HiTrans Best practice guide

4

Public transport – Mode options and technical solutions

Development of principles and strategies for introducing **High** Quality Public **Transport** in medium sized cities and regions

hi-trans

Interreg North Sea Region

HiTrans Best practice guide 4

Public transport – Mode options and technical solutions

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An introduction to HiTrans

HiTrans is an abbreviation for "the development of principles and strategies for introducing high quality public transport in medium size cities and urban regions". Examples of high quality public transport may be light rail, guided busways or frequent, comfortable buses. But the defining criterion of "high quality public transport" is the ability to compete with the private car for everyday travel in circumstances where car ownership is widespread. Established by a partnership of cities and transport agencies in the United Kingdom and Scandinavia, HiTrans is specifically aimed at cities and urban regions in countries bordering the North Sea that have populations between 100,000 and 500,000 people.

The project is jointly funded by the European Commission's Interreg IIIB North Sea Programme and the following partners:

- Rogaland County Council, Norway, (lead partner)
- Aarhus County Council, Denmark
- Edinburgh City Council, Scotland
- Helsingborg City Council, Sweden
- Stavanger City Council and Sandnes City Council (in partnership), Norway
- Sunderland City Council, England
- Jernbaneverket, the Norwegian National Executive for building and maintaining railways
- NEXUS, which operates the metro in Tyne and Wear, England
- NSB BA, the Norwegian National Railway operator
- Oslo Sporveier, which plans and operates the bus, tram and metro network in Oslo, Norway
- Statens vegvesen, the Norwegian Public Roads Administration.

The North Sea region is characterised by urban networks with few large but many medium sized cities and urban regions. Urban land use is generally low density when compared to other parts of Europe. There are also similarities in terms of urban culture and climate in the North Sea region that can affect the use of different transport modes. Car ownership and usage in European cities is generally increasing, and providing public transport that can compete with the private car is a challenge throughout Europe. But there are some challenges that particularly apply to medium sized cities and urban regions. In contrast to that of large cities, public transport in medium size cities and urban regions tends to be based on relatively low quality bus services. Smaller populations and thus lower passenger demand mean that expensive infrastructure such as heavy rail or subways cannot normally be justified.

Medium size cities that are looking for alternatives to normal bus services rarely have the resources to adequately research the advantages and disadvantages of emerging technologies and concepts of high quality public transport, particularly as these would apply in their circumstances.

HiTrans is a cooperative research effort to obtain this knowledge; to find suitable and cost effective solutions for such cities, and to learn from the best examples of relevant cities throughout the world.

But the aim is not just for high quality public transport. The aim is for high quality cities.

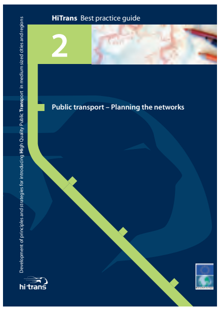
Most new concepts of high quality public transport require new infrastructure. It is a challenge to make such infrastructure fit into – and better still, enhance – the qualities of the urban landscape.

High quality public transport can also be used to restructure our cities to enhance the accessibility of the people who live in them without the choking traffic that diminishes our quality of life. At the same time it is expected that spatial planning oriented towards a city's high quality public transport network can be a critical factor in building patronage that in turn can justify more service.

HiTrans' work has been organised through 5 work packages called *strands*. This work has resulted in 5 best practice guides.

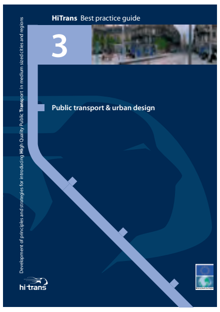
Best practice guide 1
Public transport & land use planning

How can we reshape our cities to facilitate the use of public transport? A series of case studies provides some inspirational illustrations of what can be done – as well as some salutary lessons of what to avoid. There are examples of cities regenerating run-down areas, curtailing urban sprawl, building successful public transport oriented communities, ridding themselves of traffic-chocked city streets, as well as examples of cities reinventing themselves as attractive places in which to invest and to live.
Main consultant: Lynn Devereux (WSP, Cambridge)



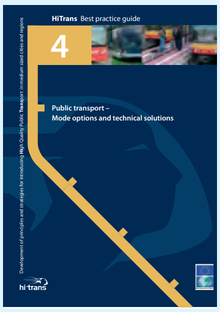
Best practice guide 2
Public transport – Planning the networks

Medium size cities face special challenges when introducing high quality public transport. How can the patronage be raised to generate the frequencies needed to make public transport a viable alternative to the car? This challenge is on top of well-known dilemmas that lie behind questions such as how far apart stops should be and whether resources should be spread between dense network of routes, or concentrated in a few, higher frequency routes. Illustrations and graphs demonstrate principles of network design, introducing concepts that simplify and clarify the planning public transport services. Also the report gives an overview of various legislative frameworks and their effects on the provision of public transport.
Main consultant: Gustav Nielsen (Civitas, Oslo)



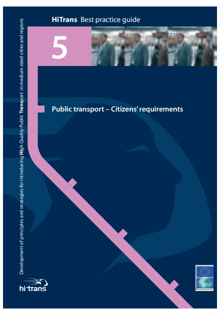
Best practice guide 3
Public transport & urban design

The introduction of high quality public transport can have profound implications for a city's urban design. It may be introduced with-out any thought about how it will look or its impact on people's ability to move about and enjoy the city's public spaces. On the other hand, it may be carefully designed to reinforce or en-hance these aspects – or to play a crucial part in the reinvention of the city's image. This guide uses case studies to examine the variety of urban design factors that should be considered when introducing high quality public transport: overhead wiring, rails, signs, stations, stops, guideways, safety barriers, as well as the vehicles themselves. It also provides advice on advertising and preventing vandalism.
Main consultant: Marie Burns (Burns+Nice, London)



Best practice guide 4
Public transport – Mode options and technical solutions

There is a wide range of options available for those planning the introduction of high quality public transport. Rail-based options range from ultra light rail to heavy rail, with various permutations and combinations such as tramtrains, light metros, metrotrains and so on. Cities opting for bus-based transport will have to choose between different forms and combinations of propulsion, as well as whether to use bus only streets, busways, and/or to adopt one of the evolving technologies to guide buses. The experiences of numerous cities are used to provide lessons of how to introduce cost effective solutions that suit the local circumstances, and avoid costly mistakes.
Main consultant: Trevor Griffin (Interfleet Technology, Derby)



Best practice guide 5
Public transport – Citizens' requirements

This report investigates what the citizens of medium sized cities require from the public transport system. The report is split into two parts. Part 1 is a desktop study analysing the findings of previous research into the requirements of both users and non-users of public transport. Part 2 presents case studies of medium sized cities and regions that are perceived as being successful in providing high quality public transport. The study identifies the qualities that have made a difference, as for example fare structure, speed, reliability and frequency.
Main consultant part 1: Alan Howes (Colin Buchanan and Partners, Edinburgh)
Main consultant part 2: Tom Rye (Napier University, Edinburgh)

About this Best Practice Guide

The objective of this guide is to give an overview of various public transport modes and technical solutions suitable for medium sized cities. As medium sized cities have smaller economies of scale than large cities, cost effectiveness is a key requirement.

This guide is a summary of 6 topic papers. To obtain a full understanding of the issues described in the guide the reader is recommended to download the topic papers from *www.hitrans.org/interfleet* as well.

The topic papers are:

1. Best practice for the six modes
2. Bus corridor transformation
3. Priority solutions for bus and tram
4. Effects
5. Tram Train guidelines
6. Cost effectiveness of solutions

Contributors

The main author of this report is Trevor Griffin (Interfleet Technology Limited, UK), who has been supported by a consultant team consisting of David Catling (Interfleet Technology Limited, UK) Nils Jänig, (TTK Karlsruhe, D) Johan van Ieperen (TTK Karlsuhe, D) Marc Perez, (TTK Karlsruhe, D) Per Andersson (Trivector, S) Daniel Svanfeldt (Trivector, S) Martin Higginson (Corus, UK) Gradimir Stefanovic (GS, UK)

Through regular meetings the consultants have been lead by the HiTrans Strand 4 working group consisting of:
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Axel Kühn, Karlsruhe, has given expert advice and Ian Radbone of QED, Adelaide, has given editorial advice.

The HiTrans international steering group (ISG) is the main responsible body of the HiTrans reports. All HiTrans partners have a member in the ISG.

Contents

1 Introduction

1.1 Challenges

The overall aim of the HiTrans project is to stimulate development of efficient and sustainable transport in medium size cities in the North Sea region by promoting high quality public transport.

The objective of Strand 4 is to explore specific high quality public transport technology within Western Europe and North America, including exploring their possible impact on passenger growth.

Good public transport can be expensive and this is the key challenge for smaller cities and communities. Forty years ago the only completely new public transport systems being built were expensive metros, these could only be afforded in the largest cities, usually catching up as their population grew with other wealthier cities, which already had them. The "discovery" of Light Rail in the 1970s allowed many medium sized cities to enter the rapid transit club and get the advantages of effective higher quality public transport. This was against a background of rapidly falling bus use in developed countries as private car ownership increased. Public Transport was still needed but for different reasons than just for mass transit such as relieving congestion and protecting the economy and historic fabric of cities.

Light Rail remained a relatively expensive form of new public transport option and in some North Sea countries it's costs rose significantly. Cities began to look for alternatives and found the promise of some new technologies very attractive, especially ones based on seemingly cheaper bus technology. Three problems quickly became apparent, which may also be seen as challenges:

1. Cost is a function of quality of service, not just of the technology.
2. Bus based options may be significantly less effective, even if cheaper.
3. The new technologies were untried and have had many problems resulting in added cost and poor performance.

However, in the same way that Light Rail tends to be a better option for medium sized cities than metros, then lower cost alternatives may well prove to be a better option for smaller cities.

During the same time period authorities began to look again at the neglected rail infrastructure in their regions instead of considering providing entirely new right of way. In some cases metros and Light Rail systems were built by converting existing railways but the scope for doing this has been limited. The new options that emerged were:

1. Operating Light Rail over existing railways in mixed operation with trains, e.g. the "Karlsruhe model".
2. Modernising local rail services with improved rolling stock, more stations and improved services.

In both cases these options might perform the function better that a new Light Rail or Metro could provide in a given area.

It is also clear that to make high quality public transport feasible in smaller cities a number of problems need to be faced:

1. Justifying the expenditure, assuming demand is low and the economic, social and environmental issues are less acute than in larger cities.
2. To make the system effective, getting priority in traffic for public transport over private transport where the flow of people using the system is not seen to be high.
3. Making best use of existing infrastructure, e.g. existing under-utilised railway alignments, and other resources.
4. Developing schemes that can be built in stages as money becomes available.

From these considerations the main challenges from a technical viewpoint are:

1. Reducing the costs of Light Rail by using simpler and/or smaller scale technology, taking risk away from suppliers, standardisation and other methods.
2. Making Bus Rapid Transit as cost effective, attractive, safe and reliable as Light Rail.
3. Introducing shared track without taking on heavy rail culture and costs.
4. Making the best use of existing railway infrastructure.
5. Getting simple and effective priority for public transport without a significant negative effect on other traffic.
6. Developing systems that can be upgraded easily as traffic grows.

These issues are themes that underline the best practice guidance given in this report.

1.2 What this report contains

The Strand 4 consultant was Interfleet Technology leading a team that consisted of Corus, TTK, Trivector and Gradimir Stefanovic. They were asked to conduct a desktop exercise examining technical solutions in high quality public transport within Western Europe and North America. Interfleet proposed extending this to other parts of the world if there is more experience of some of the less common solutions. It was asked to review existing research, not undertake original work.

