SUMMARY

This information booklet is a result of the Qian'an project funded by the program "Servicestelle Kommunen in der einen Welt (SKEW) – Nachhaltige Kommunalentwicklung durch Partnerschaftsprojekte (NAKOPA)" of the Federal Ministry for Economic Cooperation and Development. The project focussed on sustainable urban transport and tram systems. Specifically, the program supports an exchange of experiences between the Municipality of Qian'an and the City of Dresden. As part of the program an exchange took place during workshops on December 18, 2014 in Dresden, December 19, 2014 in Berlin, and from June 22-24, 2015 in Qian'an.

The United Nations mandated 17 global goals in September of 2015. The 11th goal is the creation of sustainable cities and communities that maintain safe, affordable, accessible and sustainable transportation systems that serve the needs of everyone. This goal will require the improvement of road safety, notably through the expansion of public transportation, with special attention to protect the most vulnerable; woman, children, the elderly and those with disabilities. The U.N. set a target date of 2030 for meeting these goals. By summarizing the experience of tram systems, this booklet will help identify opportunities for constructing more efficient and sustainable transportation systems.

The first chapter provides an overview of different urban railway systems and briefly describes infrastructure, traffic control and vehicles. The second chapter presents examples of German tram and light rail systems from Berlin, Dresden and Hannover. This is followed by the international examples Bordeaux (France) and Zurich (Switzerland). The fourth chapter presents Chinese examples. The concluding chapters will address the advantages of tramway systems and summarize its role as an integral part of a new urban transport culture.

ZUSAMMENFASSUNG

Diese Informationsbroschüre ist ein Ergebnis des Qian'an Projekts, gefördert durch das Programm der Servicestelle Kommunen in der Einen Welt (SKEW) – Nachhaltige Kommunalentwicklung durch Partnerschaftsprojekte (NAKOPA) des Bundesministeriums für Wirtschaftliche Zusammenarbeit und Entwicklung. Der Schwerpunkt des Projektes liegt auf dem Erfahrungsaustausch zwischen Dresden und Qian'an zum Thema Straßenbahnen als kostengünstige und nachhaltige öffentliche Verkehrsmittel. Im Rahmen des Programms fanden drei Workshops statt: 18.12.2014 in Dresden, 19.12.2014 in Berlin und vom 22. - 24.06.2015 in Qian'an.

Die UNO hat 17 globale Ziele im September 2015 beschloßen. Das 11. Ziel für nachhaltige Städte und Kommunen enthält ein Unterziel für den Zugang zu einem sicheren, bezahlbaren, gut erreichbaren und nachhaltigen Verkehrssystem für alle. Das Augenmerk soll hier auf die Verbesserung der Verkehrssicherheit und den Ausbau des öffentlichen Verkehrs mit besonderer Beachtung der Anforderungen schwacher Verkehrsteilnehmer wie Frauen, Kinder, Menschen mit Behinderungen und ältere Personen liegen. Die UNO hat als Zieldatum für das Erreichen dieser Ziele das Jahr 2030 festgelegt. Dieses Buch leistet durch die Beschreibung der Einsatzmöglichkeiten von Straßenbahnen einen Beitrag zur Schaffung effizienterer und nachhaltiger Verkehrssysteme.

Das erste Kapitel gibt einen Überblick über verschiedene Stadtbahnsysteme und beschreibt kurz deren Infrastruktur, Verkehrssteuerung und Fahrzeuge. Das zweite Kapitel zeigt Beispiele der deutschen Straßenbahn- und Stadtbahn-Systeme aus Berlin, Dresden und Hannover. Dem folgen die internationalen Beispiele Bordeaux (Frankreich) und Zürich (Schweiz). Das vierte Kapitel präsentiert chinesische Beispiele. Die abschließenden Kapitel stellen die wesentlichen Vorteile des Systems Straßenbahn und dessen Bedeutung für eine neue städtische Verkehrskultur dar.

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1 URBAN RAILWAY SYSTEMS

The public transport in Germany is a comprehensive system which consists of coordinated, complemental singular systems:

- **Regional railway systems**
- **City and suburban railway systems (S-Bahn)**
- **Metro systems (U-Bahn)**
- **Light rail systems**
- **Tramway systems**
- **Cable or mountain railway systems**
- **Trolleybus systems**
- **Ferry**
- **Taxi**
- **Bus**

Regional railways and S-Bahn (city train) belong to the group of heavy rail according to the general railway law (Allgemeines Eisenbahn Gesetz - AEG). Metro, tramway and specific types of railway systems are categorized as light rail. They belong to the category tramway according to the Passenger Transport Act (Personenbeförderungsgesetz - PBefG). While they perform a wide range of tasks and are used in different fields correspondingly, they are connected to each other to ensure through connections for travellers. Due to reasons linked with both responsibility and their legal basis as well as funding, it is necessary to separate between the multitude of transport modes as well as the locations in which they are operated – even if similarities between them make an abstraction quite difficult.

1.1 CATEGORIZATION

Until the middle of the last century, the classical transport modes in Germany were bus, tram, U- and S-Bahn as shown in figure 1. The tram systems, which mostly operated with old vehicles in narrow, congested roads were viewed as unfit the future. Buses and suburban railways began to take over their tasks. Soon it was recognized that the capacity of buses was reached and the money for suburban railways was limited. It appeared useful to combine routes worth preserving with large newly built routes of either U-Bahn or conventional railways. The first successful urban and regional rail services, which were called Stadtbahn (city railway), emerged.

The city railway is an urban and regional transport mode, which combines the characteristics of a tram and light rail system. Without the need to transfer, customers can travel on differently combined sections of tram, metro and heavy rail systems. The technical standard can lie anywhere between both extremes. The train systems can be either marketed as tram, city railway, metro or suburban rail. In the following a brief overview of the differences between the systems is given.

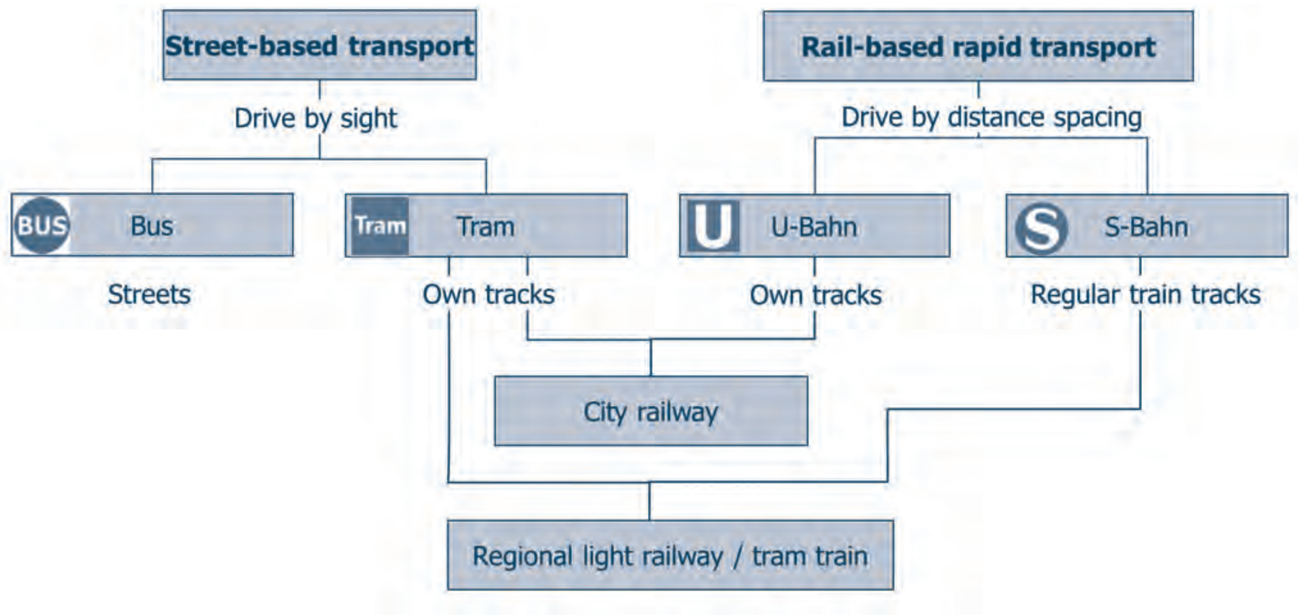


Figure 1: Classification of Urban Railway Systems [1]

1.1.1 City and Suburban Railway (S-Bahn)

The S-Bahn is one component of rail transport and dependent on the guidelines, laws and standards for railway services established by the Railway Construction and Operations Act (Eisenbahn Bau- und Betriebsordnung - EBO). S-Bahn systems are designed to service busy transport routes in metropolitan areas and to provide links between core centers in cities and the areas surrounding them. The following details are typical for S-Bahn systems (Girnau et al., 2000):

- **Top running speed: 90 to 120 km/h**
- **Operating speed: 40 to 50 km/h**
- **Stop distances in settlement areas: 500 to 1500 m**
- **Headway between rush hour train services:**
  - **Inner urban area: 1.5 min**
  - **Outer urban area: 10 to 20 min**

S-Bahn networks exist all across Germany. Although they usually operate above ground, some systems for example Berlin have parts in their network that run in tunnels beneath the city center so that tight connections between the central zones of cities and their surrounding areas as well as sound links with urban transport modes (metro, light rail, tramway, bus) can be achieved.

Figure 2: S-Bahn in Berlin [2]

[1] Source: Dutsch, 2014
[2] Source: Túrelio. (2006). https://de.wikipedia.org/wiki/Berliner_Ringbahn#/media/File:EinfahrendeSBahn_BahnhofBerlinBeusselstrasse.jpg

1.1.2 Metro (U-Bahn)

Despite the metro (U-Bahn) in Germany being defined in accordance with the ordinance on the construction and operation of tramways (Verordnung über den Bau und Betrieb der Straßenbahnen - BOStrab), metro systems are different from tramway and light rail systems in regard to their functions and operating conditions. The metro is the public transport mode with the maximum capacity and offers connections between densely populated areas, strategic spots or economic zones. Metro systems provide high volume capacities and short journey times.

The following details are typical for metro systems (Girnau et al., 2000):

- **Top running speed: 70 to 90 km/h**
- **Operating speed: 30 to 40 km/h**
- **Stop distances in settlement areas: 500 m to 1200 m**
- **Headway between rush hour train services: 1.5 min**

Metro services operate mostly on exclusive tracks, primarily in tunnels beneath city centres but also on elevated sections. Four cities in Germany operate conventional, entirely self-contained metro systems: Berlin, Hamburg, Munich and Nuremberg.

Figure 3: U-Bahn in Berlin [5]

1.1.3 Tramway

Near the end of the 19th century, numerous German cities converted horse-drawn rail carriages to electric tramways. Today more than 55 German cities operate tramway networks with a total length of over 1,500 km. Trams are designed to travel on streets and share road space with other traffic and pedestrians. Most of them operate in the road area on "road-dependent" tracks embedded in the road. (Girnau et al., 2000) Many networks also use exclusive tracks either on the central reservation of roads (median strip) or on fully segregated alignments which ensure better trip quality with higher operating speeds and greater reliability. Short tunnel sections are also being used to run tramways beneath traffic bottlenecks.

The following points show general characteristics of tram services (Ibid.):

- **Top running speed: 70 to 80 km/h**
- **Operating speed: 15 to 40 km/h** [3]
- **Stop distances in settlement areas: 400 (urban) to 600 m (suburban)**
- **Headway between rush hour train services: None, due to operation on line-of-sight (until 70 km/h)** [4]

Like metro and light rail, tramways are built and operated in accordance with the provisions contained in the BOStrab governing the construction and operation of tramways. Tramways are overwhelmingly operated in a manual mode ("line-of-sight") – a fundamental difference between them and light rail or metro systems. This allows vehicles to pull up right behind each other, meaning there is virtually no limit to track capacity. (Ibid.)

Figure 4: Tram in Berlin [6]

[3] *Operation speed over 25 - 30 km/h only with own track body and signal control*

[4] *Source: Steierwald 2008: Stadtverkehrsplanung, S. 596ff; Metrobuch, Transpress. S. 32; https://de.wikipedia.org/wiki/Straßenbahn*

[5] *Source: Jivee Blau. (2009). https://de.wikipedia.org/wiki/U-Bahn_Berlin#/media/File:Berlin-_U-Bahn-Station_Kochstra%C3%9Fe-_auf_Bahnsteig_zu_Gleis_1-_Richtung_Berlin-Alt-Tegel-_U-Bahn_BVG-Baureihe_H_5013-6_8.8.2009.jpg*

[6] *Source: Reinhard Zabel. (2012). http://www.bahnbilder.de/1024/berlin-27052012-wagen-8014-neue-603145.jpg*

1.1.4 Light Rail (Stadtbahn)

With regard to its historical development in Germany, the term Stadtbahn was associated originally with Berlin. In the second half of the 19th century, a transport system known as "Stadt- und Vorort- Bahn" (city and suburban train) came into being. This served the city's main transport routes and, at the same time, provided links with the surrounding area. Systems of this type are categorized today as "S-Bahn". Later, electric tramways in various cities were described as Stadtbahn in order to differentiate them from other transport routes in the same zone, for example regional rail routes. (Girnau et al., 2000)

The term Stadtbahn was redefined in Germany at the end of the 1960s. Cities needed to modernize and extend their tramway systems in order to bring mounting traffic problems under control. Owing to the fact that it was too expensive to construct entirely new conventional metro systems, new ways were found in order to produce better-value and offer more flexible solutions by enhancing the tramway. Tramway tracks were rerouted through tunnels in zones with traffic bottlenecks. The term underground tramway ("U-Straßenbahn" in German) was coined to describe them. (Ibid.)

Later, aspects such as route alignment and operating format were geared more towards producing the capacity of a metro system on new route developments and extensions, but without doing away with forms of tramway operation on certain sections of routes or networks. Later, the term "Stadtbahn" was coined for systems of this type. The term was designed to emphasize the improvement in tramway quality and management. (Ibid.)

Therefore, light rail systems in Germany are electric railways for local transit which developed from tramways and whose capacities lie between those of tramway and metro systems. Based on the structural situation and necessities of each city a light rail system can be adjusted more towards either a metro or a tramway system (Figure 5). This flexibility involves the infrastructure such as tracks, tram stops and power supply as well as traffic control and the vehicles, that is why there is a wide range of use for light rail which can be seen in the various fields of application in Germany (Table 1). The flexibility of the light rail systems made it possible to either develop a system from scratch or from existing systems (tramway or S-/U-Bahn).

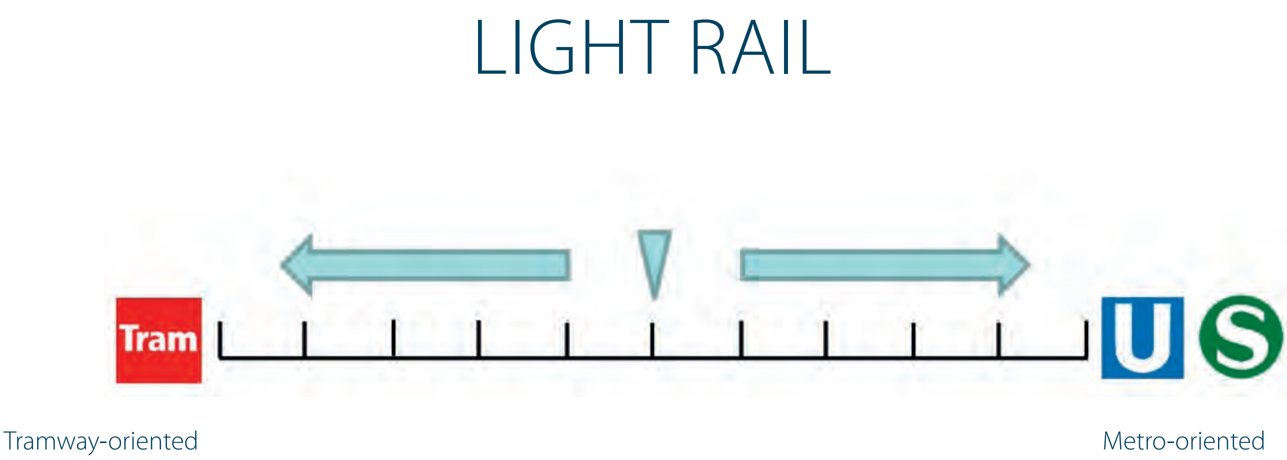


Figure 5: Flexibility of Urban Rail Standards: An urban railway can technically be closer to either a tramway or metro system. [7]

[7] Source: Dutsch, 2014

The following table demonstrates the characteristics of light rails in four different designs.

