C SCHEME	B2B SCHEME
Dispersed audience	Lower number of customers
Differentiated audience	Closer relations seller-customer
Simple decision making process	Complicated decision making process
Elastic demand	Unelastic demand

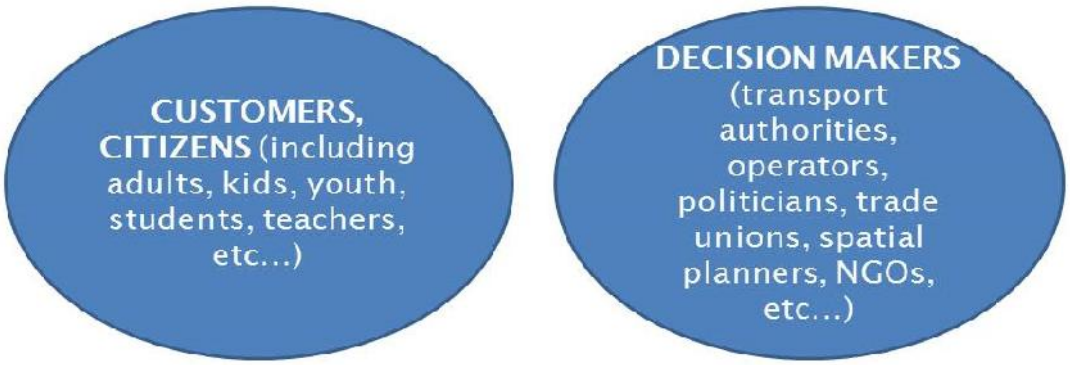


Figure 9.1 Different groups selected for marketing communication (*Source: self-study based on Ph. Kotler, K.L. Keller: Marketing. REBIS Poznań 2012, p. 202-203)*

There are significant differences in transport behavior of the residents and their evaluation of individual means of urban transport. For example, there are differences in the evaluation of quality parameters of bus and trolleybus services in Gdynia (Poland) which are described in chapter 3.4.

"It is important to understand needs and desires of people who have different motivations affected by different factors". E. Venezia states that "there is a general idea among non-users that public services are badly organized and not adequate to their needs. In fact, it may be that public transport is better than what they think, but they simply don't know anything about it or they have a distorted idea of it31". Based on data gathered in marketing research conducted by Public Transport Authority in Gdynia and then processed in the framework of TROLLEY project, it

31 E. Venezia: Sustainability in Cities: Greater Responsibility and Efficiency. [In:] Urban Sustainable Mobility. Ed. By E. Venezia. FrancoAngeli, Milano 2011, p. 101

can be said that how often people travel by public transport affects the semantic differential of transportation less than the frequency of traveling by car. Differentials created by regular or users of public transport or its frequent users, who travel by car and public transport in equal shares, are convergent, while those created by inhabitants traveling mostly by car and always by car are significantly different.[32] This means that regular users of trolleybus transport determine its image on the basis of their own experiences, while sporadic users - on the basis of ideas and fragmentary opinions he had heard from other people. This is an indirect confirmation of the previously cited Author's thesis and points to the need for various promotional activities depending on a number of factors that determine the communication behavior of residents.

Trolleybuses are a mature means of public transport. Availability of modern technologies improving its efficiency, growing independence from the network and ecological advantages are obvious among decision-makers and majority of passengers in cities operating this mode of public transport.

However, in some cases the advantages of the trolleybus transport can be viewed negatively, i.e. long life-cycle of electric vehicles might be regarded as an disadvantage in comparison to a standard diesel bus. Longer periods of exploitation, for example, results in lower modernity of trolleybus vehicles when compared to bus fleet which is renewed more frequently.

[32] K. Hebel, M. Wołek, O. Wyszomirski: WP5: Improved Image and Patronage. Output 5.1.4 - Survey on Perception of Trolleybuses. Final Report ver. 3.0. TROLLEY Project, Central Eastern Europe Programme, December 2012, p. 53-54

Strengths	Weaknesses
• Mature and tested technology. • Reliability. • Well known costs of exploitation (also in longer period). • Stable energy prices. • Lack of local emissions. • Partial independence of the network. • Long life-cycle. • Better performance in hilly terrain. • Energetic efficiency. • Strong market position in a few European countries.	• Dependence on the network infrastructure, which is regarded as factor decreasing quality of urban space. • Higher costs of acquisition of rolling stock. • Rather weak image as "out-of-date" mode of transport. • High costs of introduction due to needed infrastructure investment.
Opportunities	**Threats**
High capacity for implementation of innovative solutions (supercaps, batteries, etc…). Growing importance of ecological issues. Unstable oil market. Development of batteries and other electric energy storage technologies. Well fit into smart city concept (integrating transport, energy and ICT issues). Development of electric vehicles resulting in lower prices of components and spare parts.	Stigma of "market niche". Growth of electricity prices. Further development of hybrid bus treated as a substitute for trolleybus. Inappropriate comparison to tram system.

Tab. 9.2 SWOT analysis of trolleybus transport: a promotional perspective *(Source: self-study)*

Some weaknesses and threats presented in Tab. 8.2 are strictly a matter of image and are based on well-established stereotypes, especially in cities that do not have trolleybus transpor-

tation. This is why the framework of TROLLEY project includes activities aimed to identify interesting measures of promoting trolleybus transport, taking into account local conditions and low financing costs needed for the implementation of said measures.

Developing the image of a city is a long-term process. It is also difficult to measure. It has a significant impact on the ability of the city to compete. Public transport is one of the key components of a city mega-product and can significantly determine its image, especially among its residents, due to the fact it facilitates access to other partial products.

In conclusion, the development of the image of trolleybus transport is essential because of:

- the varied meaning of the image of trolleybus transport for a comprehensive (holistic) image of public transport;
- the fact that in some cases trolleybus transport acts as a leading factor in determining the image of a given city's transport system;
- ecological values of trolleybus transport;
- the negative stereotype of trolleybus transport among decision makers and residents of cities which do not operate trolleybuses.

IX-2 The desired scope of marketing research in trolleybus transport

The specificity of public transport determines the extent of the market research carried out in relation to the trolleybus transport subsystem.

In broad terms, marketing research in urban transport includes:

- the behavior and communication preferences of residents, their evolution and trends;
- the alignment degree of the service properties (parameters) to the residents' communication preferences;
- the residents' attitude towards the service properties (parameters);
- the degree of satisfying the needs and demand;
- decisions made by the residents in relation to transport services;
- factors determining the choice of transport services.

The subject of research of transport needs and demand is their size in relation to spatial relationships, goals and time periods (day of week and time) for which they are reported. The subject matter are residents and passengers of public transport, while the spatial scope of research often involves:

- stops and vehicles;
- households;
- workplaces;
- ticket offices.

In the framework of demand research one can specify not only the number of passengers using public trolleybus, but also their structure on the basis of the ticket they use and their authorization for a discounted or free ride. This allows not only to study the economic and financial performance of individual trolleybus lines, or even courses, but also allows to identify passenger segments distinguished on the basis of an adopted criterion.

The scope of transport behavior research usually concerns:

- the implementation of urban travel;
- the modal split;
- commuting to work and education;
- the structure of transport on an average day;
- the hierarchy of importance of transport demands;
- assessment of public transport, particularly from the perspective of meeting the transport demands;
- factors determining the choice of how to implement urban travel.

The primary purpose of researching the residents' transport behavior is developing a strategy of shaping the market in order to keep the existing and attract new passengers. To develop such a strategy it is necessary to identify the modal split between public and individual transport and the factors determining it. Complementary research is recommended to ascertain the potential reaction of residents to changes in the transport offer mirroring their preferences.

Researching transport behavior enables to determine the modal split between different types of transport. It allows to identify trolleybus transport's share of the market, measured by the number of trips made by residents within a certain period of time (usually a single day). For example, the results of a research performed in Gdynia in the year 2010 r. led to the conclusion that with the 30% share in transport measured by the number of vehicle-kilometers trolleybuses carry over 32% of passengers of public transport organized by Zarząd Komunikacji Miejskiej w Gdyni.

The share of trolleybus transport may also be determined in relation to the most important destinations, such as commuting to work and education. This allows appropriate adjustment of the transport offer in order to meet basic transportation needs. It is recommended to study the participation of trolleybus transport at particular times of day (hours) in order to identify the share of this means of transport in the implementation of urban travel for those periods of time. This ascertains the advisability of introducing certain changes to the schedule, adjusting the supply to the demand and to the adopted rules for determining the modal split between different types of transport.

While researching transport behavior one can also explore specific reasons (other than those arising from trolleybus routes and hours of operation) for choosing trolleybuses or sacrificing trolleybus travel in favor of other types of transport.

It is recommended to determine the order of importance of transport demands for trolleybus transport. As part of a comprehensive marketing research the order of importance of transport demands is most commonly aimed at public transport as an integrated form of services, but in appropriate cases, trolleybus transport can be treated as a separate segment of supply. Complementary to the research of transport demands, a research should be conducted with the aim of examining the degree of compliance with the various demands by trolleybus transport. The results achieved for the cross-section of the various segments of the supply (separately for tram, bus, trolleybus and other transport) allow for comparison and possibly finding significant differences in the perception of different subsystems' transport offer, as well as the perceived degree of integration of public transport.

In the course of research in transport preferences it is advisable to determine the required level of travel comfort. The target level can be determined by the desired access to a seated position and vehicle equipment (air conditioning, voice announcements of stops, electronic information about the vehicle's route, etc.). The passenger-required comfort raising equipment is important

only to a certain degree: it raises the costs of purchase and operation of vehicles, and it is not always required by the passenger and does not have to influence the choice of public transport in the implementation of urban travel. Results of marketing research in various cities in Poland indicate, that the most important demands recognized by the passengers are punctuality, frequency, immediacy of connections and availability. Vehicle equipment was lower in the ranking, among less essential demands. On the other hand, urban transport is increasingly being forced to compete with private cars especially at the level of the so called enhanced product, or services that meet not only the basic needs, but also include additional equipment, ensuring high comfort of travel.

In addition to research related to the offer of trolleybus transport service, its degree of adaptation to the needs of residents, the order of importance of transport demands, their degree of compliance and the image of trolleybus, research can be performed to assess the functionality and ergonomics of solutions adopted in the design of trolleybuses by manufacturers. Research can be carried out in relation to vehicles provided by manufacturers for the tests in the city's typical operating conditions. From the passenger's point of view the research can concern:

- the seating arrangement;
- the ease of entry and exit;
- interior aesthetics;
- the comfort of travel;
- efficiency of ventilation, heating and air conditioning;
- noise, vibration and shock levels.

The research in the group of drivers may concern:

- driving ergonomics;
- ventilation, heating and air conditioning efficiency;
- controls distribution functionality.

Although this research is conducted by vehicle manufacturers, and the solutions are the result of many years of experience, certain solutions may be modified based on the results of market research (e.g. the seating arrangement), and the required changes can be included in the terms of the tender specifications.

IX-3 Instruments of developing the image of trolleybus transport

Case study analysis was used in order to identify and select promotional activities for trolleybus transport. The literature defines Case Study as […] a one which investigates the problem to answer specific research questions and which seeks a range of different kinds of evidence33". Another description of case study analysis states that it is „an inquiry that focuses on describing, understanding, predicting and/or controlling the individual (i.e. process, person, household, organization, group, industry…)34" or an „empirical inquiry that investigates a contemporary phenomenon within its real life context, especially when the boundaries between phenomenon and context are not clearly evident35".

Case study research is a kind of intensive research. Opposite to survey, which is an extensive research made between units of observation, case study is a research made "within the unit of observation36". Despite this recognition, collection of selected case studies made it possible (to some degree) to compare them and to draw conclusions on the basis of „cross-case analysis" which is about the „guts" of the case, seen in its wholeness. There is a platform, though, on which sets of wholeness are compared37". In the case of this study, promotional activities related to trolleybus transport were the "platform" for comparative analysis.

The advantage of case studies in the context of research in the framework of the TROLLEY project was the fact that they are:

- far from theory;
- a living example - possible to visit, present and follow;
- very attractive when communicating with decision-makers, politicians, media and general audience;
- possible to complexly describe while using real data.

33 P. Gillham: Case Study Research Methods. Published by Continuum, London 2000, p. 1
34 A.G. Woodside: Case Study Research: Theory, Methods, Practice. Emerald, Bingley 2010, p. 1
35 R.K. Yin: Applications of Case Study Research. SAGE, Los Angeles-London 2012, p. 4
36 P. Swanborn: Case Study Research. What, why and how? SAGE Publ., London & Thousand Oaks 2010, p. 5
37 G. Thomas: How to do Your Case Study: A Guide for Students & Researchers. SAGE, Los Angeles – London - New Delhi – Singapore - Washington DC 2011, p. 141

Basic data on trolleybus transport systems in urban areas, which were identified in the case studies, are presented in Table 1. The analysis concerned nine European cities from seven countries. The largest of the presented trolleybus transport systems is Vilnius (Lithuania), while Landskrona (Sweden) is the smallest, both in terms of the number of operating trolleybuses and operational. One of the cities, Lviv (Ukraine), also uses tram transport. while two cities, Salzburg (Austria) and Gdynia (Poland), also make use of the railway.

The scope and structure of promotional activities undertaken in the analyzed cases were dependent on

- isolating specific target group for a broader operator/transport organizer marketing strategy or for an urban development strategy;
- the stage of development of trolleybus transport (e.g. celebrating round anniversaries in Salzburg, the need to emphasize various advantages of trolleybuses in order to inform the general community of Landskrona during the first period of its operation);
- implementation of specific projects of modernization and development of trolleybus transport (e.g. the introduction of new vehicles in Gdynia and Parma, plans associated with the introduction of trolleybus transport in Leeds, fleet refurbishment as an opportunity to organize an "open farewell" to old vehicles in Eberswalde);
- other celebrations and events (e.g. European Week of Sustainable Mobility, European Trolleybus Day, conferences etc.);
- educational activities usually targeted to strictly isolated target groups (like Gdynia).

Table 8.3 shows the main messages in developing the image of trolleybus transport in selected European cities.

One of the most important promotional messages related to trolleybus transport were its ecological values (among others: Eberswalde, Landskrona, Vilnius, Solingen). In some cases, the fact that the trolleybus operator contracted electricity supply from renewable sources, was in itself an attractive promotional message, which fit really well in the ecological topic (Landskrona, Eberswalde, Solingen). Moreover, in some of the cities, trolleybus transport uses associations with reliability and high service frequency, resulting from the spatial technology of trolleybus lines (like Landskrona).

City	Main message	Tools/Themes
Eberswalde	eco-friendliness	100% of non-emission energy
Gdynia	innovative system open for further development	Education of citizens
Landskrona	eco-friendliness	"humanization" of each vehicle by giving him female names starting with "El" (like "electric")
Lviv	eco-friendliness	Education of employees and passengers
Parma	Modernity	Integrated promotional toolbox to rebrand trolleybuses
Salzburg	Most comfortable	
Solingen	eco-friendliness	100% of non-emission energy
Vilnius	eco-friendlines	

Table 9.3.: Key messages in developing the image of trolleybus transport in selected European cities *Source: self-study*

Table 2 presents in a synthetic form the scope and object of actions aimed at developing the image of trolleybus transport in selected European cities. The most widely used instrument in development of the image of trolleybus transport was organizing events and campaigns, often accompanied by outdoor advertising on trolleybuses.

Figure 9.4 Formal introduction of new trolleybuses for operation in Parma became a great opportunity to showcase the environmental and operational advantages of trolleybus transport. On the picture: two generations of trolleybuses in the city centre (*Photo by M. Wołek, May 2012).*

Historic vehicles are also an often used instrument, mostly in the context of specific events (e.g. anniversary celebrations of trolleybus transport operation, the European Week of Sustainable Mobility, the introduction of new fleet). The slogan and the logo are a less commonly used instrument of developing the positive image of trolleybus transport. This category includes instruments such as humanizing trolleybuses in Landskrona by giving them female names starting with "El", which evokes associations with electric transport.

	Ebers-walde	Gdynia	Landskrona	Lviv	Parma	Salzburg	Solingen	Vilnius
Logo	✓		✓			✓	✓	
Slogan	✓					✓	✓	
Folders	✓	✓			✓	✓		✓
Journal	✓	✓						
Postcards		✓				✓		
Outdoor	✓			✓	✓			
Outdoor on vehic-les		✓		✓				✓
Regular events	✓	✓			✓	✓		
Occasional events	✓	✓	✓		✓	✓	✓	✓
Old-timers	✓	✓	✓			✓	✓	
Games		✓						
Toys	✓							
Dedicated cam-paigns			✓	✓		✓		

Figure 9.5.: Scope and object of promotional activities for trolleybus transport in selected European cities. *Source: self-study*

As an example of an integrated, yet diversified set of instruments aimed at developing a positive image of trolleybus transport one should mention Barnim Bus Company, DE, which also provides services in the regional bus transport market and other in cities in the county (Bernau and Bad Freienwalde). Trolleybus transport passengers account for about 44% of all BBG passengers.

Main BBG target groups in the urban market of Eberswalde are senior citizens, children and adolescents. There is a significant difference between those groups and they require a different set of instruments for promotional activities.

The operator widely uses social media to provide an information channel for residents and passengers. The Facebook profile complements the operator's extensive website containing, among others, photos, promotional material, a film promoting trolleybus transport, current information and trivia).

Figure 9.6 Poster informing about the benefits of green trolleybus transport in Eberswalde. Source: official Facebook profile of BBG, 18.01.2013

The traditional form of communication is a magazine "Unterwegs", which is available in electronic format, in which trolleybus transport issues are from time to time discussed.

BBG's universal message addressed to the general community is information about the benefits of green trolleybus transport. The media for the message are the website, the Facebook profile, electronic and printed brochures as well as exhibitions and conferences.

Figure 8.6 shows a poster informing about the fact that since early 2013 the trolleybus transport is supplied with electricity from fully carbon-free sources.

Being one of the leading trolleybus operators in the field of innovative technological solutions (such as supercapacitors installed in trolleybuses) and using modern vehicles is reflected in a modern logo design (designed only for trolleybus transport) and a slogan. In 2010, the logo was used as a model to create a plush mascot "Strippi" whose picture was on every new Solaris Trollino trolleybus introduced into service (Figure 8.7).

The mascot also served to create a local postage stamp available in Barnim district. In addition, the website offers downloadable wallpapers containing the image of the mascot and referring to the 70 years of trolleybus transport in Eberswalde.

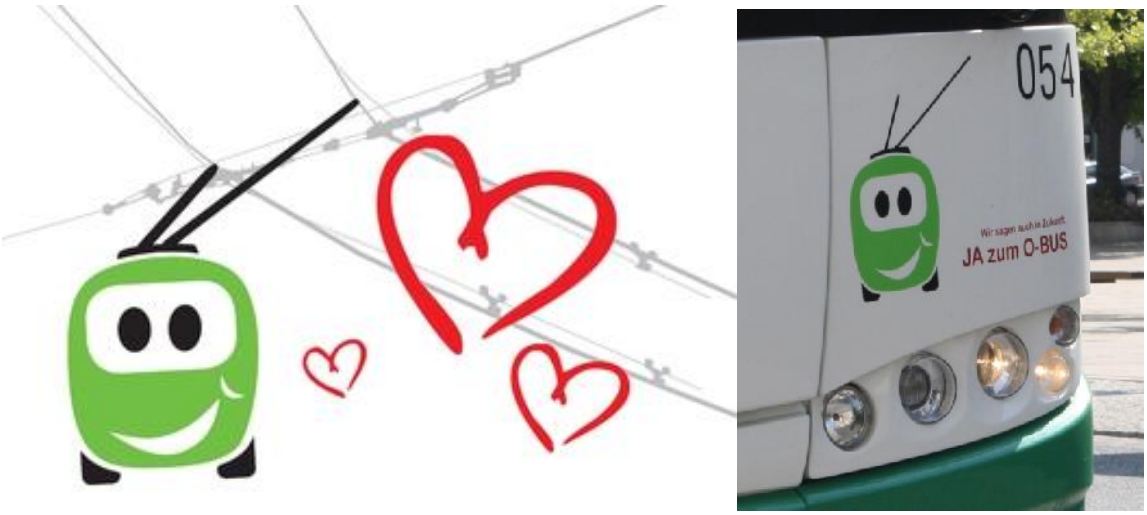


Figure 9.7 Strippi mascot and its exposure on trolleybuses in Eberswalde. *Source:* http://www.bbg-eberswalde.de/maskottchen.php*, downloaded: 18.01.2013 and M. Wołek, April 2011*

The introduction of new vehicles to the fleet made it possible to organize a series of events promoting trolleybus transport, including a solemn "goodbye" to old trolleybuses, one of which was covered with goodbye messages from residents during an "open day" (Fig. 4). For a time, the vehicle had still been operated in Eberswalde before it was transferred to Budapest.

The celebration of the 70th anniversary of trolleybus transport operation in the city has also become an opportunity to step up promotional activities, highlighting the green advantages of trolleybuses and the fact that only three cities in Germany have this kind of urban transport.

Figure 9.8 Trolleybus No 811 on the line 861 covered with "private" goodbye messages from residents of Eberswalde. Photo by M. Wołek, April 2011

The fact that the tradition of trolleybus transport in Eberswalde is more than 70-year old is also reflected in the slogan on the operator's website ("Barnimer Busgesellschaft Deutschlands ältester O-busbetrieb" - "BBG is the oldest trolleybus company in Germany").

Apart from the plush mascot mentioned before, BBG undertakes a number of other activities aimed at children and young people. One of them consisted in building the first seating space behind the front passenger door of the new trolleybuses so it would allow children to pretend to drive and observe the driver's work (Figure 8.9).

Research conducted in the framework of TROLLEY project in 2010 has shown that trolleybuses in Eberswalde are evaluated as a modern mode of transport. More than a half of respondents claimed that trolleybuses are modern (ranks „good" and „very good"), and only less then fifth stated opposite opinion. (bad and very bad)38. It should be noted that only 2% of respondents had no opinion on the matter. The study was conducted at the time of modern vehicles' entry into service, so it can be assumed that it did not have a decisive impact on the assessment of the modernity degree of Eberswalde trolleybus transport.

38 M. Wołek, K. Migdał-Najman, K. Najman: Local Trolley Guides. Final Report. TROLLEY Project, April 2011

Figure 9.9 Special seat for children in Solaris Trollino in Eberswalde. Photo by M. Wołek, April 2011

Another example of effective measures aimed at developing a positive image of trolleybus transport is Salzburg (Austria). Trolleybus transport, just like in Eberswalde, has been operating in the city since 1940 and is a key element of its urban transport system.

It is distinguished by a distinct logo ("Stadt-Bus") and slogan referring to the ecological values of the trolleybus „Sauber. Leise. Obus" - "Clean. Quiet. Trolleybus". In addition, there are other slogans used to emphasize the city-creating role of trolleybus transport, including "Where we operate, the city lives!", "Trolleybus - The highest stage of evolution" (Figure 8.10).

Figure 9.10 Using “catchy” slogans in promoting trolleybus transport in Salzburg. *Source: Salzburg AG*

One of the most important target groups for marketing in Salzburg are senior citizens. With them in view, Salzburg AG take integrated action covering, among others:

- training for older passengers to safely use trolleybus transport, so they can travel alone. Training includes issues related to the physical access to the vehicle, voyage planning, searching for information on available alternatives, finding their way on individual stops, learning the tariff-ticketing system and passenger safety. This results in not only an increase in the number of passengers and revenue from sales of services for the operator, but it also socially activates the ever growing population in the age group from 70 to 85;

- appropriate equipment of stops and trolleybus interior, including the right choice of colors and visible information visibility, providing adequate space for wheelchairs and luggage, and the distribution of at least some stop buttons so that passengers could press them without having to get up;

- promotional message addressed directly to senior passengers (Figure 8.11);

- proper dress and behavior of staff, ranging from trolleybus drivers and ending with personnel involved in customer relations;
- publishing printed materials designed for senior passengers, showing the possibilities of spending free time in the city based on traveling using selected trolleybus lines (Figure 8.12). Such folders were issued for each of the trolleybus lines operating in the city and contain the necessary information for senior citizens;
- highlighting those characteristics of trolleybus technology which are considered to be important from the perspective of senior passengers, especially in comparison with the bus, such as a smoother ride, its impact on improving safety and low noise;

Figure 9.11 Promotional materials targeting senior residents of Salzburg offered by SAG. *Source: Salzburg AG*

aus sind die
ilter befand
denen Au-
itadt. Erz-
gs im Jahr

em jetzigen
er erinnern
en Gebets
it zwei Mal
seiten sicht-
inkelig dazu

Foto: Karl Regner

8. Sterneckstraße

Der gelbe Rauchenbichlerhof nahe der Haltestelle Sterneckstraße entstand nach der Trockenlegung des Schallmooses um das Jahr 1650. Ab 1831 lebte hier Emilie Kraus Baronin von Wolfsberg, eine Geliebte Napoleons. Zuvor begleitete sie, als Mann verkleidet, Napoleon auf seinen Feldzügen und hatte einen gemeinsamen Sohn mit ihm. In ihrem Salzburger Domizil umgab sie sich mit 160 Tieren, darunter Hunde, Katzen, Affen und Raubvögel, was ihr den Namen „die Hundsgräfin" einbrachte. Sie starb völlig verarmt im Jahr 1845 und liegt am Gnigler Friedhof begraben.