Six modes were specified for study:

- Suburban and rural heavy rail with multiple units
- Light Metro
- Light Rail (including Tramway)
- Shared track
- Guided bus
- Quality bus corridors

The study was required to examine best practice on these modes and also to examine three specific issues:

- Giving priority to public transport
- Shared track operation
- Designing bus infrastructure for eventual conversion to tramway

The main tasks were summarised as follows:

- Task 1 Examine and analyse best practice in the six specified modes.
- Task 2 Advise on transforming a bus corridor into a tram corridor.
- Task 3 Advise on priority solutions for bus and tram.
- Task 4 Discuss the effects of the specific technical solutions on passenger volume/ridership/quality and effects on land use and urban design.
- Task 5 Provide guidelines on TramTrain solutions.
- Task 6 Assess the cost and effectiveness of the main solutions.

Sections 2–4 cover the results of task 1. The specified areas of study (tasks 2, 3 and 5) are covered in Section 5.

Section 6 continues by considering application in general, covering costs and effectiveness to enable options to be compared at project initiation stage (basically tasks 4 and 6.) This guidance is further summarised at a strategic level in Section 6.

The report also contains a reference section and appendices to supplement the guidance provided.

2 Glossary

Abbreviations are only used where they are in common use or assist reading.

ALRT Automated Light Rapid Transit

ATP Automatic Train Protection

BOStrab Strassenbahnbau- und Betriebsordnung (German tramway regulations)

DMU Diesel Multiple Unit (Train)

EBO Eisenbahnbau- und Betriebs-ordnung (German railway regulations)

EGB Electronic Guided Bus

EMU Electric Multiple Unit (Train)

EU European Union

GLT Guided Light Transit

GPS Global Positioning System

GSM Global System for Mobile communications

HMRI Her Majesty's Railway Inspectorate (UK)

HSE Health and Safety Executive (UK)

KGB Kerb Guided Bus

LNT Leichte Nahverkehrs Triebwagen (Light Railcar)

LRT Light Rapid Transit

LRV Light Rail Vehicle

MARIE Mass Transit Europe Initiative

MGB Magnetically Guided Bus

MU Multiple Unit (train)

OGB Optically Guided Bus

SCADA Supervisory Control And Data Acquisition

UIC International Railway Association

UITP International Public Transport Association

ULEV-TAP Ultra Low Emission Vehicle – Transport Advanced Propulsion

UNIFE European Federation of Railway Industry suppliers

3 Definitions

3.1 Sources of definitions

Defining various forms of transport that might be used in urban situations is a challenge because:

- There are no internationally accepted definitions.
- The distinctions between the technologies are "blurred", in that some types of system have some of the characteristics of others.
- There are other technologies, such as heavy metros, which need to be referred to in order to provide definitions, although they are not within the HiTrans remit.
- Specific systems, of which Oslo and Amsterdam are good examples, are often referred to as being one technology, whereas in fact individual routes are of different types.

We have decided to overcome this problem by making our own definitions, based as closely as possible on existing ones. We believe this will avoid confusion even though it may result in a few systems being "classified" differently to what people expect. We have also added some definitions for a few other technologies, that we are not covering any further, where this aids clarification. By doing this we hope to avoid lengthy and confusing discussions to fit historical definitions that may no longer be relevant.

In reality technologies should be used flexibly and there is limited value in trying to constrain them within rigid definitions. This is especially the case with Light Rail, which presents advantages through allowing flexibility in technology choice for specific applications.

3.2 Rail system definitions

3.2.1 Infrastructure

Mass Transit. Generic term for public transport systems with fixed routes and schedules that regularly carry large numbers of people, typically in urban and suburban areas at peak times.

Railway. Guided transport system using parallel rails, which provide support and guidance for vehicles carried on flanged wheels.

Heavy Rail. Conventional railways that operate as part of national networks and are capable of accommodating large passenger and freight trains.

Metro. Rail Mass Transit system that does not form part of the national or long distance rail network but uses trains that meet railway standards.

Light Metro. Rail Mass Transit system that does not form part of the national or long distance rail network that uses Light Rail Vehicles but does not usually have any tramway sections.

Light Metro systems are not clearly defined internationally but we have used this definition, which implies that they will be generally totally segregated, may have underground sections and will be operated by short light metro trains, Light Rail Vehicles (LRVs) or trams. They may be either driver operated or automated (ALRT.)

High speed reserved track Light Rail systems will also fall into this category.

Light Rail An urban passenger transport system with lower capacity than a metro and that has tramway sections.

Light Rapid Transit (LRT) An alternative name for Light Rail. The term is sometimes applied to bus based systems.

Automated Light Rapid Transit (ALRT). Driverless LRT systems using automated centralised control

Tramway. A system of transport using parallel rails used wholly or mainly for the carriage of passengers which has been designed to have a significant element that operates on line of sight on a highway.

Ultra Light Rail. A smaller capacity lower cost Light Rail/Tramway system using simpler technology and operating methods, usually including vehicles that do not require a continuous power supply.

3.2.2 Vehicles

Multiple units. Diesel multiple units (DMU's) or electric multiple units (EMU's) are self-propelled rail vehicles using either an on-board (generally diesel) or overhead electric power supply. They will either be single vehicles or more typically a permanently coupled set of vehicles, with a cab at each end, capable of being coupled together to form longer trains, i.e. operation "in multiple".

Usually DMU / EMU's are equipped with automatic couplers to facilitate multiple operation. They usually feature modern passenger information systems and allow easier access from the platform, both through the use of low-floor vehicle architecture and the improvement of station and stop architecture.

There are two important subdivisions:

"Heavy multiple units". Multiple Units that comply with all necessary regulations for heavy rail. This means, for example, that they have the standard UIC buffer load of 1,500 kN and can be freely operated on railways, currently within one member state but in the future across Europe.

Light Railcars. Multiple Units designed to have a "non-standard" lower buffer load of 600kN, and tramway braking performance, exploiting the German LNT regulations. The original German Regiosprinter was an example of this.

Tram. A self-propelled rail passenger vehicle designed to operate on tramway.

Light Rail Vehicle (LRV). A self-propelled rail passenger vehicle designed to operate on a Light Rail system.

Trams and Light Rail Vehicles are generally the same, the distinction is made because not all tramways are Light Rail systems.

3.3 HiTrans shared track definitions

Shared track. The operation on a common piece of track of rail vehicles that comply with standards for different types of network.
TramTrain. Special LRV designed to operate both on main line railways and on Light Rail or tramway systems.
TrainTram. Main line train that can operate over urban Light Rail and tram systems. In this case the urban system usually will need to be specially designed or adapted for TrainTram operation.
TramMetro. Operating LRVs and trams on Light Metro systems.
MetroTrain. Operating Light Metro trains on conventional railways.
Dual Mode. Shared track vehicles that can operate with two different electrification systems, usually via the same electrical current collector. These can be distinguished from "Single mode" a shared track vehicle that can only operate on one electrification system, and "Triple mode" etc. options, of which there are no current examples. The term "Hybrid" is used in the shared track context to describe a vehicle that uses a mix of electric and diesel or other non-current collecting form of propulsion.

3.4 Bus based system definitions

3.4.1 Infrastructure

Busway. Fully segregated purpose built roadway used for buses only.

Bus Lane. Part of a roadway reserved for buses and possibly taxis, cycles and other specific traffic.

Bus only street. Street designated for exclusive use by buses, for example through an otherwise wholly pedestrianised part of a town centre

Bus gate. Barrier through which only buses are permitted to pass. Other traffic is still able to access the street, e.g. to gain access to premises, but from a different access point. Through traffic other than buses is not permitted.

Guided bus. A passenger transport system using buses that are guided for all or part of the route. For HiTrans we are also considering the following types of system under this heading:

Electronic Guided Bus (EGB). Guided bus system where the guidance is provided by a cable or cables buried in the road that provide signals to control steering.

Guided Light Transit (GLT). A passenger transport system using vehicles that run on rubber tyres on a roadway and are guided by a device securely clamped to a central rail in the roadway.

Kerb Guided Bus (KGB). A guided bus system where the guidance is provided mechanically by rollers attached to the front wheels that engage with kerbs on either side of the bus and control steering.

Magnetically Guided Bus (MGB). Guided bus system where the guidance includes a system that detects the position of magnets set in the roadway in order to check against steering data stored electronically.

Optically Guided Bus (OGB). Guided bus system where the steering is controlled by a system that detects and responds to the position of a painted line on the roadway.

Quality bus corridors. A Quality Bus Corridor is defined as one in which buses are afforded some degree of priority over other traffic. The vehicles themselves meet current 'best practice' standards and attention is paid to ancillary aspects such as the passenger waiting environment and provision of high quality information. The provision of a quality corridor commonly involves a partnership approach between operators, transport authorities and highway authorities.

N.B. The term "bus" is sometimes used in this report as a generic term for all bus based modes, as distinct from rail based ones, so will include Busways, Guided Bus, Trolleybus, Duobus and Quality Bus in these cases.

3.4.2 Vehicles

Trolleybus. Electrically powered bus taking its power from a continuous conductor, usually twin overhead wires. This includes trolleybuses that can move very short distances at slow speeds, in special circumstances, using their batteries as a power source

Duobus. Bus that can operate in normal service either as a trolleybus or as an ordinary bus, because it has an on-board power supply as well as overhead pick-up.

4.1 Characteristics

This section briefly adds some further information to amplify the definitions for the six specific technologies being considered. The principal characteristics of the options are summarised in tables in section 4.3.

Light Metro. Tyne and Wear Metro. *(Interfleet)*

4.1.1 Light Metro

Light Metro systems typically provide inner city or short distance suburban transport with closer station spacings than conventional suburban rail and some metros. Peak loadings are likely to be relatively heavy and the capacity will be between that of metro and Light Rail systems. Because street running will be limited or not exist the following characteristics will be typical:

- Vehicles will operate in trains, coupled together (hence generally higher capacity than Light Rail.)
- Reserved track sections are likely to have full signalling.
- Stations will be more like metro stations than tram stops.
- High floor vehicles with level boarding to high platforms.
- Wider choice of power system (including conductor rail.)
- Automation option as ALRT.
- Less onerous horizontal and vertical curves and gradients than tramways.

Light Metro systems will probably have the highest capacity of any of the technical options being considered here.

ALRT can be considered as a type of Light Metro. Although the technology is very expensive, there are a number of examples of short systems being developed in medium sized cities, so it is worth consideration by HiTrans.

4.1.2 Suburban and rural heavy rail with multiple units

Traditional railway operation can be very expensive for shorter distance services with frequent stops. Various developments have taken place over the years in order to overcome this problem, including the introduction of special rolling stock, Light Railcars, multiple units and electrification, the use of unstaffed stations and more appropriate fare collection methods.

These options have been available for a long time but their introduction has been un-even. In recent years there have been some notable successes, combining these technical solutions with novel management techniques, better marketing and improved services to achieve transport systems that have proved to be very cost effective in the areas that they serve.

What we are considering under this heading is therefore the operation of existing or new railway services using multiple units, possibly using vehicles with a less onerous specification than main line rolling stock and simpler operating methods. In some cases this involves direct local management and promotion of the services and integration with local as well as national transport networks.

This technique makes better use of infrastructure and rail services that already exist but offers the opportunity to open up entirely new markets by providing improved service and more stops. It therefore has the potential of being a cost effective solution wherever it can be applied.