		Similar to tramway			Similar to metro
		Category 1	Category 2	Category 3	Category 4
City and travel demand classification	Size	Small city	Medium City	Large city/ conurbation	Metropolis/ conurbation
Criterion for choice of category	Population of service area (million)	0.2 to 0.5	0.5 to 1.0	1.0 to 2.0	2.0 to 5.0
	Population density in traffic corridor (inhabitants/km^2)	2,000	3,000	5,000	8,000
	Public transport demand of a 15 km long corridor (patronage/weekday)	30,000	60,000	100,000	160,000
	Additional demand from feeder traffic (patronage/weekday)	5,000	15,000	25,000	40,000
	Minimum specific transport performance per weekday (passenger-km/line-km)	2,000	5,000	10,000	> 15,000
Guideway	Alignment Right-of-way	At grade	5% tunnel/ elevated	20% tunnel/ elevated	> 50% tunnel/ elevated
		20% shared	10% shared		
		80% separate	85% separate	80% separate	< 50% separate
Stations	Average station spacing	500	600	750	1,000
	Platform length	40	60	90	100
Vehicles	Cabs/car	single/double-ended	double-ended	double-ended	double-ended
	Vehicle width (m)	< 2.40	2.40/2.65	2.65	2.65
	passenger capacity of 6-axle car (6 standing persons/m^2)	160	200 to 230	260	300
Operation	Max. cars/train	2	2	3	4
	Min. headway (sec.)	90	90	90	90
	Max. capacity (places/h/direction)	13,000	18,000	31,000	48,000
	Train protection	none, manual mode operation	some sections	mostly with	throughout
	Wayside control of street traffic lights	mostly	throughout	priority system	integrated in train
	Average operating speed (km/h)	20	25	30	40

Table 1: Fields of Application and Design Profiles for Various Categories of Light Rail System [8]

[8] *Source: Girnau et al., 2000*

1.2 INFRASTRUCTURE

This chapter briefly describes the basic infrastructure of a railway system, which includes the tracks, stations and power supply.

1.2.1 Tracks

Depending on local conditions, the procedures used in the design and construction of the infrastructure for light rail systems need to be as reliable and economically efficient as possible and cause a minimum of environmental disruption. The most important factors to be considered vary depending on the level at which the track is to be laid. A distinction has to be drawn between ground-level tracks, elevated tracks on embankments and flyovers, tracks in cuttings and underground tracks in tunnels, with the problems encountered becoming more numerous and more complex, and construction costs increasing for configurations in the aforementioned order. The relative expense of different systems can be calculated roughly by assuming the cost ratios 1:3-5:10-15 for ground-level tracks: elevated tracks: underground tracks. (Girnau et al., 2000)

The types of track (embedded/separate/independent track formation) used on light rail systems vary, depending on routing requirements and the local environment. Some examples are pictured in Figure 6 and an overview of the most commonly used types is presented in Figure 7.

Figure 6: Flexibility of Different Types of Roadbeds (left: embedded, middle: separate, right: independent) [9]

[9] *Source: Wittstock 2014*

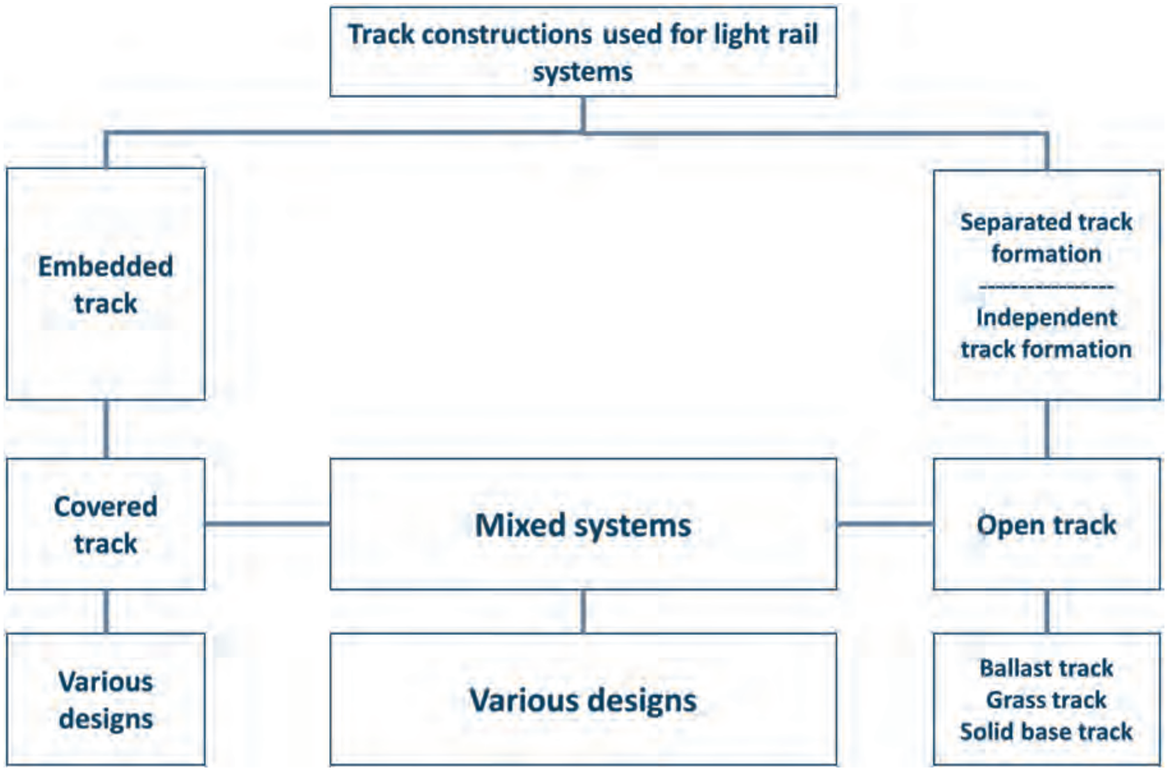


Figure 7: Basic Track Types for Light Rail Systems [10]

If light rail lines are built at ground-level on public roads (embedded tracks), priority must be given to the light rail system by separating the flows of traffic and using traffic signals. This prevents rail vehicles from getting stuck in road traffic, which would clash with the whole rationale behind and purpose of a light rail system. The conditions are more favourable when lines run on special track formations that are mainly kept segregated from other road traffic.

The most important component of rail infrastructure is the superstructure, which consists of the track itself (rails and, where necessary, sleepers and rail fastenings), a track bed made up of ballast, concrete, bituminous or similar materials, with other components laid underneath, such as under ballast mats in tunnels or on bridges and anti-frost layers on tracks running at ground level. The track must fulfil various functions and meet a range of requirements (Girnau et al., 2000).

The following areas need to be considered (Ibid.):

- **Operational safety**
- **Safe track guidance, supporting strength**
- **Electrical conductivity and insulating properties**
- **Avoidance of stray currents**
- **Ease of access for road vehicles where applicable**
- **Vibration and noise control**
- **Integration into the urban environment**
- **Service life and economic efficiency**

[10] *Source: Girnau et al., 2000*

1.2.2 Stations

The layout, design and equipment of stations or stops make a crucial contribution to the acceptance, attractiveness and performance of urban rail systems. These factors also have an effect on the ease with which passengers can board, alight and transfer between services at interchanges. (Girnau et al., 2000) A wide range of requirements is associated with this, and these are particularly important bearing in mind the high standards generally found in rail systems. The requirements that stops must fulfil relate to the following criteria:

Tram stops should…

- **have a high level of service and connectivity,**
- **be easily and safely accessible for all passengers,**
- **be clearly identifiable from a distance and have an appealing architectural design,**
- **provide the information that passengers need,**
- **be easy for different passenger groups to use,**
- **be linked effectively with other modes of transport, both public and private,**
- **provide adequate protection from the weather (passengers should be able to wait in comfort, and seating should be provided). (Girnau et al., 2000)**

Furthermore, it should be easy to board and disembark the vehicles at the stops. Stops must be integrated into the urban structure with attention to other transportation interests. Futher specifications concern safety, cleanliness and service offers at the stops. (Ibid.)

Regarding the stops, designs range from simple street-level exits to fully developed railway stations. For intermodal transport, stations can be directly connected to bus and other railway stations allowing easy and fast transfers. A typical example is when buses stop at the same platform allowing direct transfers as shown in Figure 15 (Page 20).

Regarding the entry height, the following figure shows different vehicles at different stops. The entry height is essential for barrier free access and can be reduced by either lowering the tram entry level (low floor tram) or adjusting the height of the platform.

High-Floor vehicle and platform [11]

Low-floor vehicle and platform [12]

Figure 8: Tram Stops with Different Vehicle and Platform Heights

[11] Source: Christian Weske
[12] Source: Wittstock

1.2.3 Power Supply

Light rail vehicles are equipped with pantographs and supplied with traction current via overhead contact lines. This is one characteristic that distinguishes light rail from metro systems, which have lateral power supplies because they are operated on independent tracks without crossings for their full length. Since light rail systems are usually developed from conventional tramway networks and some cases have in been operated in parallel with such systems for many years, many light rail lines are (at the beginning) run with the same nominal voltage as that used in tramway operations (600 V direct current). New lines with new vehicles are planned with a nominal voltage of 750 V direct current, since this reduces losses through the line (Girnau et al., 2000). Systems in which trains change in between different power supply systems can be found in parts of Germany e.g. Karlsruhe (see Figure 9).

The most apparent part of over ground rail lines constructed are the overhead contact lines and their catenary supports. The integration of these components as well as tracks and stops into the available road space – without reducing functionality – is important. Simultaneously, solutions with minimal environmental impacts must be found such as the catenery-free trams fitted with Alstom's APS system e.g. in Bordeaux (see Chapter 3.1) or Bombardier's Primove system, which has been tested in Augsburg (see Figure 9). These examples show that beyond classic catenary supports made from concrete or steel, there is a whole range of alternative construction methods.

Disconnection of catenaries for a change of the power supply system [13]

Wireless power supply with the primove system [14]

Figure 9: Power Supply Properties

[13] Source: (c) Bombardier Inc., http://www.zukunft-mobilitaet.net/wp-content/uploads/2011/12/bombardier-primove-induktion-strassenbahn-oberleitungsfrei.jpg
[14] Source: Reinhard Dietrich, https://commons.wikimedia.org/wiki/File:Stromsystemwechsel_Stadtbahn_Karlsruhe.JPG

1.3 TRAFFIC CONTROL

During light rail operation, communication between the control center and the vehicles usually takes place by radiophone-technique. Thus, the vehicles are guided and tracked by sophisticated system technology. The radio networks used in transport companies operate independently in the non-public frequency range, which means that both the equipment and system technology is developed and operated by the respective company. With computerized operations control systems, all important data including vehicle location, load factor, out-of-course running and duration of unscheduled stops is continuously registered and saved so that subsequent timetables can be adjusted. Using modern technologies enables passengers as customers to inform themselves about the actual situation relevant to them in particular. Thus, communication technology systems offer an excellent platform for the operators as well as passengers, who are informed as soon as possible for example in case of disruptions (Girnau et al., 2000). Figure 10 shows common technologies used in trams today.

The logistical headquarters responsible for running the transport system is the operational control center, which can be viewed as the heart of an efficient communication system. The control center ensures that both the operator and the passenger have the correct information at the right time and place. One main function of the control center planning operations, which means controlling and monitoring them and respond quickly to disruptions or deviations from the scheduled service. The control centers are company-specific. Voice and data communications is normally possible by radio with the light rail vehicles. (Girnau et al., 2000) Nowadays control centres also provide the data to the customers i.e. via smartphone applications or websites. In Berlin and Brandenburg for example the real-time location data of all transport modes is provided on a map online (See: www.vbb.de/livekarte). An example for a modern information system can be seen in Chapter 2.2.3 (Dresden).

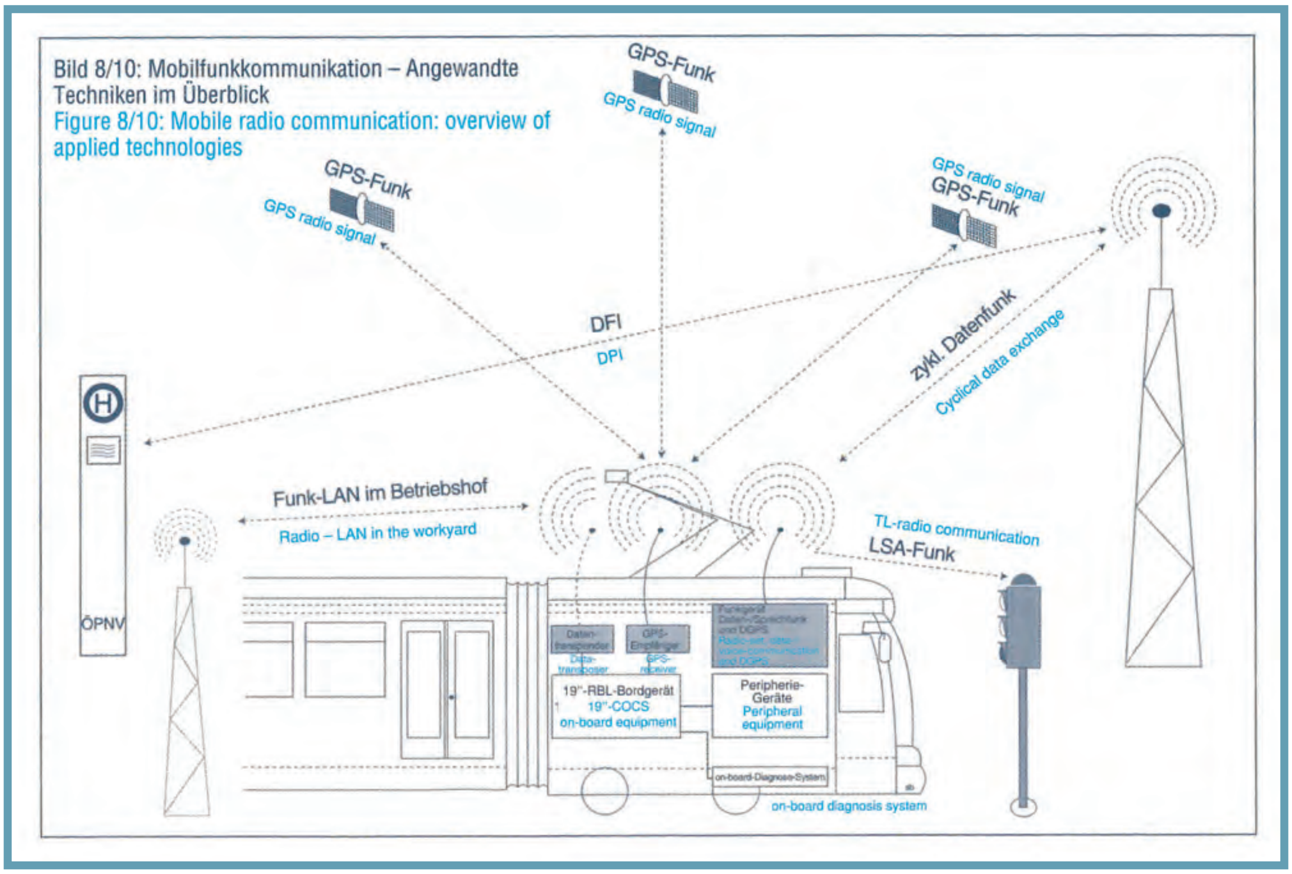


Figure 10: Mobile Radio Communication Systems in the Tram [15]

[15] Source: (c) 2000, Verband Deutscher Verkehrsunternehmen, VDV-Förderkreis e.V.

1.4 VEHICLES

To firstly gain a sense of the physical dimensions and configurations of a tram, a comparison of technical specifications from seven common tram models is presented in Table 2.

							
Model	**Leoliner NGWT6-L**	**Flexity 2**	**TMK 2200**	**ULF Typ B**	**Citadis de Bordeaux**	**120N**	**Variobahn Potsdam**
Manufacturer	**Heiterblick**	**Bombardier**	**CroTram**	**Siemens**	**Alstom**	**PESA**	**Stadler**
Length	ca. 23 m	32.5 m	32 m	35.47 m	ca. 44 m	31.8 m	ca. 30 m
Width	2.3 m	2.65 m	2.3 m	2.4 m	2.4 m	2.35 m	2.3 m
Height	3.69 m	3.42 m	3.4 m	n/a	3.27 m	3.4 m	ca. 3.3 m
Weight (Empty)	27.3 t	40.9 t	n/a	n/a	54.9 t	n/a	38.8 t
Engine Power	4 x 65 kW	4 x 120 kW	390 kW	8 x 60 kW	880 kW	420 kW	8 x 45 kW
Entry Height	290 mm	320 mm	300 mm	180 mm	320 mm	n. a.	300 mm
Floor Height LF Area	350-475 mm	320 mm	350 mm	197 mm	350 mm	350 mm	350 mm
LF Percentage	60%	100%	100%	100%	100%	100%	100%
Standing room*	118	148	156	154	140	148	112
Seats	39	74	46	66	90	63	68
Top Speed	70 km/h	70 km/h	70 km/h	70 km/h	60 km/h	70 km/h	70 km/h
Top Slope	6%	6%	n/a	n/a	n/a	n/a	n/a
Smallest Radius of Curved Track	17 m	20 m	16.5 m	n/a	n/a	n/a	18 m

LF= Low floor | *(4 persons per square meter)

Table 2: Technical Data of Selected Tram Models [16]

[16] *Source: Datasheets of Manufactures*

Taking a close look at this data, it is obvious that many specifications are similar. The vehicle weight of an empty tram per meter is approximately 1.2 t, the standardized car width amounts to circa 2.3 - 2.65 m. All of the presented trams run electrically and besides the Citadis from Bordeaux reach a maximum speed of 70 km/h. Concerning the entry height or the seating arrangement there are some differences: The ULF (Ultra-Low-Floor) Type B for example has the lowest entry height at 180 mm. The interior furnishings of the trams vary strongly and ultimately are the main reason for price differences. Longer trains can be more expensive since they require more powerful motors.