Foto: Karl Regner

Unser Tipp: Das Samer Moorwäldchen – einzigartige Natur

9. Langwied

Von der Station der Linie 4 „Langwied", führt Sie der Seitenbachweg über den Söllheimerbach zu einer bewahrten Moorlandschaft, die sich einst von Schallmoos herüberzog. In diesem geschützten Landschaftsgebiet entfaltet sich eine besondere Pflanzen- und Tierwelt, die früher für diesen Raum charakteristisch war. Dieser kurze und erfüllende Rundgang macht Sie - im Sommer, als auch im Winter - mit einem besonderen Naturbereich bekannt, in dem man bei fröhlichem Vogelgezwitscher die Zeit vergessen kann.

(siehe Detailkarte am Stadtplan)

Gehzeit: Runde durchs Moos: 40 Minuten, Runde Söllheimerbach/Schleiferbach: 40 Minuten

Die große Runde ist mit dem Rollstuhl befahrbar, der Weg direkt durch das Moor ist ein unbefestigter Weg für trockenes Wetter.

Toiletten: im Gasthof Langwied, nicht barrierefrei

Bänke: beim Marterl

SALZBURG erfahren!

4

- Besonderes entlang der Linie
- Rundfahrt mit dem Obus
- Kleine Spaziergänge
- Liefering–Zentrum–Langwied–Mayrwies

Figure 9.12 Publishing materials dedicated to senior citizens on trolleybus line No. 4 in Salzburg. *Source: Salzburg AG*

To enhance the image of trolleybus transport as a modern and ecological mode of transport, the operator informs that trolleybuses' energy supply comes 100% from renewable energy sources, thus reducing CO2 emissions by 51,000 tons a year. In addition, modern fleet serves as a reinforcing instrument of developing the positive image, including the newly purchased Solaris Trollino Metrostyle (Figure 8.13) with a modern design and rich interior. Introducing new vehicles and new lines (like line 12 at the end of 2012) is accompanied by promotional events of various types.

Figure 9.13 Solaris Trollino Metrostyle in Salzburg

In Salzburg the trolleybus network is being used for promotional activities and provides an example of how this disadvantage of trolleybus transport can be positioned as an advantage. Network is the confirmation of stability and certainty of reliable service, especially for older people. Such action, however, can only take place if other elements of the trolleybus transport create a high-quality service and clearly defined benefits for passengers.

An activity which was introduced thanks to the TROLLEY project is the European Trolleybus Day. The core idea behind it was to establish a day, during which all European cities celebrate trolleybus transport exclusively. It was celebrated for the first time on September 18, 2010. From that day on, the event is celebrated each year in September by a steadily growing number of cities, including those that don’t have trolleybus transport yet (like Leipzig). In addition, cities that do have trolleybus transport, but are not partners of the TROLLEY project, also join the celebration (in 2012 - Lublin and Tychy in Poland).

Typical activities of the European Trolleybus Day are open days (in Szeged and Brno), accompanying events with competitions and activities for children and young people (in Salzburg, Parma, Gdynia), exploring technical facilities for children and young people and exhibitions of trolleybus photos (Gdynia). The celebration of the 3rd European Trolleybus Day in Gdynia were accompanied by a photo contest "My trolleybuses, my city".

European Trolleybus Day is also becoming an increasingly important part of the European Week of Sustainable Mobility, during which special lines with historical vehicles are organized, an activity that has become a kind of tradition in Salzburg and Gdynia (Figure 8.14).

Figure 9.14 A historic Saurer trolleybus during the celebration of the Second European Trolleybus Day in Gdynia in 2011 on a special trolleybus line 68 (line number represents the number of years of trolleybus transport in the city). *Photo by M. Wołek*

Organizing the European Trolleybus Day allows to present the advantages of trolleybus transport to people who normally are not public transport users. It also allows to exchange experience in promoting trolleybus transport and to deepen the cooperation between the cities in which it maintains a strong market position.

The European Trolleybus Day constitutes an integration platform for various promotional activities and gives them an international character (through cooperation and exchange of experience). It also helps in accurate addressing of specific promotional activities aimed at a specific target group (like passenger car drivers, children and students of a specific age). The activities are predominately low-cost, which allows for easy inclusion of the European Trolleybus Day in the calendar of promotional activities of each city, which uses this mode of transport.

IX-4 Previous experience in developing the image of trolleybus transport in the framework of the TROLLEY project

The image of trolleybus transport was examined using a semantic differential, which shows the individual preferences of respondents in relation to particular properties. The study of semantic differentials of trolleybus transport was carried out in six TROLLEY project partner cities in October of 2010. The research methodology is presented in Chapter 3.3.

In total, the study included 1,070 respondents. The largest share of respondents were citizens of Szeged and Gdynia. Among all respondents 48% were male and 52% female. The study included people over 16 years of age. The oldest age group were people over 71 years of age. The participation of different age groups varied in the cities, which had an impact on the comparability of the research results in individual cities. In Szeged and Eberswalde the largest group consisted of young people, between 16-30 years old – 52.6% and 49.7% respectively. The most adequate distribution of age groups was observed in Gdynia and Parma. Employed people constituted 44.7% of the respondents, students 25%, and pensioners 21.5%. The respondents group also included people of different socio-professional status, such as the unemployed and not seeking work (8%).

The most people traveling via trolleybus transport on a daily basis live in Szeged (56.5%), Eberswalde (48.9%) and Gdynia (44%). In addition, a large group of people were traveling several times a week - 26.2%.

Respondents used trolleybuses for travel to work (20%), schools and universities (14.3%), shopping (16.8%), personal matters (23.4%), for social purposes (16.8%) and other matters (8.3%). One third of the respondents did not have a car.

The study analyzed the following image shaping features of trolleybus transport:

- speed;
- comfort;
- environmental friendliness (eco-friendliness);
- modernity;
- safety.

The semantic differential shows preferences of the respondents due to many features. These preferences are assessed for the intensity of their validity. In the present study a scale of 1-5 was used where grade 3 means neutral/ indifferent view. Values higher than 3 indicate a positive evaluation, lower values – a negative evaluation of a certain feature. For example, a grade higher than 3 granted for the speed of the trolley communication in the evaluation means that the respondent considers the journey as fast. Ratings below 3 mean that the respondent considers the journey as slow. The other levels (4-5 and 2-1) indicate the intensity of the respondent's feelings39.

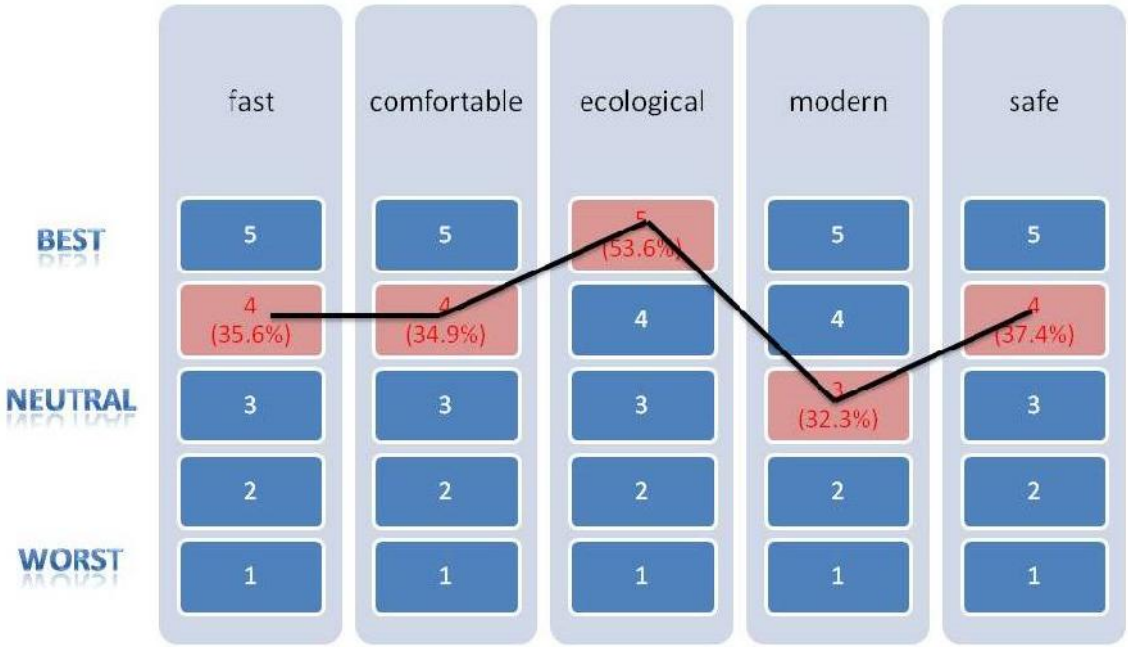


Figure 9.15 Aggregate semantic differential for cities surveyed in 2010. Source: *K. Migdał-Najman, K. Najman, M. Wołek: Improved image and patronage. Output 5.2.4 "Local Trolley Guides". Final Report. TROLLEY Project, April 2011, p. 30*

The aggregate semantic differential for trolleybus transport for all analyzed cities was presented on Figure 8.15. Semantic differentials for trolleybus transport defined for all analyzed cities are shown in Figure 8.16.

39 K. Migdał-Najman, K. Najman, M. Wołek: Improved image and patronage. Output 5.2.4 "Local Trolley Guides". Final Report. TROLLEY Project, April 2011, p. 23

In Brno, the best scoring trolleybus transport feature was its friendliness to the environment. The respondents were neutral towards safety, comfort and modernity of trolleybuses.

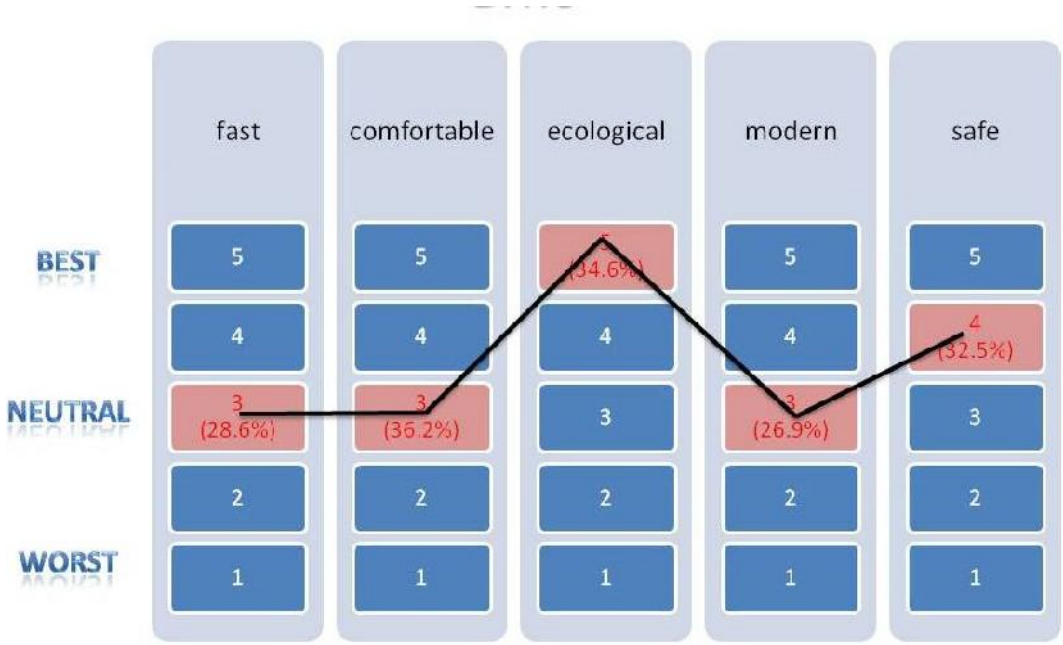


Figure 9.16 Semantic differential of trolleybus transport in Brno in 2010. *Source: K. Migdał-Najman, K. Najman, M. Wołek: Improved image and patronage. Output 5.2.4 "Local Trolley Guides". Final Report. TROLLEY Project, April 2011, p. 26*

Residents of Eberswalde recognize trolleybuses as an ecological and safe means of transport (2/3 of the respondents rated this trait the highest). Its speed and modernity was less valued (although almost half of the respondents gave that trait "4" and "5" points), as shown in Figure 8.16. It should be noted, however, that the trolleybus fleet renewal process in the city was started in the same year in which the study was conducted. Articulated trolleybuses built in early '90s were replaced by twelve Trollino Solaris 18 trolleybuses, which operate on two lines perfectly matched to the spatial structure of 40,000 city.40.

Residents of Gdynia evaluated trolleybus transport as friendly to the environment and modern - about 2/3 of Gdynia transport passengers indicated on the trolley as a modern means of trans-

40 K. Hebel, M. Wołek: Development the Image of Trolleybus Transportation. [In:] Contemporary Transportation Systems. Selected Theoretical and Practical Problems. The Transportation as the Factor of the Socio-Economic Development of the Regions. Ed. by R. Janecki, S. Krawiec, G. Sierpiński. Publishers of the Silesian University of Technology, Gliwice 2012, p. 199-208.

portation (total of "4" and "5" scores), as shown in Figure 8.17 The speed, comfort and safety have also received high scores. This is due to the consistent policy of public authorities of supporting this means of urban transport. Modern vehicles, some equipped with a traction battery, certainly have an impact on the passenger evaluation of public transport in Gdynia. Some of the modern vehicles have been introduced into operation before the start of marketing research.

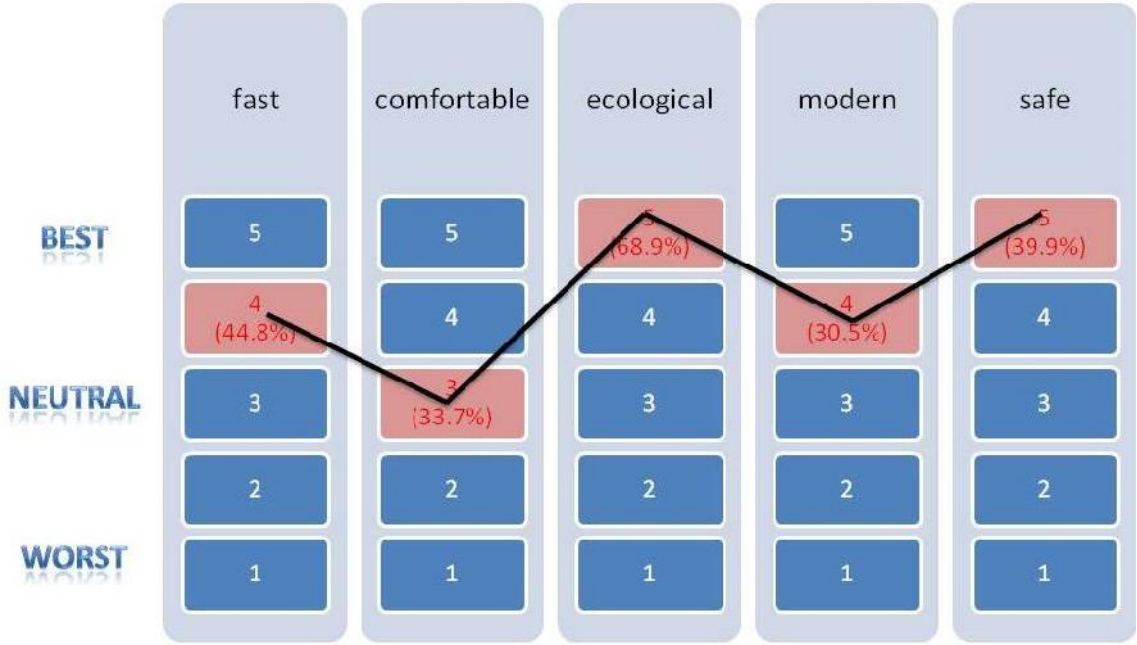


Figure 9.17 Semantic differential of trolleybus transport in Eberswalde in 2010. Source: *K. Migdał-Najman, K. Najman, M. Wołek: Improved image and patronage. Output 5.2.4 "Local Trolley Guides". Final Report. TROLLEY Project, April 2011, p. 24*

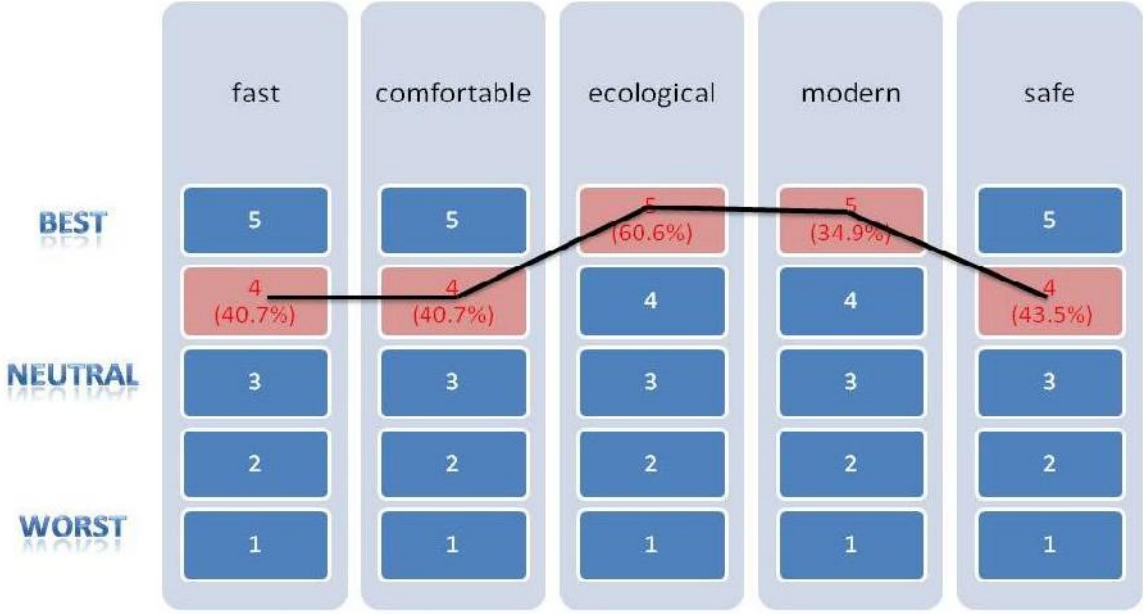


Figure 9.18 Semantic differential of trolleybus transport in Gdynia in 2010. Source: *K. Migdał-Najman, K. Najman, M. Wołek: Improved image and patronage. Output 5.2.4 "Local Trolley Guides". Final Report. TROLLEY Project, April 2011, p. 24*

In Parma, trolleybuses are evaluated as an ecologically friendly means of transport. Their safety was less valued, which is represented by Figure 8.18. The residents of Parma were neutral towards the speed, comfort and modernity of trolleybuses. The research in Parma was carried out before the purchase of new vehicles for trolleybus transport, hence the lower rating of comfort and modernity.

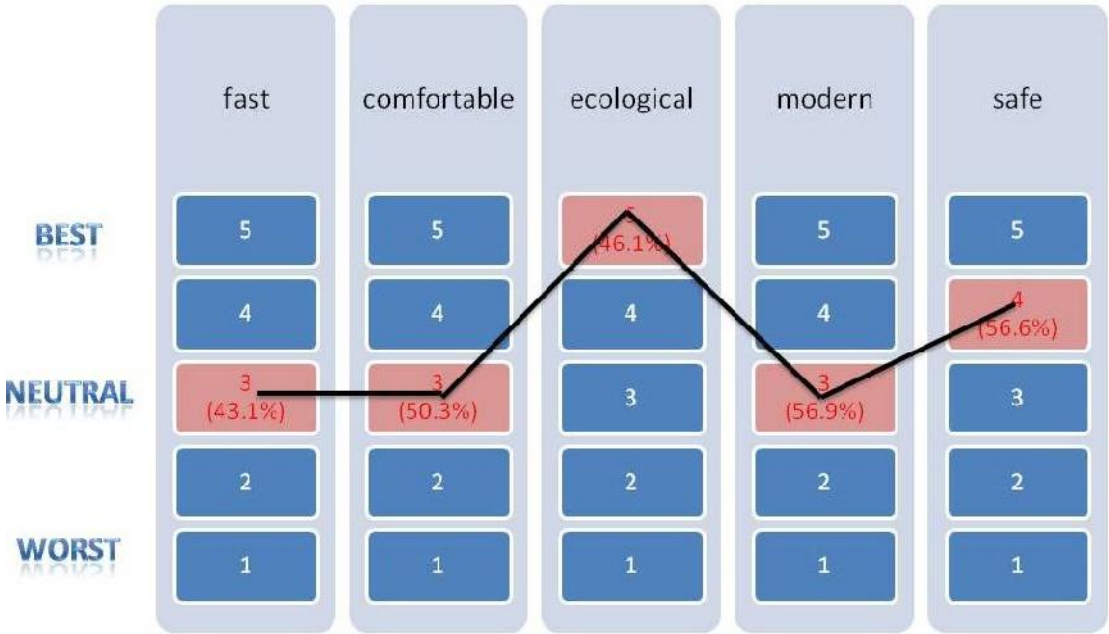


Figure 9.19 Semantic differential of trolleybus transport in Parma in 2010. Source: *K. Migdał-Najman, K. Najman, M. Wołek: Improved image and patronage. Output 5.2.4 "Local Trolley Guides". Final Report. TROLLEY Project, April 2011, p. 25*

Residents of Salzburg (Figure 8.19) evaluated the most traits on the highest level, namely, the comfort, friendliness to the environment, modernity and safety. Only speed was rated neutral, due to the low operating speed of trolleybuses in the city center, despite the existence of bus lanes on some streets. Nearly four fifths of respondents in this city consider trolleybuses a modern means of public transport (sum of respondents who gave this trait a 4 or 5).

In Szeged (Hungary), residents considered trolleybus transport environmentally friendly (almost half of the respondents gave this trait the highest score - 5). They also appreciated the speed and comfort, but had a neutral attitude towards modernity and safety of travel, as shown in Figure 8.20).

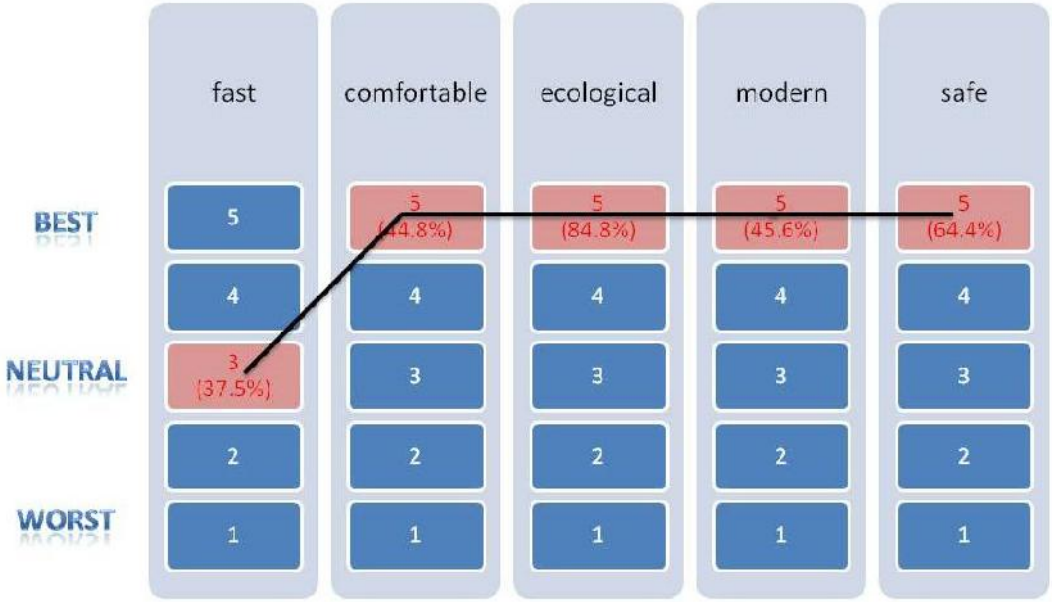


Figure 9.20 Semantic differential of trolleybus transport in Salzburg in 2010. Source: *K. Migdał-Najman, K. Najman, M. Wołek: Improved image and patronage. Output 5.2.4 "Local Trolley Guides". Final Report. TROLLEY Project, April 2011, p. 25*

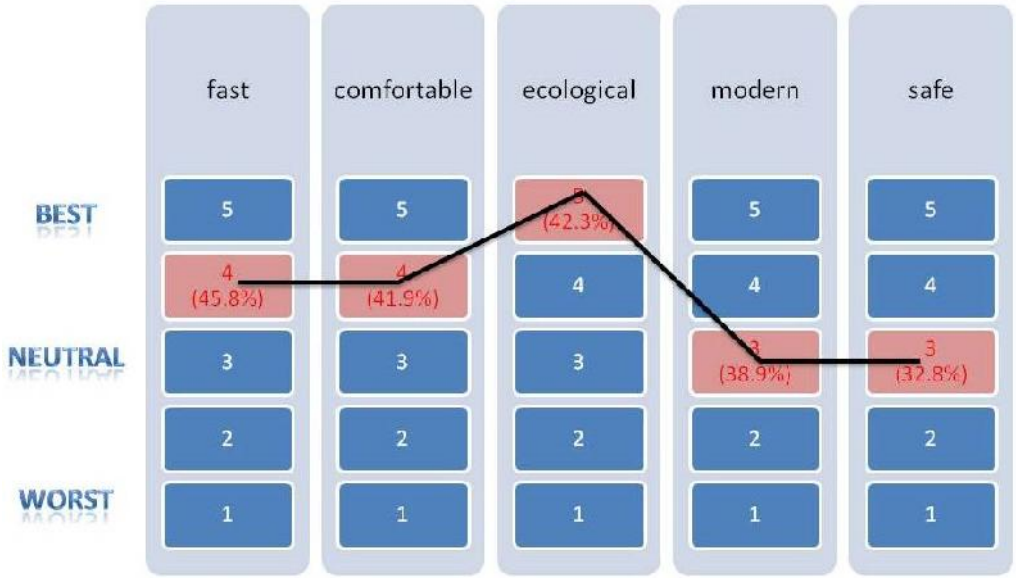


Figure 9.21 Semantic differential of trolleybus transport in Szeged in 2010. Source: *K. Migdał-Najman, K. Najman, M. Wołek: Improved image and patronage. Output 5.2.4 "Local Trolley Guides". Final Report. TROLLEY Project, April 2011, p. 26*

The positive image of trolleybus transport is deeply rooted in the matters of ecology. The next best evaluated traits are safety, comfort and speed.