Suburban and rural heavy rail with multiple units. Regio Sprinters on the Schönbuchbahn. *(Axel Kühn)*

Light Rail. Nottingham Express Transit, a modern Light Rail system. *(Interfleet)*

4.1.3 Light Rail (including Tramway)

Tramway systems traditionally provided complete urban transport systems. But as cities spread out into lower density development the bus gained a foothold and in many areas displaced trams completely. One characteristic of the surviving tramways was that they tended to remain associated with high density housing. Modern Light Rail systems and the new tramway systems usually have a strong commuter flow element and are associated with moving large numbers of people in a few corridors. They can therefore be seen as a "poor man's metro or suburban railway", unlike the traditional tram.

If a system were built new today then it would typically provide inner city or short distance suburban transport with closer station spacings than conventional suburban rail or metros (including light metros.) Peak loadings are likely to be relatively heavy and the capacity will be between that of light metro and bus based systems. Because street running will exist, the following characteristics will be typical:

- Vehicles will usually operate singly, or at most coupled together in pairs, so as not to obstruct other traffic.
- Reserved track sections will probably operate on "line of sight".
- Stops will be more like bus stops.
- Partially or totally low floor vehicles with low platforms for level boarding.
- Overhead electrification.
- Sharp horizontal and vertical curves and steep gradients.

4.1.4 Shared track

Although much of the development of the Tram-Train concept occurred in Karlsruhe, the technology there had to be adapted to the existing tram system. Karlsruhe and Saarbrücken both provide experience of successful operation. "Theoretical" best practice is more likely to be found in newer (not yet realised) systems and projects, of which there are a number of examples in Europe (as described later.)

TramTrain

- Vehicles will need to be fitted with Automatic Train Protection, or a system having similar functions, if they do not comply with railway collision requirements.

TramTrain operation in Chemnitz (Variobahn). *(Axel Kühn)*

TrainTram operation in Zwickau. *(Axel Kühn)*

- If the railway is electrified other than at tramway voltage (normally 750 V dc maximum) then either dual mode LRVs or some other traction power source is necessary.
- A moveable footstep may be required to reach platforms because platforms that suit LRV and tramway vehicle widths normally foul railway structure gauges.
- It may not always be possible to use low floor vehicles.
- Vehicles may need to operate in multiple in order to make best use of paths on the railway system.
- The top speed should be at least 80 km/h (preferably 100 km/h) to minimise the travel times on longer distance regional routes, and to avoid congestion problems on urban railways shared with faster trains.
- Special wheel profiles are required for the operation on both existing tramway and railway networks (of the same gauge.)

TrainTram

- Light Railcars often have a width of 2.9 m or more. The tramway route must allow clearance for this width of car.
- To operate on tramway routes the brake performance of these Light Railcars must be raised to tramway standards. Additional indicators, external lighting and rear-view mirrors are also required.
- Light Railcars usually will have a diesel propulsion system, which allows autonomous operation in the tramway section.
- If diesel operation in the inner city section is not allowed, alternative power sources such as energy storage might be considered. With these systems it might be possible (depending on the weight of the vehicle, the required performance, the track layout) to go for about 1–2 km without the use of the diesel engine. In this case the Light Railcar must be based on a diesel-electric motor-drive system. However diesel engine technology is improving.

TramMetro

- The Light Metro system is likely to have high platforms which may result in any LRVs and trams needing to have high floors. This can be an issue for providing platforms in urban areas on street tramway sections.

Guided bus. Kerb Guided Bus operation in Leeds. *(First Group)*

Quality bus corridors. Segregated bus and taxi lanes in Prince's Street Edinburgh. *(Interfleet)*

- Existing Light Metro systems may use wider vehicles than LRVs. A moveable step will be needed to bridge the gap that this causes between the LRV and the platform.
- Trams and LRVs will probably run in multiple to justify the occupation of paths at peak times on a Light Metro.
- Trams and LRVs will need numerous wide doors suitable for metro operation loadings.
- The power source in metro systems is often a third rail (600–750 Vdc.) For a high floor LRV it is normally not a problem to cope with this third rail. But for low-floor trams this creates more serious technical and safety problems and therefore requires in most cases an overhead wire in the metro systems resulting in additional cost.

MetroTrain

- Vehicles will need to be fitted with some form of ATP if they do not comply with railway collision requirements.
- The gap between the platform and the vehicle might be different in the metro and railway area. But this depends on the layout of the metro system, which is the basis for dimensions of the vehicles. Depending on the local situation, additional steps in the vehicle may be required to bridge this gap (horizontal and vertical.) This solution will become difficult with new requirements for disabled access.
- If the line is not already electrified then it will be normal practice to provide the electrification system of the Light Metro on the railway solely for the use of metro cars. If the line is already electrified then either the metro cars must be adapted to it or some form of dual system must be adopted.

4.1.5 Guided bus

Guided bus systems have been seen as an alternative to Light Rail and could fulfil a similar role. However some of the applications to date have been modest enhancements of existing bus routes, or single routes. Only now is the technology being more widely adopted and seriously considered. A key issue is the fact that guided buses are automatically "dual mode", i.e. they can operate both on and off the guideway. This can be seen as a significant advantage but recent thinking has tended the other way, and we are seeing new systems being developed to be 100% guided.

Guided busways can have Light Rail characteristics and be applied in similar situations. Overhead electrification is an option, using trolleybus or duobus technology. Five other key issues are:

- Doubts about the practicality of some new technologies and whether or not the public will see them as an acceptable alternative to Light Rail.
- The unsuitability of KGB for street operation in pedestrian areas.
- Limitations on vehicle length and capacity.
- The reluctance to convert railways to guided bus because of the barrier this imposes on future potential rail development (UK examples of this issue arising have included Bristol, Luton, Chester and Cambridge.)
- The possibility of introducing a guided bus system as a first stage in building up traffic to justify a later Light Rail scheme.

4.1.6 Quality bus corridors

Bus priority and other quality features are introduced in place on a complete corridor, to ensure that the service is significantly more attractive than a normal bus route. This should include ride quality, freedom from congestion, accessibility standards etc.

Busways in Canada and Australia include well-engineered private roadways with substantial stations that take up a lot of room and are probably too expensive for consideration within Europe. European quality bus systems are normally limited to provision of better than average quality passenger waiting environment, with well-lit shelter and high quality information (possibly in real time.) Consideration must also be given to safe and convenient access to and from stops: good quality, direct, illuminated walking routes and convenient pedestrian crossings.

The extent of segregation required is determined by the level of traffic on the corridor and to what extent congestion delays buses. Segregation of buses from other traffic may be achieved either by giving the buses their own lane on or off the road, or by separating buses and other traffic on different routes.

Putting buses and other traffic on separate routes may be achieved in a number of ways:

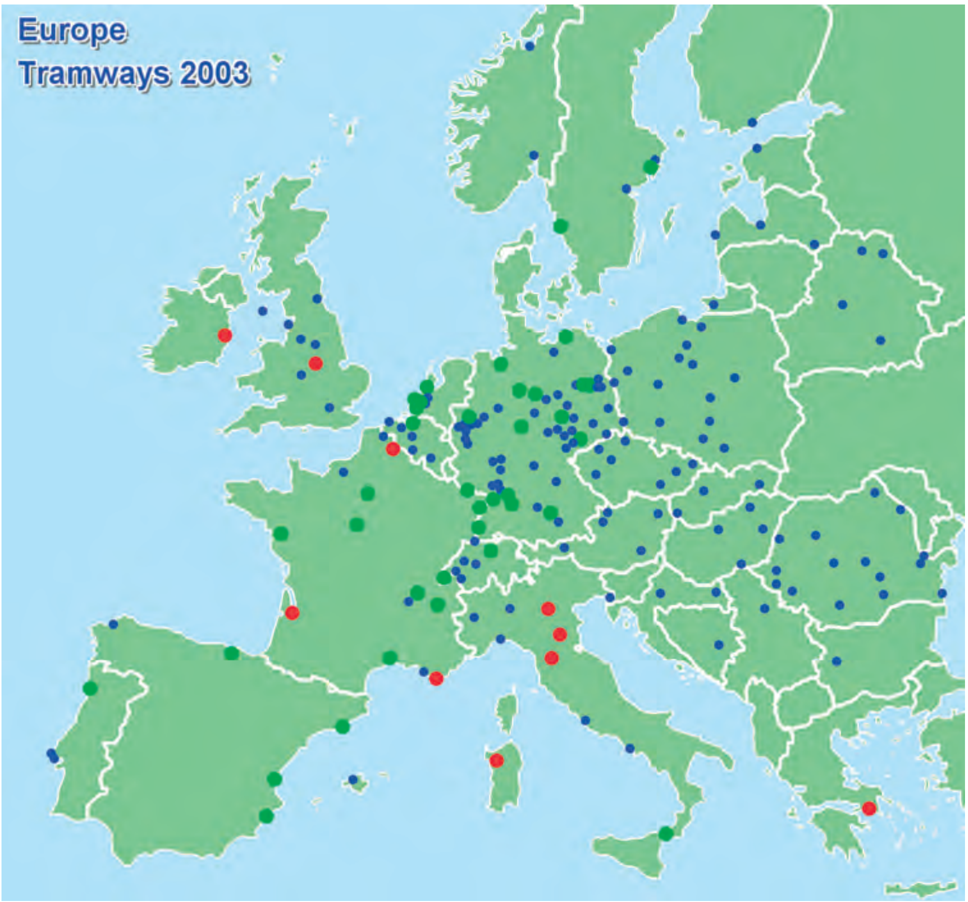
- Firstly, there must be a feasible alternative route, such as two closely parallel radial routes into a town
- The route selected for buses may be kept free of other traffic by providing a Bus Gate at the entry point, through which other traffic is not permitted to pass.
- Contra Flow Bus Lanes that permit buses to travel along a one way route in the opposite direction from the general flow of traffic.
- When a new road is built, such as one that bypasses older inner suburbs on a radial route system, it may be preferable for buses to continue to use the older road. This will now be free of most through traffic, which will divert to the new road. The buses will be able to continue to serve the local population

Bus lanes do not necessarily need to run the full length of the quality corridor, but may be restricted to short sections as required to bypass any congestion. A short section of priority lane or bus gate (banned entry) may suffice to keep traffic out of a particular road, or to enable buses to bypass a queue on the approach to an intersection.

In city centres, buses may be given exclusive access to certain streets for part or all of the working day. Servicing activity takes place outside the restricted times, or by using alternative access routes.

4.2 Examples of specific technologies

Table 1 (next page) lists around three typical examples of each type of system. Tramway, Light Metro, Light Rail and Quality Bus systems are found all over Europe. The other technologies tend to be only found in a few applications or specific regions.



Map of European tramway systems 2003. Red dot = under construction, Green dot = extension under construction or opened last year, blue dot = other tramway system. *(PG Anderson)*

Table 1 Examples of systems

Type of system	North Sea Region	Rest of Europe	Rest of World
Light Metro	Tyneside, UK Amsterdam, NL Utrecht, NL	Docklands, UK Lille, France Stuttgart, Germany Vienna Line U6	Kuala Lumpur, Malaysia Vancouver, Canada Kobe, Japan
Suburban and rural heavy rail with modern multiple units	Tag I Bergslagen, Sweden Nord-Ostsee Bahn, Germany NSB Talent, Norway	Seetallinie, Switzerland Schönbuchbahn, Germany Breisgau S-Bahn Ortenau S-Bahn Dürener Kreisbahn Regiobahn Kaarst-Mettman	No appropriate example found
Light Rail (including tramways) (1)	Gothenburg, Sweden Sheffield, UK The Hague, NL	Rouen, France Freiburg, Germany Zurich, Switzerland	Buffalo, USA Tuen Mun, China Tunis, Tunisia
Guided Bus	Leeds, UK Ipswich, UK Eindhoven, NL	Caen, France Nancy, France	Adelaide, Australia
Shared Track	Sunderland, UK (MetroTrain) Amsterdam, NL (TramMetro)	Zwickau, Germany Nordhausen, Germany Chemnitz, Germany Karlsruhe, Germany Saarbrücken, Germany Kassel, Germany	San Diego, USA Trenton-Camden, USA
Quality Bus Corridors	Copenhagen, Denmark Edinburgh, UK York, UK Zuidtangent, NL Enschede, NL	Runcorn, UK	Curitiba, Brazil Ottawa, Canada Brisbane, Australia

(1) There are some 350 Light Rail systems all over the world, that should be considered under the definition of Light Rail. Light Rail should play various roles within the city transportation system, mainly depending on the size of the city and level of development of other rail based modes. Because of its flexibility, it is possible to have Light Rail as a dominant mode of operation, or as a mode with an orbital route or as a non-dominant mode, successfully connecting different parts of the city. Light Rail can be supported on traffic grounds in cities of 100,000 population, but will also be seen in much larger cities as one of the rail-based modes. We can therefore be very selective in choosing typical examples.