Trams trains can be built very flexibly. A train can be a power car only as the smallest version. But it can be combined with several trailers to a longer train to meet higher demand (see Figure 11). Finally, the tram vehicles can be constructed as vessels with higher or lower capacities related to the traffic volume. Thus, tram systems cover a wide range of demand.

Figure 11: Example for Different Stages of Development of Trams in Germany: Combined Trailers for High Capacity Trains, Tramtrain Karlsruhe [17]

[17] Source: https://de.wikipedia.org/wiki/Stadtbahn_Karlsruhe#/media/File:Murgtalbahn_Tennetschluchtbruecke_Stadtbahn.jpg

2 EXAMPLES IN GERMANY

Germany currently has over 55 light rail systems. Light rail vehicles run in three of the four German cities with over a million inhabitants. In Berlin and Munich they complement U- and S-Bahn and are marketed as a tram. In Cologne they are marketed as subway. 14 of the 15 large cities with more than 300,000 inhabitants have light rail systems. Ten of these have underground sections and serve as subways. In the other cities the tram character prevails. In three cases small parts of the network have metro standards due to short tunnels. 14 of the 599 German medium-sized cities (50,000 inhabitants) have systems with tram character. Three more trains in small towns serve tourist or shuttle purposes (Dutsch, 2014). The following chapters present the light rail / tram systems in Berlin, Dresden and Hannover. The examples show different systems that illustrate flexible fields of application. Despite their diversity all three examples are successful.

2.1 BERLIN

Figure 12: Current Model Flexity Passing through Alexanderplatz [18]

2.1.1 Introduction

Berlin is the capital of Germany located in the north-eastern part of the country. Currently the city has roughly three and a half million inhabitants. The total area is about 892 km^2 which is more than twice the size of Amsterdam, Brussels and Paris combined. Worldwide the city is most known for its division into East and West Berlin during the Cold War. Today it is a place of great attraction for tourists, young people and increasingly persons from all over the world seeking a comparatively cheap and easy-going place of residence. Thus, the population is increasing and the city's transportation systems are subject to growing demand. The public transport system is a model example for the use of a tram in a metropolis as a main transport provider and feeder to other services.

2.1.2 Public Transportation Network

Berlin has an extensive public transportation network covering nearly all parts of the city. It includes the S-Bahn (332 km with 166 stops), U-Bahn (146 km with 173 stops), the tram (300 km with 801 stops), the bus (151 routes) and five ferries. Additionally, there are five long-distance train stops and two airports. The road network has a length of about 5,400 km.

[18] *Source: Döge, 2014*

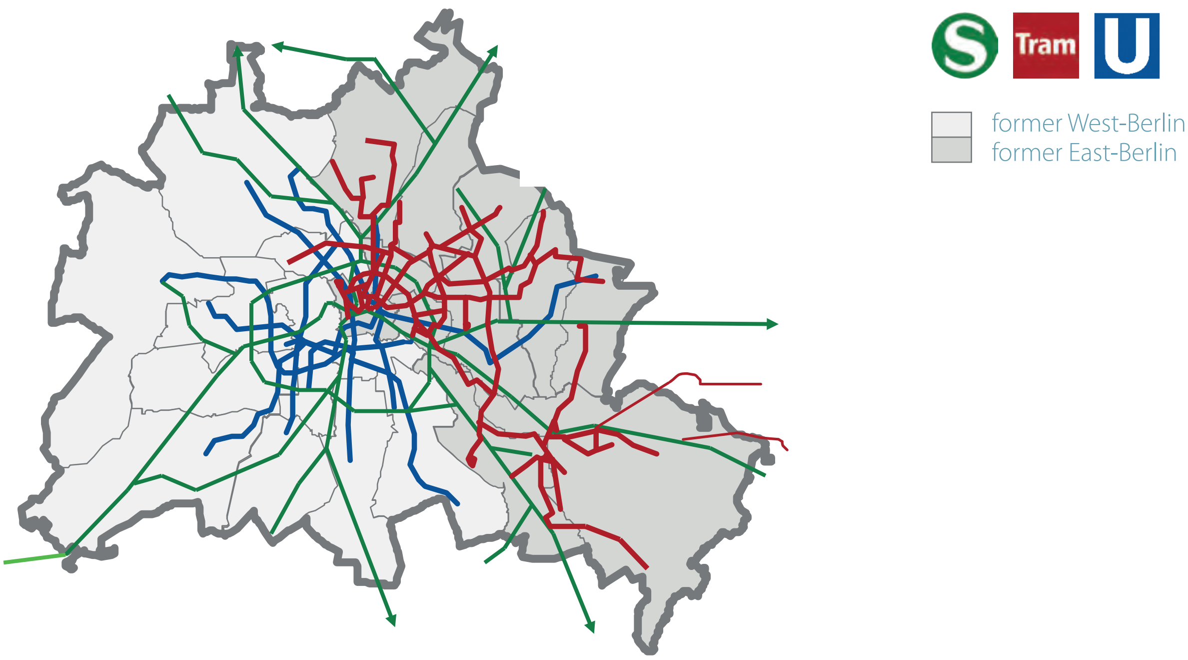


Figure 13: Public Transport Situation in Berlin [19]

2.1.3 The Tram Network of Berlin

Berlin's tram network is the fourth largest network in the world after Melbourne, St. Petersburg and Sofia. It is located predominately in former East-Berlin. After the Second World War West-Berlin shut down its tram operation and removed many tracks in favor of the U-Bahn, cars and busses. East-Berlin kept its tram system for financial reasons. As the third rail-bound transportation system (next to S- and U-Bahn) in Berlin the tram is relevant for the transportation system in different ways: On radial streets like Greifswalder Str./ Berliner Allee and Landsberger Allee between the city center and the housing areas in the city's northeast it is the main means of transportation. For the rail rapid transit system, it fulfils a feeder function mainly in tangential relations. In the northern and southern areas of Berlin it assures the accessibility of suburban areas.

The tram in Berlin is a modern, competitive and successful transportation that constitutes the backbone of public transportation in the eastern part of Berlin. It contributes considerably to the cityscape and to getting around the city in an easily accessible and efficient way.

POPULATION	**3,421,829 (2013)**
CITY AREA	**891.68 km²**
DENSITY	**3,838 persons per km²**
TRAM STATIONS	**794 (day) / 409 (night)**
TRAM LINES	**22 (day) / 9 (night)**
NETWORK LENGTH	**299.9 km (day) / 107.9 km (night) 60 % on independent tracks**
AVERAGE DISTANCE BETWEEN STATIONS	**500 m**
AVERAGE SPEED	**19.2 km/h**
NUMBER OF VEHICLES	**361**
PASSENGERS TRANSPORTED	**174,400,000 per year**

Table 3: Overview of Tram System in Berlin [20]

[19] Source: Döge, 2014
[20] Source: Own illustration based on Döge, 2014

2.1.4 Framework of Berlin's Tram Network

Berlin's tram network allows a high coverage of the city similar to busses. However, it produces much lower costs than a comparable heavy-rail system. A main problem is congestion, which is why the city promotes separated tracks for congestion-free operation often combined with prioritized traffic signals. For the effective integration with other transport modes passenger information systems are implemented at many stops (Figure 14). The stops are connected as much as possible to each other (bus to tram or bicycle to tram) to ensure easy transitions (Figure 15).

Many green tracks have been constructed to beautify the city (Figure 16). The city is updating its fleet with new vehicles. These are customized, barrier-free (low-floor) and state-of-the art Flexity trains from Bombardier. Last but not least to cope with the night crowds Berlin's tram network features an extensive night-time service for the 24-hour needs of the party capital. All these efforts put into the tram network ensure the continuous attractiveness of this transport mode, which can substantiate in constantly growing passenger numbers. .

Figure 14: Dynamic Passenger Information System "DAISY" [21]

Figure 15: Modernization of Tram Stops – Common Use for Tram and Bus [21]

Figure 16: New Standard for Track Construction "Green Tracks" [23]

[21] Source: Döge, 2014
[22] Source: Döge, 2014
[23] Source: Döge, 2014

2.1.5 Further Development of the Tram Network

Increasing passenger demand and the desire to close network gaps (also between former East- and West-Berlin) are leading to the expansion of the network. The further development of the tram network is regulated in Berlin's urban development plan (Stadtentwicklungsplan Verkehr 2025). It includes new expansion plans as shown in the below figure as well as different measures for the tram i.e. prioritization of the tram in traffic between stations, relocation of stops for quicker access or upgrading stops with bicycle stands.

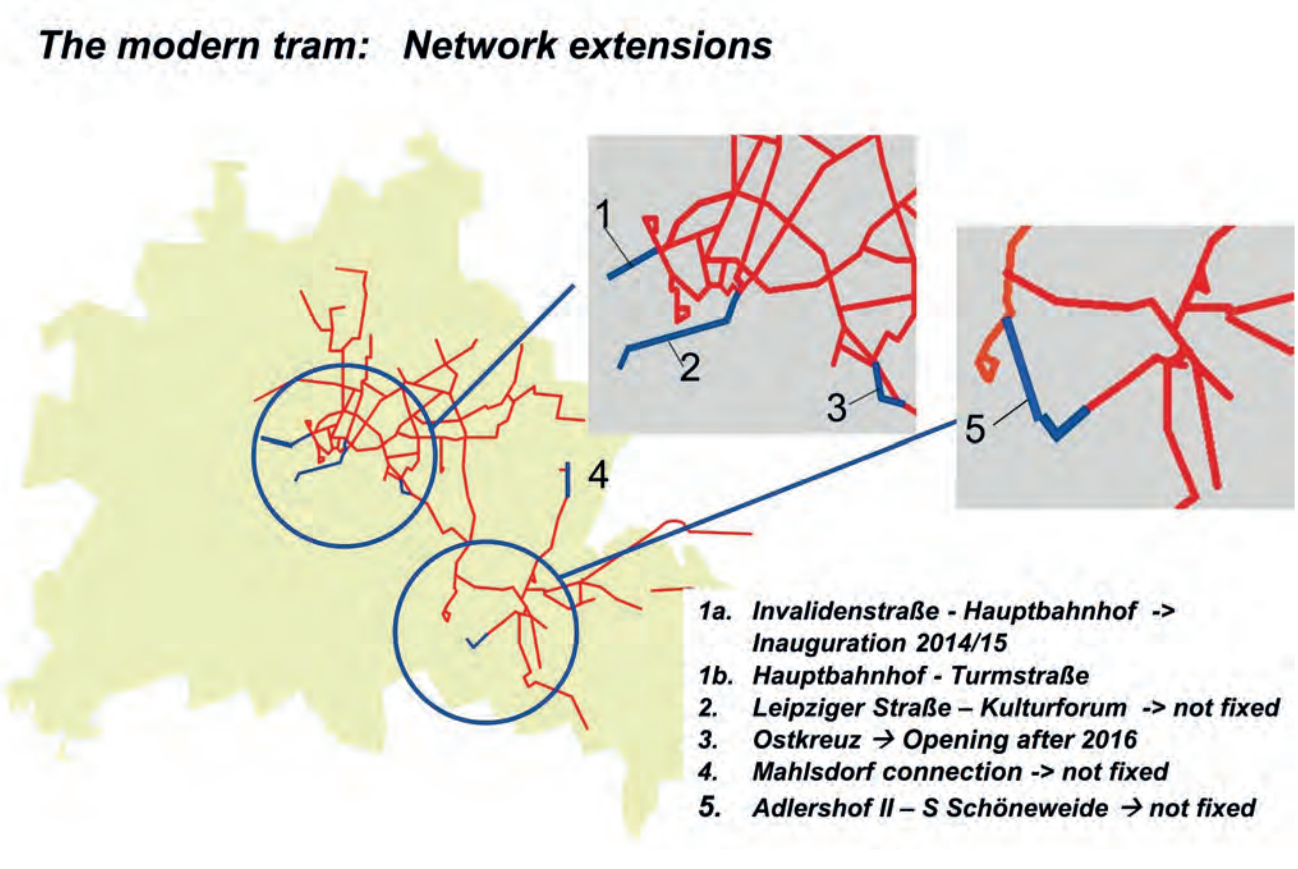


Figure 17: Tram Network Extensions in Berlin [24]

[24] Source: Döge, 2014

2.2 DRESDEN

Figure 18: City Center of Dresden with Elbe, Meadows of the River Elbe and Bordering Buildings [25]

2.2.1 Introduction

Dresden is the capital of the Free Federal German State of Saxony which is located in south-east Germany. Currently Dresden has 541,000 inhabitants in the city area of about 328 km^2. The river Elbe flows through the city center and its bordering meadows offer open spaces to experience.

Many famous buildings such as the Zwinger, the Semperoper, the Palace with the green vault and the Neumarkt with the Frauenkirche are located in the historically culturally meaningful city center as shown in the Figure 18. The tram passes through the city center, e.g. over the three bridges.

The constantly growing population, the gradual redevelopment of buildings, newly built areas, the development of infrastructure and business undertakings, especially in microelectronics, are leading to a prosperous development of Dresden. This development should not become a burden on the environment and quality of live in Dresden. For this a sustainable transportation system is required. The basis is a competitive and successful public transportation system. Dresden tram system can be regarded as a best practice example for an extensive, above-ground tram network in a large city.

[25] Source: G.Otto Niederwillingen 2013

2.2.2 Public Transportation Network

Dresden has a public transportation network with almost full area coverage, which is historically grown and integrated. It compromises heavy rail (60 km rail network with 25 stops), the tram (about 134 km rail network), the bus (48 routes), three ferries and two funicular railways. Additionally, there are two long-distance train stops and one airport. The road network has a length of about 1,470 km.

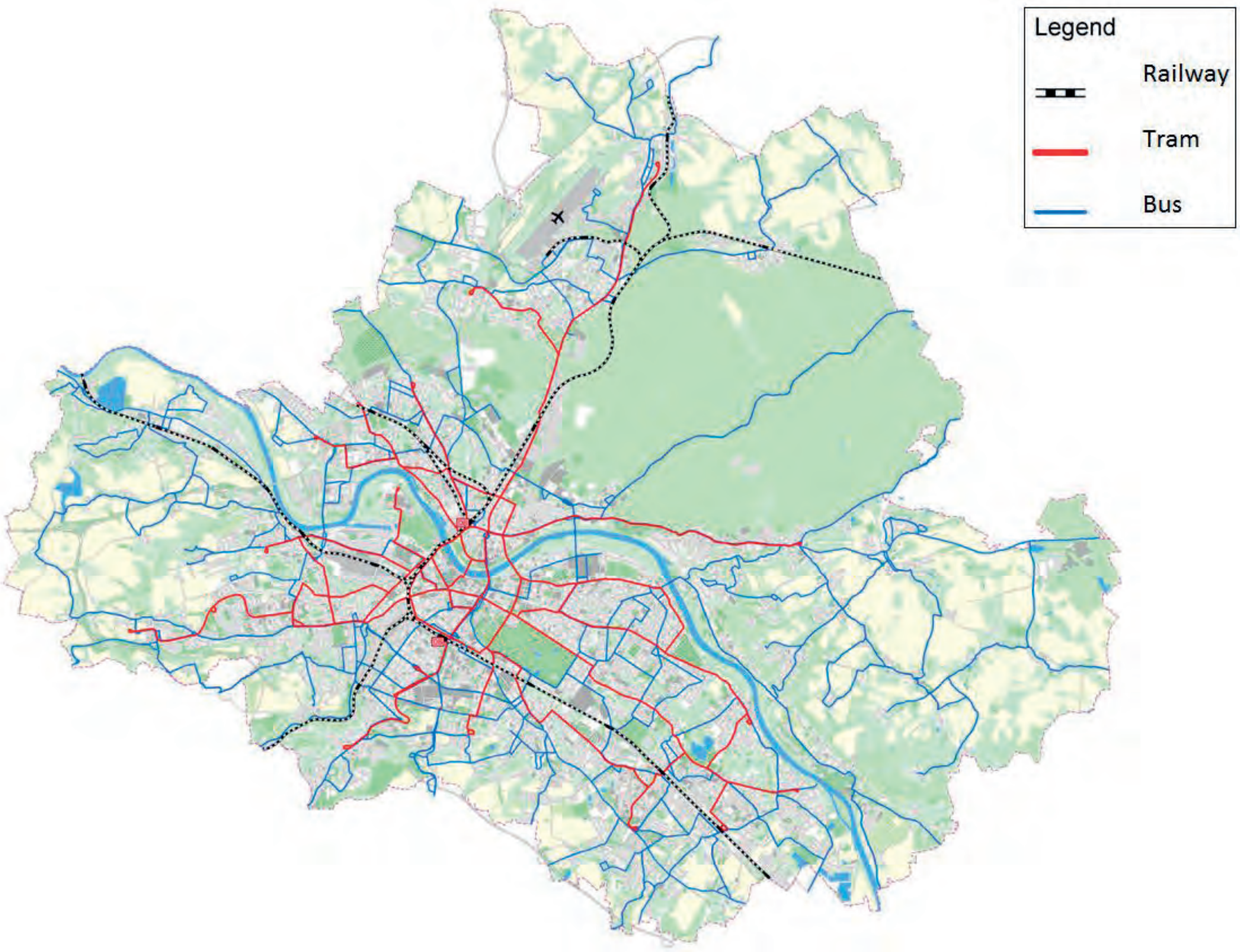


Figure 19: Public Transportation Network of Dresden [26]

[26] Source: Wittstock, 2014

2.2.3 The Tram Network of Dresden

The tram network of Dresden historically grew with the city. In the course of time there were changes. The tram still operates in many city areas today.