The declarations of all surveyed respondents in regards to the five attributes were summed up in order to assess the diversity of the researched cities. Figure 8.22 represents a map of cities' perception. Axes in the chart are abstract evaluation of cities' similarity. The closer the cities are to each other, the more similar they are. Each part of the graph shows the importance of surveyed five factors.

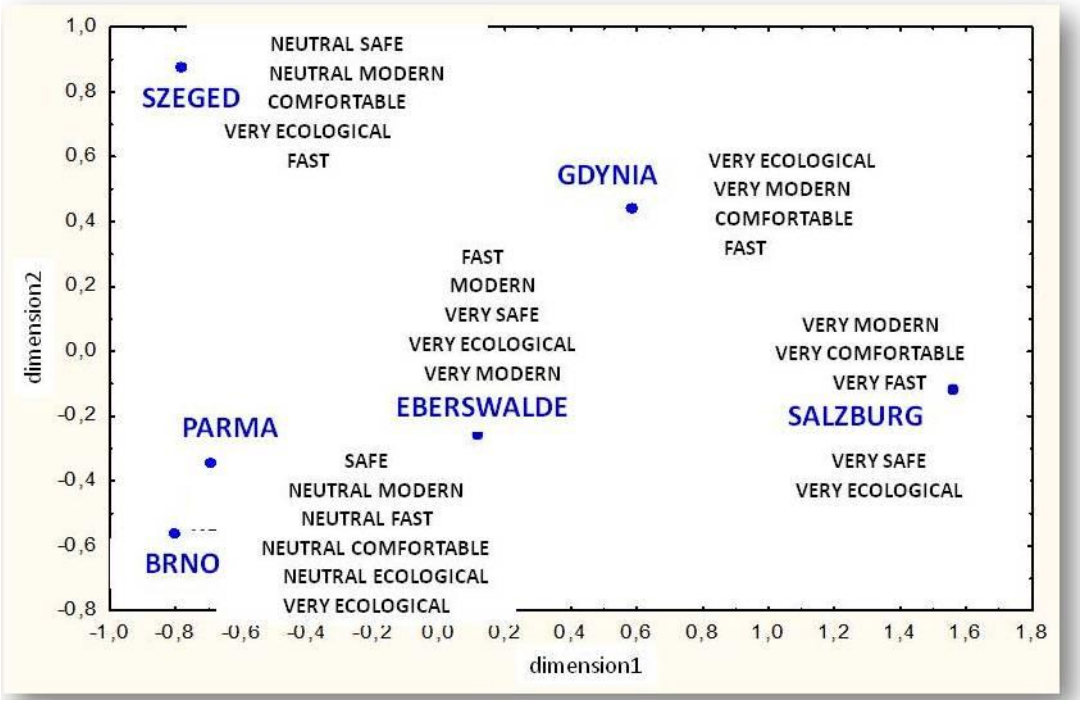


Figure 9.22 Map of perception of the cities in regards to the surveyed travel features. *Source: K. Migdał-Najman, K. Najman, M. Wołek: Improved image and patronage. Output 5.2.4 "Local Trolley Guides". Final Report. TROLLEY Project, April 2011, p. 33*

In regards to Figure 8.22 it might be stated that eco-friendliness was preferred in Szeged. Also the importance of comfort and speed was pointed out. Safety and fashion received neutral ratings. In Gdynia the respondents considered the aspects of eco-friendliness and modernity, as very important. Comfort and speed were important. In Eberswalde the respondents preferred safety and cco-friendliness as very important. The speed and modernity were also important.

Comfort received neutral rating. Modernity, comfort, safety and eco-friendliness, were graded highly, while the speed of travel remained neutral in Salzburg.

Parma and Brno have very similar characteristics. Respondents indicated eco-friendliness as very important and safety as important factor. The other features were graded as neutral.

The differences in the image of trolleybus transport in individual cities stem on one hand from the experience of trolleybus travel, and on the other hand, from the specificity of the community sample.

Trolleybuses are a key characteristic of transport systems of the cities in which they operate. In all cities under research they received the highest ratings because of their eco-friendliness. Regardless of the city being researched, ecological friendliness was evaluated very high among passengers of trolleybus transport. It proves of high environmental awareness of trolleybus transport among in researched cities. 54% of respondents find a trolleybus transport as „very ecological". There are significant differences in the assessment of parameters such as speed, comfort and safety. Trolleybus transport may therefore become an important element in developing a positive image of public transport, in some cases, becoming its "flagship", as it is already in Salzburg (Austria)41.

In order to improve the image of trolleybus transport in the framework of the TROLLEY project, a wide promotional campaign named "EBUS - the smart way" was launched. The aim of this campaign was to show the trolleybus as a modern means of transport, a flexible platform for a number of innovations that are currently in an experimental phase, which promise to make trolleybuses a very attractive and effective means of transportation.

41 K. Hebel, M. Wołek: Development the Image of Trolleybus Transportation. [In:] Contemporary Transportation Systems. Selected Theoretical and Practical Problems. The Transportation as the Factor of the Socio-Economic Development of the Regions. Ed. by R. Janecki, S. Krawiec, G. Sierpiński. Publishers of the Silesian University of Technology, Gliwice 2012, p. 199-208.

X Case Studies

X-1 Szeged: Authorization and implementation of reconstruction of trolleybus junction's overhead wire and trolleybus stop

On the first view the following report should be one of the case studies of part II, but this report written by Dr. Zoltan Adam Nemeth from SZTK, the transport authority of the Hungarian city of Szeged is more a description of the implementation process than of technical details of the measure. This way it is a good reminder of a lot of items in detail to be thought about just during the planning process.

X-1-1 Introduction

This report focuses on management issues of the project implementation. We assume that a trolleybus project had its feasibility study and proper cost-benefit analysis done in order to decide its viability in a city. In our case, since this was a pilot reconstruction of a part of an existing trolleybus network, this step was skipped, and thus it is not in our focus of discussion. Our project was based on the need of reconstruction of a 30 year old junction facility and a trolleybus stop. We highlight the modern technical solutions and requirements for designers of trolleybus overhead catenary as well as trolleybus stops, and follow through all problems, risks and solutions through the authorization and implementation process. Many textbooks overlook the intricacies of the legal environment and the usual requests of the collaborating road, park and utility operators which are a key to a successful, finished in time construction project. Our attempt is to focus on these issues, in order to prepare for them in future projects.

X.1.1.1 Szeged and trolleybuses

Szeged is with 169.000 inhabitants the fourth largest city in Hungary, located in the south, close to the border to Serbia and Romania. The city is a major administrative centre of the south-east region, as well as Csongrád County. It is situated on the Great Hungarian Plane, alongside the river Tisza.

The city reached its today shape after the devastating flooding of 1879, after which Szeged was reconstructed with new radial and circle boulevard system.

Szeged Transport Company (SZKT) leads back its predecessors to 1884, to the opening of the first horse-tramway service in the city, which was followed by the electric tram in 1908. The first trolleybus was introduced in 1979, and the route structure reached its today shape in 1985, serving mostly the city center and new housing estate areas in the north-east part of the city.

In the last decade the car traffic increased significantly, together with the passenger loss of the worn down public transport. SZKT started reorganization in 2003, with concentrating its resources on the renewal of its old trolleybus and tram fleet, partly from self-labor in its existing workshops. After joining to the EU in 2004, part of national cohesion funds on the reconstruction of the electric transport in the provincial cities was granted to Szeged.

A 100 million Euro worth of investment started in 2008, including the extension of the trolleybus network and fleet, as well as reconstruction of the depots and the power supply to hopefully change the trend of the passenger loss, which most significantly occurs on the bus routes.

The network of trams and trolleybuses in Szeged (end of 2011)

Figure 10.1 Network of trams and trolleybuses in Szeged

X.1.1.2 Planning the overhead wires


Figure 10.2 and 10.3: The trolley catenary situation at Deák Ferenc utca and Vár utca before the project

X.1.1.2.1 The pre-project wire layout

In order to explain the evolution of the planning of the overhead wires, first let's explain the motivation behind the previously existing layout. On the plan below one can see the project area.

The first trolleybus route 5 ran from left to right from Széchenyi tér (square) stops (left) towards the bridge (right) since 1979. On the left one can see tram crossings as well (route 1).

In 1985 a second route of trolleybus was constructed (route 9) coming from the direction Széchenyi tér stops (left), and turning at the bridge head parallel to the direction of the river Tisza (up). A quasi-roundabout geometry was formed, so the route 9 trolleybuses were able to turn back here (coming from above), and both routes 5 & 9 were able to turn back coming from Széchenyi tér (left). However, there was no possibility of turning back for the route 5 coming from the bridge (right).

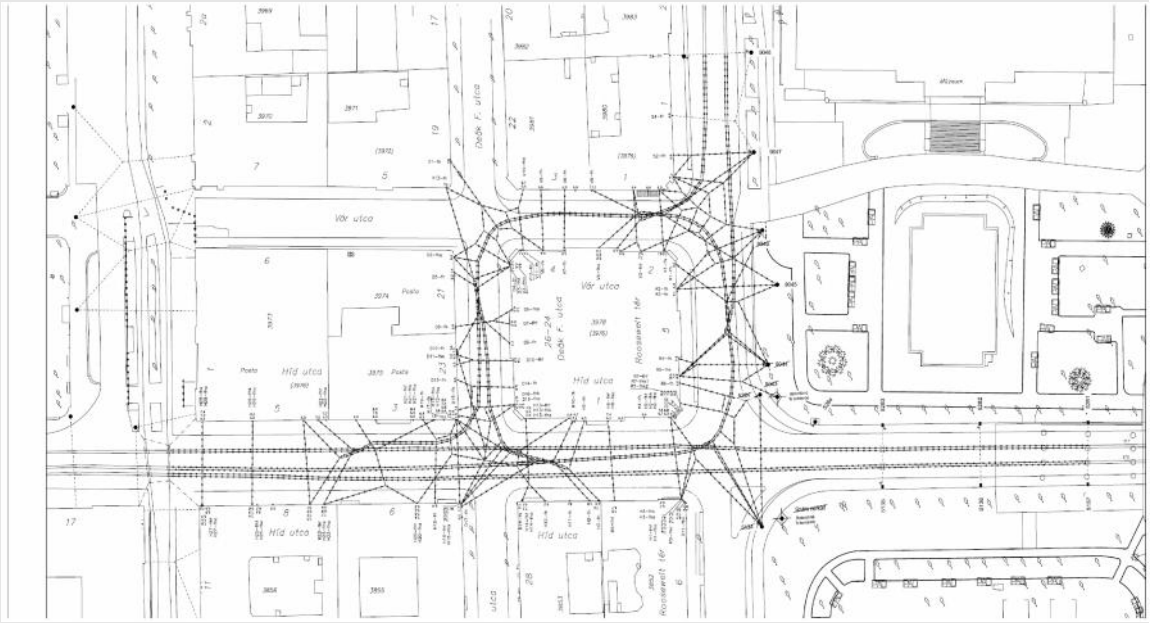


Figure 10.4 The wire deconstruction plan of the project area (the previous state to the project). On the left is Széchenyi tér, on the right is the bridge's ramp over the river Tisza. Trolleybus route 5 goes left-right, route 9 goes from left to the top

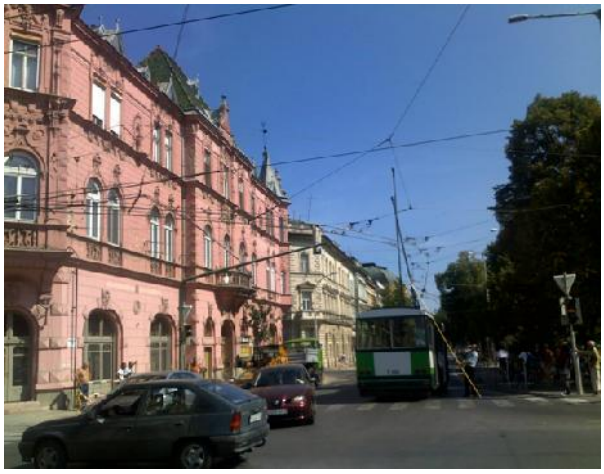
One more peculiarity to observe: from the left there are three pairs of wires arriving instead of two. There is a turnout on the other end of Széchenyi tér where the routes 5 & 9 bifurcate. The reason of this layout (even if it meant to construct six tram-trolleybus crossings instead of four) was, that starting from the tram crossing there is a steady 2,1 % slope towards the bridge upwards, with streets corners, and even a traffic-light. One could have put the bifurcation of the routes 5 & 9 exactly before the bridge head. However the old version of the trolleybus turnouts is operated by the accelerating trolleybus's current consumption. On occasions of no turnout operation, the trolleybuses needed to coast without current. Since this area was uphills, and often trolleybuses started at traffic lights, the previous designer avoided this turnout to be put on the slope in order to precede the unwanted turnout operation of trolleybuses that accelerated for other reasons.

An important feature of this project was that it required no interference with the trolleybuses power feeding system. This meant a simplification, no further electric planning, authorization and implementation was needed above the overhead wire planning.

X.1.1.2.2 New trolleybus technology on crossings and turnouts

Figure 10.5 The old catenary at the bridge head with a crossing and a turnout

The project area in the previous stage contained five turnouts (two of them are bifurcations operated by the trolleybus driver) and two crossings. These were built in 1985, with a state-of-the-art system of that time. In this system the crossings' and the turnouts' wire system are supporting a series of tubes, that actually guide the trolleybus's contact shoes. The disadvantage of this system is that these tubes can get loose leading to the loss of guidance and to derailments. The tubes also cause vertical irregularities leading the increased possibility of trolleys to jump out at higher speeds. These elements mean a 10-15 km/h speed limit to the trolleybuses. This system requires constant maintenance and checking.



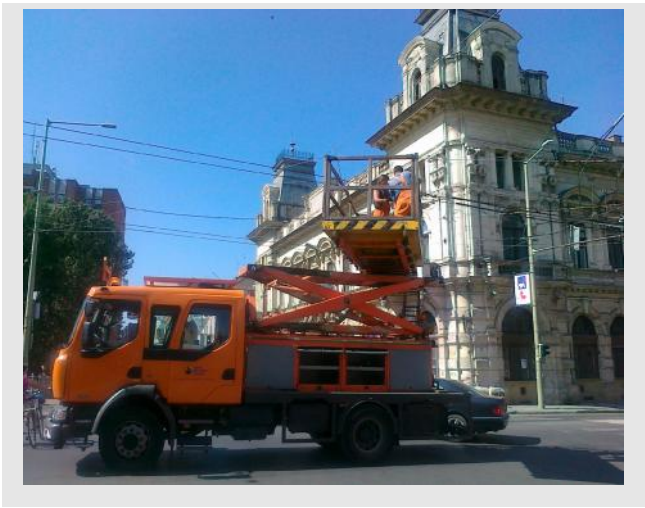


Figure 10.6 and 10.7 The old overhead elements lead often to derailments and interruption of the traffic

The new layout was designed with the crossing elements and turnouts from a today's state-of-the-art system. There is principal difference from the old trolleybus elements, that there are no tubes, which makes the whole system lighter and vertically smoother by the strained wires that the trolley's contact shoes use. There are special crossing and turning point elements that have to be cut directly to their geometrical place. The manufacturers offer a wide variety, but finite number of geometry for these special elements. The designer's job is to fit the most suitable element from the catalog in his layout geometry. These elements can be used up to 40 km/h speed with significantly lower risk of derailment.

Figure 10.8 Modern strained trolleybus symmetric 10º turnout

As it will be described later, we used hooks on the walls of the buildings extensively. In order to decrease the noise and vibration conducted to the walls through the wire, we used at the end of each hook a parafil element. Parafil not just insulates, but also elastic and can diminish the vibrations. These parafil inserts are also used at the “delta” type hanging that we used for straight wire sections.

As for the applicability of hooks: there was no individual static planning for each building, which would be very difficult and unnecessary. The overhead geometry designer chooses to place the hooks at locations, where there is a supporting part of the building, measuring the width of the walls. Also the designer took into account, that the wires should not be in front of windows, balconies, or any other way that would disturb the residents. Before using the newly built in hook, the designer prescribed a method of testing the strength of the hook, by applying extra force for a period of hours to examine the stability.

Figure 10.9 New hooks on the wall with elastic parafil insert

Figure 10.10 The "delta" type hanging that we used on straight sections

X.1.1.2.3 Variation on the geometry

It is very important to have a good communication between the project leader and the designer in order to find the optimal layout *both* for the overhead wire and the traffic situation below. The overhead designer is not an expert in traffic geometry and does not have driving experience with trolleybuses. For this purpose, a detailed disposition needs to be given to the designer, or give him the possibility to interact with people who are going to use this trolleybus geometry (in our case the traffic operation department of the Szeged Transport Company).

For the beginning we gave the instruction to the designer that he should replicate the existing layout with modern overhead elements, with expanding the directions in order to make possible to turn back also from the direction of the bridge.

A further direction was given to the overhead designer, to try to avoid exchanging masts which support not just trolleybus catenary, but street lights as well. These common-use masts always mean authorization difficulty. The street lights in Szeged are operated by the local electric energy company DÉMÁSZ. DÉMÁSZ is currently owned by the French national electric company

EDF. DÉMÁSZ acting as a profit oriented company to Szeged and always asks for the exchange of the mast with street light to exchange all the connecting cables to the neighboring streetlight as well as a condition to permit any activity on its operation area. This extra, non-trolleybus related ground digging could lead at any trolleybus project to a bunch of problems (a new electric designer's involvement is needed, further authorization by a third agency, lots of possible utility interferences) we try to avoid as much as we can.

The designer made four separate rough layouts, which can be seen in the following figures.

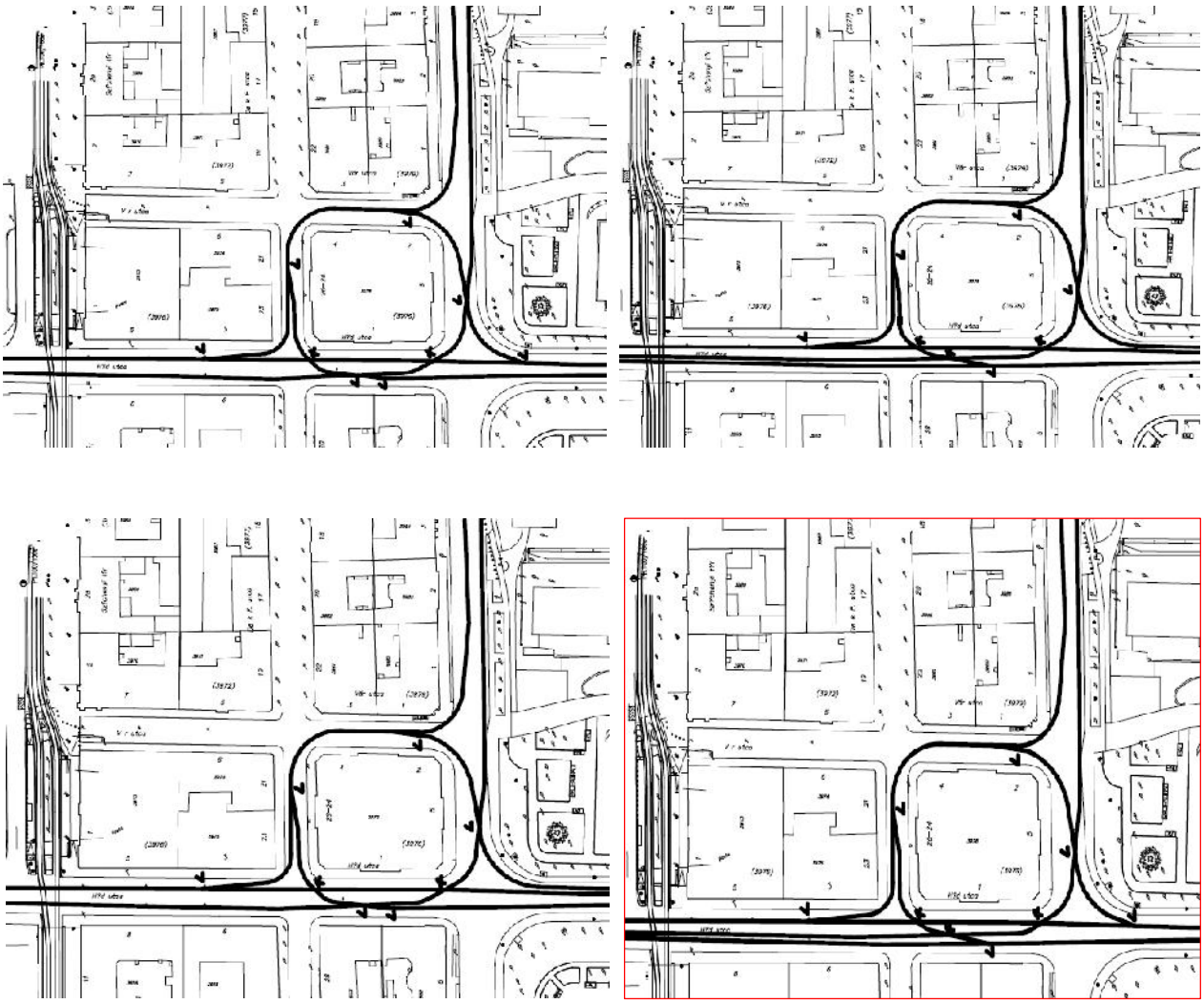


Figure 10.11 The four variations for the junction's trolleybus catenary layout. The realized one marked red

These choices pointed out solution 2. We decided to keep the bifurcation of routes 5 & 9 behind the tram crossing because of its traffic-technology advantages on the right, so still three pairs of wires come from the left.

To explain the reason why there were options of three pairs of wires arriving also from the right we must realize, that this junction is the bridge head, and on the right the masts are already standing *on the bridge itself*. To place a turnout on the bridge is risky, so either we could put this turnout just in front of the bridge-head, or 800 meters away, to the other side of the bridge. The bridge had masts and hooks that supported trolleybus catenary, for which the static planning of the bridge was not available for the Szeged Transport Company. However, while an extra pair of wires give hardly a change in supporting forces, a turnout gives many times above the normal force on masts and hooks, and to avoid risk of overforce them, the turnout was placed according to the second solution, just in front of the bridge-head (which was not the optimal placing to the existing traffic situation). Even an extra trick was added in order not to affect the bridge masts.

The normal catenary wire not just hanged on hinges. In order to make the wire smooth, it is strain with 9 kN force by around 30 meters of hanging distances. At turnouts, two wires become four. The extra 2 x 9 kN force is lead away by anchoring wires, which end at masts or hooks. In order to save the bridge from this extra force of anchoring wires, these were not built. Instead, the arriving wires 2 x 9 kN strain is compensated with 4 x 4,5 kN strain wires. It is acceptable to strain less the wires, if the hangings are much closer than 30 meters, which is the case of the bridge head layout. Thus sections of the wire of this project-area are strained abnormally only with half force.