4.3 Technology details

The first three tables in this section indicate which types of technology tend to be used on each type of system. They cover rolling stock, infrastructure and signalling and control systems.

4.3.1 Rolling Stock

Table 2 (overleaf) excludes TrainTram, TramMetro and MetroTrain. Very few of each of these currently exist and the examples that do may not be typical of what is possible. In general a TrainTram may have similar characteristics to a Modern Multiple Unit, a Tram-Metro to a Light Rail Vehicle or Tram and a MetroTrain to a Light Metro vehicle.

Most existing guided busways operate with standard buses fitted with the appropriate guidance technology, which normally consists of small lateral wheels for kerb guidance acting on the front axle.

More technologically sophisticated electronically, optically or centre-slot guided systems sometimes use vehicles that are closer to LRVs than to buses. The prices of such vehicles are also closer to those of LRVs. For example Caen's 24 vehicles cost Euro38 million, or Euro1.58 million each, compared with Euro 1.2–3.0 million range that applies to trams.

Quality bus systems will use standard buses, but for 'quality' to be achieved, it is essential for buses to meet more than the legal minimum standards. Ideally, there needs to be a requirement for services to be run with vehicles meeting the latest 'best practice' standards, for example with regard to emissions, noise and accessibility. The ease with which minimum standards can be guaranteed will depend on:

- The regulatory regime in force in the country or city concerned – is it legally permitted to stipulate that services must only use vehicles the specification of which exceeds legal minima?
- The extent to which services originating or terminating beyond the Quality Corridor pass along it. Although the principal services may meet the desired standards, to what extent is it desirable or legal to require all services in the corridor to conform? A particular issue may arise, for example, when services from a rural hinterland travel along an urban quality corridor to reach a city centre. It may be prohibitively expensive to require every rural bus to meet the standards stipulated for the corridor.

Table 2 Rolling stock

Vehicle type	Light Metro	Light Rail / TramTrain	Tram	Modern Multiple Unit
Support system	Steel wheels on steel rails (1)	Steel wheels on steel rails (1)	Steel wheels on steel rails (1)	Steel wheels on steel rails (1)
Guidance system	Flanged wheels (2)	Flanged wheels (2)	Flanged wheels (2)	Flanged wheels (2)
Traction	Electric but alternatives possible	Electric but alternatives possible	Electric but alternatives possible	Various (3)
Overhead electrification	Yes	Yes (15)	Yes	Possible
Conductor rail electrification	Yes	No (4)	No (5)	Possible
Voltages (V dc)	750/1500	750 (7)	600/750	Various
Automated (driverless)	Possible	No	No	No
Maximum speed km/h	80	100	70–80	100–160
Commercial speed km/h (8)	30–40	22–38 (16)	17–28	30–50
Track brakes	Possible	Yes	Yes	Possible (19)
Single axles	No	Possible but not proven	Possible but not proven	No
Single bogie	Possible	No	Yes	Yes
Bogies	Yes	Yes	Yes	Yes
Articulation	Yes	Yes	Yes	Possible
Cabs	End cars	One or both ends (20)	One or both ends (20)	Both ends
Inter-unit passenger connections	Gangway or full width	Full width	Full width	Gangway or full width
Standing/seating ratio	High	High	High	Medium
Maximum capacity per "train"	750	750	500	900
Cars per train	2–6	1–3 (13)	1–2	1–6
Level boarding	Yes	Yes	Yes	Possible
"Gapless boarding"	Yes	Yes	Yes	Yes
Doors provision	High	High	High	Medium
Ticket sales	Off train	On or off vehicle (10)	On or off vehicle (10)	On or off vehicle (10)
Maximum vehicle length (m)	12–14	50	50	50
Maximum vehicle width (m)	2.65 up (11)	2.65	2.65	2.65–3
Minimum horizontal curve radius (m)	50	25 (18)	12-20	100
Maximum Gradient	5%, or exceptionally 10%	5%, or exceptionally 10%	5%, or exceptionally 10%	4%

GLT	Bus
Rubber tyres on road	Rubber tyres on road
Mechanical	See 4.1.4
Electric	Diesel or Electric
Yes	Possible
No	(6)
750	600/750
No	No
70	70–100 (17)
20 (Caen)	20
No	No
Yes	Yes
No	No
Yes	No
Yes	Possible
One or both ends	One end
Full width	Full width
High	Low/ Medium
210	100
1	1
Yes	Possible
Possible (9)	Possible (9)
High	Low/ Medium
On or off vehicle (10)	On or off vehicle (10)
39	18
2.5 (12)	2.5 (12)
12	10
13%	25%

1. Some Light Metro cars use rubber tyres
2. Some Light Metro cars use horizontal guidance wheels.
3. Transmission systems may be direct mechanical, electric or hydraulic. Light Railcars can use overhead electric traction but this is unusual.
4. Dual overhead/conductor rail LRVs exist.
5. Bordeaux trams are pioneering a new form of buried conductor rail system.
6. The Ansaldo Stream was an experiment using a buried conductor rail system.
7. Dual voltage TramTrain will use railway voltages as well, e.g. 15kV ac.
8. Typical of stopping patterns and traffic conditions.
9. Only reliable when vehicle is guided.
10. Smaller vehicles may have payment to driver, otherwise ticket machines/conductor.
11. Automated systems may use smaller cross-section cars to save costs on tunnel construction.
12. Unless used on own right of way.
13. Length of train is limited to 75m on a street tramway in some European countries.
14. Shorter formations (1,2 or 3 cars) are more typical in urban and local services.
15. Some TramTrain applications involve non-electric vehicles.
16. Up to 50km/h for TramTrains running on regional railways.
17. Achieved on the Adelaide KGB line.
18. 20m in depots.
19. A requirement for LNT.
20. TramTrain will always have cabs at both ends.

Table 3 Infrastructure

System type	Light Metro	LRT (and off-street tramway)	Street tramway	Railway	GLT	Busway
Rail	Steel flat bottom rail (1)	Steel flat bottom rail	Steel grooved rail	Steel flat bottom rail	Steel central guide rail	None (2)
Sleepers	Wood, steel or concrete	Wood, steel or concrete	None (3)	Wood, steel or concrete	None	None (2)
Ballasted track	Yes	Yes	No	Yes	No	No
"Grassed track"	Possible	Yes	No	Possible	No	No
Slab track	Yes	Yes	No	Possible	No	No
Track surfaced to road level	Possible	Possible	Yes	No	Yes	Yes
Segregation	Most of route	Part of route	Usually un-segregated	Whole route	Usually un-segregated	Varies
Level crossing protection	Railway standards	Tramway standards	Tramway standards	Railway standards	Tramway standards	Highway standards
Tunnel sections	Possible	Possible	Possible	Possible	Possible	Possible
Underground stations	Possible	Possible	Possible	Possible	Possible	Possible
New bored tunnels	Possible	Un-economic for HiTrans size communities	Un-economic for HiTrans size communities	Possible	Un-economic for HiTrans size communities	Un-economic for HiTrans size communities
Elevated sections and stations	Possible	Possible	No	Possible	No	Possible (5)
Open stations (4)	Possible	Normal	Normal	Normal	Yes	Normal
Staffed stations	Common	Possible	Unusual	Possible	Unusual	Unusual
*Maximum vehicle length (m)	12–14	50	50	50	39	18
*Maximum vehicle width (m)	2.65 up (6)	2.65	2.65	2.65–3.0	2.5 (7)	2.5 (7)
Minimum curve radius (m)	50	20–25	12–20	100	12	10
Maximum Gradient	5%, or exceptionally 10%	5%, or exceptionally 10%	5%, or exceptionally 10%	4%	13%	25%

* To indicate what the infrastructure needs to allow for. Platform lengths and alignment width will depend on clearances and local conditions and national regulations.

1. Some forms of ALRT and Light Metro use a concrete track.
2. KGB can use concrete "rails" and sleepers. Use of cast or slip formed paving improves ride.
3. Typical track form is rails supported by continuous concrete slab with tie-bars to keep gauge.
4. An "open " station is one to which the public have access without passing through a barrier or ticket check.
5. The Adelaide KGB route is mainly a low level elevated track in place of using earthworks.
6. Automated systems may use smaller cross-section cars to save costs on tunnel construction.
7. Unless used on own right of way.

4.3.2 Infrastructure

See table 3. Some technologies have the advantage of being able to use more attractive infrastructure. This can be a key to their acceptance in urban environments. Rail systems can use grassed or cobbled track without affecting vehicle ride.

4.3.3 Signalling and control systems

See table 4. If shared track operation is introduced onto a system that has radio equipment then it will be a requirement that the system is also applied to those vehicles.

Table 4 Signalling and control systems

System type	Railway	Light Metro	LRT (4)	Shared-track operation (5)	Tramway/ GLT (4)	Busway
Full signalling (lineside or cab)	Yes	Yes	Possible	Yes	No	Possible
"Line of sight" operation	No	Possible	Possible	(1)	Yes	Normal
Speed dependent moving block (3)	No	Possible	No	No	No	No
Automatic Train Protection or Irrevocable Train Stop	Possible	Advisable	Possible	Yes	No	No
Automatic Driving	No	Possible	No	No	No	(2)
Automatic Operation	No	Possible	Possible	No	No	No
SCADA power control	Possible	Yes	Yes	Possible	Possible	Possible

1. "Line of sight" possible on a shared track route for vehicles with short braking distances under specific conditions.
2. Some guided systems, but driver remains in cab.
3. Allows trains to run closely at speed where a signalling system exists.
4. Swedish regulations require Automatic Train Protection (a system that automatically controls the speed of the train in response to signals) for speeds exceeding 60km/h.
5. Applies to the shared track section of the system only.

Table 5 Accessibility of types of stop

Station/stop type	Location	Access to station	Movement within station
Elevated station	Very restricted	Via steps / ramps / escalators / lifts	Via steps / ramps / escalators / lifts
Underground station	Unrestricted	Via steps / ramps / escalators / lifts	Via steps / ramps / escalators / lifts
Surface station on high speed segregated alignment	Restricted	Direct/across track	Via steps / ramps / escalators / lifts
Surface station on low speed segregated alignment	Restricted	Direct/across track	Level track crossing
Stop in a street in traffic	Unrestricted	Across traffic	Level track crossing
Stop in a traffic free street	Unrestricted	Direct/across track	Level track crossing

Table 6 Types of stop associated with different infrastructure

Station/stop type	Railway	Light Metro	Light Rail / Tramway	Guided Busway	Quality Bus Corridor
Elevated station	Possible	Typical	Possible	Possible	Possible
Underground station	Possible	Typical	Possible	Possible	Possible
Surface station on high speed segregated alignment	Typical	Typical	Possible	Possible	Typical
Surface station on low speed segregated alignment	Possible	No	Typical	Typical	Typical
Stop in a street in traffic	No	No	Typical	Typical	Typical
Stop in a traffic free street	No	No	Typical	Typical	Typical

4.3.4 Accessibility to and within stops

Choice of mode will influence how accessible the stops are and how easy it is to move around within a stop or station as shown in table 5.