POPULATION	**541,304 / serviced population 600,764**
CITY AREA	**328.31 km² / serviced area 428 km²**
DENSITY	**1,617 persons per km²**
TRAM STATIONS	**260 (platform height for barrier-free entry: 23 cm)**
TRAM LINES	**12**
NETWORK LENGTH	**134 km 45 % on independent tracks**
AVERAGE DISTANCE BETWEEN STATIONS	**470 m**
AVERAGE SPEED	**20 km/h**
NUMBER OF VEHICLES	**166**
PASSENGERS TRANSPORTED	**100,000,000 p.a.**

Table 4: Overview of Tram System in Dresden [27]

The tram in Dresden is a modern, versatile, competitive and successful transportation system that constitutes the backbone of public transportation. Through the exclusive over ground operation the tram is part of different streets and city areas. The vehicles are barrier-free and have a modern information system, which offers real-time information in the vehicles. Departure times of intersecting lines are displayed inside the vehicle at connecting stations (Figure 20). Another part of the information system is the display panels inside buildings which show the departure times of nearby stations (Figure 21).

Figure 20: Real-Time Display of Intersecting Lines Inside Vehicles [28]

Figure 21: Display Panel Inside Buildings Showing Departures at Nearby Stations in Real-Time [29]

[27] Source: Wittstock 2014 based on DVB AG
[28] Source: Oelmann, 2014
[29] Source: Wittstock, 2014

2.2.4 Framework of Dresden's Tram Network

The over ground guided and extensive rail network on the one hand mean a high area coverage, experience of the city during the journey as well as presence of public transportation in the street scene. On the other hand, the tram should be integrated into the available street space with other modes of transport, including car- and bicycle traffic and pedestrians. Thus, special demands on the traffic facilities arise, to maintain operative and appealing street environments. Cooperative solutions for all road-users are necessary, especially in dense built-up city areas with narrow streets spaces. That also means adapted traffic control. The following examples show how such solutions can look like. These are subdivided in tracks and stops. There is a separated guidance (Figure 22), partly separated guidance (Figure 23) and joint guidance (Figure 24) for tracks.

Figure 22: Separated Guidance in Different Streets [30]

Figure 23: Partly Separated Guidance (Visual Separation) in Different Streets (Left Turn Traffic between the Tracks in the Middle) [31]

Figure 24: Joint guidance in different streets [32]

[30] Source: Wittstock, 2014
[31] Source: Wittstock, 2014
[32] Source: Wittstock, 2014

There is a variable design for passenger friendly tram stops. All kinds of tram stops allow barrier-free access. Islands can be used with or without a barrier on the road side (Figure 25).

The so called raised road surface (Figure 26) preserves a straight street character (avenue). The passenger waits on the pavement and reaches the tram from the raised road. The further development of this innovative tram stop is a raised cycle lane (Figure 27). Curb extension is another possibility for tram stop design with direct boarding from pavement (Figure 28).

Additionally, there is a cargo tram that supplies a company at the city centre's border. The cargo tram connects the company with a logistic centre.

Figure 25: Islands for Tram Stops with or without Barrier on the Road Side [33]

Figure 26: Tram Stops with Raised Road Surface [34]

Figure 27: Tram Stops with Raised Cycle Lane [35]

[33] Source: Wittstock, 2014
[34] Source: Wittstock, 2014
[35] Source: Wittstock, 2014


Figure 28: Tram Stops with Curb Extension [36]

2.2.5 Further Development of the Tram Network

Besides the gradual revaluation of existing routes and the barrier-free extension of stops, new tram routes, that should replace bus routes working to full capacity, are planned. The basis for the further development is the Dresden Sustainable Urban Mobility Plan (SUMP) "Transport Development Plan 2025plus".

2.3 HANNOVER

Figure 29: Hannover Light-Rail-System [37]

2.3.1 Introduction

The Region Hannover is a district in federal state of Lower Saxony which includes the capital of the state – the City of Hannover - and another 20 communities. There are 1,15 million inhabitants in the Region Hannover and about 520,000 of them live in the City of Hannover. The light rail system is a best-practice example for an extensive and partically underground urban rail system in a large city.

[36] Source: Wittstock, 2014
[37] Source: Weske, 2014

2.3.2 Public Transportation Network

More than 200 million people per year use the public transport system which mainly consists of heavy rail, light rail and bus services. Nowadays, 73 % of the city and its suburbs have a rail link and the goal is to increase this 77 % by 2030 as seen shown in the following figure.

Hannover compromises a heavy rail network which links the surrounding urban centres with the city of Hannover, a light rail network which connects the city with its suburbs and busses, which complete the service to the communities. The city and region of Hannover support a settlement development which is orientated towards the main rail lines.

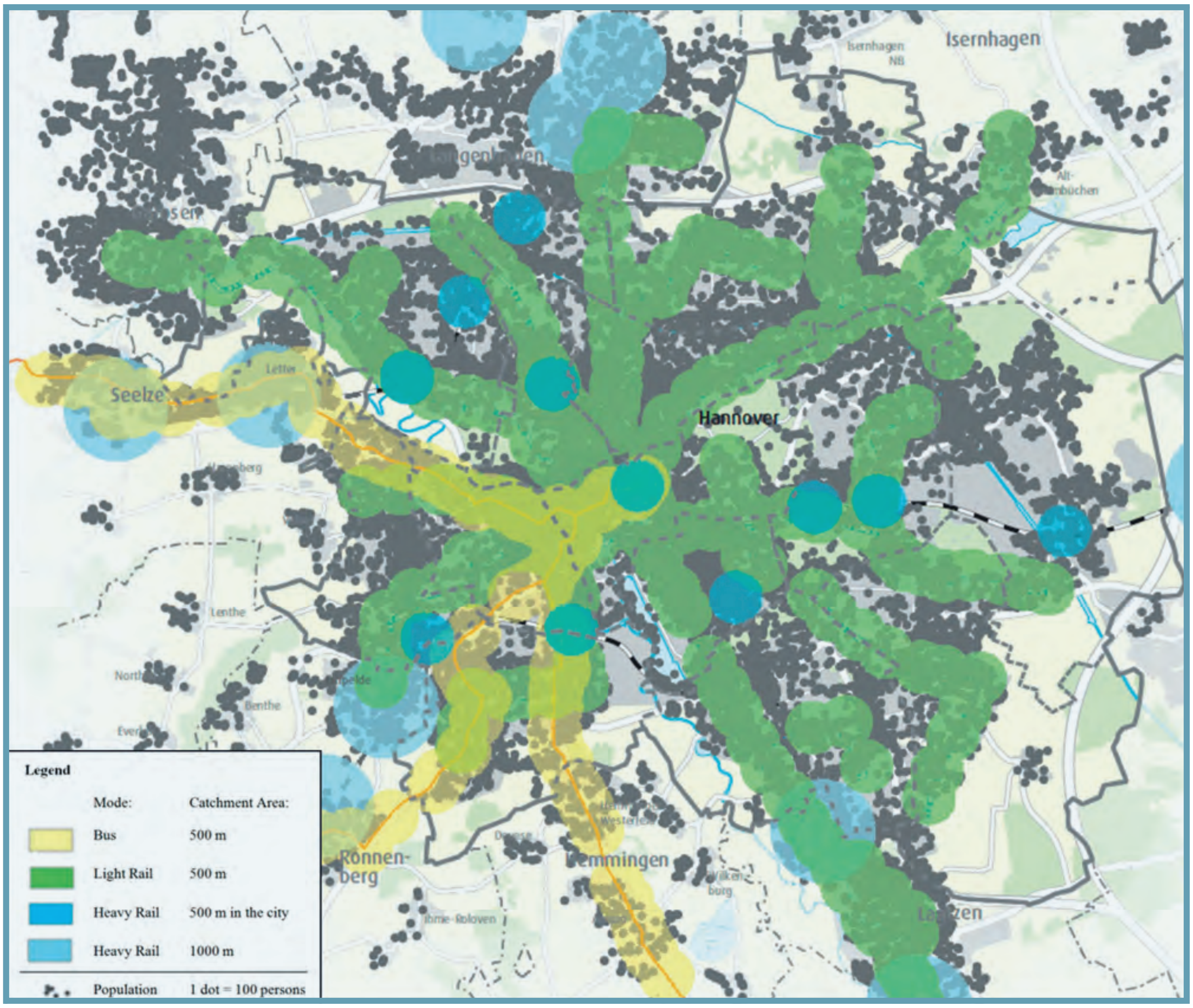


Figure 30: Service Coverage of the Region Hannover [38]

[38] Source: Weske, 2014

2.3.3 The Light Rail Network of Hannover

As the backbone of the traffic system 12 light rail lines with 127 km networks of tracks connect the city of Hannover to the suburbs (Figure 31). To fulfil the development of the region, the light rail traffic should be independent from other traffic, faster than the tram before, more efficient and run without interference. Therefore the light rail system in Hannover is a combination of surface and underground lines. Tunnels were constructed across the city centre. In outlying areas the light rail runs faster on tracks separated from the roads. Unaffected by traffic congestion, the trams are on time and more efficient.

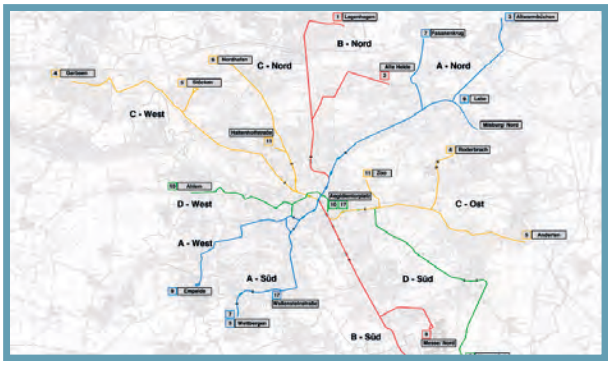


Figure 31: Light Rail System Hannover [39]

POPULATION	**518,386 (2013)**
CITY AREA	**204.15 km²**
DENSITY	**2,539 persons per km²**
TRAM STATIONS	**202 (entry height 86 cm)**
TRAM LINES	**12**
NETWORK LENGTH	**127 km² 84 % on independent tracks**
AVERAGE DISTANCE BETWEEN STATIONS	**650 m**
AVERAGE SPEED	**26 km/h**
NUMBER OF VEHICLES	**300**
PASSENGERS TRANSPORTED	**130,000,000 (light rail) p.a.**

Table 5: Overview of Light Rail Network Hannover [40]

2.3.4 Framework of Hannover's Light Rail Network

Hannover's location between the North German Plain and the Lower Saxony Highland with the nearby valley of the river Leine is the reason why there are many important crossings of transport axes in north-south and east-west direction.

2.3.5 Further Development of the Light Rail Network

In general the growth of new settlements in the region is controlled in the „Program of the regional planning 2015". Its main intention is to prohibit further overdevelopment in the region. New settlements should mainly be established in the central villages in close proximity to the rail stations.

In regard to the tram network specific development goals include the linkage of stations, completion of a fourth city track, continuation of lines, barrier-free retrofitting of stations, testing of the economic value of new tracks and keeping areas free for future tracks.

[39] Source: Weske, 2014
[40] Source: Weske, 2014

3 INTERNATIONAL EXAMPLES

The following chapters present examples of tramway systems outside of Germany.

3.1 BORDEAUX, FRANCE

Figure 32: Alstom Citadis Tram in Bordeaux on Catenary-Free Section [41]

3.1.1 Introduction

Bordeaux's tramway system is one of the first catenary-free systems in the world. The city once radically abandoned its tram system in the 1950s. In the 1970s when the city started to experience traffic problems it thought about a metro system. However it first took a change in the mayor's office until in 1995 a decision was made to bring back the tram. The APS (System Alimentation Par le Sol) system in Bordeaux in the beginning turned out to be vulnerable to heavy rain, standing water and snow which caused short circuits. Since the technology was brand new when implemented it was very expensive and difficulties lead to extreme high overall costs. The operating costs are slightly higher than those of normal trams but in the end the system was accepted and is viewed as a success and example to follow for many other French cities.

[41] *Source: Pline. (2008). https://commons.wikimedia.org/wiki/File:XDSC_7576-tramway-Bordeaux-ligne-B-place-des-Quinconces.jpg*

3.1.2 Tram Network

The complete network consists of independent tracks that are only used by the tram – many of which are also green tracks. The system is laid out for 70 km/h. Practically the maximum speed is limited to 55 km/h. The trams clear all traffic signals so that it can reach the next station without stopping. This makes an average travel speed of up to 21 km/h possible which is the highest in France. The train interval is four minutes during rush hour and otherwise eight minutes. Inside the city 37 % of inhabitants have a tram stop closer than 500 m to them

POPULATION	**241,000 (2012)**
CITY AREA	**49 km²**
DENSITY	**ca. 4,900 persons / per km²**
TRAM STATIONS	**86**
TRAM LINES	**3**
NETWORK LENGTH	**44 km**
AVERAGE DISTANCE BETWEEN STATIONS	**ca. 450-500 m**
AVERAGE SPEED	**21 km/h**
NUMBER OF VEHICLES	**74**
PASSENGERS TRANSPORTED	**40,000,000 p.a.**

Table 6: Overview of Tram Network in Bordeaux [42]

Figure 33: Tram Network of Bordeaux [43]

[42] Source: Bordeaux-metropole.fr, 2015

[43] Source: Otourly. (2008). https://en.wikipedia.org/wiki/Bordeaux_tramway#/media/File:Tramway_Bordeaux.svg

The tram operates without overhead wires in the center of the city and some suburbs. The vehicles draw power from existing overhead wires as well from a conductive rail system in order to avoid disturbing the cityscape.

As shown in Figure 34, there is an underground electrified track between the two normal tracks with eight meter conductive sections between three meter isolated sections. The conducting sections are only activated via radio signal when the train crosses. Therefore, they are not harmful to pedestrians crossing the tracks.

Outside of Bordeaux the tram runs conventionally with overhead wires. The shift to overhead wires is initiated by the conductor, takes place at the stop and requires about 20 seconds.

Figure 34: Citadis Tram powered by Third Conductor Rail [44]

3.1.3 Future Extension

Currently the tram system is in its third expansion phase. This phase includes 33 km new tracks and seven km of a tram train. 582 million Euros will be invested. Lines A, B and C will be extended and a new line D will be constructed (completion in 2017/18). New and longer Citadis models have been ordered.

A tram-train service will be introduced on the SNCF route from Ligne du Médoc. Line C Trams will diverge from their usual route onto the normal rail system and make a direct connection between Bordeaux and Blanquefort possible without transfer. First a separate route will be constructed next to the SNCF tracks. A real tram-train operation is anticipated in a later phase.

[44] *Source: Eyquem Christophe. (2004). http://www.freemages.fr/album/vehicules/tramway_0.jpg*

3.2 ZURICH, SWITZERLAND

Figure 35: Tram in Zurich [45]

3.2.1 Introduction

Compared to other European and American cities, Zurich never placed emphasis on only one mode of transport such as car or trains. Zurich actually decided to keep its tramway system instead of replacing it with metro. Unlike in Germany and Austria the tram in Switzerland is known as „das tram "instead of „die tram".

3.2.2 Tram Network

Today Zurich has one of the densest tram networks in the world. 80 % of the population uses it thanks to consequent traffic policy. Trams are reliable and clean, but quite slow (18 km/h average) compared to other systems. This is because the stations are closer than in other cities (300 m instead of 500-600 m). However, the travel time to the stations is lower.

POPULATION	404,000 (2014)
CITY AREA	92 km²
DENSITY	ca. 4,400 persons / km²
TRAM STATIONS	ca. 350
TRAM LINES	14
NETWORK LENGTH	118 km
AVERAGE DISTANCE BETWEEN STATIONS	300 m
AVERAGE SPEED	18 km/h
NUMBER OF VEHICLES	ca. 260
PASSENGERS TRANSPORTED	201,000,000

Table 7: Overview of Tram Network in Zurich [46]

[45] Source: Andreas Praefcke. (2007). https://en.m.wikipedia.org/wiki/Z%C3%BCrich_tram_route_2#/media/File:Zürich_Paradeplatz.jpg

[46] Source: Stadt Zürich, 2015

Wherever new city quarters are created, trams are part of the planning process. That automatically adds value to the real-estate. There is an on-going discussion whether residents who profit from the tram should contribute financially.

The Cobra tram is custom made for Zurich by Bombardier (Figure 37): Passengers are considered "first class": The city spends nearly 2.5 million Euros per vehicle. These feature innovative technology: The rail squeaking is steered into the train rather than the outside of it. With innovative lubricants for the rails the tram is very environmentally friendly regarding noise emissions. In Zurich unemployed citizens get a job for cleaning the trams ("clean team") which adds to attractiveness.

Since 2003 citizens of Zurich can dispose of bulk waste with the cargo tram. In regular intervals they can bring their large waste to certain stations, where it is picked up by the tram free of charge (Figure 36).