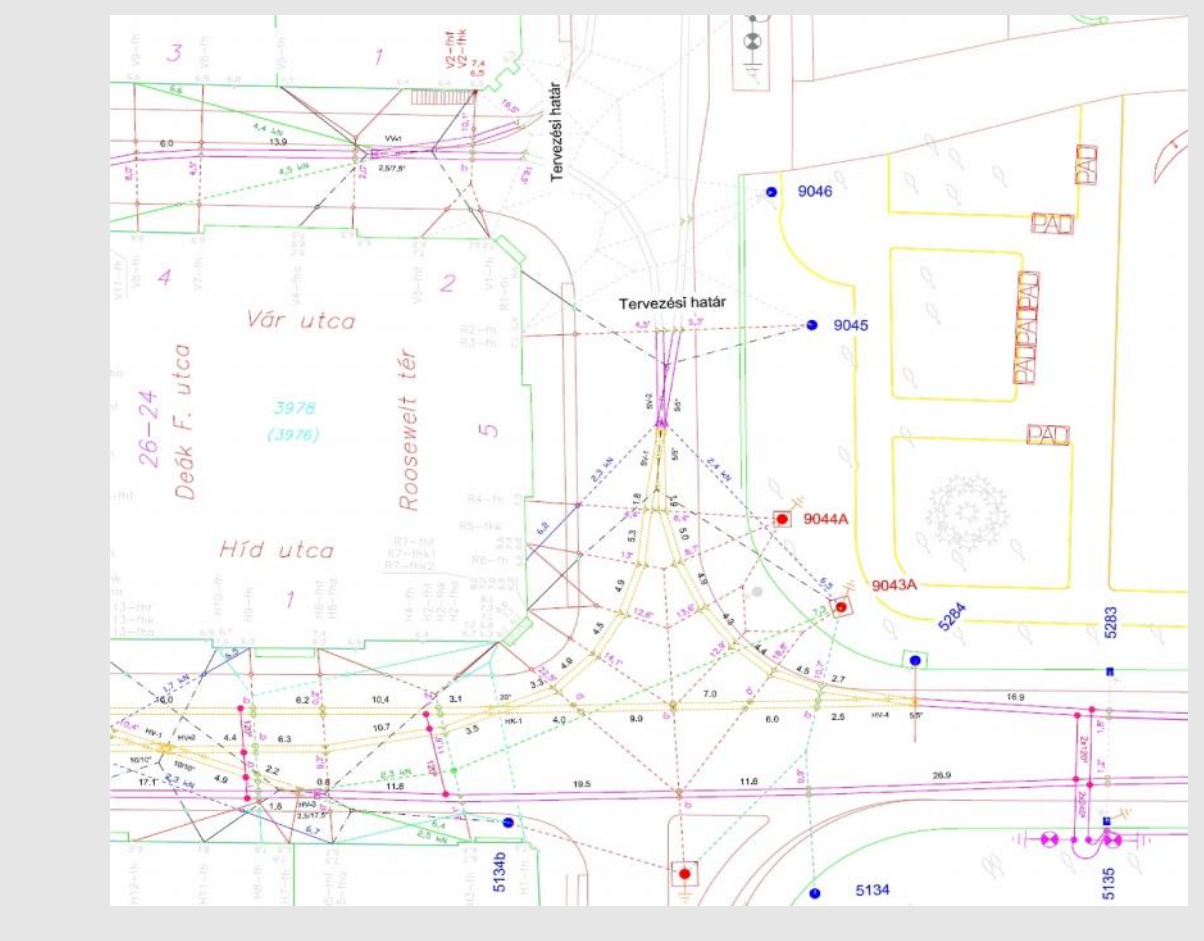


Figure 10.12 The bridge head in its almost final implementation plan version, with no anchoring for the turnout in the bridge head. Instead, the yellow wires are only strain with 4,5 kN, while the purple wires are with 9 kN

At the bridge head there were some unused masts with concrete pillar that we planned to be dismantled. These were probably built at the end of the 70s with the first trolleybus route. Since the ground level here is around 2 meters below the road surface, we designed masts built near the bridge, but longer ones than usual. For each turnout one needs an upper net to stabilize the switch elements. In the case of the bridge head turnout, we exchanged part of the upper net with a holding arm attached on the mast, which previously supported the traffic lights.

It is always advantageous by masts to use holding arms instead of spanning wires to support the catenary, although architecturally wires are usually better. Spanning wires always need to be strained, thus giving bigger force on the supporting mast which also means bigger foundation. However, naturally spanning wires are the natural choice in case of wall hooks.

Figure 10.13 The holding arm for the switch at the bridge head for the turnout, that has no anchoring. Its produces relatively small extra force on the mast, so we could use the existing mast of the traffic-lights. In the background behind the trolleybus one can already see one of the unknown type of rectangular masts that are used on the bridge

Another round of discussion through emails was conducted in order to find the best solution for the junction of Deák Ferenc utca – Híd utca. Here the priorities were to keep the original wire structure separate for the bridge heading route 5 wires from the turning route 9 wires. The bifurcation of the route 9 in Deák Ferenc utca needed to be placed in such a way, that the turnout's insulation bothers the least the trolleybuses in normal traffic situations. All trolleybus turnouts have a certain length of insulated sections (round 2 meters at high-speed 10º turnouts, round 1 meters for 20º turnouts), where the trolleybus must coast through without power. Thus it is preferred to place the insulation such a way, that the head of the trolleybus (12 meters ahead for

solo cars, 18 meters ahead for articulated cars) is not at a place, where there is a junction with right-of-way dilemmas for the driver.

X.1.1.3 Authorization of the overhead wires

X.1.1.3.1 Authorities and Laws

In this description we need to make a special emphasis on the authorization process of any trolleybus overhead wire. Although the term trolleybus was already known in Hungary since 1933 and in Szeged since 1979, still authorities are struggling to find correct legal frame to give out permissions to construct. Authorities can be just plain old boring institutes putting stamps on plans, but in our case they are the “battlefields”, where any policy or favor towards and against trolleybuses are translated to application of the law, and can make or break the case of the future of the existence of this mode of transport. We will see this especially in the involvement of the Cultural Heritage Authority. Szeged naturally has a favor, since we have existing trolleybus network, but we will see in the course of this description, how at a certain point still **there was a considerable jeopardy to this project caused by the non-supportive nature of the laws on trolleybuses in Hungary, especially in the cultural heritage area**. We managed to get out of this quagmire through good management skills and a thorough knowledge of overhead wires with cooperation of our designer.

Since trolleybus overhead wires are considered “railway” in Hungary, its primary law is the Law about the railways (2005. évi CLXXXIII. Törvény a vasúti közlekedésről) which defines trolleybus overhead wire and its construction as subject of this law (since 2012 however, the trolleybus vehicles themselves are not considered railway vehicles anymore). However, the rules and lesser laws subjected to these laws don’t have any more details specific to the trolleybus overhead catenary.

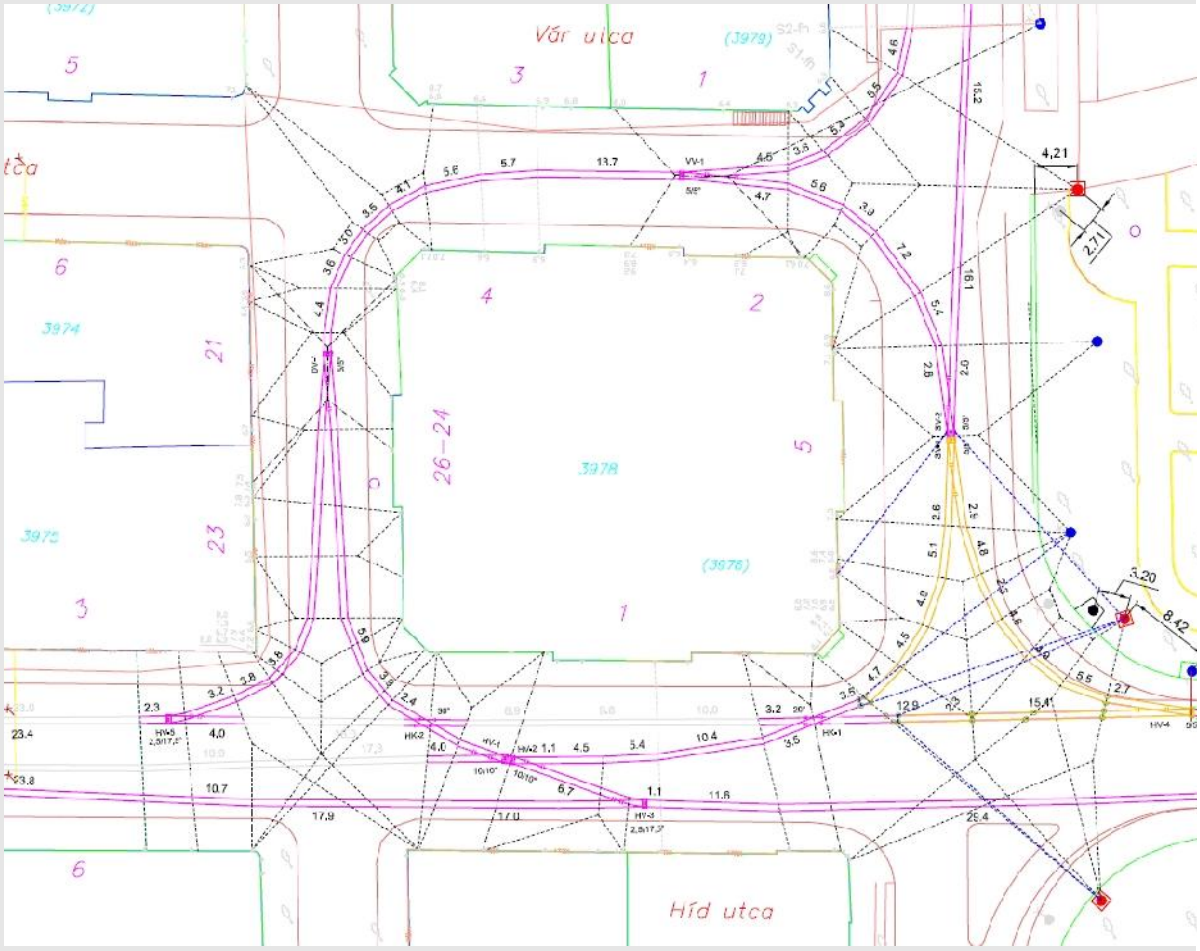


Figure 10.14 The final version of the authorization plan submitted to the National Transport Authority

In October 2010 we submitted the plans for authorization to the National Transport Authority (Nemzeti Közlekedési Hatóság). The authority in this case requires the plans as well as declarations from the utility operators for agreeing or giving conditions for the building. The utility operator's (gas, water, heat, electricity, phone companies) permission was gotten by the designer of the catenary, and since it is mostly in the air, no utility operators indicated any problematic affect. Also we got the permission from the municipality.

The National Transport Authority has the right and required to consult with other authorities. In this case the following authorities were pulled in the process:

- The environmental authority (Alsó-Tisza-vidéki Környezetvédelmi, Természetvédelmi és Vízügyi Felügyelőség), who later declared, that it was by mistake to get pulled into the process, and revoked its declaration of affection;
- The Cultural Heritage Authority (Kultúrális Örökségvédelmi Hivatal), since the inner city of Szeged, and the nearness of the former castle of Szeged (which is buried under ground) makes the project area a protected cultural heritage area. In this case the Cultural Heritage Authority acts as also as an issuer of a separate building permission.

The National Transport Authority, after its site visit (February 2011) released its authorization on the spring 2011 with conditions. The major conditions, that were affecting the further authorization of the condition of the permission of the Cultural Heritage Authority (described above), and the condition of the owners' permission for the hooks on the neighboring buildings walls. This second condition needs explanation.

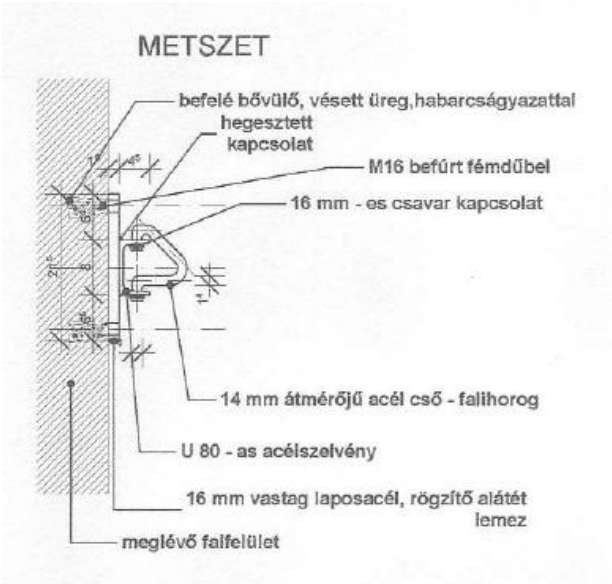
X.1.1.3.2 Hooks

The cheapest way to construct trolleybus overhead wire in densely populated city centers is to use the walls of the neighboring buildings. In fact, it is cheaper to build the overhead on wall hooks than to erect masts, which needs clearance for foundations from utility lines, and creates opposition from architects because of their look. Often the utility situation is such that a mast is impossible to build on the sidewalks. Almost all buildings that have the main facade over 7 m of height (i.e. has an upper floor) is suitable to carry the overhead, without concerns on their static state.

However the neighboring buildings are often belong to other owners than the municipality, since basically municipalities in Hungary sold out their building properties in the end of the 90s, often even without clearing the legal status of the existing catenary hooks. Since the new laws made after the collapse of the communist state about railways were simply not concerned catenaries in inner cities, the intent was to hand over the responsibility of catenaries to the authority, that authorize power supply lines (Hungarian Trade Licensing Office – Magyar Kereskedelmi Engedélyezési Hivatal). The problem is, that catenaries are not considered by the Trade Licensing Office as power lines, where there is a way to enforce to make the house owners to tolerate even if the power line goes through their property. Thus catenaries were thrown back to the Na-

tional Transport Authority, who without any legal power makes the project developers' duty for trams and trolleybuses to get the permission from each property owner for each new hook. This proves to be almost an impossible job, even in our case of the relatively small project area, where there was trolleybus service in the project area for three decades (and a tram service since 1909), and there are more than a hundred (!) hooks. Naturally each owner is hostile to the idea, that their building would get a new hook.

Figure 10.15 Different used and unused hooks of the trolleybus catenary on a private building before the project. One can spot a historic unused one, which belonged since 1909 to the ancient tram



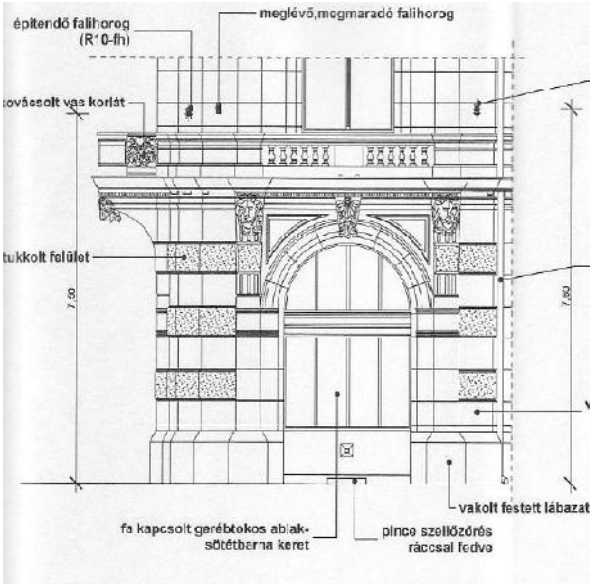


Figure 10.16 and 10.17 The planned new hooks and its placing on the above shown building (part of the architecture plan)

By the reconstruction of the overhead wires we used by far the most the existing hooks (106 pieces) and only planned 14 new due to changes of the geometry of the overhead. For these 14 new hooks the Cultural Heritage Authority prescribed, that they can be built only designed by an architect. So we hired an architect (Krizsán Katalin) to do this job.

These new hooks were made into three groups:

- new hooks on buildings, that are 100 % owned by the Municipality;
- new hooks on buildings, that are owned by a state entity, non-profit organization or a company;
- new hooks on buildings, that are partly owned by the Municipality, or entirely owned by more than one owner.

The first group was relatively easy to get permission, since the Municipality normally supports its transport company's efforts in reconstruction. Though, since the 2010 election the political situation became such in Szeged, that since then we need two committees of locally elected politicians to get the owner's permission of the Municipality of Szeged, but it was relatively easy to get an agreement with some lobbying effort form the director of the company.

The state and non-profit entities or even private companies have the tendency to view their office buildings differently than private resident owners. Thus they normally give permission without any qualms for a normal inquiry. This time however the result was mixed:

- The Hungarian Post Office gave permission without any major condition;
- The Hungarian Treasury however categorically denied a single new hook on their office building although two hooks existed already. This we managed to avoid by a modification on the overhead wires once again by redistributing the strain of sections of the wire from 9 kN to 4,5 kN;

The biggest concern was the case, where the building had more than one owner. According to the Hungarian laws, in this case there should be a legal entity, which is the building itself, with community board formed by the owners. The outside facades of the buildings belong to the house, and not to any of the owners. Here we had two peculiar cases:

- The Hungarian Catholic Church was the minority owner one of the residential buildings, where even there was a dispute of the ownership between the Municipality, the Hungarian State and the Church. Thus the building did not have a community board. The Cultural Heritage Authority did not accept the majority owner's permission; they required the permission of the Church as well. First there was no agreement from the church, which meant that we needed to exchange the hook with a planned new mast. Luckily, with some lobbying from the transport company's deputy director the church changed its mind at the "last minute" in October 2011.
- Two buildings needed a new hook each only in case the old ones are not suitable to carry the weight anymore. In each case the majority owner (Szeged Municipality) gave explicit permission for the hooks. However, the Cultural Heritage Authority demanded that each community board must decide on this permission. The operator of these buildings (also a municipality company) only agreed, if we pay compensation fee for each hook. These community board meetings were done also in the last minute (October 2011), and finally each of them gave permission with majority vote. But this was still not enough, because the Cultural Heritage Authority demanded in the end, that all owners give permission (even those, who were not attending in the community board, or did not vote for the

permission). Luckily it turned out, that none of these hooks were needed to exchange, so finally we dropped the inquiry for permission. But the moral of this story, that on a cultural heritage area in Hungary, basically one owner's disagreement is enough for forbidding hooks for trolleybus catenary, no matter how minor is the ownership. In the case outside of cultural heritage, where only the National Transport Authority is in charge, it is sufficient that the building as an entity gives permission (i.e. the majority of owners).

X.1.1.3.3 Archeology

A further complication occurred concerning the cultural heritage. Although the project area supported trolleybuses for three decades, and around a dozen masts stand around, it was impossible to exchange one of the tilted masts.

During the Authorization process around June 2011 the Cultural Heritage Authority directed us to get permission from the local Móra Ferenc Museum as well. The Museum pointed out, that under this peculiar tilted mast in Móra Park (which supported trolleybus overhead since 1985) is probably the old wall of Szeged castle 4 meters deep. The new mast was supposed to have 3,5 m deep foundation, thus the Museum decided to forbid to exchange this mast. To relocate the mast proved to be impossible due to the neighboring utility lines and the trees (the fact of the cultural heritage area also forbids us to cut down any trees). A committee from the Museum, the Cultural Heritage Authority, the Municipal Park Service, the designer of the overhead and Szeged Transport Company on location decided to anchor this existing mast with an auxiliary mast 4 meters away, supposedly away from the wall of the castle. The museum took the opportunity, and Szeged Transport Company hired them to dig out the foundation of this auxiliary mast.

Figure 10.18 Proposed information table for the auxiliary mast, which finally was never erected. It shows the project area with the Museum's data about the castle's walls 4 meters deep below ground.

The result was sensational for the Museum in July 2011, but very disheartening for the project: in this supposedly clean new location, after the Museum dug around a 6 meter deep hole, they found further parts of the wall of Szeged castle, which the archeologists later theorized belonged to one of the gates guard houses. The committee from the Museum, the Cultural Heritage Authority, the Municipal Park Service, the designer of the overhead and Szeged Transport Company again assembled trying to find another way to support the catenary. We agreed on location, that with two more masts we can exchange the problem mast by using a Y-geometry of the supporting wires. However, although we agreed on location, in two weeks the Cultural Heritage Authority revoked its position in written form, and did not allow any new position of the masts. The 6 meter hole with the found wall was buried back.

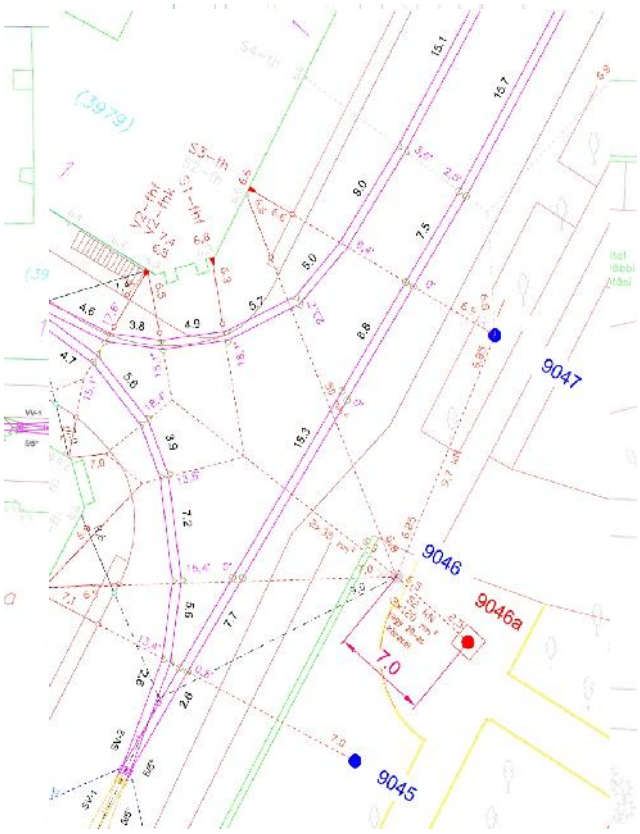


Figure 10.19 The figure shows the proposed two mast exchange of the previous solution after it turned out, that the foundation of the auxiliary mast contained also an archeological wall. This second solution was refused by the Cultural Heritage Authority in the end, agreeing to it beforehand

Finally after redesigning once more, we decided not to abandon completely the tilted mast, but by changing the geometry of the overhead wires we reduced significantly the weight of the overhead on this tilted mast, by putting the weight on the neighboring mast, which was exchanged instead with the permission of the Museum. The compromise is, that sometime in the future one need to do something with this tilted and for now not-to-be touched mast.

X.1.1.4 Implementation of the catenary reconstruction

X.1.1.4.1 Material purchase

Although we were far from having finished implementation plans in the end of 2010, due to project spending reasons we decided to use the authorization plan for material purchase. Our thinking was, that any change should be minimal to the authorization plan, and we will be able

to use the usual spare material that is sent by an order for flexibility. (It turned out that the changes were much bigger, see the previous chapter about archeology.) We organized public procurement, and the delivery was in spring 2011. We put the materials in storage.

X.1.1.4.2 Tree cutting

One of the serious considerations about project starts in Szeged is the tree cutting problem. Our project area included Móra Park, where we needed to erect masts. Some wires went through the foliage of trees, and some branches were in the way. Getting permission from the Municipality to allow cutting a branch of a tree always proves to be extremely difficult.

Tree cuttings are always values choice, and the politics are always whirling around the issue: on one hand we want to improve one aspect of the city's function, and it often affects trees and greenery. On the other hand, one wants to keep and protect the trees as much as possible. This set up leads to the continuous harassment of the municipality office which is responsible for handing out permission for tree cutting and gardening by environmentalist NGOs and green politicians.

This is the reason why the Municipality issues permission for cutting even a branch of a tree on two conditions:

- one needs to make a gardening plan;
- tree cutting must be done in non-vegetation time (i.e. from November to March).

Figure 10.20 Cutting tree branches in March 2011, seven months before the actual works

Both conditions prove to be a challenge. It is almost impossible to measure the positions of branches of trees, and predict which catenary wire will be hitting a branch. The Municipality normally compromises on vaguer sketches, and with on location of the overhead wire designer we manage to choose the branches to be cut. The gardening company usually uses this occasion to trim the trees within their maintenance anyway. However, the tree cutting has to always be done in winter, outside of the normal construction time interval. Which often means, by the time of the project starts the leaves and the greenery grows back into the cleared area. A further complication was, that due to the authorization problems and the movement on the problem mast some tree cutting turned out to be redundant.

In our case, also some trees came apparent to be in the way for the new catenary at Deák Ferenc utca as well. In this case the municipality gardening company was flexible, and cut down the trees in frame of their maintenance work.