Table 6 gives an indication of the types of station associated with the infrastructure types associated with each mode so that the relationship between the mode and accessibility can be considered. Actual station types will depend however on the specific application and will usually vary along the route.

The locations of stops are important as they need to be close and accessible to the places that they are planned to serve.

Access to the platforms once one has arrived is important:

- The time it takes to enter and leave the station needs to be added to journey time.
- Changes of level are undesirable and cause problems for many users including anyone carrying anything or those looking after elderly people or children.
- Stairways, ramps, escalators and lifts all restrict the capacity of stations to cope with crowds.

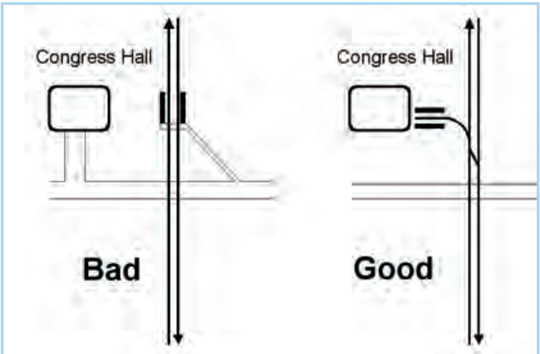
Movement around the station is important if one has to change platforms or access to the station is from one side only. Again changes in level are undesirable.

Providing lifts or ramps to provide access for the mobility impaired is very expensive compared with simple level crossings and should be avoided if at all possible in the context of smaller cities and regions.

The following measures should be designed into systems in order to avoid problems where passengers can cross on the level, in order of priority:

- Locate stops so that passengers do not need to cross the track or busway in order reach major traffic generators (This is also true of platforms at stops.)
- Direct passengers into clearly defined safe crossings rather than indiscriminate movement.
- Locate such crossings in an appropriate safe location:
- On street tramways and busways the driver will drive on sight and must have adequate visibility of people approaching the stop from every direction.
- Locate segregated alignment crossings so that people will tend to cross behind rather than in front of departing vehicles by use of staggered platforms where possible.
- Provide safety measures at crossings (see 5.1.3.)
- Co-ordinate pedestrian crossing lights with vehicle movements.

The upstands of Kerb Guided Bus systems form a barrier to pedestrian movement. *(First Group)*



Example of how to improve access. *(Interfleet)*

If island stops cannot be avoided (i.e. stops in the centre of a highway with general traffic), the pedestrian traffic lights should be co-ordinated with arriving public transport vehicles. This means that the pedestrian light turns green just before the vehicle stops, thus avoiding the annoying and potentially dangerous situation of having to wait and seeing the vehicle leave just because general traffic has priority.

In some countries it is a requirement that road vehicles stop to allow people to access a tram in the centre of the road. This is no longer a guarantee of passenger convenience or safety however, because many motorists will disregard or be unfamiliar with aspects of law that they rarely encounter.

Examples:

- **Midland Metro, Birmingham–Wolverhampton, England.** The track within stops is paved, even on segregated track sections, so that pedestrians can wander freely between the platforms. This does mean however that trams have to move slowly through the whole length of stops and some experts have commented that specific crossing locations would have been better.
- **Green Line, Los Angeles, USA.** At most stops passengers can only access the system after passing through over or underpasses across a freeway because the route is in a median. The patronage of this route proved to be well below that of the Blue Line, where stops are much easier to access.

Good accessibility by use of low platforms in Saarbrücken. *(Axel Kühn)*

4.3.5 Accessibility to Vehicles

Accessibility requirements vary both by country and by type of technology. For example, the distance between the platform and the vehicle step for different types of vehicle is specified in Belgium, Germany, Sweden and the UK. There are also guidelines in the Netherlands but no requirements in Denmark or Norway. In general, legislation is being progressively introduced in EU countries to make public transport more accessible to all. This has the "spin-off" advantage that boarding and alighting are quicker and safer for all passengers and thereby reduces journey times. It is also of benefit to occasional users, (e.g. when visiting an unfamiliar city), and those carrying heavy luggage or travelling with young children. Safe and convenient access is also necessary to all parts of a system, e.g. to elevated or underground platforms and at modal interchanges.

In order to improve accessibility there has been a move towards introducing low floor vehicles for street running public transport systems. It is possible to provide "level" access from higher floor vehicles by providing high platforms. But city planners will often object to these, partly because the ramps required to access them can form an obstruction, and because high platforms are a hazard to traffic.

Many modern front entrance buses are fitted with air systems so that they can "kneel" at stops. It is also possible to use air suspension to provide closer height levelling on other types of vehicle. The floors will often slope upwards from the doorway areas and there may be internal raised areas, accessible only by steps. The same is true of low floor trams and LRVs. "100%" low floor LRVs and trams involve more costly engineering and may compromise other technical features of the design unfavourably. It is also questionable if a complete low floor is that essential for meeting passenger needs, providing passengers

High platforms on a railway using Multiple Units (Regiobahn Mettmann). *(Axel Kühn)*

with mobility problems can enter and leave by the same low floor door area, because some passengers appreciate the separation and better views that a raised floor area provides. However it should be emphasised that 100% low floor LRVs and trams are now in common use, with a floor height of 300/350mm.

Light Metro systems can provide 100% level floors with level access by means of high platforms (800–1000mm.) However it is not possible for them to provide 100% low floors if they need to meet railway buffing load standards.

Multiple units need to use existing low railway platforms at stations. In many countries, although there are standards for platform height, the actual heights of platforms can vary considerably. For example in the UK the standard height is 915mm but platforms existed recently that ranged from 600–1100mm. In order to achieve more acceptable "stepping distances" it has been necessary to reconstruct many platforms, and as others become due for reconstruction this has to be done to the standard height. Lower platform heights are common in much of Europe; one issue being that vehicles designed for local branch lines in Germany with a 550mm platform height cannot be used on systems that use higher platforms.

Tram Trains ideally should have low floors to facilitate street operation but 100% low floor is difficult where the vehicles also have to operate at speed. Low platforms need to be accepted on the railway system in this case. An alternative for TramTrain, TrainTram and TramMetro is to use high platforms on the urban tramway sections, but this can cause problems as already mentioned. This topic is discussed in more detail later.

Future urban systems in the North Sea Region should aim to provide a maximum difference in height and distance between platform edge and vehicle floor at doors of 50mm.

4.3.6 Information systems

At the higher traffic densities associated with a light metro system, real time information systems become even more important at all levels – between control centre, emergency services, station and other supervisors, drivers and passengers – to ensure not only the good reputation and hence the patronage of the system, but more important to avoid potentially unsafe situations, e.g. excessive build up of passengers if the system experiences a major failure or a security alert. This must of course be two-way, because the Control Centre cannot take appropriate safe action until it knows what is actually happening at the source of an incident, especially if this occurs in tunnel.

The GoTiC (Gothenburg Traffic Information Centre) a joint research centre of the Gothenburg Traffic and Public Transport Authority and the Chalmers University of Technology, has done much useful work in this field. However, while increasing use of the Internet to provide real time travel information is to be welcomed, it is still very important to remember the needs of those (perhaps elderly, less well off) who do not have access to, or are not familiar with the Internet, and are perhaps unlikely to use it in the future.

Good information systems are also important for other forms of public transport, as they facilitate integration with other modes. It is essential to provide users with possible connections with other modes, as well as the location of Park and Ride facilities, as well as with on-line information about the availability of parking spaces and the departure time of the next vehicle. It is easy but expensive to provide real time information at stops about the arrival of the next vehicle due to the presence of such information for transport control systems. It is possible for a centrally controlled system to show the arrival times of vehicles of more than one operating company. A functional and efficient system of passenger information was introduced in Gothenburg several years ago. Together with active information at every stop it is possible to obtain information via mobile phones or the Internet.

The provision of information to more remote locations should be facilitated as GSM communication gets cheaper.

4.3.7 Ticketing systems

No new transit system, however well designed, can be viable unless revenue collection is assured, and fare evasion and other fraud by passengers or staff is minimised. Light metro has the advantage that, like a full metro, it can be set up as a "closed" system with controlled access, unlike an "open" non-segregated Light Rail system.

Traditionally, other more "open" forms of system have suffered from fare evasion, especially the larger Light Rail vehicles and trams.

Various combinations of these options exist. There is no one "answer"; what works best depends on the type of technology, the character of the system and its operation, the intensity of use, local culture and other factors. Some of the key issues that determine the "best choice" for a specific application are listed here:

- Paying on entry to the driver affects journey time and reliability significantly
- A system that depends on "honesty" will never be 100% effective and in some locations may prove very ineffective.
- Machines at stops increase the time that passengers need to allow to make a journey.
- Machine issuing is complicated unless the ticketing regime is very simple.
- Machines at stops are expensive, prone to vandalism and need emptying and servicing.
- Payment to a person in a fixed location on a vehicle means that entry has to be via one point and movement within the vehicle can be restricted.
- Machines and complex systems put off people who are unfamiliar with the system.
- Contact with staff makes the journey experience easier, more convenient and secure.
- Conductors will not be able to collect all fares on crowded vehicles.
- Modern technology may reduce cash handling.

Contactless stored fare ticketing systems are being developed that will be applicable to all forms of public transport in due course.

4.3.8 Weather

The ability of modes to operate reliably in adverse weather conditions is important in the HiTrans region. Some of the problems that need to be considered are listed below:

- Track, guideways and segregated roadways blocked by snow or snow drifts.
- Long periods of sub-zero temperatures.
- Passengers waiting for prolonged periods in exposed locations.
- Road salt corrosion.
- Vulnerability of overhead electrification in high winds.
- Flooding.
- Snow interfering with optical guidance systems.
- Need for real time information on bad weather days.

Table 7 Ticketing systems

Ticket Types	Point of Sale	Payment Method	Validation Method	Ticket Material	Recognition Method	Checking Method
Single trip no transfer	From driver	Cash	Not validated	Paper	By eye	Driver
Return trip no transfer	From a nearby shop	Cash transfer	By passenger by hand	Card	Magnetic	Conductor
One trip within set period	From staff at stop	Card	By driver	Plastic	Optical	Inspector in uniform
Two trip ticket	From roving conductor		By conductor			Inspector in plain clothes
Day ticket	From fixed conductor		By machine on vehicle			At stop
Multiple trip ticket	From system office		By machine at stop			
Period ticket	From machine on vehicle					
Carnet of tickets	From machine at stop					
Season ticket	From another transport operator (through ticket)					

4.4 Future developments

This section describes a few key developments that could have an impact on which mode is chosen in future for specific applications.

Track mounted flywheels/high performance ultra capacitors
Applicable to all rail based technologies.

These are trackside energy storage systems that can store power when demand is low and release it when demand is high. They can reduce peak power demand, which makes more effective use of electricity power stations and reduces costs for the user.

Flywheels are a mechanical storage system. To be effective they should operate in a vacuum and have very well engineered bearings. They transmit energy by generating electricity.