Figure 36: Cargo Tram[47]

[47] *Source: Sunil Prasannan. (2009). https://commons.wikimedia.org/wiki/File:Cargo_Tram_outside_Zurich_Hauptbahnhof.JPG*

Figure 37: Cobra Tram[48]

3.1.3 Future Extension

Several lines are being extended or adapted to passenger needs. The city of Zurich follows five main goals regarding the further development of the tram network:

- **The development of the tram and bus network should be coordinated with the goals of urban development, the adjacent communities, the investors and regional planning groups.**
- **The passengers transport needs should be satisfied through demand-oriented management.**
- **Mid- and long term perspectives should be developed, possible extensions should be prioritized and integrated into the network.**
- **The different public transport carriers in Zurich should be harmonized and linked together.**
- **The basis for an updating of the public transportation master plan should be created.**

These goals as well as specific strategies and expansion plans can be found in the "VBZ Linienkonzept 2025".

[48] *Source: Stefan Baguette. (2005). https://commons.wikimedia.org/wiki/File:Zurich_Be_5-6_Cobra_3002_Letzistrasse.jpg*

4 CHINESE EXAMPLES

The urbanization rate of the People's Republic of China is increasing and expected to reach 70 % in 2030. This means over 1 billion people will live in cities, whose infrastructures must be further developed and rapidly extended. Besides the construction of metro systems China is also experiencing a tram renaissance. The Central People's Government of the PRC released a notice on strengthening the urban rapid rail transit construction management in 2003. It set up conditions for cities applying for metro or light rail projects: For metro projects, the local financial budget should be over RMB 10 billion, the GDP of the city over RMB 100 billion, the urban population over 3 million and the traffic volume of planned route for one-way on peak-hour over 30,000 per hour; for light rail projects, the local financial budget should be over RMB 6 billion, the GDP of the city over RMB 60 billion, the urban population over 1.5 million and the traffic volume of planned route for one-way on peak-hour over 10,000 per hour. According to these rules, many cities in China do not meet the conditions required for the construction of a metro or light rail system. Therefore, most of them are shifting their attention towards the tram: A 2000 km long tram network is anticipated, in the long term even 4000 km. Shanghai alone is thinking about a 600 km network. Zhengzhou is planning 37 lines with a total network length of 550 km. Wuhan is planning a 200 km network. The following table gives an overview of tramway systems in China.

City	Launch	In Operation (Lines)	In Operation (km)	Under Construction (Lines)	Under Construction (km)	In planning stage (Lines)	In planning stage (km)	Total (km)
HONG KONG	1904	6	13.0	-	-	-	-	13.0
DALIAN	1909	2	23.4	-	-	-	-	23.4
CHANGCHUN	1941	4	63.2	-	-	-	-	63.2
TIANJIN	2007	1*	7.8	-	-	-	-	7.8
SHANGHAI	2010	1*	9.8	2	28.0	6	79.4	117.2
SHENYANG	2013	3	54.8	1	11.3	4	65.0	131.1
NANJING	2014	1	7.7	1	9.1	-	-	16.8
SUZHOU	2014	1	18.1	1	16.0	4	81.9	116.0
GUANGZHOU	2014	1	7.8	-		6	66.5	74.3
BEIJING	2015	-	-	1	9.4	4	76.0	85.4
ZHUHAI	2015	-	-	1	8.7	8	147.3	156.0
HUAI'AN	2015	-	-	1	20.3	-	-	20.3
SHENZHEN	2015	-	-	1	11.5	-	-	11.5
CHENGDU	2015	-	-	1	22.3	5	57.7	80.0
HEFEI	2015	-	-	2	29.3	-	80.4	109.7
QINGDAO	2015	-	-	1	8.8	-	-	8.8
XUZHOU	2015	-	-	1	14.4	3	-	14.4
LIUPANSHUI	2016	-	-	1	49.2	1	18.1	67.3
FOSHAN	2016	-	-	1	13.1	-	-	13.1
WUHAN**	2016	-	-	1	10.0	13	204.0	214.0
KUNSHAN	2017	-	-	-	-	8	243.0	243.0
NINGBO	2017	-	-	1	8.2	-	-	8.2
HAIKOU	2017	-	-	1	24.7	-	27.6	52.3
CHONGQUING	2017	-	-	2	24.7	2	-	24.7
ZHENGZHOU***	2018	-	-	-	-	31	466.0	466.0
SANYA	-	-	-	-	-	4	60.0	60.0
XIAMEN	-	-	-	-	-	3	-	0.0
LHASA	-	-	-	-	-	3	63.9	63.9
ZHUZHOU	-	-	-	-	-	4	98.7	98.7
TOTALS	-	14	192.6	21	319.0	109	1835.5	2347.1

*Translohr-system; **estimation; ***plan until 2030, more lines afterwards

Table 8: Tramway Systems in China: Existing, Under Construction and Planned [49]

[49] Source: Schulz, 2015 added

It is mostly the low costs in comparison to metro construction on which make tram systems attractive for China. Some of the systems operate with long station times and small fleets. Most often these can be found in urban development areas, which's construction is yet to be realized. If urbanization continues however, the usage will strongly increase. It is indisputable that China has a strong demand for transport vehicles and needs long term and sustainable solutions.

Figure 38 shows cities in China, in which tram systems are in operation, under construction and in the planning stage, some of which are presented the following chapters.

Figure 38: Cities in China with tram systems in operation, under construction or in the planning stage

4.1 TRAM VEHICLES IN CHINA

As the Chinese modern tram market continues to heat up, it has drawn the world's leading tram manufacturers' attention. However, it is not common for companies like Bombardier, Siemens and Alstom to receive tram orders from Chinese market. In the context of localization, China has been followed the "market for technology" investment strategy for many years which has been proven successful in the automobile and the high-speed railway industry. Chinese tram manufacturers also have designed and produced Chinese Tram models through independent research, intellectual property outright and research and development cooperation. Those models are more competitive in the Chinese market compared to European models because of the low manufacturing costs and short maintenance times.

In contrast to the models typical in the European market, the following table presents some of the vehicles used in China.

LOCATION	Dalian	Changchun	Tianjin, Shanghai	Shenyang	Guangzhou
Model	DL6WA	900 series	Translohr STE 3	n.a.	CNDDB
Manufacturer	Tram Factory of Dalian Public Transport	SMEST CO., LTD	Translohr France	Changchun Railway Vehicles Company (CNR)	CSR Zhuzhou Electric Locomotive Co., LTd.
Operation since	Nov. 2002	End of 2012	May. 2007 Jan. 2010	Sep. 2013	End of 2014
Length	22.5 m	15.85 m	25.00 m	28.8 m, 34.4 m	36.5 m
Width	2.6 m	2.5 m	2.2 m	2.65 m	2.65 m
Weight (Empty)	35.44 t	22 t	23-44 t	n.a.	n.a.
Engine power	455 kW	150 kW	n.a.	700 kW	n.a.
Low-floor Percentage	70 %	70 %	n.a.	70 % (28.8 m) 100 % (34.4 m)	100 %
Capacity	242	150	127	300 (28.8 m) 360 (34.4 m)	386
Top Speed	60 km/h	60 km/h	70 km/h	70 km /h	70 km/h
Top Slope	n.a.	n.a.	13 %	5 %	6 %
Power Supply System	750 V DC	750 V DC	750 V DC	n.a.	n.a.
Special Features	Jacobs bogie, Electromagnetic brakes, AC drive system	Electric and pneumatic combined braking	rubber tired vehicles with central guide rail, top slope 13 %	700 m driving without overhead wires	Driving without overhead wires (Supercap-Drive)

Table 9: Tram Models in China [50]

[50] Source: Datasheets of Manufactures

4.2 TRAM SYSTEM

4.2.1 Tram Reborn

In China, there are only three cities that have a continuously running tram system: Changchun, Dalian and Hong Kong. The first tram line was constructed in 1909 in Dalian by the Japanese, when Dalian was under occupation. In 1945, the tram network reached its maximum length with 11 routes. In the 1970s, eight routes were removed because of urban development. The system was cut down to the three remaining lines 201, 202 and 203. Line 201 and line 203 were merged as the new line 201 in 2006. It operates on a 10.8 km long route from the Station Huale Square towards Xinggong Street (Figure 39). The 202 route was extended and passes for example the Xinghai Square, which is referred to as the world's largest square. Line 201 runs mostly on the street while Line 202 almost exclusively runs on independent tracks. Historic trams (Type DL 3000 – Japanese production from the 1930s and modernized in 2000) and modern articulated vehicles (DL6WA – see Tram Models in China) serve on Line 201 while Line 202 is served only by the modern DL6WA (Figure 40).

Figure 39: Dalian Tram Network

Figure 40: Dalian Tram Model DL3000 [51] (Right) and DL6WA [52] (Left)

[51] Source: 陳炬燵. (2008). https://commons.wikimedia.org/wiki/File:Dalian_Tram%E5%A4%A7%E8%BF%9E%E6%9C%89%E8%BB%8C%E9%9B%BB%E8%BB%8A1007.jpg

[52] Source: https://en.wikipedia.org/wiki/Trams_in_Dalian#/media/File:DL6WA.jpg

Changchun is the first Chinese city to add a new tramway system to its existing one and both systems cross each other without a rail connection (Figure 41). There are also two light rail systems (line 3 and 4) which are built elevated. The light rail line 3 was operated in 2002 and was the first light rail line in China. The light rail network is 48.2 km with 49 stations. The tram line 54 operates on a 7.6 km long route between the Stations Xi'an Dalu and Gongnong Dalu. In 2014, a 5 km branch (line 55) which leads to the new Station "Changchun West Railway Station" was added. The Line 55 cost around RMB 20 million (3 million Euros) per kilometer which is cheaper than the other tram lines. The modernization of the fleet was completed in 2012. The vehicles used are "Changchun Tram Type 900" (Figure 42). The type 900 tram is designed with the consideration of the climate conditions in Changchun: it can operate at -40°C. A tram-oriented transportation master plan was developed by Changchun for future extensions of the network. It foresees a network consisting of four tram lines ("one horizontal, three vertical") with a total length of 38.16 km.

Figure 41: Changchun Tram and Light Rail Network

Figure 42: Changchun Tram Type 800[53] (Right) and 900[54] (Left)

[53] Source: https://upload.wikimedia.org/wikipedia/commons/8/8a/YK4-600.jpg
[54] Source: Belinsky. (2014). https://upload.wikimedia.org/wikipedia/commons/2/21/Trams_in_Changchun_900_series_%283%29.JPG

4.2.2 Double-Decker Tram

One of the most famous trams networks in China is the Hong Kong Tramway, a unique system that has been in operation since 1904. The first 10 double-decker trams were introduced in 1912 to meet the demand of increasing passengers. Until now the Hong Kong tram system is the only one in the world operated exclusively with double-decker trams. Nowadays, the double-decker trams are not only the backbone for transportation, but also a symbol for Hong Kong. In other words, it is a witness of Hong Kong's history. The residents in Hong Kong normally call the Hong Kong tram "Ding Ding" which comes from the sound of the tram bell.

Figure 43: Hong Kong Tram Network [55]

The tram system includes seven lines with a length of 13 km, 123 stations and the total track length is 30 km (Figure 43). The vehicles run on a double track tramline built parallel to the northern coastline of Hong Kong Island from Shau Kei Wan to Kennedy Town and a 3 km single clockwise-running circular track around the Happy Valley Racecourse. In 2015, there are 178 double-decker vehicles in Hong Kong including 48 of the latest seventh-generation tram, two open-balcony dim-sum tourist trams (No. 28 and No. 128) for tram tours, private parties and promotional purposes (Figure 44). The seventh-generation tram was launched on November 28th 2011. It is a combination of modern interior design with traditional tram body exterior. It is also the first batch of VVVF (Variable Voltage Variable Frequency) drive vehicle. Each tramcar can carry 115 people. Passenger information is provided on board the trams and at stops, and services will be rescheduled to match passenger demand. Direct current motors were replaced with alternating current motors to improve reliability and efficiency and a new magnetic emergency braking system was installed. Track maintenance was improved by introducing automatic submerged arc welding robots and grinding machines to prolong rail life and reduce operating noise. The interval between two stations is quite short (around 250 m) and the headway for one station is approximately one and a half minutes. The number of passengers using trams is about 180,000 per day in 2015.

Figure 44: The Seventh-Generation Hong Kong Tram [56] *(Left) and the Antique Tram No. 28* [57] *(Right)*

[55] Source: http://vignette1.wikia.nocookie.net/hk-rail/images/7/78/Tram_58.JPG/revision/latest?cb=20121213031625&path-prefix=zh
[56] Source: Mike Peel. (2013). https://en.wikipedia.org/wiki/Hong_Kong_Tramways#/media/File:Hong_Kong_tram_28.jpg
[57] Source: Hong Kong Tramways. https://www.hktramways.com/images/schedulesFares/map_6_en.png

4.2.3 Rubber Tire Trams

The Tianjin TEDA Modern Guided Rail Tram is the first high speed modern rubber tired tram system in China. This tram system has been operating in TEDA, the Tianjin Economic-Technological Development Area, since May 2007. The rubber-tired tramway system Translohr is 7.86 km long with 14 stations, from TEDA towards North of College District. The vehicles were manufactured by Translohr of France and are 100% low-floor (Figure 45). The rubber tires offer more traction than steel wheels and can be used to climb up to a grade of 13 % at a cost of greater rolling resistance. The Translohr system is more expensive than other conventional tram systems and it is a proprietary system. It increases both construction and running costs. The project cost around 500 million Yuan, of which 190 million[58] are used for testing purposes (excluding vehicles). The second stage construction of line 1 will be 30 km long and run from Binhai Waitan Park to Binhai Aircraft Theme Park. Tram line 2 and 3 are being planned and line 2 will be 15 km long.

Figure 45: Tianjin TEDA Tram[59] (Left) and Its Interior View[60] (Right)

[58] Source: http://www.teda.gov.cn/html/teda_index2011/SHZN11094/List/htm/index_26.html?type=sh
[59] Source: https://upload.wikimedia.org/wikipedia/commons/1/13/New_Tram_in_Tianjin.jpg
[60] Source: https://upload.wikimedia.org/wikipedia/commons/e/eb/Interior_Translohr_Tianjin.jpg

4.2.4 Tram for Commuting

After the previous network was shut down in 1975 in Shanghai, the new tram line is operating since 2010 in Zhangjiang (Figure 46). It is also the only tram line operating in Shanghai today. For the Zhangjiang district a Translohr-System was constructed that connects the Zhangjiang High-tech Park and the residential area. It is a rubber-tired tram system, the same as the Tianjin TEDA modern guided rail tram. The tram line is 10 km long with 15 stations and eight vehicles. The operation time is from 5:45 a.m. to 11:00 p.m. The daily passenger flow is about 6000. A report from the Shanghai Morning Post said that the Zhangjiang tram line has been running up losses of more than 20 million yuan (3 million euros) per year [61]. There are two main reasons for the losses: the expensive cost for monorail system maintenance and insufficient passenger numbers.

Most passengers commute from downtown and only take the tram during rush hour. That means most of the daily trips are work trips and only take place in the morning and evening peak hours. The tram is rarely used for shopping or social trips. The traffic flow is extremely unbalanced throughout the day. Besides, the over ten minute headway and low speed are also two reasons for passengers choosing the subway rather than tram. The operation cost is RMB 1.5 million [62] because imported parts are expensive and the maintenance process is time-consuming. To solve this problem, the combination of tram and bus could be a solution in the near future. After the second and third stage, the length of Zhangjiang tram system will be 30 km.

Figure 46: Zhangjiang Tram [63] (Left) and Its Interior View [64] (Right)

[61] Source: ShanghaiDaily.com: http://www.shanghaidaily.com/metro/society/Tramway-cites-losses-for-shelving-expansion-plans/shdaily.shtml
[62] Source: http://news.163.com/11/0421/10/725H3MH200014AED.html
[63] Source: https://commons.wikimedia.org/wiki/File:Zhangjiang_Tram.jpg
[64] Source: http://i1.dpfile.com/groups/grouppic/2010-01-14/zhoubianyou_1968332_2900904_l.jpg

4.2.5 Tram as the Main Means of Public Transport in Suburban Areas

Songjiang is a district of Shanghai municipality with a total land area of 605.64 km^2 and a population of around 1.58 million. Songjiang is also planning new and separate tram networks. A network of 90 km and six lines is planned until 2020 with several interchanges with metro lines 9 and the Jinshan Railway. In the first stage, the first two lines (T1 and T2) are under construction since 2014. Operating tests should begin in 2016 and operation should start in 2017. The T1 route is 15.6 km and T2 is 15.34 km long. They will solve the "last kilometer" problem by connecting the old town, new town, university town and living quarters. The expected passenger volume is up to 173,000 per day. The joint venture of Alstom and Shanghai Rail Traffic Equipment Development Co., Ltd. (SRTED) - Shanghai Alstom Transport Co.[1] (SATCO) will provide 30 Citadis trams for these two tram lines which are worth about €72 million (Figure 47).