X.1.1.4.3 Technical inspector

We hired a required technical inspector both for the stop reconstruction and the overhead wires' reconstruction through regular procurement process. The winner was Metróber Kft., they were in charge of construction procurement's technical documentation, assembling the project-area handovers, implementation controls and assistance in case of deviations from plans.

X.1.1.4.4 Implementation

The implementation was done by the overhead repairing crew and the track maintenance crew of Szeged Transport Company, in two month. The project was implemented from November 2011 until January 2012. For three weeks no trolleybus could run in this area, and replacement buses were used. Then within two weeks gradually we reintroduced the trolleybus service: first on route 5, than two weeks later on route 9 as well. The rest of the turning directions were finished by the end of January 2012. The works could only be carried through during the night not to disturb the normal day traffic. After the trolleybuses route 5 came back, in the evening there was an early shutdown of power, and the last evening services were carried out by buses. In January, only in the four hours of service brake was suitable for finishing works.

Two more problems occurred during implementation: there were non-used mast foundations and boxes of the traffic lights, that needed to be dismantled or some electric connections to be relocated. For this work we hired the traffic-light maintenance company, which is a routine work for them.

The second problem was erecting the mast 9043A, since after digging its foundation one found the large diameter water pipe connecting the two side of the river Tisza. Utility plans are unfortunately notoriously wrong in Szeged, so by each project one can expect unforeseen utilities. This time however we were lucky, by replacing the mast with 2 meters, with a slight change of the geometry of the wires we managed to erect the mast on its new location. However, we could have gotten into much bigger troubles and extra expenses for such reasons.

Figure 10.21 Replacement bus service during the catenary reconstruction

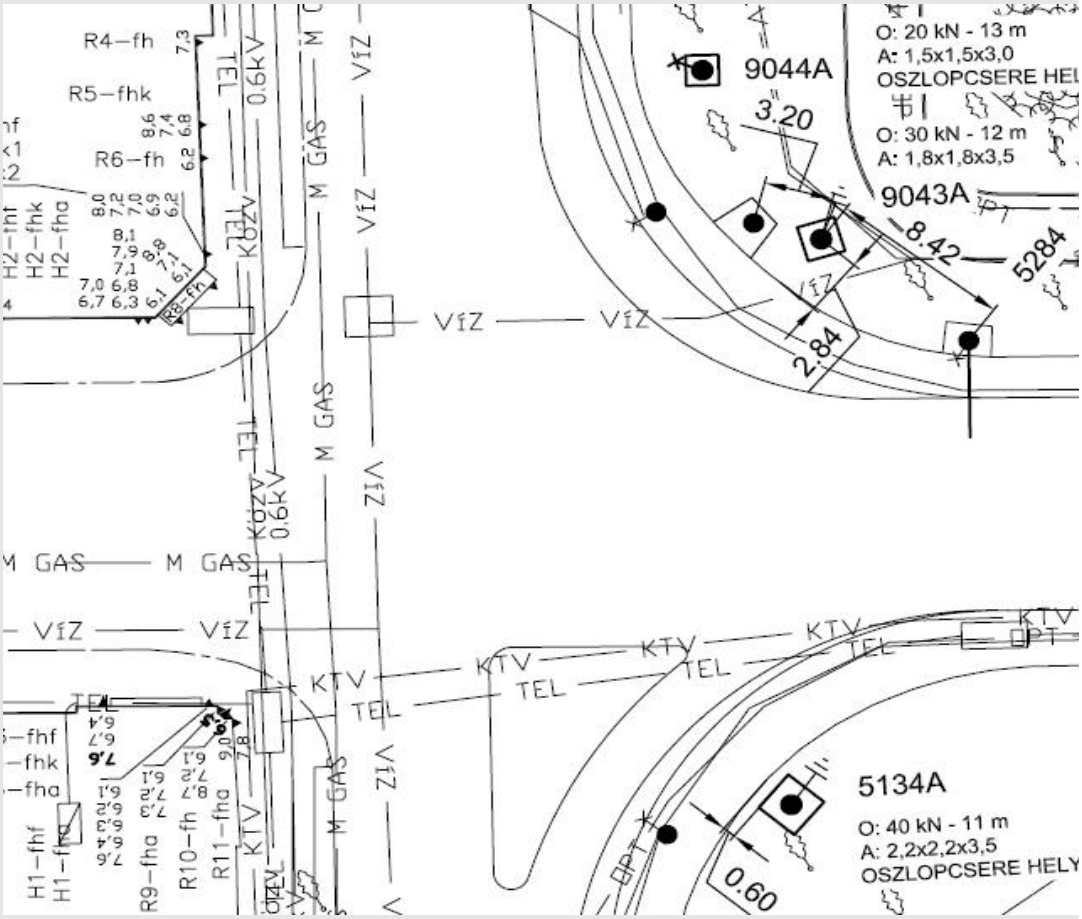


Figure 10.22 Part of the original utility plan with planned masts at the bridge head. The mast 9043A was impossible to plant, due to the water pipe which was not running according to plan. The sign VÍZ means the water pipe

X.1.1.5 Planning the stop reconstruction

Figure 10.23 The pre-project state of the stop. Notice the cracked asphalt sidewalk in front of the post-offfice building and the worn down concrete pavement of the road surface

X.1.1.5.1 Selection of the kerb elements and other materials

In Szeged and in Hungary general, trolleybus and regular bus stops were constructed for decades. However, the challenge of low-floor vehicles and accessibility requirements did not really translate to planning practices. The low-floor vehicles make possible for handicapped persons to travel, but at normal height (13-15 cm) of kerb elements assistance is needed for them to enter or exit the vehicle. That is why low-floor vehicles use foldable ramps and together with the kneeling ability of the air-suspension of the trolleybuses or regular buses. Assistance free accessibility is possible with trams, where we use high platforms (30 cm from the rail level) and the track guidance lets the tram to approach the kerb in the range of 5 cm.

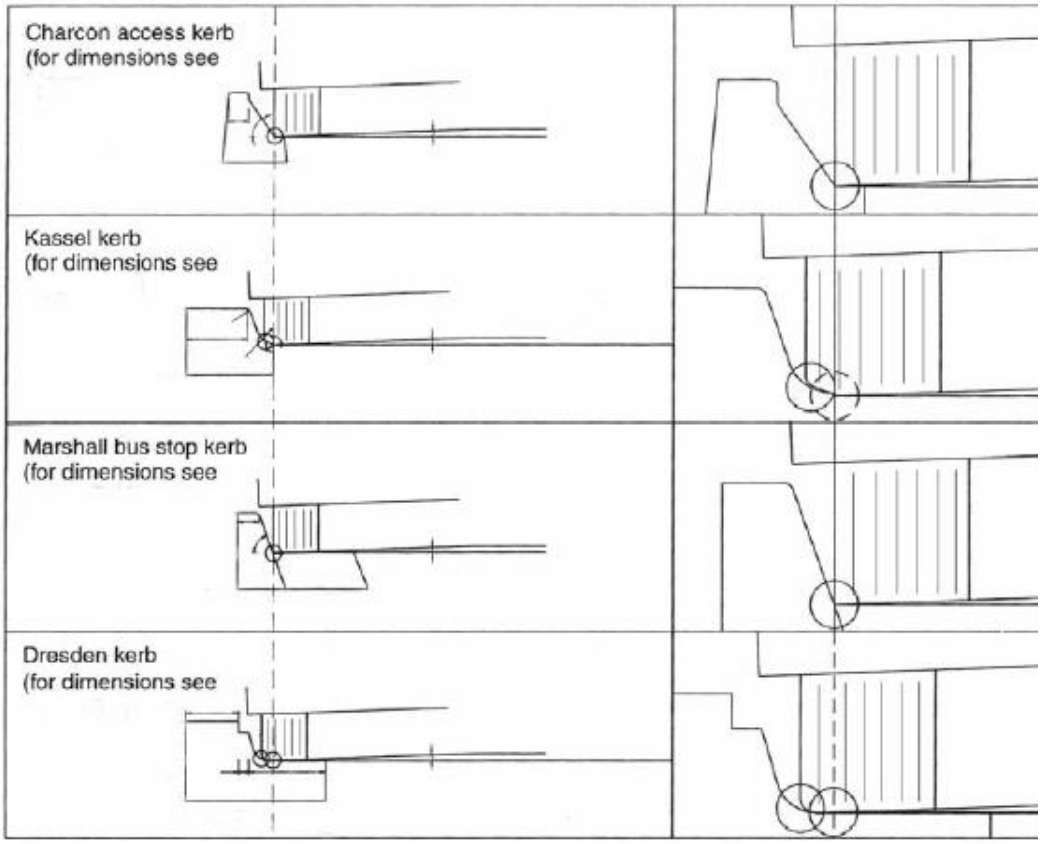


Figure 10.24 Kerb solutions for buses

By trying to find the best approach for assistance free accessibility, we used the “Dresden kerb”, where there is a guidance of the tires, and possible to drive closely parallel to the kerb, without the fear of hitting the front of the vehicle to it. By kneeling the vehicle, the 20 cm height of the kerb makes possible to have only a small gap vertically and horizontally to roll out of the interior. These kinds of kerbs are not used in common tram-bus lanes, since low-floor trams usually cannot kneel.

We asked our hired road designer to plan also these kerb elements, and using this opportunity we ordered the concrete factory (Csomiép Kft.) to make these concrete patterns for their production also for future constructions.

For the materials of the stop we used concrete for the road instead of asphalt or cobblestone. In the Hungarian practice it proved that the newer buses and trolleybuses that use smaller diame-

ter of wheels wear down the asphalt or “viacolor” concrete or basalt cobblestones much quicker. In recent years practice almost all stops were built with concrete. This stop was also built with concrete more than three decades ago, and although cracks were all over the pavement held itself together for long over its supposed lifetime.

The pavement of the sidewalk was made of red “Klinker” bricks, which is extensively used in Szeged allover for a decade of inner city rehabilitation. Here we built in tactile stripes for the blind and visually impaired persons leading to the first door of the trolleybuses. These elements can be purchased in the style of the “Klinker” bricks, but they are rather expensive. Unfortunately Szeged City Architect Office insisted using also red tactile stripes, which is not contrasted color enough for the visually impaired to be able to see.

The stop is fitted with stylistic stop post for trolleybuses, which will be accommodating electronic display in the future. This is realized from an outside project. The City Architect Office did not permit rain shelter to be built near the historic post-office building.

X.1.1.6 Implementation of the stop reconstruction

X.1.1.6.1 Authorization

Since this reconstruction did not alter the geometry of the road, we did not need permission from the National Transport Authority. The Municipality gave permission without problem.

X.1.1.6.2 Procurement

The procurement process for the stop reconstruction was done in August-September 2011 in two rounds. The first round was declared by us unsuccessful, because the prices given by the competitors turned out to be around 50 % higher than predicted. The reason was, that the official prices appearing on the Chamber of Building Industry were not correct (lower than the actual market values), that was obliged to be used by the road designer. After simplifying the water drain system in the stop we reran the procurement, which was successful this time. The start of the work was in middle October 2011, and it was finished by the middle of November. In order to give a proper hardening for the concrete (which was important due to the lower temperatures), we allowed one more month without usage by the trolleybuses.

X.1.1.6.3 Implementation

The construction company's first job was to prepare a temporary traffic layout during the construction. Since there are four lanes in this road, it seemed to be relatively straightforward to give out one lane for the construction, and one more for the machinery and for storage area. This however was not allowed by us, since the trolleybus service was not allowed to be interrupted. The catenary lays here above the two lanes, and the trolleybuses cannot infinitely get out under the wire (4,5 meters maximum). That is why we prescribed to the construction to use the end of the site to enter, and forbade to use the neighboring lane. The construction company accepted, and rearranged its work in a way, that they mostly used the construction site for loading, unloading, and stored their material elsewhere. Thanks to the unusually relatively warm nights, the pouring of the concrete was possible to do during one night's service brake. (In case of colder weather we would have given a day of replacement of trolleybuses on one Sunday, because the pouring of the concrete was only possible to do without interruption, and could only be performed from the neighboring lane.)

A problem occurred on the sidewalks as well. After removing the previous, bad state asphalt cover of the pavement, it turned out, the neighboring post office buildings artificial stone footing was attached sometime after the pavement on the asphalt: meaning the footing lacked a proper foundation to the ground, and was in danger of split off. The designer changed the level of the pavement and once again modified the drainage system.

Figure 10.25 Two stages of the reconstruction of the trolleybus stop. The neighboring lane was mostly kept free for traffic.

The municipality road operator prescribed also in hindsight to form a drain also to connect the buildings rainwater pipes to the water siphonage system in order to protect the brick elements from washout. Since the road is in a 2,1 % slope the rainwater naturally flows away alongside the kerb elements to the water drainhole at the bottom of the slope, so we decided rearranging the drains to lead out all rainwater to the road. This meant, that on spot there was inserts to the kerb elements, with cuts to the drains; and the drains were so arranged, that they end up at the meetings of two 1 meter long kerb element. Also, the construction company took care about the water insulation at the footing of the post office building, which is necessary in case of brick surface, that can lead the rainwater down in the gaps between elements.

X.1.1.7 Results

The project finished in the beginning of 2012. The stop was in regular use after 16th December 2011, with no objection of any stakeholders. For the trolleybus overhead wire we need the approval of the final state by the National Transport Authority, which will be requested in the spring 2012. By preliminary discussion with the Authority we expect no difficulty.

The new layout was greeted positively by the trolleybus drivers, and since then there was no derailment of the current collectors. The new configuration makes possible to turn around from each direction, which is a great advantage for the trolleybus network in case of interruption.

During the project there were reporting by the local newspapers and television about the necessity of the improvement, the residents accepted the temporary construction status without any major complaint. The project itself was recorded by a permanent information plaque for the future years.

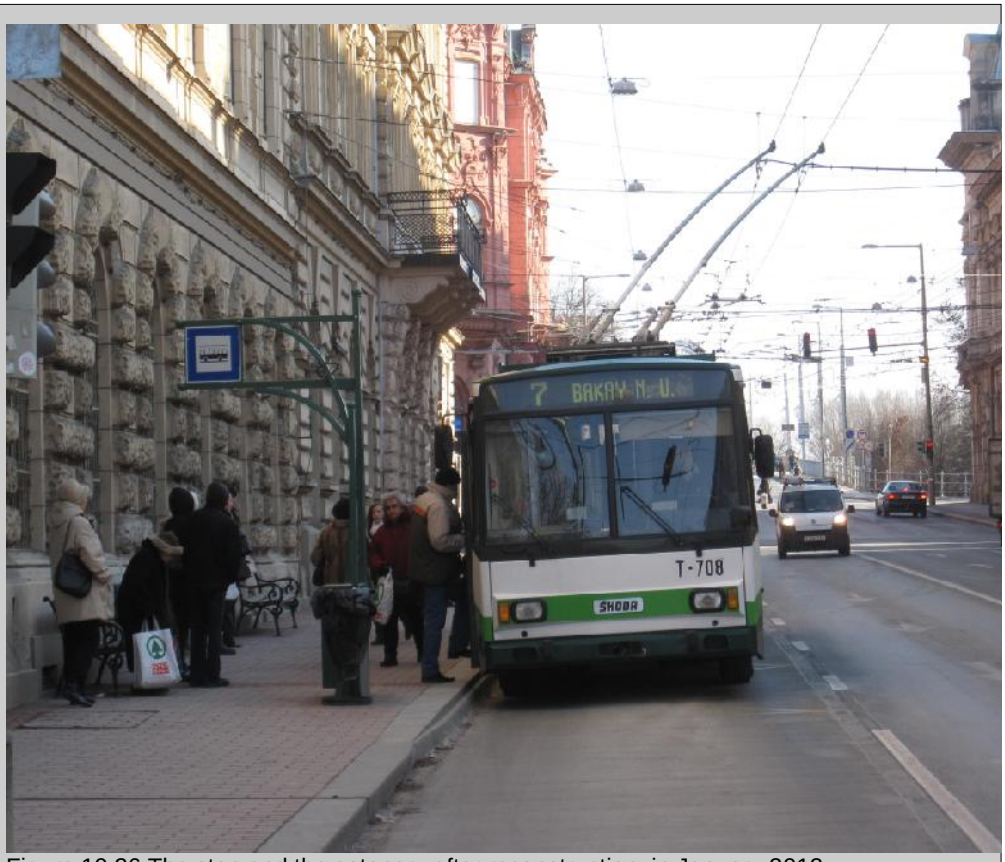


Figure 10.26 The stop and the catenary after reconstruction, in January 2012

X.1.1.7.1 Sustainability

Both investments are made at the key junction of Szeged city's trolleybus network existing since 1979, which ensures long term sustainability. The city's long-term traffic-development concept (released in 2007 accepted by the local government) aims to make a "green inner city" (aim LXI.), where the preferred mode of traffic is zero-emission, electric public transport (trams, trolleybuses) as well as pedestrians, cyclists.

X.1.1.7.2 Transnational added value and foreseen impact and leverage

The aim of the investment of Szeged "Intermodal Corridor Pilot Action" in the framework of the Central Europe Trolley project is to show in practice the kind of overhead elements that are capable of providing a safe contact between the trolley and the wires at high speed and complicated configurations (switches, crossings). These elements are decrease the number of derailments of the trolleys as well as reduce the vibration to the walls of the neighboring houses. It is not an easy job to do the urban planning of a wire system to provide track to the clean, low-

noise, low-vibration electric buses, but in our report we will give a step by step guide and a case study of possible problems and their solution.

Also we reconstruct a trolleybus stop in order to provide accessibility to the low-floor trolleybuses. The aim of the pilot to show the local and international community a best practice for trolleybus stops, where with using the kneeling capability of the trolleybuses enhance the accessibility due to the special kerb elements. We will show that a trolleybus stop can be made emphatic while it matches the urban environment.

We expect the shown new design elements to be used further on in other construction projects, and the promotion of the clean electric public transport. Future trolleybus corridors are prepared with these overhead elements and stop arrangements.

X-1-2 Conclusion

In general we would like to emphasize the role of a good and a flexible management in the success of such projects. All designs must be ordered in such a way, that any change due to the unforeseen external affects during the authorization and the implementation must be possible to handle. For such purpose one can use also a general designer company, but it is more expensive, and it is difficult to contract such unknown affects in advance, which can often lead to cost increases for the general designers. In our case Szeged Transport Company was acting in the role of the general designer, thus we had no problem of our decision making process to run according to our own interests. Another way to try to foresee the possible problems is a more detailed feasibility study, however at that early stage it is not possible to the foresee the authorization problems are coming forth too late in the process. Often the stakeholders are not willing to give their conditions for the permission at that stage of the process.

We have shown in this report step-by-step how an idea of a trolleybus overhead building realized through the process of designing, authorization and implementation. We show affect of all stakeholders in such projects, and how is it possible to get a consensus between the very different entities (politicians, residents, authorities, utility operators, neighboring institutions, etc.) in order to realize a trolleybus construction project.

X-2 Leeds – planned take up

On 5 July 2012, the UK Government announced Programme Entry funding approval of £173.5m towards the Leeds New Generation Transport (NGT) trolleybus network. This would be the first modern trolleybus network in the UK, and this announcement brings the start of exciting times for Bus Rapid Transit in Leeds. But what is NGT all about, and could it be the first of several such schemes in the UK?

X-2-1 What is NGT?

NGT is being promoted jointly by Metro (West Yorkshire PTE) and Leeds City Council. It is a 14km trolleybus-based rapid transit scheme including a South Line to Stourton to the south of Leeds, and a North Line to Holt Park in the north west of the city. The total capital cost is £250m, and predicted patronage is 15 million per annum.

The South Line will run between city centre and a 1500 space Park & Ride site adjacent to a major Motorway. This route will serve several major redevelopment sites on the southern fringe of the city centre and will also pass through a District Centre, serving commercial, industrial and residential areas. The route includes a new segregated alignment approaching the Stourton Park & Ride site.

The North Line will run from the city centre to a new 800 space Park & Ride site, and then on to a local district centre. It will serve the heavily congested A660 corridor, catering both for local trips and the longer distance market. NGT will link the city centre with Leeds Universities and campuses and the Hospital. It will also provide links to and through a number of key local communities.

NGT will provide a high quality, highly segregated rapid transit service with greater reliability and faster journey times than existing bus services – and will provide a much needed step change in the quality of public transport in Leeds. NGT has been developed to deliver the majority of the benefits of a tram system (by having many comparable characteristics to a tram system) but at a substantially lower cost.

This includes being designed to achieve high levels of segregation – with approximately 56% of the NGT route segregated from general traffic, 6.1km of which is new NGT-only route where NGT is fully segregated. Priority and traffic management measures are planned where NGT is mixed with general traffic to deliver suitable levels of reliability

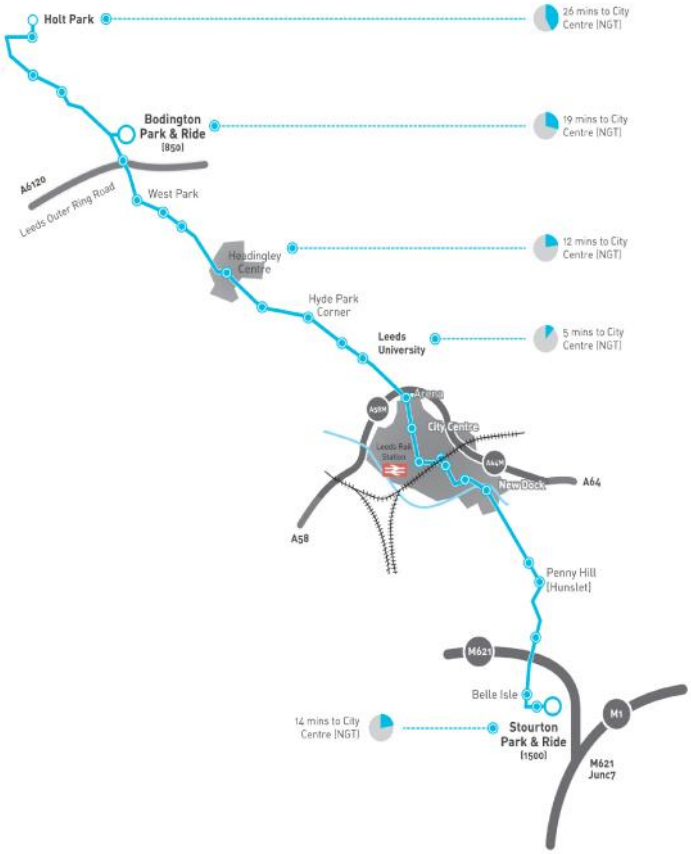


Figure 10.27 Proposed NGT Trolleybus route in Leeds, UK. Source: http://www.ngtmetro.com/route/

X-2-2 Why trolleybus now?

Trolleybus systems are widely in use across Europe and beyond. There are over 300 systems currently in operation, with a mix of original first generation systems still in operation together with new systems and modern expansions and renewals of existing networks. This includes for example high profile and successful networks in Lyon, Athens and Rome which demonstrate in practice the high levels of quality and results that can be achieved.

Leeds, as the third largest (and one of the fastest growing) cities in the UK with one of the most diverse and successful economies in the UK, is surely deserving of a modern rapid transit system. But the development of the ground-breaking trolleybus proposals are certainly not a vanity project; instead they have evolved from a comprehensive option generation and selection process since 2007 which identified the existing and likely future problems on the key radial corridors approaching Leeds city centre and considered the applicability of alternative interventions. This identified an integrated package of measures, with NGT at the heart – playing a key role in delivering the 3 core Local Transport Plan objectives addressing economic activity and growth, low carbon transport system, and enhancing quality of life. NGT is predicted to provide a £160m per annum boost to the local economy and to lead to the creation of 4,000 permanent jobs by 2030.

Trolleybus technology brings a number of advantages that were key to the adoption of this mode. Electric traction of course also provides environmental advantages including zero emissions at point of use, an important benefit in a dense city centre setting. The investment in significant new infrastructure including segregated sections of route and overhead lines obviously brings considerable permanence and certainty of continued operation, which are generally recognised as important factors in encouraging longer term changes to how people travel and in encouraging sustainable development. This infrastructure investment is combined with a strong identity and feeling of quality of the system as a whole.

X-2-3 Option selection process

The Promoters have taken a rigorous approach to option selection not just for the overall selection of corridor intervention and mode technology, but also to more detailed decisions on localised routeing and layout options. The process started with the identification of a broad range of applicable sustainability indicators which could include for example cost, health and safety, constructability, environment, community, operations and maintenance, and resilience. For complex projects such as NGT, the main indicators can be broken down into a range of sub-indicators (for example air, water, noise, carbon footprint for the environment indicator). The project team then agreed on the relative importance of the indicators. This feeds into a decision support tool, allowing each option to be scored against the weighted indicators – in the case of NGT, using an optioneering workshop involving the wider project team. This rigorous approach has helped

to provide the strong and clear audit trail for key decisions on NGT, which will essential to withstand close scrutiny at a future Public Inquiry.

X-2-4 What next?