Ultra capacitors (also called super capacitors) store energy electrostatically by polarising an electrolytic solution. They are electrochemical devices but there is no chemical reaction involved. The process is reversible, allowing the capacitor to be charged and discharged hundreds of thousands of times. They consist of two non-reactive porous plates suspended within an electrolyte, with a voltage applied across the plates. Ions are attracted to each plate.

To be economically effective, conventional regenerative braking on one train depends on a high probability of finding a “market” of another train simultaneously motoring in the same electrical section to absorb most of the regenerated energy. A flywheel system or ultra-capacitor is continuously available to absorb regenerated energy and not only reduce the consumption and cost of energy but potentially to lower the “maximum demand” fixed charge. The technology is proven and there are several installations by different makers.

Conservation of braking energy using flywheel, hydraulic or capacitor technologies
Applicable to all rail based technologies.

Hybrid traction
Applicable to all technologies.

The ULEV-TAP project (Siemens Avanto) is working towards providing LRVs that will operate without any external power supplies. The first prototype used a flywheel system to provide surges of power for acceleration etc. The concept was to use a gas turbine as the power source for this but on the prototype the power was still taken from the electrical overhead.

The Lirex developed by Alstom uses single axles, electric traction coupled with a diesel engine generator set, overhead power collection and a flywheel to assist in braking and acceleration.

The Regio-Citadis, the new TramTrain for Kassel from Alstom LHB, will use overhead electrification within the city and a diesel generator set for non-electrified regional lines. It was decided not to use flywheel energy storage in this case.

Fuel cells
Applicable to all technologies.

One can imagine a world where all transport is powered this way, almost eliminating pollution and removing the need for electrification. The problem is that the costs of initial vehicles will be very high and there is little incentive for industry to undertake the necessary research.

Fuel cells will be more expensive to provide for high power demands and will not be effective at dealing with changes in demand. It is likely that they will be developed as small units running at constant power and linked to on-board energy storage.

Ground level street electrification
Bordeaux is using a new form of this technology for its new tramway system. But based on historic experience with this technology and the recent problems that arose with the similar Ansaldo Stream system for buses, many engineers have their doubts about practicality. Initial reports indicate that difficulties are arising as predicted. A key issue is the harsh environment in which such systems have to function.

Composite materials and light weight construction

Applicable to all technologies.

Developments are already taking place that will reduce power requirements and improve performance.

Standardisation and harmonisation

Applicable to all technologies.

The various rail and novel rapid transit technologies are backward compared with the bus industry in achieving benefit from the scale of production through standardisation. The European Union recognises this problem and the scope for improving the situation, especially in regard to new Light Rail and tramway systems. The UITP/UNIFE "MARIE" project identified the issues and the LibeRTiN Thematic Network is one of the main EU sponsored activities for taking this forward.

This is especially relevant for TramTrain vehicles, which need to adapt to railway infrastructure that will vary, for historical reasons from country to country. One of the main hurdles to introducing this concept into the UK, for example, has been the fact that the TramTrains developed to date in Germany and France would not be suitable for UK use and there has not been any agreement on a suitable "go anywhere" design for the UK. An international study known as "Crossrail" has taken place to identify the opportunities and issues associated with the cross border operation of TramTrains[126].

Guided buses without kerbs

A crucial factor in achieving greater acceptability of guided buses will be to improve the reliability of single rail guidance systems and the other novel "kerbless" systems. Early users of these technologies have experienced widespread safety and reliability problems. These have resulted in services having to be withdrawn entirely for lengthy periods in Nancy, France and to resort to emergency bus substitution in Caen, due to the non-availability of the guided vehicles. The difficulties in Nancy were associated with derailments, notably due to the rear section of the vehicle failing to pass through curves.

The "Safeguide" system being developed in the UK by Minitram seeks to overcome the problem that "kerbless" non-mechanical guided bus systems have if the steering system fails. The concept involves electronic guidance monitored against a fail-safe constant checking system.

GPS

The application of Global Positioning to buses will enable their position to be better monitored and assist in giving them priority.

4.5 Legislation and regulation

In order to acquire the land and build a new transit system of any kind it will be necessary, among other requirements, to obtain authority, by means national legislation in the respective country of the North Sea Region. There will be three situations where this may not apply:

- Where a new system is created without the need for any new infrastructure, e.g. providing a service of Light Railcars on an existing railway (although this may require a vehicle acceptance process to take place.)
- Where the system is confined to the highway without affecting its infrastructure or other road users, e.g. a quality bus operation and in some cases a busway. However this does not apply generally to tramways or trolleybus overhead electrical wiring.
- Where the system is built entirely on private land and does not affect any highways. This is unusual but could happen, for example if a system was built in a new urban area development, airport or leisure park.

Urban transport systems also need to meet safety legislation, that is regulated by various institutions. The extent of this regulation varies between countries. The notes that follow give an outline of the legislation and safety regulation position in each of the countries of the North Sea Region in relation to the forms of public transport considered in this report. In countries where the legislation is considered inadequate one option is to adopt the legislation of another country, this has happened for example in the case of the planned Bergen Light Rail system, which has adopted German tramways standards (BoStrab.)

All trains need to meet the acceptance requirements of the railways concerned. Where non-compliant vehicles would offer advantages there are generally three courses open:

- Adoption of special standards that apply provided certain restrictions are observed (e.g. The German Light Railcar Regulations.)
- Special dispensation for specific services.
- Taking the railways concerned out of the national railway network and converting them to "Light Railway" or "tramway" status.

It should be noted that in some countries there is a lack of legislation to cover all options but this is due to the fact that some of the options have not yet been applied there.

Quality bus systems will generally be implemented using highway legislation and powers. They will be subject to the regulations that apply to buses in each country. There is one specific safety issue in that if buses move at speed in their own bus lane, they may not be noticed by pedestrians when they see other traffic moving slowly and congested. Mitigation measures are required to avoid this.

Different legislation and regulatory regimes apply in the seven countries of the North Sea Region. The following table shows those that apply. It also shows the shared track requirements that apply in those countries where it has been introduced. No entry in this column means that there are no requirements because there is no shared track, not that shared track is feasible without any such requirements.

Shared track is one of the three specific topics covered in more detail in this report and the legislative and safety experience of these systems is discussed in section 5.7.1.

In a few cases there are relatively detailed standards, for example the BoStrab regulations that apply to Light Rail and tramways in Germany. It is possible for these to be used as guidance in other countries, as already stated, although care needs to be taken because of the differences in context.

Table 8 Legislation and regulation by country

Country	Light Rail/Tramway legislation	Responsibility for regulation of Light Rail/Tramways	Shared Track regulations
Belgium	National Regulations of 1976	Provinces	None
Germany	General Rail Transport Act (AEG). EBO.BOStrab	Federal Ministry of Transport, Building and Housing	LNT-Richtlinien
Denmark	Railway Safety Act 1996	Ministry of Transport. Railway Inspectorate	None
Netherlands	Railway legislation. Metro and Tram legislation.	Provinces	Being developed
Norway	None.	Systems are responsible controlled by Railway Inspectorate	None
Sweden	General legislation covering all types of rail system	Railway Inspectorate	None
UK-England	Transport and Works Act 1992	H&SE (HMRI) DoT (highway issues only)	Railway Group Standards for operation of Light Rail on Network rail Infrastructure
UK-Scotland	Light Railways Act 1896 and other early legislation.		

4.6 Safety

In general public transport will be seen as safer than private transport, so far as the user is concerned. The public also expects this. Some forms of pubic transport will be safer than others but for the modes we are considering the differences are not going to be significant.

Rail modes, especially ones that operate over railways rather than tramways, will probably have more safety measures in place. But in the urban context other modes will not be at a disadvantage because the stricter requirements may only be necessary for high speed lines with long heavy trains.

Accidents that cause death or serious injury to passengers remain relatively rare. For example, there has not been an incident of this kind on any of the shared track applications introduced since 1990.

On the other hand accidents in which public transport vehicles are in collision with other vehicles, pedestrians and cyclists are relatively common. In these cases the most serious consequences tend to be for the latter. This is not an issue confined to public transport in the street – it also applies to reserved tracks at level crossings and where people trespass. One cannot say that any form of public transport is "safer" in this respect The issue comes down to detail design and safety measures in place.

Some technologies introduce more hazards and therefore will be more dangerous. Acceptable safety levels can be achieved however, provided mitigation measures are taken. Examples are:

- Overhead electrification, associated with electrified railways, Light Metro, Light Rail, trolleybus and duobus systems.
- Third rail electrification, associated with electrified railways and Light Metro.
- High platforms associated with some railways, Light Metro and Light Rail.
- Upstands (i.e. raised guidance kerbs) associated with Kerb Guided Buses.

Safety standards exist in all cases. These may vary across the modes but tend to give a level of safety, that is appropriate to the mode. For example vehicles that operate in tunnels have to meet tougher fire standards than those that do not.

Staff safety also needs to be considered. In general however there is no real difference between the modes. It is true to say that bus systems do not require track workers who are exposed to high risk levels but each industry must comply with general safety at work legislation, so the exposure to risk of individuals should meet an acceptable standard. Personal security for staff can be a less easily managed issue Drivers on one person operated vehicles can be exposed to a very high risk in some areas. Again all forms of public transport are vulnerable to attacks on staff and vandalism – there is no clear distinction by mode.

5 Selected topics

5.1 Priority solutions

This section of the report provides advice on a specific topic of interest that was identified for this Strand, i.e. the priority solutions available for bus and tram systems operating in the street.

Priority can be defined as "a right to preferential treatment". It does not apply to totally segregated rights of way such as Light Metro and railways because there is no other type of traffic present to have priority over. Where level crossings exist on such systems they do not degrade the priority enjoyed by trains because it is assumed that trains cannot stop, so they are no more restrictive than grade separated crossings.

For the purposes of this report we can consider all the technical options being studied in this strand as either "bus" or "tram" and the priority solutions that exist will generally apply to either. Where this is not the case, or there are issues about a specific technology, we note this in the text. We also discuss issues that arise when buses and trams share a traffic lane.

The report describes the types of priorities that can exist, specific methods of providing priority and some specific issues that are associated with the topic. In all cases we give some best practice examples and discuss effectiveness. It should be noted that in some countries relatively detailed requirements and guidance exist. These will determine the detailed design of the infrastructure for most of the technology options described here and in particular the details of priority measures discussed in this section. This report does not generally repeat this information and readers are advised to take note of the national requirements listed in the references.

Reasons for priority

The main advantages of giving public transport priority are generally stated as:

- Faster journey times for public transport passengers.
- More reliable public transport services.
- Cost reductions from a smaller fleet and fewer staff to provide the same level of service and other factors (in general a 7–10% cost reduction can be expected from a 10% reduction in journey time due to priority.)
- Safety due to less conflict with other traffic.
- Ability to extend the network without increasing the fleet size from the pre-priority level.
- Better use of urban infrastructure.
- A more reliable and faster public transport system is likely to be more effective in causing modal shift.

There are however a number of disadvantages that need to be considered:

- Costs (investment and maintenance)
- Impact on other traffic, especially cars.
- Possible loss of road space for other uses, including other public transport.
- Impacts on the urban environment, e.g. tree removal.

Priority targets

System costs will increase if more priority is provided from the outset. The relationship may not be a simple curve – the costs of achieving high priority; either by segregation or advanced traffic signalling and associated measures, might be dis-proportionally high. So there is an issue about the appropriate level of priority for a given system. Some of the factors that need to be considered in order to determine the appropriate level are listed here.