Figure 47: Design of Tram Fleet [65]

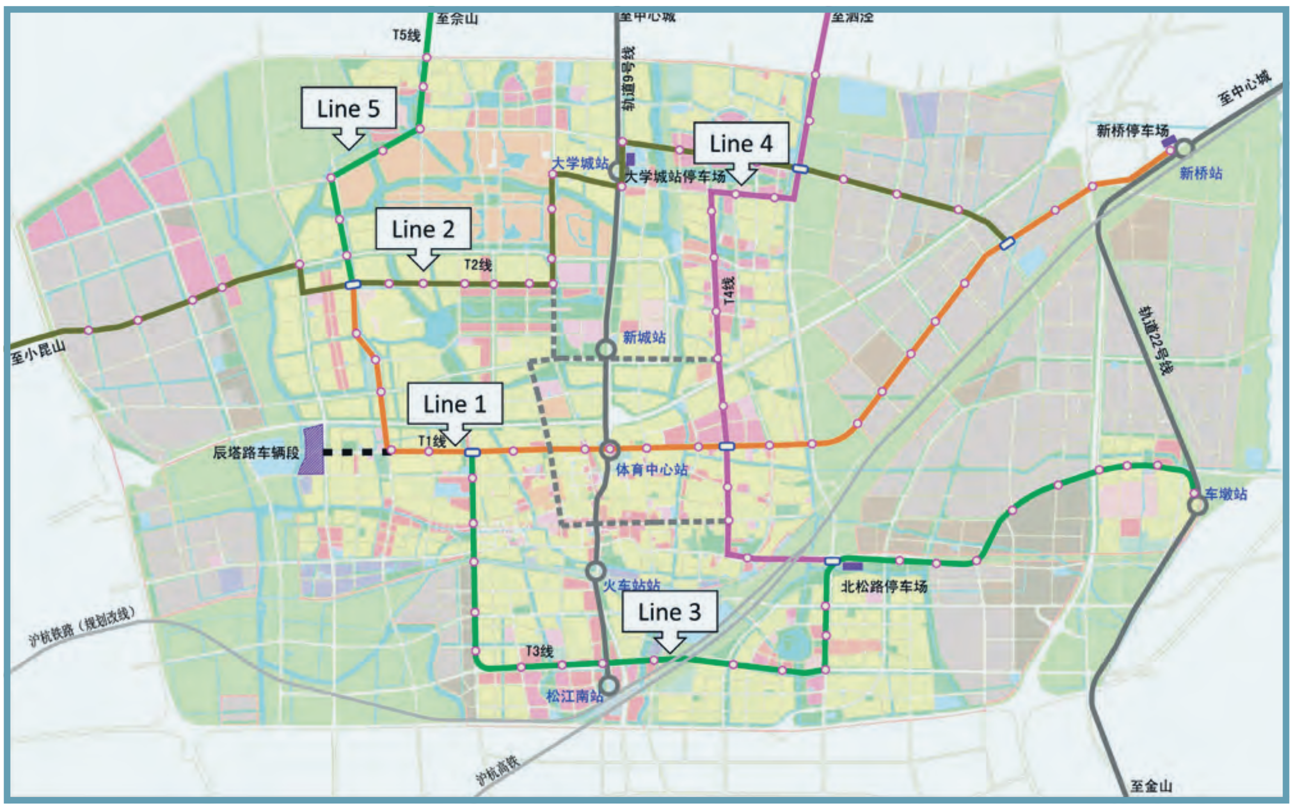


Figure 48: Tram Network [66] in Songjiang

[65] Source: SATCO. (2015). http://www.alstom.com/Global/OneAlstomPlus/Group/Images/Press%20Releases/Press%20photo-Shanghai%20Songjiang%20tram%20initial%20design.jpg
[66] Source: http://www.shgtj.gov.cn/hdpt/gzcy/sj/201309/W020130905569696259726.jpg

4.2.6 Tram as the Extension of Metro Line

Suzhou is a prefecture-free city on the east coast of China and located ca. 80 km west of Shanghai. The fast growing city is currently the 9th largest on the Chinese mainland with a population of 10 million. The tram network is located in the Suzhou New District (SNB) which is a special zone for high tech industries and several foreign companies. The district, which is also called "Ecological City", is already characterized by approaches on sustainable transport including a public bike sharing system, separated bike lanes, emission restrictions for combustion engine vehicles, and support for e-scooters as well as green spaces. The present public transport system is characterized by bus and bus rapid transit (BRT) as well as two metro lines which should be extended to seven (Figure 50).

Figure 49: Suzhou's First Tram Line[67]

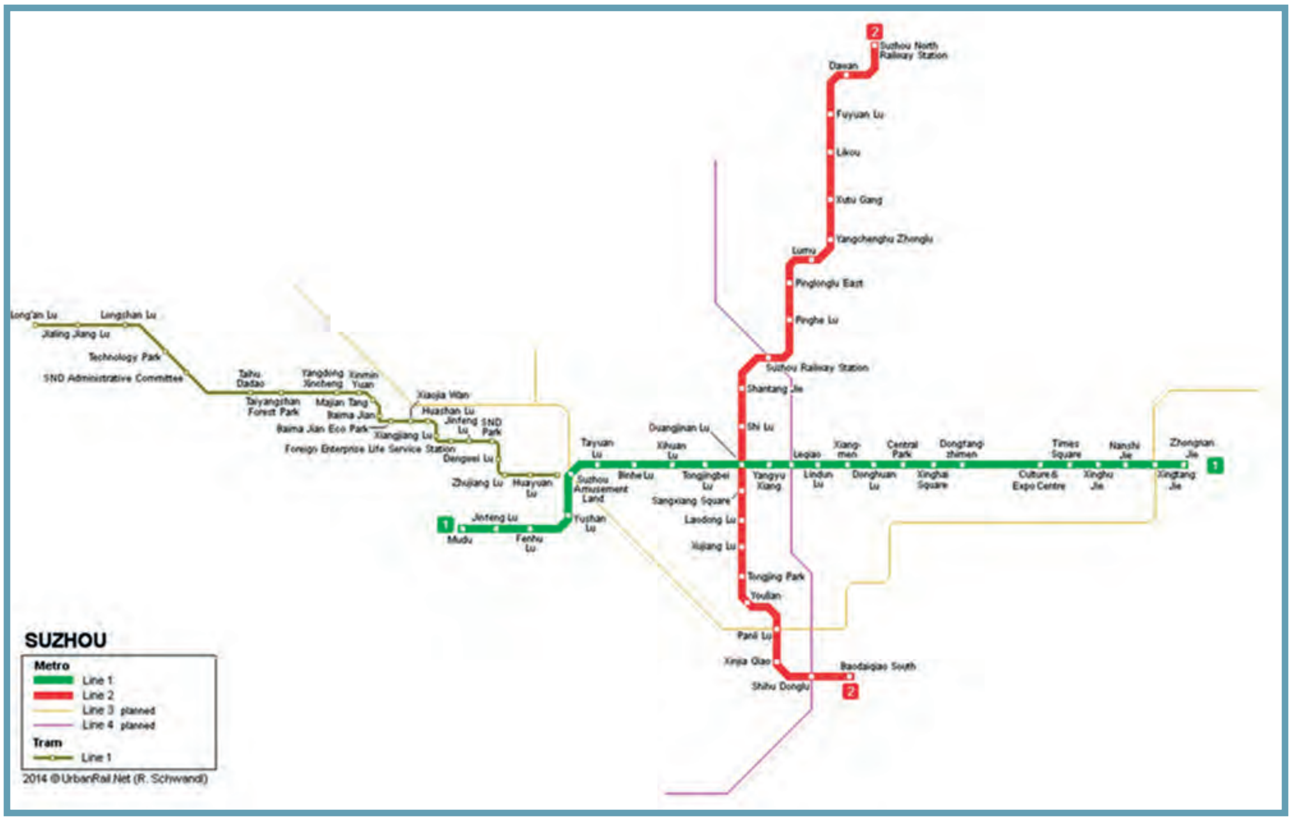


Figure 50: Suzhou Metro and Tram Network in 2015[68]

[67] Source: Andrew Benton. (2014). http://www.railwaygazette.com/uploads/pics/tn_cn-suzhou_tram-Andrew_Benton.jpg
[68] Source: Robert Schwandl. http://www.urbanrail.net/as/cn/suzh/suzhou-map.png

On October 26th 2014 Suzhou put its first tram line into operation which connects the "New District" with western parts of the inner city on a separated track system (Figure 49). Starting in Suzhou Leyuan it offers an interchange to the metro line 1. The track consists of eleven stations which are accessible by under- or overpasses. Special station features are station doors at the platform through which passengers can access the vehicle doors, thus requiring exact parking manoeuvres.

The operation started with three trains running every 10 to 20 minutes. The 100 % low-floor bidirectional Flexity-2 trams (Bombardier and CSR Puzhen) consist of five modules with a length of 32 m offering capacity for 299 passengers. Stations and tracks were complexly equipped with trees, bushes and plants. There is one depot offering tracks for 36 trains at the half of the line near to Yangshan South Station.

Increasing the number of trains will gradually lead to regular service on line 1. With 15 vehicles the circulation time will be 90 minutes with a 30 seconds stop in the stations and 30-45 seconds at traffic lights. With a maximum speed of 60 km/h the average will be 24 km/h. In addition to the existing tram line 1, the whole Suzhou New District should become accessible by tram in the near future. In total there will be six tram lines. Two are already being planned. The construction of line 2 started in July 2014 and should be finished by the end of 2016. Line 1 (18 km), line 2 (18.7 km) and line 3 (8.8 km) will provide basic network of 45.5 km in total. Future extensions will lead to network of 88 km (Figure 51).

POPULATION	**10,060,000**
CITY AREA	**8,488 km²**
DENSITY	**1,249 persons/km²**
TRAM STATIONS	**11**
TRAM LINES	**1 (5 planned)**
NETWORK LENGTH	**25 km (160km planned)**
AVERAGE DISTANCE BETWEEN STATIONS	**ca. 230m**
AVERAGE SPEED	**24 km/h**
NUMBER OF VEHICLES	**3 (15 ordered)**
PASSENGERS TRANSPORTED	**12,000 (on the first day)**

Table 10: Overview of Tram Network in Suzhou [69]

[69] Source: Beckendorff, 2014

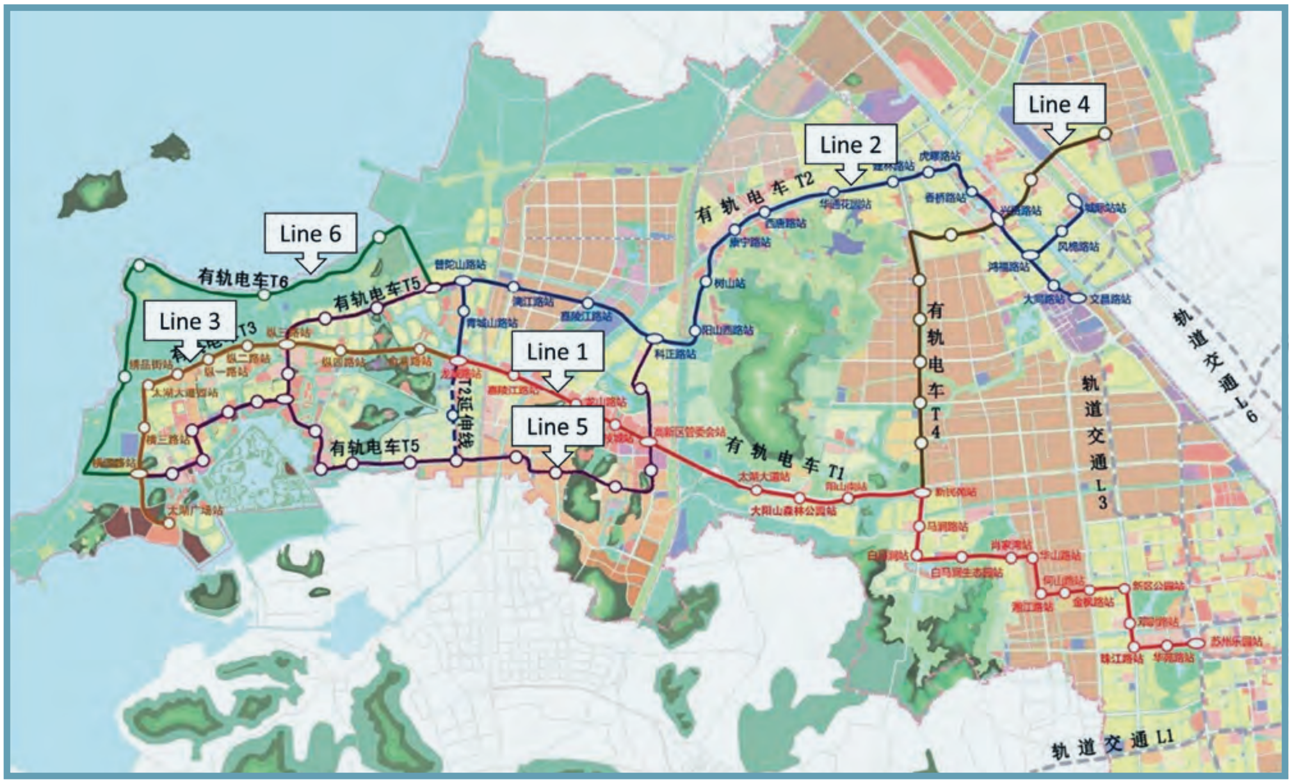


Figure 51: Suzhou Tram Lines – Existing and Planned [70]

4.2.7 Bus Rapid Transit to Light Rail

Xiamen is a modern, international tourist city with harbour on the southeast coast of China with an area of 1,699 km^2 and population of 3.5 million. In 2010, a total of 30 million domestic and foreign tourists visited Xiamen. To improve the tourism quality, Xiamen is planning to build a 43 km long island tram line (formally light rail line 4). Construction should be started in the end of 2015. The island line was planned to be a light rail line. It turns out as a tram line because the daily traffic volume was expected to lie between 4000 and 7000. The plan of metro system in Xiamen was applied firstly in 2006. Because of underpopulation and costs, this plan was postponed and Bus Rapid Transit (BRT) was adopted in 2008 to solve the traffic problem. The first three BRT lines were operated in 2008. And during the construction, it was considered that the BRT will be upgraded to light rail if all conditions are met. Multi-form combinations was adopted for the BRT construction, including elevated lanes and ground lanes, tunnels and bridges, BRT and normal buses. The daily traffic volume of the BRT reached 300,000 in 2014. BRT now is the main means of transportation in Xiamen and the BRT to light rail transformation would compromise the current traffic situation. Therefore, the BRT to light rail transform plan is postponed after the first three metro lines are finished in 2020.

[70] *Source: http://www.sndtram.com/UploadFile/201501/06//15083269629.jpg*

5 ADVANTAGES OF A TRAM SYSTEM IN URBAN DEVELOPMENT

Tramway systems have several advantages compared other public transport systems such as bus or metro systems. The most important are summarized in the following chapters. The advantages have a greater effect when the railway is linked with the urban and transport development. This can include supplementing measures influencing car traffic, parking space, the connection with bus services and bicycle traffic but also street design.

5.1 FLEXIBILITY

Tramway systems are well adjusted to their environment. The first advantage that comes to mind when thinking about tram networks e.g. is the sharing of road space with other vehicles. The integration of rail- and road based traffic means less space requirements opening more flexible construction options. These also result from the small curve radiuses that make them suitable for curvy and narrow streets e.g. and many more different street design options as can be seen in Chapter 2.2 (Dresden).

Furthermore, the flexibility of tramway systems derives from their different functions. They can be used as a single means of transport, as an intermodal transport vehicle with feeder function or to supplement another transport system such as metro as seen in the Berlin example. As the main means of transport it delivers heavy rail like services on a smaller scale. As an intermodal transport vehicle it carries passengers between different transport modes for example busses and metro systems. As a supplement for a heavy rail system it transports passengers on routes that are used less frequently and do not require full heavy rail services.

There are various vehicle designs: Regarding the vehicle body, most trams are based on a modular construction set. Trams from a common series have many identical parts including the drive and doors. The front and backend are usually customized according to the cities' ideas. There are endless choices for interior furnishings and on-board equipment.

Regarding the entire system, different variations can be identified. Three examples are underground trams, two-system trains and freight trams.

Underground trams for example navigate mainly through a tunnel network similar to underground metros. Thus, they are independent from other traffic. Most underground trams operate on former underground metro routes which were shut down, could not be completed for financial reasons or were planned for heavy rail or (underground) metro systems. Often they are called pre-metro for this reason. An example can be seen in Chapter 2.3 (Hannover).

The two-system-train which is also known as tram-train (in Germany "Regional-Stadtbahn") is a unique system that is based on the Karlsruhe model. It was developed in the late 1980s and first implemented in 1992. The special feature of two-system-trains is their ability to drive on regular urban tram tracks as well as on tracks used by regional heavy rail vehicles for example outside of the city. Trams usually only operate with 500-750 V direct current whereas the regular rail network has a voltage of 15 kV alternating current. Through technical re-equipment, it is possible for the two-system-trains to use both power supplies. The system exists in Germany (e.g. Zwickau, Karlsruhe, Kassel, Chemnitz), Spain, Italy and France. In a few cases a diesel hybrid version is used for example in Kassel and Nordhausen (Germany). Two-system trains are designed to link rural areas with special infrastructure or areas with several medium-sized centres.