Following the positive funding announcement in July, the Promoters and their advisors are in the process of developing the scheme proposals and planning further public consultation and stakeholder engagement. This will lead to an application in early Summer 2013 for a Transport and Works Act Order to give the necessary powers for construction and operation, followed by a Public Inquiry in early 2014. Subject to successful approval from this process, construction could then begin in Late 2016 with trolleybuses running in Leeds from 2019. Given the increasing focus on local decision making including through the new City Deal arrangements for transport funding, could NGT show the way for other transport authorities to consider modern trolleybuses for their cities?

X-2-5 Public Consultation Up to funding approval

A two-stage approach to public engagement on the NGT project was implemented during the phase of project definition through to the point of Government approval of the project.

The initial period of NGT public engagement involved undertaking a series of public exhibitions, held jointly with the Transport for Leeds project, in Leeds City Centre in November 2008. The purpose of these exhibitions was to raise awareness of the emerging NGT proposals and to seek feedback from the public on certain key attributes of the scheme.

The second phase of NGT consultation commenced in June last year and closed in early September. The aim of this second phase was to present the more detailed proposals for NGT at exhibitions along the proposed routes as well as in Leeds City centre to obtain as wide a consultation as possible of the public's views on the scheme.

At the same time a series of detailed briefings were given to Local Politicians, together with presentations to local Area Committees (open meetings) and attendance at Community Forums where requested.

The consultation materials presented the Preferred Option routes and vehicle (Trolleybus). A series of public exhibitions were held on each of the NGT routes and exhibition visitors had the opportunity to discuss the proposals with project staff and if desired go through the concept design plans in detail.

An NGT questionnaire was also distributed to ascertain respondents' thoughts on trolleybuses, route proposals, park and ride proposals and the NGT scheme in general. Overall 20,000 questionnaires were handed out as part of the consultation exhibitions and an online version was also available on the NGT website.

The summer 2009 consultation consisted of six public exhibitions each lasting two to four days across Leeds including evenings and Saturdays with nearly 1,400 people attending. Information was also available on the internet, in libraries, to local groups and distributed to members of the public on-street. Feedback was sought via a questionnaire which over 2,500 people completed. The questionnaire responses showed a positive reaction to the proposals and 77% of all respondents supported/ strongly supported them. The mains reasons for such support related to:

- Reduced car use/congestion;
- Environmental reasons;
- Provision of reliable/quick/good quality, modern public transport; and
- Positive impact of the scheme on Leeds.

A similar level of support was shown for the use of trolleybuses, which were primarily supported due to environmental reasons. Over 70% of all respondents supported/strongly supported the introduction of Park & Ride sites at the end of the North and South routes; such support was even higher amongst car owners. The feedback questionnaire asked about potential use of NGT and 88% of those living within a ten minute walk of one of the routes said they would consider using it. 42% of car owners responding said they would consider using one of the Park & Ride sites.

A number of comments and suggestions were received in relation to the NGT proposals. Common themes from all responses included the following:

- A desire for more NGT routes and wider coverage of Leeds

- The need for low fares to encourage use
- The need for competitive Park & Ride pricing to encourage car drivers
- Concern about how NGT would integrate with existing bus services- some felt it is not necessary if existing services are improved
- The impact of the scheme on traffic, with some concerns that NGT would create additional congestion

Since Summer 2012

Following the reinstatement of Programme Entry Approval in July 2012 a programme of consultation and stakeholder engagement activities has taken place. This has included distribution of an NGT update leaflet to all properties which are within 600 metres of the NGT route, this equates to approximately 45,000 properties.

In addition public drop-in sessions have been held at venues along the proposed trolleybus route for people to find out more about the proposals, meet members of the Project Team to discuss any concerns they might have. At these sessions the detailed plans for the scheme have also been on display.

Letters have been sent to all landowners along the route who will be directly affected by the scheme and one-to-one meetings are now being held with these landowners. Meetings have also taken place with a range of other stakeholders and groups who have an interest in the scheme. Examples include Accessibility/mobility groups, Environmental groups and local residents groups.

Frequent updates with local councillors have been taking place and there has been a good level of television and radio coverage to publicise consultation events and raise awareness of the trolleybus scheme more generally. Extensive use of Facebook and Twitter is also being made to publicise events and to provide updated information to a wider audience.

Further consultation events and stakeholder meetings are also in the process of being programmed.

In terms of the feedback received through the consultation to date the main issues that have been raised can be summarised as follows:

- Why not simply make improvements to existing bus services;
- Environmental concerns – particularly around tree loss and impact on open space along the route;
- Will the trolleybus scheme really help to reduce congestion; and
- Why not use hybrid buses instead of trolleybus.

X-3 Salzburg – Network extension to Esch

X-3-1 Business Analysis (Feasibility Study)

To meet the focus on „efficiency enhancement“, the Salzburg AG and the Hallwang municipality authorized the investigation of a trolleybus network extension into the surrounding area. As since trolleybus line 4 was successfully extended to Hallwang Mayrwies in 2007, the question was raised whether further extensions of the network into the agglomeration would make sense.

Starting point of the investigation was a general comparison between the diesel bus and trolleybus systems. Based on these findings, concrete use cases were applied to shed light on the effects of network extensions, including extension of the trolleybus network within the municipality Hallwang from Mayrwies to Esch. Then the impact on the environment, passenger volumes and economic viability could be investigated. The results of a passenger and citizen survey conducted in Hallwang could be used to gain information on acceptance of the trolleybus service and its network extension.

For a system comparison between diesel bus and trolleybus, the impact on the environment is also relevant. Trolleybus operation has the advantage that it is locally emission-free. As the Salzburg AG operates their trolleybuses with water-generated power, no emissions are produced for power generation either.

The analysis shows that the extension of the trolleybus line broadens the PT services offered. It thus makes public transport services more appealing and helps win new customers. It also reduces car volumes and their negative effect on the environment. Broadening the service offer involves additional costs. These can partly be offset by the additional revenue generated.

X.3.1.1 Variants of Technical Organizing

The principal purpose of this project is the development of a solution for the power supply of trolley bus lines across open land track sections.

The measurements during the test journeys served the determination of the bus data as input data for the simulation, as an energy-based line analysis and for verification of the simulation, as well as for the inclusion of the geometrical data of the bus network.

X.3.1.2 Bus parameters and the extension section to Esch

The parameters for the simulation were determined on a test track in urban areas at a maximum of 50 km/h and without gradient and were used unchanged for the simulation on the extension track section. The bus manufacturers have yet to address the following questions:

- Is the maximum performance uphill also available for a longer time of up to 2 min.? In town, the speed range for the maximum performance during acceleration is already exceeded after approx. 5 seconds.
- Does derating uphill start at the same speed and does it have the same magnitude as on a straight line?
- Can the back-fed electricity become as big as the fed-in electricity or is it limited beforehand? Without limitation, regenerative feedback electricity of up to 500A would flow when braking at a stop downhill.
- When braking downhill, is the pneumatic brake switched on? In the simulation, this is not considered.

X-3-2 Simulation of trolleybus networks

With the complexity of electric grids like that of a Trolley bus network, the influence of the numerous parameters and the interaction variety of the variable consumers, if at all, is at most only qualitatively predictable. In order to gain a quantitative idea, too, it makes sense to make use of a computer simulation. The analytical focus is on the preparation of energy balances and network losses (overhead contact system (OCS) losses, braking resistors), the review of the capacitive limit of the electrical network and its stability and the support of the planning process for proposed route extensions. It should be pointed out that, although many time-related parame-

ters are received because these contribute on many different ways to the energy balance, the software is not supposed to issue traffic forecasts, etc.

X.3.2.1 Planning and optimization of a track extension

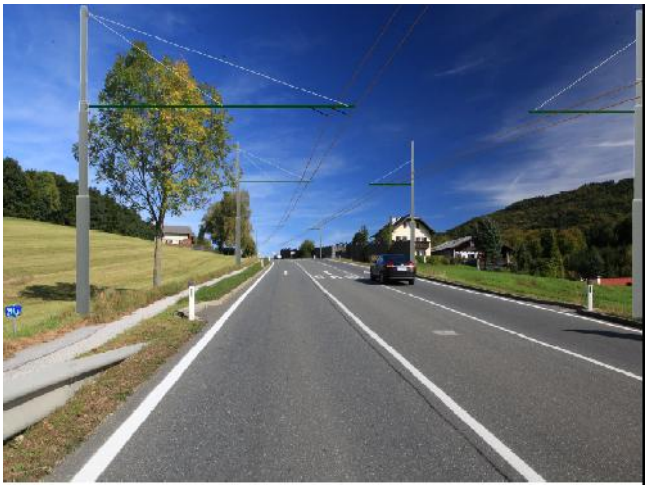
The extension section has special requirements. It concerns an overland route (between the stop Schmiedbauer and the stop Rechl) with gradients of up to 9%. The track section length amounts to 3 km.

It is now a matter of obtaining an energy consumption evaluation as well as an appraisal of the network stability for various versions with the help of the simulation. Here, the positioning of new substations, possible energy stores and the contact wire cross section to be used is by choice. Attention is paid primarily to a stable power supply (particularly in regard of further extensions) and to the height of the regularly appearing power peaks in the planned substations in order to determine the necessary transformer output.

On the sections downhill from Esch to Mayrwies, large outputs can be recuperated. Hence, attention will be paid on the pages to follow also to the energy lost in brake resistors and to options for the reduction of these losses. For the simulation, there is the assumption that braking only takes place electrically.

X.3.2.2 Analysis of Variants

The analysis of variants has been carried out for cross sectional areas of the catenary wire of 80mm², 100mm² and 120mm²,



Variant 1

In Variant 1 the existing mobile infeed station is replaced by a stationary substation. This corresponds to the conventional intuitive approach for network expansion. It is predictable that the voltage drop towards the planned terminus in Esch is problematic owing to the special requirements. This is confirmed by the results of the simulation.

Variant 2

In order to reduce voltage drops in variant 2 towards the track section end, the planned substation is moved to the gradient-intensive part of the new section. By the positioning of the substation in the power-requiring area of the track section, overhead contact system (OCS) losses are meant to be reduced.

Variant 3

Variant 3 is now a combination of the two preceding variants. There are two substations that are newly erected. One of them (substation Mayrwies) replaces the existing mobile substations as in variant 1, while the other one (substation Esch) in turn is positioned midway on the slope of the upgraded line, as in Variant 2.

It strikes immediately that the voltage drops are very low between the two newly positioned substations and also towards the end of the extension to Esch, the voltage on the bus is always more than 540V.

Because of the additional substations, the voltage drops are more favorable in the track section course all together than in Variant 2, and there is no especially high drop between substations 16 and substation Mayrwies. This affects the network losses. Also, the peak loads are distributed better; now between three substations instead of two. In particular, the subnetwork is better decoupled from the power feed of the substations 16 which is thereby subjected to a lower additional load by the planned new stretch. This becomes clear from the independence of the overhead contact system (OCS) cross section from the peak loads in the substations 16.

X.3.2.3 Summary

According to customary planning, one would break down the network into about 3 km feeder segments and have it supplied by the substation without nevertheless finding a concrete esti-

mate for the necessary performance capacity of the transformer installed in the substation. In this manner, trolley networks grow in a natural manner. Variant 1 complies with this intutive approach.

Expected voltage drops were able to be determined by specific simulations (particularly on the critical points), as were power consumptions, network losses (overhead contact system (OCS) losses, brake resistors) and transformer variables. Also, the effect of energy stores can be estimated. On this occasion, beside the reduction of the losses in brake resistors, the contribution of energy stores is to be emphasized particularly to the network stability between feed-in points and to the reduction of the load peaks in the substation. The comparison of the influence of substations and energy stores on the electric grid has shown that it is most sensible to refrains from operating these in a mutually exclusive manner but rather top operate them side by side.

X-4 Eberswalde – Network extension

X-4-1 Introduction

Within the EU-Project Trolley – Promoting Electric Public Transport (WP4) we per-formed an “Analysis of traffic areas regarding the possible grid expansion of Trolley bus networks”. The Trolley bus system under Barnimer Busgesellschaft mbH, which operates in Eberswalde, was central to this study.

In connection with a study in Salzburg which was undertaken at the same time, some general requirements for potential Trolley-bus-grid-extension were found.

The following matters were examined at the core of this analysis:

- Analysis of the Trolley bus system in Eberswalde,
- Demonstration of existing economical parameters,
- Examination of different options to expand the grid in Eberswalde,
- Comparison of matching requirements in Salzburg und Eberswalde,
- Summary of generalised criteria.

It is difficult to compare the studies from Salzburg and Eberswalde as both transport net-works differ significantly in size. Nevertheless, similarities could be found regarding essential parameters.

Generally, it can be said that Trolley bus systems which operate at an average capacity are more economical than similar Diesel bus systems. The future development in energy prices is likely to strengthen Trolley bus systems in the coming years.

The spending used to build the needed infrastructure is a significant cost factor. There-fore, grid expansions have to be seen in this context. The plans in Eberswalde are generally focused on economic requirements of a grid expansion.

It can be generally expected that an improved Trolleybus system would make public transport in general more attractive. Furthermore, Carbon Emissions could be reduced provided that the replacement of Diesel buses is made possible.

It can be said that Trolleybus grid expansions into nearby towns require either a certain amount of travel demand or, respectively, a good operationally and economic integration due to the high investment costs.

X.4.1.1 Fundamentals

There are two central options for a grid expansion for the area under investigation which will be analyzed in more detail. These options are:

- Option A: grid expansion into urban peripheral areas/ suburbs (Section 3.2),
- Option B: grid expansion into nearby towns (section3.3).

Options A and B are presented with a further selection of developed options which will be explained and evaluated.

The following central stages have been developed in the process:

- Decision about business concept,
- Enquiry into the necessity of buses,
- Enquiry into kilometers driven,
- Evaluation of investment and operation cost.

X.4.1.2 Option A: Grid expansion into urban peripheral areas/ suburbs

Option A stands for a grid expansion into urban peripheral areas. In total central option A has 3 alternatives whereby, A2 includes option A1 and offers a further extension.

X.4.1.3 Central Option

The following expansion options can be considered for central option A:

- (A1) Northern area: Termination of circle line,
- (A2) Eastern area: Creation of a circle line,
- (A3) Western area: Diversion into Fritz-Weineck-Straße, Expansion of services towards Wasserturm and Biesenthaler Straße.

Options A1 - A3 are shown in the following map (Fig. 7). Based on the existing data, a concrete evaluation of the travel demand for these 3 options could only be made partially. Essentially, we used regional expertise and conclusion by analogy.

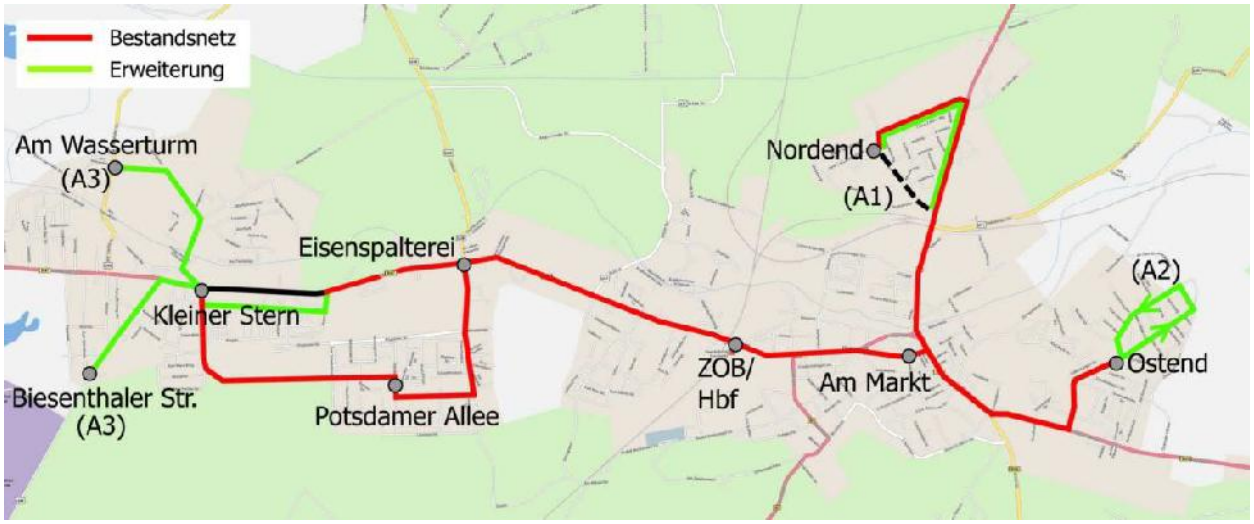


Figure 10.27: Grid expansion into suburbs

(A1) Northern Area: Termination of circle line

The aim in the area north is to end the circle line service which only operates one way via Porazstraße. The stop Rosengrund would no longer be needed. Services to all other stops would

operate in both directions and therefore, the service will be more attractive for the majority of passengers. The following parameters should be considered for this option:

- Interval: 12/15-minutes (no modification),
- Demand for vehicles: no modification,
- Overhead contact wire:
  - New construction of double wire circuit 1,9km (at present only single wire),
  - Deconstruction contact wire Poratzstraße,
- Investment cost: ca. 500.000 € (Prospect: Contact wire poles exist),
- Operating cost: no modification,
- Estimated additional demand: approx. 81.000 trips p.a.

(A2) Eastern area: Creation of a circle line

The aim in the area east is to create a better connection of the area through a grid expansion. This grid expansion would be in form of a 1.7km long circle line which could connect the entire settlement with the Trolley bus network.

The following parameters should be considered for this option:

- Interval: 12/15-minutes,
- Demand for vehicles:
  - 12-minutes-interval: +1 (otherwise no journey time reserve),
  - 15-minutes-interval: no modification,
- Timetable-km (additional demand): ca. 33.000 km/year,
- Overhead contact wire:
  - New construction of single contact wire max. 1,7 km,
  - Depending on configuration of street, currently not possible,
- Investment cost:
  - Contact wire: ca. 680.000 € (80 % double wire circuit),
  - Vehicle: 680.000 €,
- Operationg cost per year (additional demand):
  - Energy: 12.000 €,
  - Staff: 37.000 €,
  - Repair/ maintenance: 16.000 €,
  - Vehicle insurance: 4.000 €,
  - Operating cost total/year: + 69.000 €,

- Estimated additional demand: approx. 62.000 trips p.a..

(A3) Western Area: Diversion of service into Fritz-Weineck-Straße

A diversion of the Trolley bus service from Eberswalder Straße into Fritz-Weineck-Straße allows a better connection of the local settlement.

The following parameters should be considered for this option:

- Interval: 12/15-minutes,
- Demand for vehicles: no modification,
- Overhead contact wire:
  - New construction of double wire circuit 1,1 km,
  - Deconstruction contact wire Eberswalder Str. is needed,
- Investment cost: overhead contact wire 550.000 €,
- Operating cost: constant,
- Estimated additional demand: approx. 44.000 trips p.a..

Extension towards Wasserturm

In recent years a new settlement with private properties was developed in the area Wasserturm in the suburb of Finow. An extension of the Trolleybus network would make this settlement more accessible.

The following parameters should be considered for this option:

- Interval: 12/15-minutes,
- Demand for vehicles: + 1 vehicle (only in 12-minute interval),
- Timetable-km (additional demand): approx. 58.000 km/year,
- Contact wire: New construction of double wire circuit 1,5 km,
- Investment cost:
  - Contact wire: ca. 750.000 €,
  - Vehicle: 680.000 €,
- Operating cost per year (additional demand):
  - Energy: 21.000 €,
  - Staff: 91.000 €,
  - Repair/ maintenance: 28.000 €,

  - Insurance vehicle: 4.000 €,
  - Operating cost total/year: + 144.000 €,
- Estimated additional demand: approx. 31.000 trips p.a..

Extension Biesenthaler Str.

The extension into Biesenthaler Straße will lead to an improved connection with the former city centre in the suburb Finow.

The following parameters should be considered for this option:

- Interval: 12/15-minutes,
- Demand for vehicles: + 1 vehicle (only in 12-minute-interval),
- Timetable-km (additional demand): approx. 50.000 km/year,
- Contact wire: New construction of double wire circuit 1,3 km,
- Investment cost:
  - Contact wire: ca. 650.000 €,
  - Vehicle: 680.000 €,
- Operating cost per year (additional demand):
  - Energy: 18.000 €,
  - Staff: 91.000 €,
  - Repair/ maintenance: 24.000 €,
  - Insurance vehicle: 4.000 €,
  - Operating cost total/year: + 137.000 €,
- Estimated additional demand: approx. 72.000 trips p.a.

X.4.1.4 Supplementary Option

This supplementary option is an extension of option A3. It is suggested to connect the extensions Wasserturm and Biesenthaler Straße in the area west to a circle line (see figure 8).

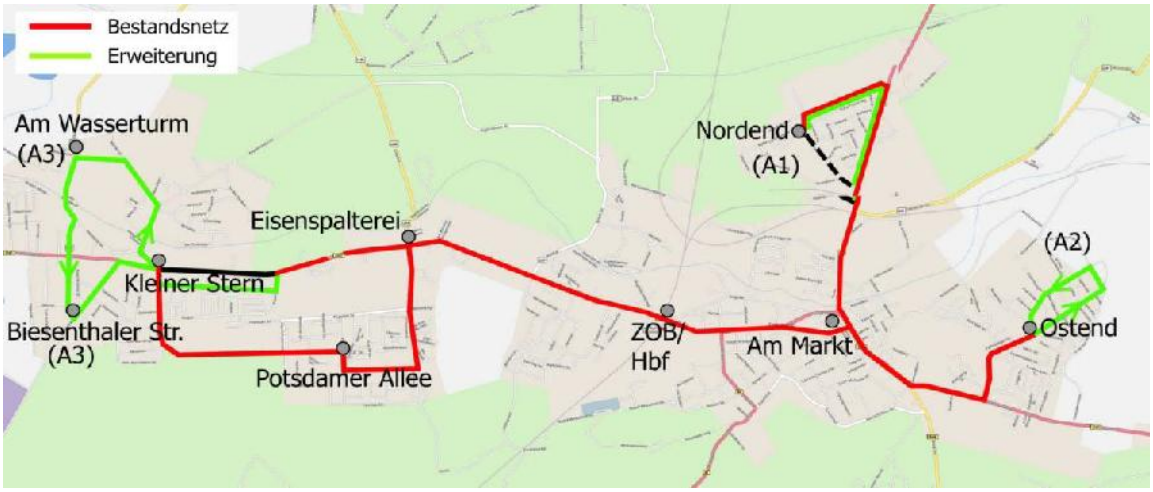


Figure 10.28: Grid expansion into suburbs–Supplementary option

The following parameters should be considered for this option:

- Interval: 12/15-minutes,
- Demand for vehicles: + 2 vehicles (only in 12-minute-interval),
- Timetable-km (additional demand): approx. 76.000 km/year,
- Contact wire: New construction of singe overhead contact wire 3,9 km,
- Investment cost:
  - Contact wire: ca. 1.560.000 € (80 % double wire circuit),
  - Vehicle: 1.360.000 €,
  - Operating cost per year (additional demand):
  - Energy: 27.000 €,
  - Staff: 185.000 €,
  - Repair/ maintenance: 36.000 €,
  - Insurance vehicle: 8.000 €,
  - Operating cost total/year: + 256.000 €,
- Estimated additional demand: approx. 94.000 trips p.a..

In summary, this option appears to be problematic in traffic terms. The busstop Kleiner Stern could be the first possible destination on the route into area west. The introduction of a circle line connecting Wasserturm and Biesenthaler Str. would, due to the distance that would have to be covered, become unattractive as scheduled departure times would fall out of relation with normal service intervals in a public transport system.

X.4.1.5 Option B: Grid expansion into nearby towns

In order evaluate the grid expansion into nearby townships of Eberswalde the following options were investigated:

- Option B1: Extension West: Kleiner Stern – Finowfurt (Section 3.3.1),
- Option B2: Extension North: Nordend – Britz (Section 3.3.2),
- Option B3: Extension East: Ostend – Niederfinow – Oderberg (Section 3.3.3).

The following map (Figure 9) shows the locations of the towns and the routes of the different options. The expected number of passengers derives from conclusion by analogy of the existing transport characteristics.