- Journey times must be seen to be attractive compared with other competing modes e.g:
  – High quality public transport must provide faster journeys than conventional bus services at all times.
  – High quality public transport must provide faster journeys than private car traffic at congested periods.
- When traffic is at a standstill caused by congestion, high quality public transport must be seen to either be on the move or only held up for a few seconds.
- Services should run reasonably to time. This is especially critical for short distance urban services where the service interval means that people can "turn up and go". For example imagine a journey

taking 6 minutes on a route where the service interval is 6 minutes. A turn up and go trip will take 6–12 minutes. But if the gap is increased by just 3 minutes the trip could take 15 minutes, which is a lot longer than the 6 minutes anticipated.
- Connections are important, especially transferring from a frequent to a less frequent service, which will happen at interchanges with national rail services. Imagine a service that takes 5 minutes and runs every 10 minutes connecting with an hourly train service that takes half an hour. It should be possible to do the journey in a little over 35 minutes assuming a good connection, but if the connection is missed then it will take 95 minutes and the passenger will have to take an earlier connection to avoid this, i.e. taking 45 minutes or 28% longer than should be needed.

Three conclusions of earlier studies give some useful guidance on the effectiveness and impact of priority measures, although it must be remembered that these conclusions are based on specific conditions and studies in just a few cities:
- Priority can save public transport on average 20seconds at each traffic signalled junction[106].
- Giving public transport priority has little effect on other road users[107].
- Giving buses priority did not have a significant effect on modal shift[98].

The following list of typical commercial speeds gives an indication of the time savings to be expected.
- In street, no priority: 17km/h
- In street, with priority: 28km/h
- Segregated track: 35km/h

5.1.1 Types of Priority

Traffic direction

There are basically two types of traffic that a vehicle can encounter:
1. Linear traffic
2. Cross traffic

Linear traffic

Traffic sharing the same lane, either in the same direction or in both directions, a situation that might arise in a narrow street for example.

Cross traffic

Traffic crossing the path of the vehicle.

These terms are used subsequently in this report. Linear traffic, where vehicles might share a lane in both directions is called “Opposing traffic” here.

There are other possibilities that have been omitted from the above table to aid clarity:
- Commercial vehicles may be allowed to enter restricted lanes, but perhaps only to make deliveries and at certain times of day. In general this should be planned so the effect on public transport should be no different to lanes from which they are normally excluded. For example delivery vehicles might use the lane for access but would have to clear it in order to stop and unload.
- High Occupancy Vehicles (HOVs), i.e. cars carrying a minimum specified number of passengers, might be treated as public transport. This needs additional monitoring and enforcement measures to make it effective. The following points need to be considered:
  – It is more difficult to distinguish HOVs from cars than public transport and taxis from cars.
  – There is little value for HOVs using lanes with frequent public transport stops. HOV lanes tend to be found on longer sections of higher speed roads.
  – This choice depends on achieving a balance so that the mix makes overall optimum use of the road space.

Table 9 Traffic mix examples

Option No.	Option	Note
1	Buses on an exclusive bus lane in the street with no traffic crossing it	This is only likely to be encountered where the value of fast unimpeded travel outweighs the negative severance effect. However, short sections of this type are relatively common.
2	Trams on a segregated track in the street with no traffic crossing it	
3	Bus lane for buses and emergency vehicles only	
4	Segregated track street tramway to which emergency vehicles have access	
5	Shared tram and bus lane	
6	Buses mixed in traffic	The traditional mixed traffic situation but it is possible to give priority (see 4.6.2)
7	Trams mixed in traffic	
8	Buses in a pedestrian zone	A tramway or bus lane in a pedestrian "traffic free" street. Pedestrians will be walking randomly in the paths of vehicles.
9	Trams in a pedestrian zone	
10	Bus lane to which cyclists also have access	Sharing with other "public transport" and environmentally friendly modes. Cyclists may be allowed access to bus lanes also because of the longer distances and hazards they are exposed to when traffic is diverted from direct routes, but this requires a wider lane. Sharing is only appropriate where there is capacity.
11	Bus lane shared by taxis	
12	Segregated track street tramway shared by taxis	
13	Bus lane shared by taxis to which cyclists also have access	
14	Segregated track street tramway shared by taxis to which cyclists also have access	
15	Bus only lane which can be used by other traffic purely for access	This could be delivery vehicles, private cars accessing private car parks, garages etc. possibly restricted by time of day.
16	Segregated track street tramway which can be used by other traffic purely for access	
17	Pedestrian crossing of a segregated bus lane	
18	Pedestrian crossing of a segregated track street tramway	
19	Cycle track crossing a segregated bus lane	
20	Cycle track crossing a segregated track street tramway	
21	Two bus lanes crossing	Two priority lanes crossing or a crossing between a tramway and a bus route, both of which might be a priority route.
	Bus lane crossing a segregated track tramway	
22	Road crossing a segregated bus lane or a segregated track street tramway	There are many types of road ranging from minor access lanes to multi-lane motorways. The different approaches required are not distinguished in this table but are later.

Options 1–16 apply to "linear traffic" and 17–22 to "cross traffic".

Where it can be seen
Very common
Very common
Very common
Very common
Very common
Typical use of buses
Traditional practice, still very common
Relatively common
Relatively common
Relatively common
Relatively common
No known example
Relatively common
No known example
Very common
Very common
Very common
Very common
Relatively common
Relatively common
London
Manchester
Very common

Although cyclists and tram rail do not mix, one will find many examples of cyclists using paved tramway track as a convenient path, as here in Amsterdam, which has a heavy cycling tradition. *(Rob van der Bijl)*

Table 10 Segregated track/bus lane positions compared

Tracks	Single			Double
Location	**Side with flow**	**Side contra flow**	**Middle**	**One side**
Width required	Least=	Least=	Highest	Least
Access for passengers			Worst	
Access for other road traffic to roadside	Poor	Poor	Best	Poor
Pavement safety			Best	
Cyclist in traffic lane		Potentially dangerous	Safest	
Traffic use of opposing lane to overtake	Not relevant if only two lanes	Not relevant if only two lanes	Not relevant if only two lanes	Possible
Parking at roadside	One side only if space available	One side only if space available	Best	One side
Speed of public transport			Best	

- Encouraging HOV use reduces car traffic for given passenger throughput which in turn may free up roadspace for public transport.

The issue of where segregated tracks or bus lanes (Options 1 and 2) are placed in the street is linked to that of priority:

Table 10 shows an analysis of the merits of placing segregated tracks or bus lanes in various positions in the street. The cell is shaded where there is no clear distinction, or the effect is not significant.

These issues were recently considered in London for the West London Tram project. The conclusion was that local circumstances dictate which lanes should be used. The project manager expressed the view at a recent conference that access to pavements by all traffic is very important but that on the West London Tram route there are very few central medians available.

5.1.2 Priority for linear traffic

There are four types of priority measure:

1. Measures that divide the traffic lane from other traffic lanes.
2. Measures that prevent entry into the traffic lane.
3. Measures that dissuade entry into the traffic lane.
4. Measures that control the use of the lane by other traffic.

See table 11. These solutions are discussed below:

Solid barriers between traffic lanes

See table 12. Solid barriers should only be used as a last resort if other means of lane separation would definitely not work. Giving public transport exclusive use of kerbside lanes can be made more effective and attractive by use of closely separated bollards (allowing pedestrians to cross) or railings.

The disadvantages of solid barriersare safety risks

	Centre	One track Each side
		Highest
		Best
	Best	Worst
	Best	
	Safest	
	Impossible if only one lane available per side	Possible
	Best	None
	Best	

Table 11 Methods for providing linear priority

Solution	Type
Solid barriers between traffic lanes	1/2
Non continuous barrier between traffic lanes	1/3
Change of height between traffic lanes	1/3
Lane markings	1/3
Surfaces that cannot be used by other traffic	2
Surfaces that discourage use by other traffic	3
Bus gate	2
Bus ramp	3
Signage	3
Providing lay-bys for delivery vehicles and off street parking	4
"Head start" traffic signalling and lane arrangements	4
Vehicle recognition	4
Vehicle charging	4

Table 12 Solid barriers between traffic lanes

Options where it applies	High concrete barriers	Kerbs	Crash barriers	Fences	Hedges
1 2 3 4 5 10 11 12 13 14	Appropriate where space is limited. Hazardous to road traffic. Ugly and prone to graffiti.	Or two kerbs with paving in between. Unobtrusive. May be used as a refuge by pedestrians. Road traffic might cross but with difficulty.	Appropriate where space is limited. Less hazardous to road traffic than concrete barriers. Ugly.	Would need to be on a wider kerbed verge where there is road traffic on either side. Various designs are possible. Can be at-tractive.	Appropriate where the segregated lane is in a "green environ-ment". Hedges need to get established and be maintained. Risk of breaks. Can use internal wire fence to overcome these problems.
15 16	Only for short distances				

Examples of barriers between trafic lanes

Decorative screen of bollards – Amsterdam. *(Rob van der Bijl)*

Valencia – stud barriers permit access to some road traffic. *(Gradimir Stefanovic)*

Low "solid" barriers – Grenoble. *(Axel Kühn)*

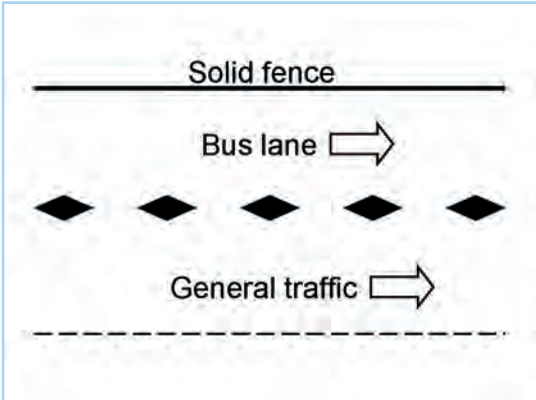
Montpellier. *(Gradimir Stefanovic)*

Valencia – stud barriers prevent road traffic. *(Gradimir Stefanovic)*

Rome. *(Gradimir Stefanovic)*

Table 13 Examples where continuous barrieres may be of value

Option No.	Option	Note
3	Bus lane for buses and emergency vehicles only	Emergency vehicles can access the segregated lane but other traffic has difficulty
4	Segregated track street tramway to which emergency vehicles have access	
10	Bus lane to which cyclists also have access	Cyclists can weave in. Other traffic has difficulty. Pedestrians are made aware of hazards.
15	Bus only lane that can be used by other traffic for access only	Access traffic can weave in and through the lane.
16	Segregated track street tramway which can be used by other traffic for access only	



A form of "lozenge" stud used to separate bus lanes in Taipei, Taiwan. The studs are fairly substantial and about 200mm high. The sides are sloped so that if a vehicle hit them at speed it would be tilted but would not crash or over turn. It is possible for vehicles to transfer between lanes by moving slowly between the studs to enable tight turns. *(Interfleet)*

to other traffic and pedestrians, visual intrusion and a relatively high cost if they have to be provided over a long distance.

Examples:

- London. Piccadilly contra-flow bus lane separated by kerbs.
- Amsterdam
- Frankfurt

Non-continuous barrier between traffic lanes

Options available:

- Studs
- Bollards
- Flexible cones/bollards

Studs and bollards need to be made in such a way that an accident would not occur if they were hit by traffic at speed. The cones and flexible bollards used during motorway repair work are examples, but more permanent methods are required. These appear as a barrier to a passing motorist but do in fact allow vehicles to pass through at slow speed.

The main merit of non-continuous barriers is that traffic is generally prevented from changing lanes except with a slow deliberate action. This is likely to be of value in the traffic mix possibilities shown in table 13.

Examples:

- Lozenge shaped studs used on bus lanes in Taipei; see above.
- Paris. Flexible plastic bollards. Outer circular bus route PC.
- Budapest. Large (about 0.2m diameter) inverted saucer shaped separators.