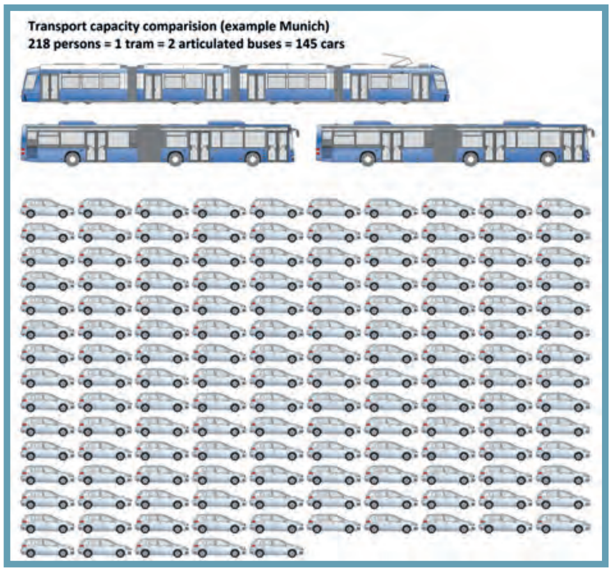
Some cities use freight trams in addition to their normal tram operations. After a pilot project in 2007 in Vienna there has not been any further need for the "Güterbim". Merely Zurich and Dresden consequently use freight trams. In Zurich they are used for disposing bulky waste of citizens who have no car or other means of transport. In Dresden a freight tram supplies a Volkswagen production plant with components from the logistic centre nearby. Thus, the need for trucks running through the city centre is eliminated. All freight trams are custom made and therefore expensive to purchase.

5.2 EFFICIENCY

Electric motors in general have a very high degree of efficiency regardless if a vehicle is operating fully or partially loaded. The acceleration is powerful and more comfortable than diesel motors. Only little space is required for the motors making it possible to install them near to the wheels. The life expectancy of electric motors is generally high and they require little maintenance due to mostly wear-free parts.

The capacity which is associated with the tramway's performance is often double to quadruple to that of a bus. Modern trams can reach almost 80% of a subway's transport capacity. Should passenger numbers however drop or increase temporarily, the vehicles can respond appropriately with flexible multi-functional areas (e.g. with drop seats) or additional cars can be coupled flexibly. When sharing the same road space trams are affected by traffic congestion just as well as buses. In such areas trams often have independent railways or are routed past traffic jams through priority traffic lights. As a result, the average speed is heavily increased and trams run efficiently, stopping only at the stations.

The next figure demonstrates the efficiency of a tram compared to articulated buses and cars.



*218 persons = 1 Tram = 2 Articulated Busses = 145 Cars

Figure 52: Transport Capacity Comparison Example from Munich [71]

Figure 53 shows the space required by a tram compared to that of cars in a real life setting. A neighbourhood association in Heidelberg, Germany initiated this comparison. This Variobahn, operating at 90% capacity as it does during rush hour, carries over 200 passengers. This is equivalent to about 170 cars assuming an average 1,21 persons per car. These would require an enormous amount of parking and road lanes (3,3 km).

Figure 53: Capacity of a Tram Demonstrated in Heidelberg [72]

[71] Source: MVG mbH, https://www.mvg.de/.imaging/stk/mvg/halbbild/dam/mvg/ueber/projekte/tram/westtangente/galerie-01/diagramm-kapazitaet.png/jcr:content/diagramm-kapazitaet.png.2015-07-14-15-13-26.png

[72] Source: UPI-Institut, Heidelberg, http://www.tiefburg.de/images/StauPKW4.jpg

5.3 TRANSPORT QUALITY AND ACCEPTABILITY

Tramway systems have many advantages over other public transport modes when it comes to transport quality and acceptability. Firstly, the acceptability by passengers is higher than that of busses. The majority of newly implemented systems exceed forecasted demand.

One example is presented in the following figure. It shows a continuous increase of passenger demand from introduction of a tram line in 1994 to 2013 in Strasbourg.

seating availability, noise emissions, comfort and the availability of information and so forth. Tram routes in the long-time become very memorable leading them to be perceived as more reliable than for example a bus route.

At the same time, tramways benefit their surrounding area indirectly. Compared to buses e.g. the rails can be perceived as a promise that "something is passing along here". They symbolize a long-term investment into the area and its future transportation options. Generally speaking, the acceptability of tramway systems can be derived from their perception as an orientation

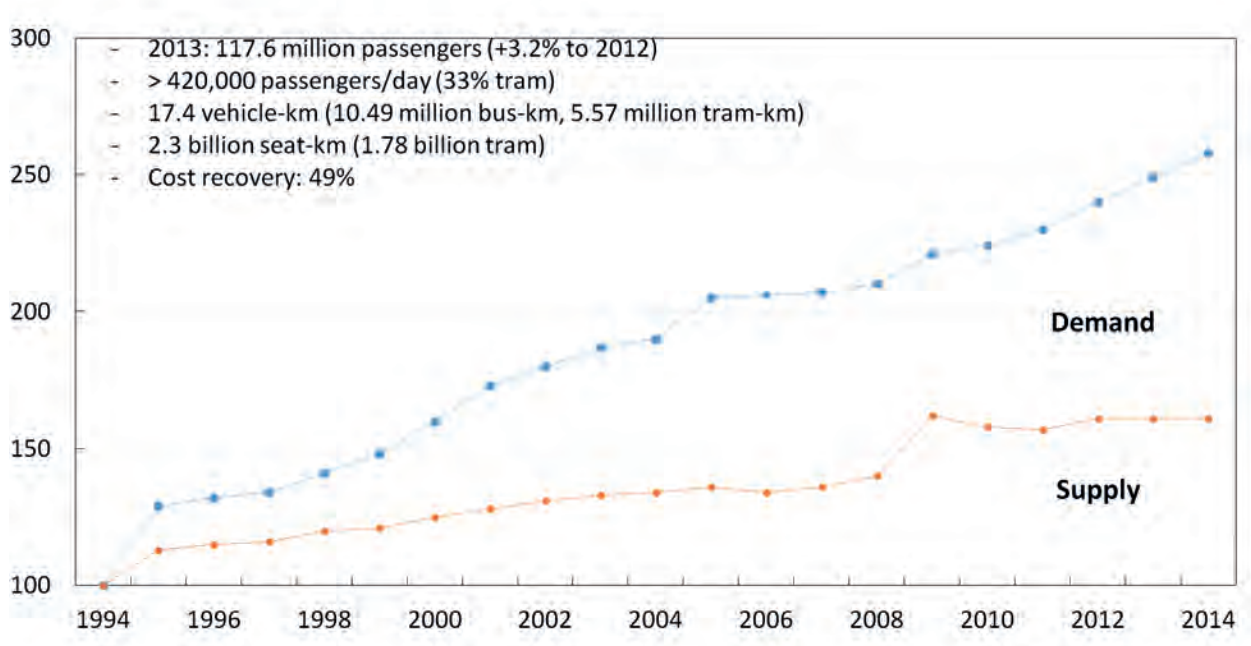


Figure 54: Development after Begin of Tram Service in 1994 in Strasbourg [73]

This is the result of several factors. They include e.g. the feeling of security in the vehicle and waiting environment (mostly over ground operation compared to deep underground entrances to subways), the ease of getting on, off and around the vehicle (growing percentage of low-floor and easily accessible vehicles), aid, an opportunity for experiencing the area (adjacent retail stores, landmarks etc.) and transport vehicles that fascinate as a dynamic, urban vehicles.

[73] Source: CTS; Naumann, 2014

5.4 COSTS OF A TRAMWAY SYSTEM

The goal of achieving a "genuine" cost for tramway systems is difficult and can only be done by determining the life-cycle-costs. (Girnau et al., 2000) Too often, transport companies are surprised later on by the financial consequences of its decisions. Not enough is yet known about the effects of a decision on the multitude of involved cost factors.

Thus, a realistic representation of the total costs is shown in form of an iceberg in the Figure 55.

The total costs of a tramway system include the acquisition of vehicles (up to 55% for a high floor vehicle), infrastructure, energy, maintenance, operational costs (human resources, the cleaning of vehicles and stations etc.) (Figure 56). A separation of investment and operating costs makes sense in terms of different funding sources. (Ibid.) Table 11 shows a cost estimation including acquisition cost in 2008 (+/- 10%) with operation costs based on a 2007 survey of ten operators.

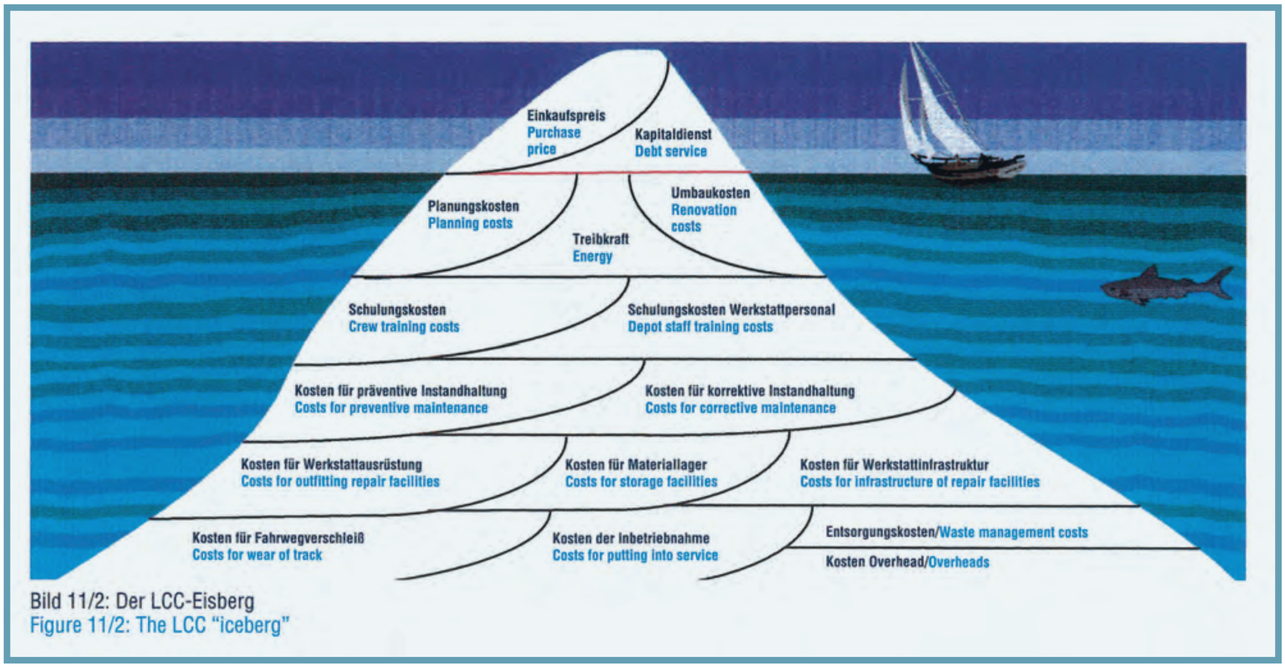


Figure 55: Life-Cycle-Costs Iceberg [74]

[74] Source: (c) 2000, Verband Deutscher Verkehrsunternehmen, VDV-Förderkreis e.V.

	Bus 12m	Articulated bus 18m	Tram 30m	Tram 40m
Total capacity seated/standing	82 32/50	127 47/80	218 64/154	290 88/202
Duration of use	12 years	12 years	40 years	40 years
Acquisition costs in Euros	260,000	330,000	2.6 million	2.9 million
Acquisition costs in Euros per seat	3,293	2,598	11,972	10,000
Acquisition costs in Euros per year	274	216.5	298	250
Operation costs in Euros per vehicle km	3	3.5	6	6.5
Operation costs in Euros per travelled km	0.037	0.028	0.038	0.022

Table 11 Cost Estimation of Bus and Trams [75]

The following figure is a breakdown of the key cost factors in the life of a tram; debt service in this case includes the investment costs.

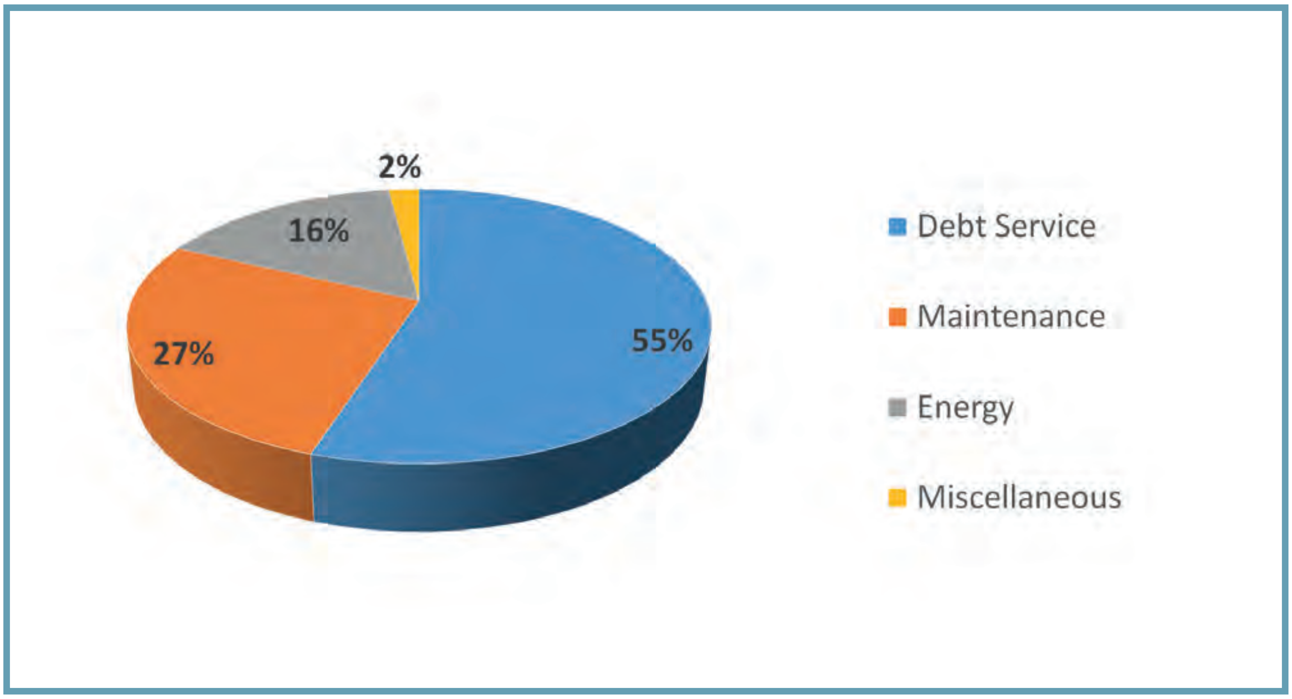


Figure 56: Breakdown of Life-Cycle-Costs for a Light Rail Vehicle [76]

[75] Source: Arndt/Busse, 2009
[76] Source: Girnau et al., 2000

5.4.1 Investment Costs

The investment costs for routes including the acquisition of vehicles and construction of needed infrastructure are a great effort for many cities. Buses on the one hand are much cheaper and faster to put into operation, since they require only little infrastructure and are more flexible in terms of route planning. Trams on the other hand, persuade with their durability and thus, if planned wisely, investment costs pay off in the long term. A comparison of different modes of public transport is complicated because every city has a different situation. Investment costs include the acquisition of property for placing the traffic facilities. In some cases, compensation measures must be met. The chosen route itself is also a major cost factor. (Girnau et al., 2000)

The following table shows a comparison of costs between a 14.5 km tram line built in Besancon and an 18.9 km line built in Dijon.

		Besancon (14.5 km)		Dijon (18.9 km)	
	Asset	**Total**	**Per km**	**Total**	**Per km**
1	**Planning/Studies**	1,190,717	82,118		
2	**Project management 1**	11,159,649	769,631	7,000,000	370,370
3	**Project management 2**	13,649,718	941,360	19,200,000	1,015,873
subtotal 1-3		**26,000,084**	**1,739,109**	**26,200,000**	**1,386,243**
4	**Property acquisition**	5,000,100	344,835	14,000,000	740,741
5	**Relocation of facilities**	2,150,000	148,276	23,000,000	1,216,931
6	**Preparation**	8,823,850	608,541	12,100,000	640,212
7	**Civil engineering works**	18,776,200	1,294,910	10,100,000	534,392
8	**Route construction**	8,495,725	585,912	18,400,000	973,545
9	**Track construction**	39,074,100	2,694,765	41,500,000	2,195,767
10	**Guideway design**	10,437,175	719,805	7,400,000	391,534
11	**Streets and places**	13,785,800	950,745	41,000,000	2,169,312
subtotal 8-11		**71,792,800**	**4,951,228**	**108,300,000**	**5,730,159**
12	**Furniture of public spaces**	8,185,200	564,497	14,900,000	788,360
13	**Traffic lights**	3,241,125	223,526	4,300,000	227,513
14	**Stations**	2,201,600	151,835	6,000,000	317,460
15	**Electrification (high)**	20,521,750	1,415,293	24,700,000	1,306,878
16	**Electrification (low)**	10,504,900	724,467	17,400,00	920,635
subtotal 12-16		**44,654,575**	**3,079,626**	**67,300,000**	**3,560,847**
17	**Depot and maintenance**	13,112,702	904,324	24,500,000	1,296,296
18	**Vehicles**	35,296,094	2,434,213	73,600,000	3,894,180
18	**Induced measures**	2,393,595	165,076	3,500,000	185,185
	Total	**228,000,000**	**15,724,138**	**362,600,000**	**19,185,185**

Table 12: Cost Comparison between Besancon and Dijon, France in € [77]

[77] Source: Naumann, 2014

The construction costs of trams or tram routes are difficult to quantify, because of the different situations in cities (old town, new town, wide/narrow roads etc.).