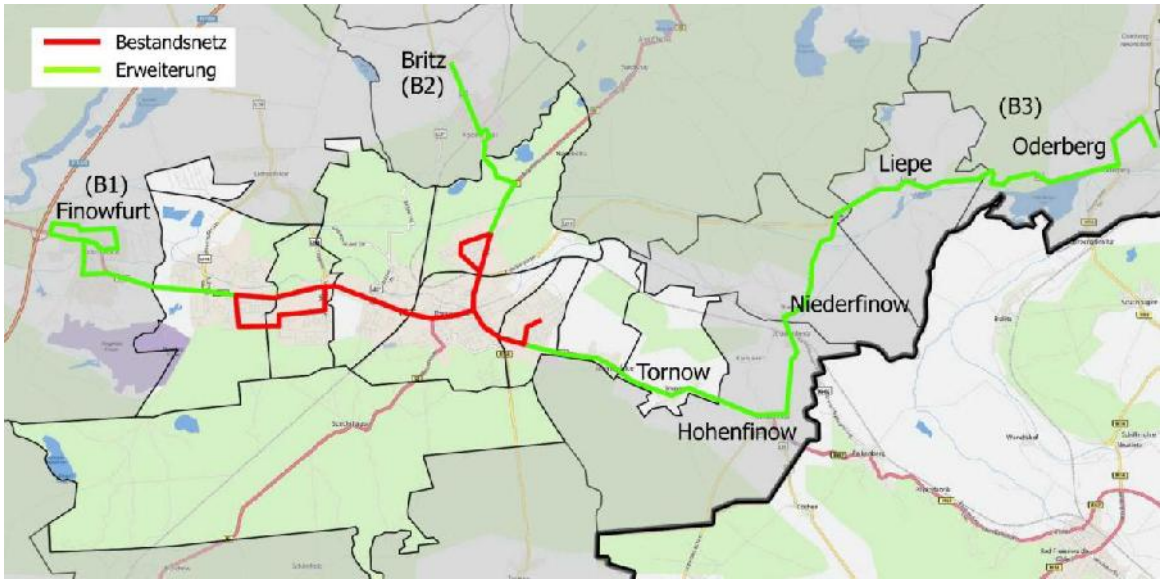


Figure 10.29: Grid expansion into nearby towns

Option B1: Extension West: Kleiner Stern – Finowfurt

Finowfurt is the largest township in the surroundings of Eberswalde with a population of 4.600. The Trolley bus grid extension into this direction would open a fundamental new potential for the system. The new route to Finowfurt would be 8.6km long and would operate as a circle line in the town of Finowfurt.

The following parameters should be considered for this option:

- Interval: 30 minutes,
- Demand for vehicles: + 2 vehicles,
- Timetable-km: approx. 164.000 km/year (05:00-22:00),
  - Savings: Buslinie 910 Finowfurt – Eberswalde Busbf., 2 Diesel buses,
- Investment cost:
  - Overhead contact wire: 3.900.000€ (4,6km double wire circuit - und 4,0 km single contact wire),
  - Vehicle: 1.360.000 €,
  - Traction substation: 1 (1,3 Mio. €),
  - Operating cost per year: Energy: 59.000 €,
  - Staff: 74.000 € (Longer working hours),
  - Repair/ maintenance: 78.000 €,
  - Insurance vehicle: 8.000 €,
  - Operating cost total/year: 219.000 €,
- Estimated additional demand on the extension routes p.a.: 168.000 trips.

X.4.1.5.1 Option B2: Extension North: Nordend – Britz

The nearby township Britz has a population of 2.200. A grid expansion reaching Britz Dorf (approx. 5 km) would at the same time offer better access for Trolleybuses to the suburb Nordend.

The following parameters should be considered for this option:

- Interval: 60 minutes,
- Demand for vehicles: + 1 vehicles,
- Timetable-km: approx. 62.000 km/year,
  - Savings: Bus line 922 Eberswalde Busbf. – Britz, 1 Diesel bus,
- Investment cost:
  - Overhead contact wire 2.500.000 €,
  - Vehicle: 680.000 €,
  - Traction substation: 1 (1,3 Mio. €),
- Operating cost per year:
  - Energy: 23.000 €,
  - Staff: 37.000 € (Longer working hours),
  - Repair/ maintenance: 30.000 €,
  - Insurance vehicle: 4.000 €,
  - Operating cost total/year: 94.000 €,
- Estimated additional demand on the extension routes p.a.: 80.000 trips.

X.4.1.5.2 Option B3: Extension East: Ostend – Niederfinow – Oderberg

Option B3 represents a new route from the suburb Ostend to the town Oderberg, Fonta-neplatz with a total length of 22km. Compared with the previous plans for grid expansions into nearby towns, this options takes it one step further. The route will extend through the following towns:

- Tornow (ca. 200 residents),
- Hohenfinow (ca. 500 residents),
- Niederfinow (ca. 600 residents),
- Liepe (ca. 800 residents),
- Oderberg (ca. 2.200 residents).

This will cover a total of 4.300 residents.

Furthermore, this option would provide access to the ship hoist Niederfinow with around 500.000 visitors per annum.

The following parameters should be considered for this option:

- Interval: 60 minutes,
- Demand for vehicles: + 2 vehicles,
- Timetable-km: approx. 273.000 km/year,
  - Savings: Bus line 916 Eberswalde Busbf. – Oderberg, 2 Diesel buses,
- Investment cost:
  - Overhead contact wire: 11.000.000 €,
  - Vehicle: 1.360.000 €,
  - Traction substation: 2 (2,6 Mio. €),
- Operating cost per year:
  - Energy: 98.000 €,
  - Staff: 73.000 € (Longer working hours),
  - Repair/maintenance: 129.000 €,
  - Insurance vehicles: 8.000 €,
  - Operating cost total/year: 308.000 €,
- Estimated additional demand on the extension routes p.a.: 307.000 trips.

X-4-2 Summary

Precisely, the following parameters can be established for Option A.

Option / Area	Additional vehicle demand	Timetable-km/year (additional demand)	Investment cost [€]	Operating cost / year [€]	Estimated potential for demand [trips p.a.]
Central Options					
A1 / North: termination circle line	none	none	500.000	0	ca. 81.000
A2 / East: Creation of a circle line	max. 1	33.000	1.360.000	69.000	ca. 62.000
A3 / West: Diversion into Fritz-Weineck-Str.	none	none	550.000	0 (compared with old route)	ca. 44.000
Extension Wasserturm	1 (at 12'-interval)	58.000	1.430.000	144.000	ca. 31.000
Extension Biesenthaler Str.	1 (at 12'-interval)	50.000	1.330.000	137.000	ca. 72.000
Supplementary Option					
Circle Line Wasserturm / Biesenthaler Str.	2 (at 12'-interval)	76.000	2.920.000	256.000	ca. 94.000

Table 10.30: Parameters Option A

Based on the expected cost consideration it can be generally said that the options

- A1 termination circle line North and
- A3 Trolley bus diversion into Fritz-Weineck-Straße

are rational options. As there is no additional expenditure in the production cost, only long term investment costs have to be considered.

The circle line Ostend (A2) cannot be rationally realized due to the high investment cost. This also applies for all other options under A3 and for the supplementary option.

The results for option B are summarized in the following table.

Area	Demand for vehicles	Timetable-km / year	Investment-cost [€]	Operating cost / year [€]	Estimated potential for demand [trips p.a.]
B 1: West: Kleiner Stern - Finwofurt	2	164.000	6.560.000	219.000	168.000
B 2 North: Nordend - Britz	1	62.000	4.480.000	94.000	80.000
B 3 East: Ost-end - Niederfi-now - Oder-berg	2	273.000	14.960.000	308.000	307.000

Table 10.31: Key data Option B

All three options for the expansion of the Trolley bus system have to be viewed critically due to high investment costs and the in comparison relatively little expected demand. Additionally, the Trolley bus operation across longer distances in the country site shows some disadvantages, for example:

- Trolley buses have a lower high-speed than Diesel buses,
- The advantage Trolley buses have in their ability to accelerate quickly is irrelevant because distances between bus stops are greater than in town.

Therefore, especially Option B3 is problematic. Nevertheless, there is some potential present between Eberswalde and Niederfinow.

When only considering costs of operation in relation to expected usage economic relations can be seen.

Checklist

The following checklist provides an overview of the essential information and fundamentals which can help to recognize the value of a possible Trolley bus grid expansion. It is not the aim to replace technical and economical detailed analyses but to provide regional policy makers and action groups with a list of general conditions and test measures in order to start analyzing a project. In doing so, the following questions and aspects should be examined and considered in the initial planning.

Activity	Criteria	Aim
I. Conceptual Requirements	• Which extensions should be included in the considerations? • Where will the extension join the existing grid? • How could a potential route look like? • Which Diesel bus lines already operate in or near the planned vicinity? • Is it possible to replace those or to relocate them? • Which other aspects should be considered? • Would the project offer any economic advantages?	**Classification of the project and identification of significant requirements**
II. Travel Demand	• What is the current travel demand in the area under investigation for the Diesel bus? • Can the Trolley bus provide a better accessibility for the existing settlements? • Can additional potential demand be developed for public transport?	**Evaluation of potential de-mand**
III. Operational Requirements	• Which lines or which particular line shall operate in the expansion area? • In what intervals are the buses planned to operate? • What is the demand for staff and vehicles? • What costs incur from	**Outline of the expected operational performance parameters and of the connected cost for vehicles, staff and the com-**

	that? • What distance and how many kilometers will the service cover? • Can capacities be saved in the conventional Diesel bus system?	**pany**
IV. Infrastructural Needs	• Which infrastructural adjustments have to be made? • What costs incur for: o Contact wire? o Traction substation? o Bus stops? o Other parameters (e.g. new terminal loop)?	**Assessment of the to expected Investment needs**
V. Tariff and Returns	• Do negotiated conditions have to be considered? • What returns can be expected?	**Overview over expected revenue**
VI. Total Assessment	**Overall decision of the value** derived from the parameters • Achievable travel demand and return situation • Estimated operational costs • Estimated investment cost.	

Annex 1

Criteria used for the Montreal study for the classification of potential routes/corridors for trolleybus operations

When the study was launched, there were no trolleybuses circulating in Montreal, nor in the province of Quebec for that matter. Hence, customer service planners had to develop a decision matrix to identify, on the one hand the bus lines that could be good candidates for a roll-over to trolleybus lines. On the other hand, they had to identify roads that were appropriate for the operation of trolleybuses. They decided to start with the identification of potential bus lines. The basic premise was that, given the magnitude of the investment that would be required, trolleybuses would have to be operated on bus lines that:

- Have a significant ridership (to optimize the cost/passenger investment);
- Are busy throughout the day (not only during peak hours – to optimize the return on investment);
- Require the same number of buses in both travel directions. (In Montreal we operate an interlined system; hence a bus will travel in the direction of the travel demand and when it reaches the end of the line, it is assigned to another line. It does not necessarily return on the same line in the opposite direction. This system optimises the use of buses without penalizing the customers. Because trolleybuses will need to remain under the overhead wires, it was cost effective to plan their use on lines where the need for buses is the same in both directions;
- Operate on roads where the commercial speed remains fluid (to avoid having expensive trolleybuses stuck in traffic and not moving);

  After applying these four criteria, the STM was able to select 16 of its more than 200 bus line, as potential trolleybus lines.

The next task was to assess the potential of the roads, on which these 16 bus lines travelled, to support a trolleybus network. Given the complexity of the task and the significant number of determining factors, a decision matrix was prepared. Initially, the matrix contained 43 criteria which fit into four categories: feasibility of implementation, operational feasibility, urban integration feasibility, and impact on fuel consumption. Upon careful analysis of these criteria and with the expert assistance of the personnel from Lausanne Transport in Switzerland, it was quickly concluded that, to achieve the objective of shortening the list of potential roads/bus lines, only 12 of them needed to be retained. These criteria and their relevant weights are:

- **Criterion 1** – Aerial obstacles with contact lines
  - Objective of the criterion - Penalize those streets that have several aerial electrical lines crossings which would interfere with the trolleybus overhead contact lines. These lines would likely require to be buried, thus increasing network implementation costs.

    The weight factor of this criterion 5%.

- **Criterion2** – Crossings under works of art
  - Objective of the criterion - This criterion is divided into two separate criteria, to highlight the difficulty of implanting electrical equipment to permit passage of the trolleybus.
    The penalty associated with the first case (clearance ranging from 4.95 m to 4.15 m) relates to the risk associated with a typical power equipment installation under a bridge.
    The penalty associated with the second case (clearance less than 4.15 m) refers to the additional operating costs that the lowering and raising of poles upstream and downstream of these structures would generate, in view of the inability to install overhead contact lines on these very low clearance works of art.

    The weight factor of this criterion 10%.

- **Criterion 3** – Crossing over works of art
  - Objectives of the criterion – highlight the difficulty of implanting electrical equipment on structures whose deck length exceeds 30m. Indeed, it is unlikely that new equipment be installed on these structures to avoid damaging their structural integrity.

    The weight factor of this criterion 5%.

- **Criterion 4** – Geometric complexity
  - Objectives of the criterion - highlight the impact on the landscape and the important capital costs that complex geometries such as sharp bends (45 °turns) and crossing of major intersections (intersections over 30m in length) may generate.

    The weight factor of this criterion is 10%.

- **Criterion 5** – Area of the canopy

- Objectives of the criterion - to penalize the streets whose canopy cover would significantly interfere with the overhead contact lines.

  The weight factor of this criterion is 5%.

- **Criterion 6** – Patrimonial sectors
  - Objective of the criterion - assesses the risk associated with the installation of electrical power equipment in a protected area (as defined at article 47.1 of the Cultural Property Act).

    The weight factor of this criterion is 5 %.

- **Criterion 7** – Number of vacant lots for the installation of electrical sub-stations
  - Objective of the criterion - to favour streets lined by 150 m2 lots, to facilitate the installation of electrical substations.

    The weight factor of this criterion is 10 %.

- **Criterion 8** – The density of population affected by the passing of buses
  - Objective of the criterion - to quantify the gains relating to atmospheric pollution and noise reduction for local communities.

    The weight factor of this criterion is 10 %.

- **Criterion 9** – Directional equilibrium ratio
  - Objective of the criterion –to penalize the streets on which the number of bus departures in each direction is not balanced. Bus lines on these streets are significantly interlined with bus lines on other streets; introducing trolleybuses on these lines would significantly affect the efficiency of the interlining system.

    The weight factor of this criterion is 10 %.

- **Criterion 10** – Distance to the terminus
  - Objective of the criterion - The criterion relates to the distance between the bus depot and the line's terminus. The shorter is the distance, the better it is for operations.

The weight factor of this criterion is 10 %.

- **Criterion 11** – Number of passengers per kilometre
  - Objective of the criterion - Prioritise bus lines with very important ridership. Given the important cost of electrical network infrastructures it was thought advisable to transport a maximum of passengers with the new trolleybus network.

  - The weight factor of this criterion is 5 %.

- **Criterion 12** – Commercial speed
  - Objective of the criterion – Prioritise streets on which circulation is more fluid. Given the important cost of trolleybuses and of their electrical network infrastructure, it was thought advisable to avoid having «brand new» trolleybuses continuously stuck in traffic.

  The weight factor of this criterion is 15 %.

The criteria listed above are specific to Montreal's environment and have been provided as examples. However, discussions with experts from Lausanne Transport indicate that some of these criteria are universal.

The identification, collection and analysis of the data required to carry out the ordering of the roads/bus lines originally selected, from best suited to worst suited represents a significant effort in coordination and communication. For example, the required data for the Montreal study project had to be obtained from over 20 municipal and public organizations. Once the data is collected and the multicriteria matrix is completed, a sensitivity analysis of the various criteria can be carried out by modifying the assigned weight factors.

Three (3) primary trolleybus infrastructure implementation principles

1. Leave the existing urban furniture as is and interpose the trolleybus infrastructure between existing infrastructures;

Figure 1: Trolleybus infrastructure interposed amongst existing infrastructure.
Source: Feasibility study for the implementation of the trolleybus in Laval, Québec

2. Pooling of services: integration of public services (Technical Urban Network and lighting) on new Masts necessary for electrification;

Figure 2: Public technical services pooled with trolleybus requirements on new poles.
Source: Feasibility study for the implementation of the trolleybus in Laval, Québec

3. Burial of all aerial components of the urban technical network

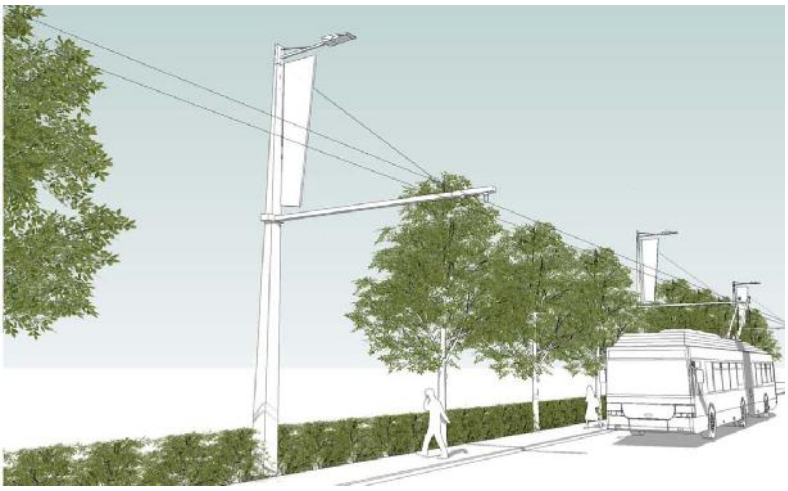


Figure 3: Burial of all aerial components of the urban technical network.

Source: Feasibility study for the implementation of the trolleybus in Laval, Québec

Four (4) mast types for new implementations

1. Type A : Mast with contact lines only

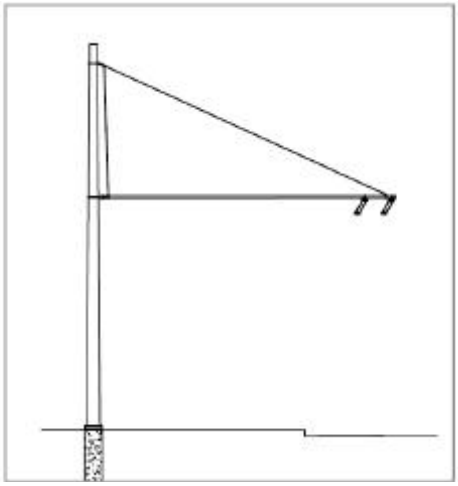


Figure 4: Type A – contact lines only

Source: Feasibility study for the implementation of the trolleybus in Montreal, Québec

2. Type B: Mast with contact lines and public lighting

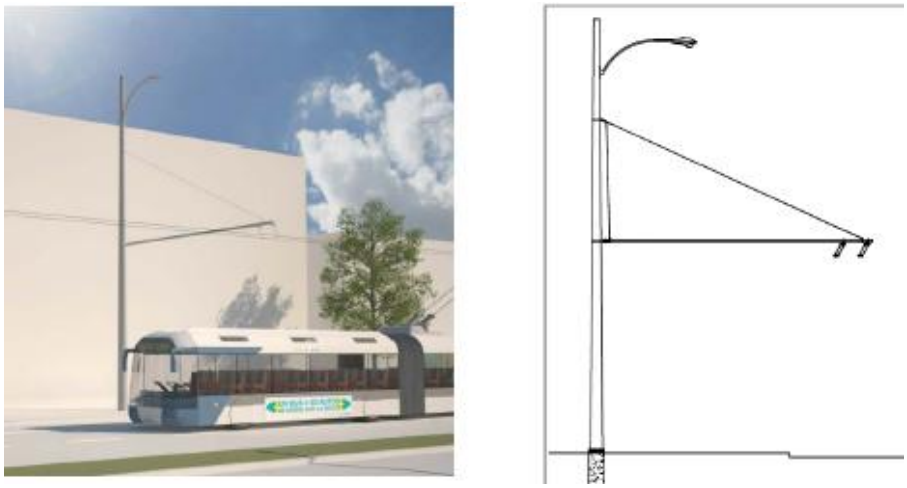


Figure 5: Type B – contact lines and public lighting

Source: Feasibility study for the implementation of the trolleybus in Montreal Québec

Type C: Mast with contact lines, public lighting and Urban technical network

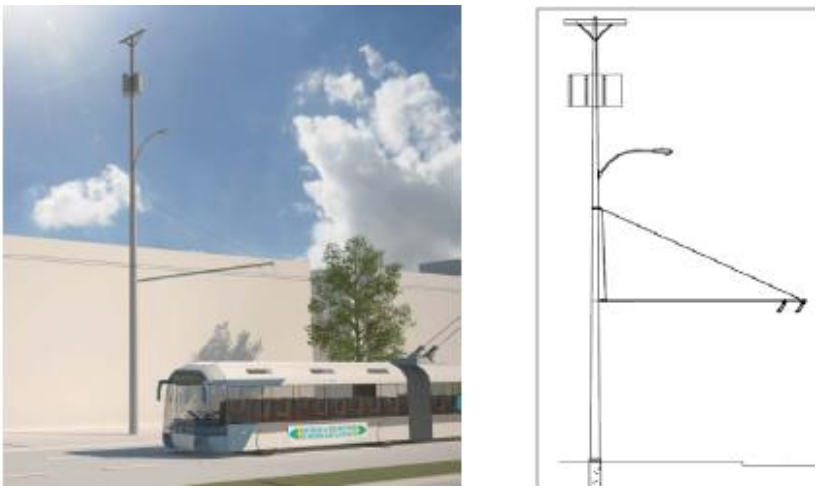


Figure 6: Type C – contact lines, public lighting and Urban technical network

Source: Feasibility study for the implementation of the trolleybus in Montreal Québec

3. Type D : Mast with contact lines and Urban technical network

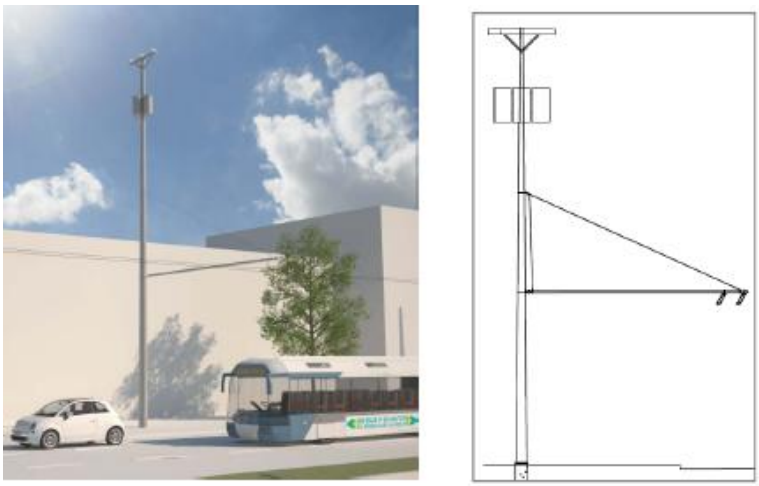


Figure 7: Type D – contact lines and Urban technical network

Source: Feasibility study for the implementation of the trolleybus in Montreal Québec

Four (4) electrical network configurations

1. **Configuration 1: Simple "one way" console:** it is a pole with brackets; the latter may have a length varying between 1 and 10 meters. It takes two consoles to address both travel directions of the trolley;

Figure 8: Configuration 1 - Simple "one way" console

Source: Feasibility study for the implementation of the trolleybus in Montreal Québec

2. **Configuration 2: Double console:** it is a Mast with a pole extending an equal distance on each side. It can hold the contact lines for both travel directions of the trolleybuses. The length of the pole extensions are the same as for the basic console "one way", that is 1 to 10 meters per direction (2-20 meters in total).

Figure 9: Configuration 2 - Double console

Source: Feasibility study for the implementation of the trolleybus in Montreal Québec

3. **Configuration 3: flexible portal (or rope cross)**: This is a Mast to which is attached a transverse rope. This system, often called "PARAFIL", is usually installed with two poles facing each other. However, if existing poles are staggered, it is still possible to install the flexible portal, but the contact line installation will be more complex and the visual impact will likely be greater;

Figure 10: Configuration 3 – flexible portal

Source: Feasibility study for the implementation of the trolleybus in Montreal Québec

4. **Configuration 4: Simple "two way" console:** it is a Mast with a pole extending to one side sufficiently far to reach two lanes. The pole is longer than that of the Simple "one way" console, allowing it to serve two traffic lanes of traffic circulating in opposite directions. This implementation is typically used on very narrow routes/corridors.