Approximate costs of route and stop construction are specified in table 13. These are based on average costs in France.

Most Chinese experts assume that the capital expenditures of tram construction are 20 – 30 % of those of a new metro system. The construction costs of the "Hexi Tram" in Nanjing are 104 million CNY per km. Shenzen calculates with 100 million CNY per km. Wuhan calculates with more generous 130 million CNY pro km (Schulz 2015).

	Million Euros / km	Comment
Tram route (including stops)	10	electrified
Tram route (without stops)	8	electrified
Tram stops	1 / 2 stops	double track
Street modifications (facade)	5-10	depends on width and level of difficulty
Bridges (single track)	25	
Bridges (double track)	50	
Tunnel (double track)	100	

Table 13: Costs per Km Including 30% Costs for Planning / Unforeseen Events [78]

A recent example from Frankfurt/Main shows that the construction costs for a 3,5 km double-track line with eight new stops with distances in between from 325 to 630 m and low platform floors amounted to 44,5 million Euros. The construction of metro routes can be up to 20 times higher than those of trams. Currently it can be assumed that in the future costs will decline because Bombardier, Siemens and Alstom are intensively working on tram improvements, partially without expensive overhead wires and low cost tram models. Whether these projects will be realized cannot be said yet. Most notably Alstom's tram project in Bordeaux has shown that new technologies bear childhood diseases that can only be eliminated with high investment costs.

The manufacturers keep information about costs for tram models undisclosed. At the moment, a tram can cost between 1.5 and 4 million Euros. This can be calculated from budget figures and order volumes. The price differences derive from chosen technical equipment and the interior quality of the coach.

[78] Source: Busse, 2009

5.4.2 Operating Costs

The operating costs, excluding energy costs and maintenance, consist mostly of labour costs as seen in Figure 57:

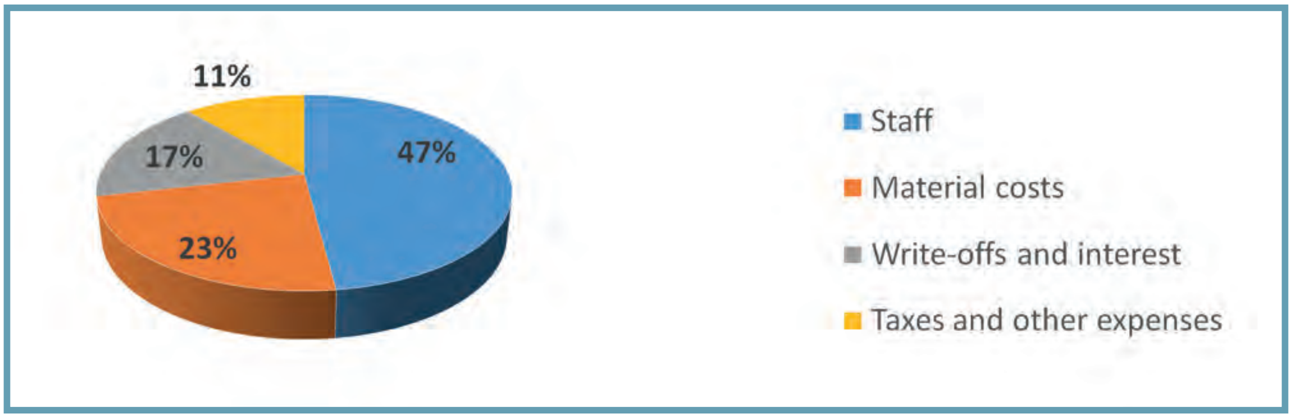


Figure 57: Operating Costs of a Tram [79]

From the operator's point of view, there are several costs factors, depending on vehicle availability and reliability that include

- **energy consumption in relation to vehicle weight,**
- **speed of replacement parts deliveries,**
- **delays in manufacturing and guarantee periods,**
- **supply of spare parts and**
- **employee training. (Girnau et al., 2000)**

Wear-out, depending on the amount of ridership, weather and other factors lead to further costs. Affected components of an tramway system include the rails, the roadbed, drainage systems, artificial fortifications, crossings, traffic lights, underpasses or tunnels. Moreover, communication systems along the route must be maintained as well as stations that include ticket machines, lighting, escalators, lifts etc. Annual costs for maintenance can make up 20% of the original investment costs. (Ibid.)

In many cities railway systems are often used as an advertising medium in order to secure additional financial resources. Advertisement can be placed on the vehicle's free space. In Germany there are only minor limitations on the percentage of windows surface that must stay uncovered. Trams e.g. usually run above ground though inhabited areas which makes them eye catchers not only for advertising purposes but for urban tourists as well. Last but not least, an individualized tram with attractive and unique design can represent its city thus indirectly promoting tourism. A prominent example for heavily advertised trams that are also recognized worldwide can be found in Hong Kong.

[79] Source: Girnau et al., 2000

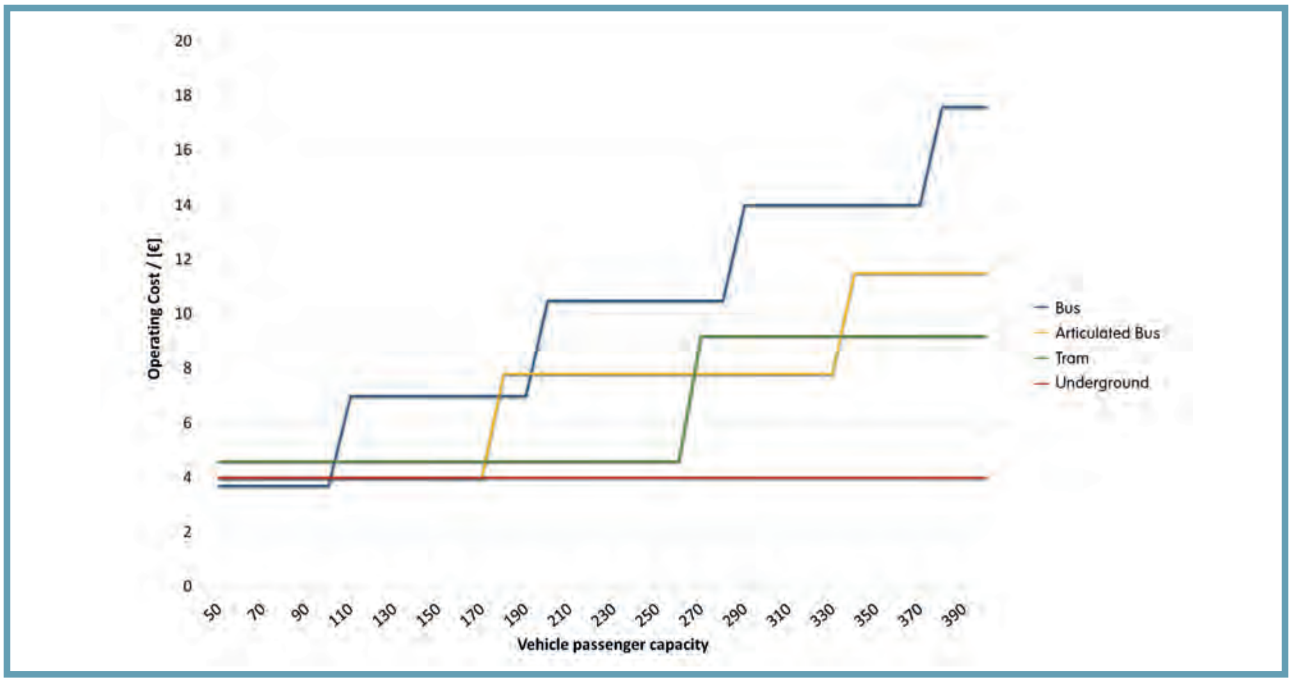


Figure 58: Operating Costs and Vehicle Capacity [80]

As shown in Figure 58 the costs of e.g. tram operation (Flexity Tram) are stable for a longer time than those of buses, which increase sooner, when more capacity is required.

The capacity of a tramway can be flexibly adjusted. Vehicles can be lengthened or shortened according to passenger demand. A tram is laid out for passenger numbers from 5,000-60,000 per day and direction. However, it is possible to raise the capacity to 90,000.

The investment in the construction a tram line in Germany is considered when passenger numbers are estimated to be between about 15,000 and 50,000 per day and direction. For passenger numbers below buses are preferred whereas above metro services should be considered (Figure 59).

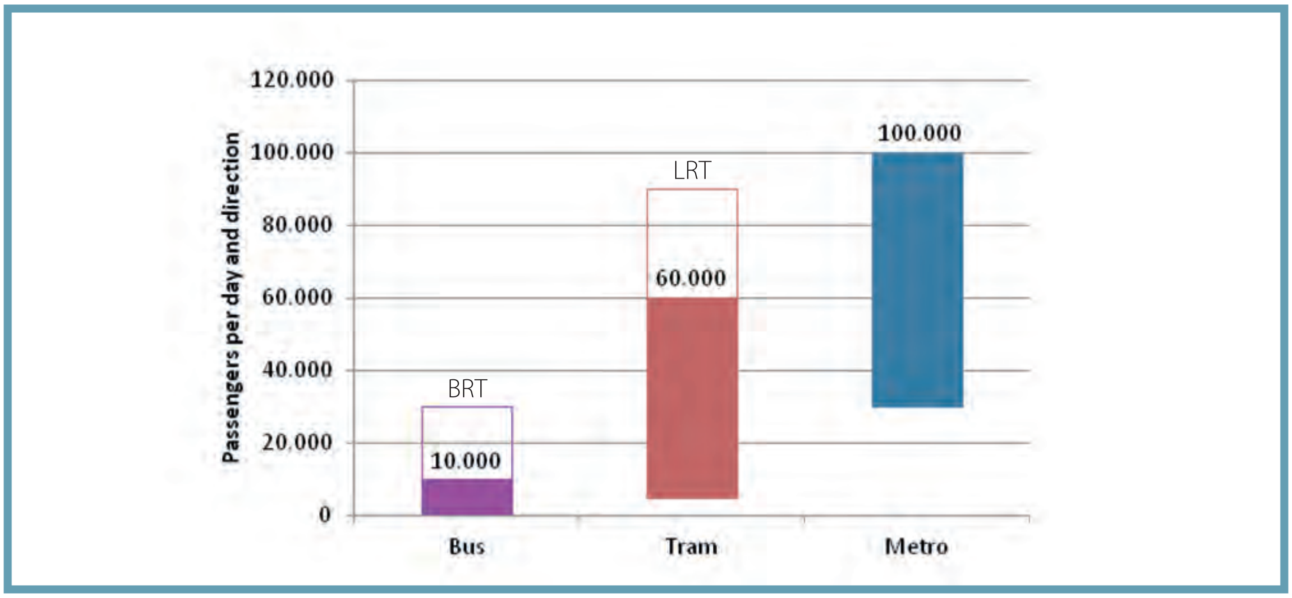


Figure 59: Passenger Capacity of a Tram in Comparison with Bus and Metro [81]

[80] Source: Foljanty, 2009
[81] Source: Döge, 2010; complemented by Arndt

5.5 ENVIRONMENTAL IMPACTS

Due to its electric nature the environmental impacts of tramway systems can be considered low. There is no air pollution in the urban area. Noise emissions are being continuously reduced through improved rails and vehicles. Altogether the tram can be considered a transport mode with very low environmental impacts.

5.5.1 Sound Emissions

Noise emitted by tramway systems can be reduced by green tracks or technological features. The electrification also ensures that silent electric motors are used. Especially the rail bed plays an important role for the sound emissions. Rails and vehicles that are not well maintained cause more squeaking, especially in curves. Vehicles like the new Cobra tram for example - custom made for Zurich by Bombardier - feature innovative technology that moves the rail squeaking more to the inside of the train than the outside. With innovative lubricants for the rails emissions can be reduced even further making the tram very environmentally friendly regarding noise emissions. Even though the sound emissions from trams are not necessarily lower than those of buses or cars, they are more steady and predictable. By aggressive driving, cars for example can generate a significant noise impact.

In summary the total sound emissions for trams can be perceived as low, especially if their capacity, which is much higher than cars and busses, is taken into account thus, reducing the amount of noise compared to several separate vehicles in traffic.

5.5.2 Greenhouse Gas Emissions

Almost all modern tramway systems nowadays run on electricity. This energy source is perceived as environmentally friendly. However, this is only truly the case if it has been generated from renewable energy sources. Nonetheless, if a tram e.g. runs on electricity produced by conventional energy sources there is still the advantage that generated pollution is not emitted in the city during operation and therefore the tram does not burden the local residents as for example a diesel engine would. Of course the construction and operation of the systems at whole do produce emissions.

As shown in the following figure the tram's CO_2-Emissions from operation are slightly higher than those of the subway, but much lower than those of bus and car. The reduction of CO_2 emissions is greater than 75 % in comparison to private cars.

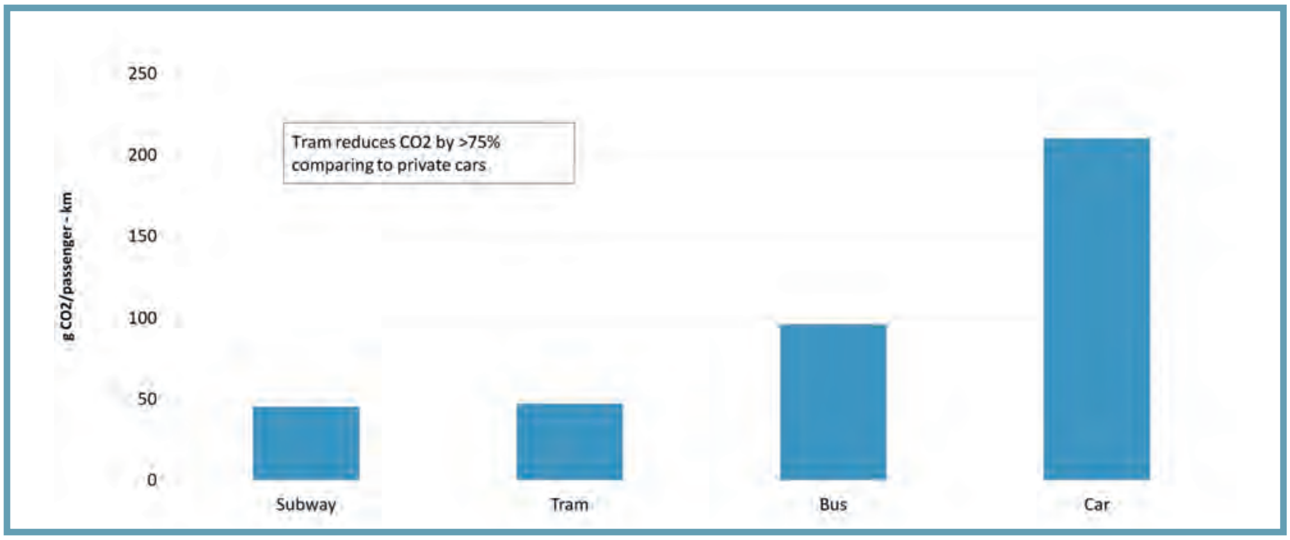


Figure 60: Carbon Balance of Transport Modes [82]

[82] Source: http://urban-gallery.net/txl/wp-content/uploads/2012/10/diagramm-co21.gif

6 TRAMWAY AS A PART OF A NEW TRANSPORT CULTURE

In the second half of the 20th century worldwide many cities reduced their tram systems to a minimum or shut them down completely. They were substituted by buses and metro systems and more space was given to private transportation with cars. The further expansion of individual transport induced more car traffic, which resulted in negative consequences for above ground public transport.

Environmentally friendly design of transport is becoming a more important job, especially because the deficits and failures of the past must be resolved. It is a challenge to find solutions to conflicting mobility, prosperity, environmental and freedom goals in a constructive manner. That means achieving certain improvements without affecting others negatively.

Due to these developments, near the end of the 20th century a worldwide rethinking took place in regards to the idea of mobility and amongst others a renaissance of the tramway, that was rediscovered as a low priced means of transport and also an element of the urban form. This was especially the case in France, where many tram systems had been shut down.

As a connecting element of different city areas, even districts, the tramways work best: They usually drive neither under nor above the street, but mostly in their middle. Generally visible by tracks, stops and the overhead wires, they not only serve transportation needs but also function as a marker for orientation. Access structures and stations are usually useable by all, because the heights to overcome are usually low and easy to compensate. A new tram system can change the streets, the traffic and the environment. People can see and feel it.

In summary the tram is a transportation vehicle with unique features of urban adaptability and connection capabilities for all kinds of public transport vehicles. It persuades with environmental friendliness due to its high electric efficiency as a constantly running public conveyance. It can be used for many different functions due to its flexibility. The development of trams networks is on its way. In Europe, North America, the MENA (Middle East North Africa) region and Asian governments are recognizing the impact of economic and coherent traffic growth and facing a choice how to handle it. Urban railway systems and specifically tramways certainly have a great future ahead.

Figure 61: A Combino Tram Running through a Green Area in Freiburg [83]

[83] Source: Verband Deutscher Verkehrsunternehmen 2014: VDV Das Magazin. Verband Deutscher Verkehrsunternehmen e.V. Köln, 03 2014, P: 4&5

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