Figure 11: Configuration 4 – Simple "two way" console

Source: Feasibility study for the implementation of the trolleybus in Montreal Québec

Annex 2: Line data for line 70

Anlage III-4.1
Blatt-Nr.: 1

Liniennr.: **70**
von: **Mockau-West**
nach: **Connewitz, Kreuz**

Fahrzeit A Mo - Fr 6.00 - 18.00 Uhr
Fahrzeit B tägl. 22.00 - 5.00 Uhr, Sa+So bis 10.00 Uhr
Fahrzeit C So 10.00 - 22.00 Uhr, Mo - Fr 20.30 - 22.00 Uhr
Fahrzeit F Mo - Fr 18.30 - 20.30 Uhr, Sa 10.00 - 20.30 Uhr

Haltestelle		Entfernung zur vorherigen Haltestelle	Lage / Position der Haltestelle auf Linie	Fahrzeit (incl. Haltezeit)				Ø Haltezeit / Wendezeit am Endpunkt	Höhenmeter		Gefällesituation		Fahrgastwechsel				Besonderheiten (z.B. längere verkehrsbedingte Halte)
Epon / Kenn-Nr.	Haltestellenname			A	B	C	F	A	(+) steigend	(-) fallend	Ø Steig.	Ø Gefälle	Ø Einsteiger	Ø Aus-steiger	Differenz	Änderung Zuladung	
		(m)	(m)	(min)	(min)	(min)	(min)	(s)	(m)	(m)	(%)	(%)	(Pers.)	(Pers.)	(Pers.)	(kg)	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	Mockau-West	319	0	1	1	1	1	600					7,5				
	Schildberger Weg	351	319	1	1	1	1	8	112	207	4,21	1,85	2,2	2,2	0	0	
	Otto-Michael-Straße	658	670	2	2	2	2	11	41	292	0,22	1,31	3,0	3,0	0	0	
	Mockau, Post	440	1.328	1	1	1	1	18	114	541	0,22	1,33	4,2	4,2	0	0	
	Samuel-Lampel-Straße	254	1.768	1	1	1	1	7	318	122	1,71	2,00	1,3	1,3	0	0	
	Mockau, Kirche	615	2.022	2	2	2	2	5	177	77	1,01	0,96	0,7	0,7	0	0	
	Thekla, Buswendestelle	58	2.637	0	0	0	0	0	100	497	0,57	1,38	0,0	0,0	0	0	
	Thekla, Tauchaer Straße	512	2.695	2	2	2	2	17	58	0	2,55	0,00	1,8	1,8	0	0	
	Neutzscher Straße	581	3.207	2	1	1	1	14	381	114	1,85	2,02	2,0	2,0	0	0	
	Sosaer Straße	355	3.788	1	1	1	1	4	432	149	1,61	0,46	0,3	0,3	0	0	
	Freiberger Straße	498	4.143	1	1	1	1	13	19	336	1,76	1,23	2,4	2,4	0	0	
	Bf. Thekla	394	4.641	1	1	1	1	3	100	497	0,93	1,57	0,8	0,8	0	0	
	Heiterblickstraße	470	5.035	1	1	1	1	3	248	146	0,77	1,55	0,4	0,4	0	0	
	Stöhrer-/Theklaer Straße	590	5.505	1	1	1	1	4	210	243	2,06	1,56	0,3	0,3	0	0	
	Stöhrer-/Braunstraße	303	6.095	1	1	1	1	5	548	42	1,33	1,19	1,4	1,4	0	0	
	Schönefeld-Ost	326	6.398	1	1	1	1	4	143	160	0,85	1,03	1,0	1,0	0	0	
	Braun-/Bautzner Straße	213	6.724	1	1	1	1	4	132	190	0,92	1,55	0,3	0,3	0	0	
	Bertolt-Brecht-Straße	387	6.937	1	1	1	1	12	114	92	0,70	0,78	2,2	2,2	0	0	
	Julian-Marchlewski-Straße	535	7.324	2	2	2	2	16	93	294	0,56	1,23	6,3	6,3	0	0	
	Löbauer Straße	533	7.859	2	1	1	1	14	87	448	0,60	1,74	4,3	4,3	0	0	
	Stöckelstraße	491	8.392	1	1	1	1	20	429	104	1,15	2,18	5,6	5,6	0	0	
	Stannebeinplatz	591	8.883	2	2	2	2	16	310	181	0,53	0,69	5,6	5,6	0	0	
	H.-Liebmann-/Eisenbahnstraße	405	9.474	1	1	1	1	19	377	131	2,34	3,55	7,4	7,4	0	0	
	Dornbergerstraße	334	9.879	1	1	1	1	13	151	254	0,75	1,84	1,8	1,8	0	0	
	Bergstraße	328	10.213	1	1	1	1	9	134	200	0,41	0,94	1,5	1,5	0	0	
	Reudnitz, Koehlerstraße	509	10.541	2	2	2	2	24	236	92	1,93	0,77	5,7	5,7	0	0	
	Breite Straße	566	11.050	2	2	2	2	20	293	216	1,29	2,03	6,8	6,8	0	0	
	Riebeck-/Oststraße	413	11.616	1	1	1	1	17	335	176	2,41	1,21	3,7	3,7	0	0	
	Riebeck-/Stötteritzer Straße	306	12.029	1	1	1	1	13	247	166	2,12	1,00	2,0	2,0	0	0	
	Technisches Rathaus	552	12.335	2	2	2	2	9	91	215	0,92	1,68	1,2	1,2	0	0	
	Altes Messegelände	345	12.887	1	1	1	1	11	503	49	1,60	0,15	1,2	1,2	0	0	
	Naunhofer Straße	425	13.232	1	1	1	1	17	247	98	1,66	0,59	2,9	2,9	0	0	
	An der Tabaksmühle	841	13.657	2	2	2	2	4	119	306	5,40	0,83	0,7	0,7	0	0	
	R.-Lehmann-/Zwickauer Straße	839	14.498	2	1	2	2	10	216	625	0,63	1,51	0,7	0,7	0	0	
	Altenburger Straße	272	15.337	1	1	1	1	9	308	531	0,85	2,04	0,7	0,7	0	0	
	A.-Hoffmann-/R.-Lehmann-Str.	330	15.609	2	1	1	1	7	174	92	1,01	1,07	0,4	0,4	0	0	
	K.-Liebknecht-/R.-Lehmann-Str.	490	15.939	2	1	2	2	11	139	177	0,24	0,57	0,2	0,2	0	0	
	Connewitz, Kreuz		16.429					554	347	143	1,08	1,83	9,5	9,5	0	0	
Summe		16.429		50	45	47	47	1543	8.086	8.200							
	durchschn. Haltestellenabst. (m)	444	Ø- SOLL Geschw.(km/h)	19,71	21,91	20,97	20,97										

Anlage III-4.1

Blatt-Nr.: 2

Liniennr.: **70**
von: **Connewitz,Kreuz**
nach: **Mockau-West**

Fahrzeit A Mo - Fr 6.00 - 18.00 Uhr
Fahrzeit B tägl. 22.00 - 5.00 Uhr, Sa+So bis 10.00 Uhr
Fahrzeit C So 10.00 - 22.00 Uhr, Mo - Fr 20.30 - 22.00 Uhr
Fahrzeit F Mo - Fr 18.30 - 20.30 Uhr, Sa 10.00 - 20.30 Uhr

Haltestelle		Entfernung zur vorherigen Haltestelle	Lage / Position der Haltestelle auf Linie	Fahrzeit (incl. Haltezeit)				Ø Haltezeit / Wendezeit am Endpunkt	Steigungs- / Gefällelänge		Gefällesituation		Fahrgastwechsel (Mittelwert je Haltestelle ohne Bezug zum Fahrtverlauf)				Bemerkungen
Epon / Kenn-Nr.	Haltestellenname			A	B	C	F	A	(+) steigend	(-) fallend	Ø Steig.	Ø Gefälle	Ø Einsteiger	Ø Aus-steiger	Differenz	Änderung Zuladung	
		(m)	(m)	(min)	(min)	(min)	(min)	(s)	(m)	(m)	(%)	(%)	(Pers.)	(Pers.)	(Pers.)	(kg)	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	Arno-Nitzsche-Straße	206	0	1	1	1	1	543					3,1				
	Connewitz, Kreuz	403	206	2	2	2	2	15	92	114	3,19	1,50	6,9	6,9	0	0	
	K.-Liebknecht-/R.-Lehmann-Str.	233	609	1	1	1	1	13	18	385	0,11	0,90	3,6	3,6	0	0	
	A.-Hoffmann-/R.-Lehmann-Str.	317	842	1	1	1	1	9	142	91	0,81	1,17	1,6	1,6	0	0	
	Altenburger Straße	794	1.159	2	1	1	1	10	204	113	0,62	0,99	1,7	1,7	0	0	
	R.-Lehmann-/Zwickauer Straße	981	1.953	2	2	2	2	12	441	353	2,01	1,35	2,0	2,0	0	0	
	An der Tabaksmühle	388	2.934	1	1	1	1	6	787	194	1,93	0,26	0,2	0,2	0	0	
	Naunhofer Straße	427	3.322	2	2	2	2	21	207	181	1,14	3,56	1,7	1,7	0	0	
	Altes Messegelände	470	3.749	2	1	2	2	16	78	349	0,27	2,88	3,4	3,4	0	0	
	Technisches Rathaus	198	4.219	1	1	1	1	5	66	404	0,51	2,17	2,2	2,2	0	0	
	Riebeck-/Stötteritzer Straße	439	4.417	1	1	1	1	12	21	177	0,85	0,91	2,4	2,4	0	0	
	Riebeck-/Oststraße	519	4.856	2	2	2	2	15	242	197	1,63	1,72	0,4	0,4	0	0	
	Breite Straße	641	5.375	2	2	2	2	17	248	271	0,80	1,84	11,0	11,0	0	0	
	Reudnitz, Koehlerstraße	258	6.016	1	1	1	1	24	290	351	1,05	2,97	5,8	5,8	0	0	
	Bergstraße	397	6.274	1	1	1	1	9	19	239	1,72	1,34	1,1	1,1	0	0	
	Dombergerstraße	261	6.671	1	1	1	1	11	221	174	0,72	0,40	1,3	1,3	0	0	
	H.-Liebmann-/Eisenbahnstraße	716	6.932	2	2	2	2	23	152	109	3,56	0,40	3,6	3,6	0	0	
	Stannebeinplatz	474	7.648	1	1	1	1	16	216	500	3,39	1,51	3,5	3,5	0	0	
	Stöckelstraße	375	8.122	1	1	1	1	13	270	204	0,51	0,68	1,8	1,8	0	0	
	Löbauer Straße	662	8.497	2	2	2	2	18	113	262	1,01	0,97	3,9	3,9	0	0	
	Julian-Marchlewski-Straße	388	9.159	1	1	1	1	14	512	132	1,39	1,62	1,2	1,2	0	0	
	Bertolt-Brecht-Straße	228	9.547	1	1	1	1	8	281	107	1,13	1,08	0,4	0,4	0	0	
	Braun-/Bautzner Straße	307	9.775	1	0	0	0	2	81	97	0,39	0,93	0,2	0,2	0	0	
	Schönefeld-Ost	484	10.082	1	1	1	1	3	199	108	1,42	2,15	0,0	0,0	0	0	
	Stöhrer-/Braunstraße	442	10.566	1	1	1	1	4	146	338	0,97	0,78	0,1	0,1	0	0	
	Stöhrer-/Theklaer Straße	483	11.008	1	1	1	1	3	17	407	2,90	1,85	0,1	0,1	0	0	
	Heiterblickstraße	390	11.491	1	1	1	1	3	207	276	1,69	1,84	0,1	0,1	0	0	
	Bf. Thekla	531	11.881	1	1	1	1	3	199	191	1,51	0,83	0,3	0,3	0	0	
	Freiberger Straße	287	12.412	1	1	1	1	11	425	106	1,34	1,19	1,3	1,3	0	0	
	Sosaer Straße	586	12.699	2	1	2	2	3	227	60	1,77	0,73	0,2	0,2	0	0	
	Neutzscher Straße	498	13.285	2	2	2	2	10	80	506	1,68	1,33	1,0	1,0	0	0	
	Thekla, Tauchaer Straße	558	13.783	2	2	2	2	15	148	350	1,34	2,00	0,8	0,8	0	0	
	Mockau, Kirche	254	14.341	1	1	1	1	6	450	108	1,07	0,67	0,3	0,3	0	0	
	Samuel-Lampel-Straße	468	14.595	1	1	1	1	8	128	126	1,32	1,81	0,3	0,3	0	0	
	Mockau, Post	791	15.063	2	2	2	2	20	215	253	1,39	1,15	5,4	5,4	0	0	
	Rosenowstraße	445	15.854	2	2	2	2	10	732	59	1,43	0,15	0,4	0,4	0	0	
	Mockau-West		16.299					600	327	118	1,08	0,40	5,4		0	0	
Summe		16.299		50	46	48	48	1.533	8.199	8.014							
	durchschn. Haltestellenabst. (m)	453	Ø- SOLL Geschw.(km/h)	19,6	21,3	20,4	20,4										

Anlage III-4.1
Blatt-Nr.: 3

Liniennr.: **70**
von: **Mockau-West(Pleißenburgw)**
nach: **Connewitz, Kreuz**

Fahrzeit A Mo - Fr 6.00 - 18.00 Uhr
Fahrzeit B tägl. 22.00 - 5.00 Uhr, Sa+So bis 10.00 Uhr
Fahrzeit C So 10.00 - 22.00 Uhr, Mo - Fr 20.30 - 22.00 Uhr
Fahrzeit F Mo - Fr 18.30 - 20.30 Uhr, Sa 10.00 - 20.30 Uhr

Haltestelle		Entfernung zur vorherigen Haltestelle	Lage / Position der Haltestelle auf Linie	Fahrzeit (incl. Haltezeit)				Ø Haltezeit / Wendezeit am Endpunkt	Steigungs- / Gefällelänge		Gefällesituation		Fahrgastwechsel (Mittelwert je Haltestelle ohne Bezug zum Fahrtverlauf)				Bemerkungen
Epon / Kenn-Nr.	Haltestellenname			A	B	C	F	A	(+) steigend	(-) fallend	Ø Steig.	Ø Gefälle	Ø Einsteiger	Ø Aus-steiger	Differenz	Änderung Zuladung	
		(m)	(m)	(min)	(min)	(min)	(min)	(s)	(m)	(m)	(%)	(%)	(Pers.)	(Pers.)	(Pers.)	(kg)	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	Mockau-West	319	0	1	1	1	1	600					7,2				
	Schildberger Weg	351	319	1	1	1	1	8	112	207	1,05	1,85	2,2	2,2	0	0	
	Otto-Michael-Straße	658	670	2	2	2	2	11	41	292	0,22	1,31	3,1	3,1	0	0	
	Mockau, Post	440	1.328	1	1	1	1	18	114	541	0,22	1,33	3,9	3,9	0	0	
	Samuel-Lampel-Straße	254	1.768	1	1	1	1	7	318	122	1,71	2,00	1,3	1,3	0	0	
	Mockau, Kirche	615	2.022	2	2	2	2	5	177	77	1,01	0,96	0,6	0,6	0	0	
	Thekla, Buswendestelle	58	2.637	0	0	0	0	0	100	497	0,57	1,38	0,0	0,0	0	0	
	Thekla, Tauchaer Straße	512	2.695	2	2	2	2	17	58	0	2,55	0,00	2,3	2,3	0	0	
	Neutzscher Straße	581	3.207	2	1	1	1	14	381	114	1,85	2,02	2,9	2,9	0	0	
	Sosaer Straße	355	3.788	1	1	1	1	4	432	149	1,61	0,46	0,3	0,3	0	0	
	Freiberger Straße	498	4.143	1	1	1	1	13	19	336	1,76	1,23	2,7	2,7	0	0	
	Bf. Thekla	199	4.641	1	1	1	1	3	110	365	0,93	1,57	0,3	0,3	0	0	
	Pleißenburgwerkstätten	365	4.840	1	1	1	1	3	164	35	2,07	4,30	0,4	0,4	0	0	
	Braun-/Heiterblickstr.	350	5.205	1	0	1	1	4	281	54	1,12	0,52	0,6	0,6	0	0	
	Stöhrer-/Braunstraße	303	5.555	1	1	1	1	5	261	89	1,87	0,75	0,6	0,6	0	0	
	Schönefeld-Ost	326	5.858	1	1	1	1	4	143	160	0,85	1,03	1,3	1,3	0	0	
	Braun-/Bautzner Straße	213	6.184	1	1	1	1	4	132	190	0,92	1,55	0,3	0,3	0	0	
	Bertolt-Brecht-Straße	387	6.397	1	1	1	1	12	114	92	0,70	0,78	2,2	2,2	0	0	
	Julian-Marchlewski-Straße	535	6.784	2	2	2	2	16	93	294	0,56	1,23	6,3	6,3	0	0	
	Löbauer Straße	533	7.319	2	1	1	1	14	87	448	0,60	1,74	3,9	3,9	0	0	
	Stöckelstraße	491	7.852	1	1	1	1	20	429	104	1,15	2,18	5,8	5,8	0	0	
	Stannebeinplatz	591	8.343	2	2	2	2	16	310	181	0,53	0,69	5,6	5,6	0	0	
	H.-Liebmann-/Eisenbahnstraße	405	8.934	1	1	1	1	19	377	131	2,32	3,55	7,3	7,3	0	0	
	Dornbergerstraße	334	9.339	1	1	1	1	13	151	254	0,75	1,84	2,1	2,1	0	0	
	Bergstraße	328	9.673	1	1	1	1	9	134	200	0,41	0,94	1,3	1,3	0	0	
	Reudnitz, Koehlerstraße	509	10.001	2	2	2	2	24	236	92	1,93	0,77	5,8	5,8	0	0	
	Breite Straße	566	10.510	2	2	2	2	20	293	216	1,29	2,03	7,2	7,2	0	0	
	Riebeck-/Oststraße	413	11.076	1	1	1	1	17	335	176	2,41	1,21	3,5	3,5	0	0	
	Riebeck-/Stötteritzer Straße	306	11.489	1	1	1	1	13	247	166	2,12	1,00	2,1	2,1	0	0	
	Technisches Rathaus	552	11.795	2	2	2	2	9	91	215	0,92	1,68	1,3	1,3	0	0	
	Altes Messegelände	345	12.347	1	1	1	1	11	503	49	1,50	0,15	1,0	1,0	0	0	
	Naunhofer Straße	425	12.692	1	1	1	1	17	247	98	1,66	0,59	2,4	2,4	0	0	
	An der Tabaksmühle	841	13.117	2	2	2	2	4	119	306	5,40	0,83	0,9	0,9	0	0	
	R.-Lehmann-/Zwickauer Straße	839	13.958	2	1	2	2	10	216	625	0,63	1,51	0,6	0,6	0	0	
	Altenburger Straße	272	14.797	1	1	1	1	9	308	531	0,85	2,04	0,7	0,7	0	0	
	A.-Hoffmann-/R.-Lehmann-Str.	330	15.069	2	1	1	1	7	174	92	1,01	1,07	0,3	0,3	0	0	
	K.-Liebknecht-/R.-Lehmann-Str.	490	15.399	2	1	2	2	11	139	177	0,24	0,57	0,3	0,3	0	0	
	Connewitz, Kreuz		15.889					554	347	143	1,08	1,83	8,7		0	0	
Summe		15.889		50	44	47	47	1.544	7.796	7.815							
	durchschn. Haltestellenabst. (m)	429	Ø- SOLL Geschw.(km/h)	19,1	21,7	20,3	20,3										

Anlage III-4.1

Blatt-Nr.: 4

Liniennr.: **70**
von: **Connewitz,Kreuz**
nach: **Mockau-West(Pleißenburgw)**

Fahrzeit A Mo - Fr 6.00 - 18.00 Uhr
Fahrzeit B tägl. 22.00 - 5.00 Uhr, Sa+So bis 10.00 Uhr
Fahrzeit C So 10.00 - 22.00 Uhr, Mo - Fr 20.30 - 22.00 Uhr
Fahrzeit F Mo - Fr 18.30 - 20.30 Uhr, Sa 10.00 - 20.30 Uhr

Haltestelle		Entfernung zur vorherigen Haltestelle	Lage / Position der Haltestelle auf Linie	Fahrzeit (incl. Haltezeit)				Ø Haltezeit / Wendezeit am Endpunkt	Steigungs- / Gefällelänge		Gefällesituation		Fahrgastwechsel (Mittelwert je Haltestelle ohne Bezug zum Fahrtverlauf)				Bemerkungen
	Haltestellenname			A	B	C	F	A	(+) steigend	(-) fallend	Ø Steig.	Ø Gefälle	Ø Einsteiger	Ø Aus-steiger	Differenz	Änderung Zuladung	
		(m)	(m)	(min)	(min)	(min)	(min)	(s)	(m)	(m)	(%)	(%)	(Pers.)	(Pers.)	(Pers.)	(kg)	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	Arno-Nitzsche-Straße	206	0	1	1	1	1	543					3,3				
	Connewitz, Kreuz	403	206	2	2	2	2	15	92	114	3,19	1,50	7,2	7,2	0	0	
	K.-Liebknecht-/R.-Lehmann-Str.	233	609	1	1	1	1	13	18	385	0,11	0,90	4,3	4,3	0	0	
	A.-Hoffmann-/R.-Lehmann-Str.	317	842	1	1	1	1	9	142	91	0,81	1,17	1,8	1,8	0	0	
	Altenburger Straße	794	1.159	2	1	1	1	10	204	113	0,62	0,99	1,7	1,7	0	0	
	R.-Lehmann-/Zwickauer Straße	981	1.953	2	2	2	2	12	441	353	2,01	1,35	2,4	2,4	0	0	
	An der Tabaksmühle	388	2.934	1	1	1	1	6	787	194	1,93	0,26	0,4	0,4	0	0	
	Naunhofer Straße	427	3.322	2	2	2	2	21	207	181	1,14	3,56	2,0	2,0	0	0	
	Altes Messegelände	470	3.749	2	1	2	2	16	78	349	0,27	2,88	4,2	4,2	0	0	
	Technisches Rathaus	198	4.219	1	1	1	1	5	66	404	0,51	2,17	2,2	2,2	0	0	
	Riebeck-/Stötteritzer Straße	439	4.417	1	1	1	1	12	21	177	0,85	0,91	2,4	2,4	0	0	
	Riebeck-/Oststraße	519	4.856	2	2	2	2	15	242	197	1,63	1,72	0,4	0,4	0	0	
	Breite Straße	641	5.375	2	2	2	2	17	248	271	0,80	1,84	12,7	12,7	0	0	
	Reudnitz, Koehlerstraße	258	6.016	1	1	1	1	24	290	351	1,05	2,97	5,9	5,9	0	0	
	Bergstraße	397	6.274	1	1	1	1	9	19	239	1,72	1,34	1,1	1,1	0	0	
	Dornbergerstraße	261	6.671	1	1	1	1	11	221	174	0,72	0,40	1,3	1,3	0	0	
	H.-Liebmann-/Eisenbahnstraße	716	6.932	2	2	2	2	23	152	109	3,56	0,40	4,4	4,4	0	0	
	Stannebeinplatz	474	7.648	1	1	1	1	16	216	500	3,39	1,51	4,9	4,9	0	0	
	Stöckelstraße	375	8.122	1	1	1	1	13	270	204	0,51	0,68	2,8	2,8	0	0	
	Löbauer Straße	662	8.497	2	2	2	2	18	113	262	1,01	0,97	4,5	4,5	0	0	
	Julian-Marchlewski-Straße	388	9.159	1	1	1	1	14	512	132	1,39	1,62	1,3	1,3	0	0	
	Bertolt-Brecht-Straße	228	9.547	1	1	1	1	8	281	107	1,13	1,08	0,5	0,5	0	0	
	Braun-/Bautzner Straße	307	9.775	1	0	0	0	2	81	97	0,39	0,93	0,2	0,2	0	0	
	Schönefeld-Ost	450	10.082	1	1	1	1	3	199	108	1,42	2,24	0,0	0,0	0	0	
	Stöhrer-/Braunstraße	340	10.532	1	0	1	1	4	239	211	1,02	1,27	0,1	0,1	0	0	
	Braun-/Heiterblickstr.	299	10.872	1	1	1	1	3	142	198	0,47	1,14	0,2	0,2	0	0	
	Pleißenburgwerkstätten	208	11.171	1	1	1	1	3	63	222	0,26	0,90	0,3	0,3	0	0	
	Bf. Thekla	531	11.379	1	1	1	1	3	62	146	1,56	3,21	0,1	0,1	0	0	
	Freiberger Straße	287	11.910	1	1	1	1	11	425	106	1,34	1,19	1,6	1,6	0	0	
	Sosaer Straße	586	12.197	2	1	2	2	3	227	60	1,77	0,73	0,3	0,3	0	0	
	Neutzscher Straße	498	12.783	2	2	2	2	10	80	506	1,68	1,33	0,9	0,9	0	0	
	Thekla, Tauchaer Straße	558	13.281	2	2	2	2	15	148	350	1,34	2,00	0,8	0,8	0	0	
	Mockau, Kirche	254	13.839	1	1	1	1	6	450	108	1,07	0,67	0,3	0,3	0	0	
	Samuel-Lampel-Straße	468	14.093	1	1	1	1	8	128	126	1,32	1,81	0,4	0,4	0	0	
	Mockau, Post	791	14.561	2	2	2	2	20	215	253	1,39	1,15	5,6	5,6	0	0	
	Rosenowstraße	445	15.352	2	2	2	2	10	732	59	1,43	0,15	0,6	0,6	0	0	
	Mockau-West		15.797					600	327	118	1,08	0,40	6,0		0	0	
Summe		15.797		50	45	48	48	1.533	8.137	7.577							
	durchschn. Haltestellenabst. (m)	439	Ø- SOLL Geschw.(km/h)	19,0	21,1	19,7	19,7										