Change of height between traffic lanes

There are examples of this type of special traffic lane on tramways that are about 75–80mm higher than adjacent traffic lanes. To be effective as a "barrier" they need to be higher. The German VDV recommends a minimum height of 120mm, and UK guidelines 125mm.

This can be a useful "soft" way to divide different kinds of traffic. Visual intrusion is low. Both lanes can have a similar surface or, to show differences between the different types of traffic, can have different surface treatment. This method is only sensible where the amount of traffic needing to cross lanes is relatively low, i.e. it only happens on exceptional occasions, e.g. to provide access for emergency vehicles.

The lower height (80mm) is little more effective than a lane marking, whereas a larger step (+120mm) will form a more positive barrier. The use of the former will match that of lane markings and the higher step will have the same uses as non-continuous barriers. It should be noted however that high changes of level are not suitable for ambulance traffic crossing into priority lanes in an emergency, and the non-continuous barrier is much better in this respect. The gaps in non-continuous barriers must be designed so as to allow vehicles that are able to use them to do so safely.

The "step" will take up road width because of the need to engineer it as a slope with radii at each end for safety reasons. The angle of the slope has to be such that it is safe but does not lose its "barrier" function.

Karlsruhe–Stuttensee, slightly raised (80mm) paved track. *(TTK)*

Brussels, traffic lanes either side. *(Gradimir Stefanovic)*

Hannover – track raised by over 120mm. *(Gradimir Stefanovic)*

Lane markings

The simplest form is a painted line, but other options also exist.

Tramlines set into the street can generally be seen but both these and bus lanes can be distinguished by painting the whole width of the lanes in distinctive and readily apparent colours, e.g. Red in London, Green in Edinburgh.

In Manchester's city streets distinctive paving has been used both to mark the swept envelope of trams and an area in which it was too close to stand or park vehicles in order to be safe. This marking helps keep the tracks clear of pedestrians and vehicles when a tram is passing and of parked vehicles at other times. A significant feature is that no effort has been made to indicate to the public what the colours meant. It was assumed, correctly, that they would quickly real-

Table 14 Traffic mix examples – use of lane markings

Option No.	Option	Note
1	Buses on an exclusive bus lane in the street with no traffic crossing it	Limited effectiveness will need to be "enforced" by signage etc.
2	Trams on a segregated track in the street with no traffic crossing it	
3	Bus lane for buses and emergency vehicles only	
4	Segregated track street tramway to which emergency vehicles have access	
5	Shared tram and bus lane	
6	Buses mixed in traffic	To indicate swept path/routes only.
7	Trams mixed in traffic	
8	Buses in a pedestrian zone	
9	Trams in a pedestrian zone	
10	Bus lane to which cyclists also have access	Limited effectiveness will need to be "enforced" by signage etc.
11	Bus lane shared by taxis	
12	Segregated track street tramway shared by taxis	
13	Bus lane shared by taxis to which cyclists also have access	
14	Segregated track street tramway shared by taxis to which cyclists also have access	
15	Bus only lane which can be used by other traffic purely for access	
16	Segregated track street tramway which can be used by other traffic purely for access	

Use of lane markings on a traditional tramway (Brussels). This and the retention of a cobbled surface impose some "respect" for priority. *(Gradimir Stefanovic)*

Bus lane with slightly raised "markings" in Lyon, with associated cycle lane. *(TTK)*

ise by association on the basis that people who were less familiar would tend to be more cautious any way.

Lane markings can be made with a ribbed texture so that the motorist hears a noise if he runs on to them. They can be made even more visible and apparent by use of more solid texture. For example in Krakow, Poland, old tyres are cut and stretched to form a kerb to designate bus lanes.

Often the lines used to separate public transport lanes are wider than normal.

Lane marking and colouring rely totally on the "good behaviour" of other road uses for their effectiveness. Policing and fines can help enforce conformity but will not guarantee success. There is widespread abuse of such lanes in North Sea countries and sometimes this totally destroys the value of the measure. Typical examples are:

- Cars stopped in a bus lane at a bus stop while the driver buys a newspaper, so preventing use of the bus stop by buses.
- Traffic merging into a bus lane early, in advance of a road junction so they do not have to queue in order to turn.

In general lane markings should only be used where segregation is not essential but might be used where desirable and more effective measures are either too expensive or not feasible. The "advisory" traffic lane has value; for example many classic tramways with mixed operation in street traffic had their performance improved simply by having white lines painted down each side of the tracks.

If a city has both bus lanes and tram lanes then the lanes may need to be distinguished in the same way, since it may not be desirable to have the confusion of two types of lane. In this case some special method needs to be introduced to control the shared and non-shared sections of these lanes, for example where a segregated tram lane becomes ballasted track so it cannot be used by buses.

Surfaces that cannot be used by other traffic

Segregated tramways can easily use either ballasted or types of grassed track that will not support other road vehicles. There has been some resistance to the use of conventional grassed tramway track in the UK due to fears about electrical earth currents causing damage to buried pipes etc. (earth leakage), but there are many successful applications elsewhere. Grassed tracks look good, the route looks more like a roadside lawn than a railway track, and noise levels are reduced. For busways these options are not practical because of the need to provide a smooth running surface.

Kerb Guided Busway track provide a surface that cannot be used by other traffic. There have been instances of unauthorised vehicles trying to drive on

Table 15 **Examples where surfaces that cannot be used by other traffic can be applied**

Option No.	Option	Note
1	Buses on an exclusive bus lane in the street with no traffic crossing it	Only if the bus lane is KGB
2	Trams on a segregated track in the street with no traffic crossing it	
5	Shared tram and bus lane	One past example, in Essen (Tram plus KGB)

"Unfriendly surface" in Croydon. *(Interfleet)*

this type of system in Leeds but they have been damaged or become stuck.

The use of ballasted and grassed tramway track in an urban environment can provide visual relief from expanses of surfaced areas and therefore may be considered beneficial. On the other hand ballasted track may impose a "railway" character to the urban scene and provide a supply of missiles for vandals. Grass track needs to be maintained and may develop muddy ruts if other traffic drives onto it.

A kerb-guided busway acts in the same way as ballasted or grassed track for buses but again can be an obtrusive feature in an urban environment.

These solutions are in common use but sensible application is related to good urban design.

Examples:

- Rouen, attractive grass track.
- Leeds Scott Hall Road (Kerb guided bus)
- Brussels, Avenue Louise, ballasted track in a central reservation.

Surfaces that discourage use by traffic other than that intended

This is practical with trams, e.g. rough cobblestones between the rails that make driving unpleasant but the ride in the tram is unaffected due to rail running.

Smooth surfaces just wide enough for bus wheels could be provided, but that would impose speed restrictions and make driving difficult. A short section might be used as an alternative to a bus gate.

So the use of surfaces that discourage other traffic is only really practical for trams and then can be used as an alternative to, or in addition to, a change of height in situations where a change of height was used as a method of segregation. As with a change of height, this method is not suitable if the emergency vehicles that can use the track are ambulances.

The use of cobblestones can be an improvement to the urban environment. In the past traditional tramways had a slight benefit as car traffic was introduced into historic centres that had retained them because the slow speeds they "enforced" on rubber tyred vehicles.

Examples

- Brussels. Trams run on cobbled track with traffic lanes either side

Restricting entry to lanes

- **Signage.** Simple signs/standard traffic signs that restrict entry, usually supported by byelaws.
- **Bus gates**. Bus (or tram) activated barriers of various designs.
- **Rising bollards.** Bollards set in to the roadway, which lower in order to permit the passage of vehicles that activate an associated detection system.

Table 16 Examples where restricting entry to lanes may be applied

Option No.	Option	Note
1	Buses on an exclusive bus lane in the street with no traffic crossing it	
2	Trams on a segregated track in the street with no traffic crossing it	More likely to use a cattle grid or short section of unfriendly surface.
5	Shared tram and bus lane	

Bus entering pedestrian zone in Lindau, Lake Constance, Germany; entry restricted by sign only. *(VDV "Stadtbussysteme in kleinen und mittelgroßen Städten")*

- **Cattle grids/short sections of impassable track.**
- **Bus ramps.** Short ramps set at the "track gauge" of buses intended to use them that make passage for other traffic either impossible or difficult.

Restrictions will either be "absolute" i.e. allow specific public transport vehicles to enter only, or "permissive" i.e. allow other specific traffic in as well but possibly only in emergencies.

This approach is of special interest for buses, as some of the options discussed so far are only really valid for trams. For a bus, a good priority measure can involve bus gates or rising bollards, which are only set to allow passage when a bus arrives. Bollards are less visually intrusive than a standard gate and can allow passage for pedestrians and cyclists. They may be more difficult to repair than a bus gate however, if they are struck by a vehicle.

Cattle grids or similar measures, such as ballasted track or the bus ramp shown above, should only be used where pedestrian traffic is low, as they can introduce additional risks. Bus ramps will not prevent all traffic entering but just make it more difficult and impossible for some.

Simple signage, without any form of barrier, is the most cost effective way to restrict the entry to these lanes, provided they are respected. Mistakes can be reduced by design of the road layout. The opportunity also exists to have fines for unauthorised use.

Trams can make use of the "passive" solutions whereas buses are forced into "active" solutions, i.e. gates, rising bollards, if they are to be totally effective.

Measures such as bus ramps might damage cars and in legal cases in the Netherlands car owners received compensation for damage caused when they tried to enter priority lanes.

Examples:

- **Lindau,** Germany, entry into pedestrian zone restricted by sign only.
- **Croydon**, entry to tram and bus lanes controlled by signs only, associated with diverting other traffic.
- **Lemgo**, Germany, use of sign and bus ramp.
- **Cambridge**, England, bus activated rising bollards in town centre.
- **York**, England, rising bollards at entry to bus only section of city centre.
- **Hürth**, Germany, bus activating rising bollards.
- **Neustadt/Saale**, Germany, bus gate.
- **Lomma**, Sweden, a bus ramp has proved very effective. It incorporates a raised beam between the treads that will either lift a low slung car, or frighten high slung car owners from trying to pass through it. The only significant problem has

Tamworth Road, Croydon, tram and bus lane entry restricted by sign only. *(Gradimir Stefanovic)*

Lemgo, Germany. Entry restricted by sign and bus ramp. *(VDV "Stadtbussysteme in kleinen und mittelgroßen Städten")*

been that it ceases to be visible in snow and cannot be cleared by the conventional snow plough.

- **Cambridge,** The Cambridge Core Traffic Scheme (CCTS) is an important part of the city's overall transport strategy, developed to cut congestion in the centre.
  It involves restricting through traffic to the city centre at key entry points using rising bollards. Local buses, taxis and bicycles are exempt from the restrictions. The main problem in Cambridge was perceived as the high traffic levels in a relatively compact city. This, in turn, resulted in a range of adverse impacts such as poor pedestrian safety, air quality concerns and delays to public transport. Traffic restraint is provided on Bridge Street in the town centre by means of rising bollards acting as a bus gate. Bus services in the town are operated by "Cambus", a Stagecoach operation; these include "park and ride" services at 10 minute intervals.

Lay-bys for delivery vehicles/off street parking

Lay-bys need to be provided for delivery vehicles in order to avoid such vehicles blocking public transport. On-street parking should also be provided in designated areas where this is permitted.

The principle is that by providing designated and

Rising bollards in Cambridge. *(David Catling)*

Rising bollards can cause significant damage to any car that attempts to follow a bus. Adequate warning is essential! *(Cambridge Evening News)*

Bus activating rising bollards in Hürth, Germany. *(VDV "Stadtbussysteme in kleinen und mittelgroßen Städten")*

Bus passing through a bus gate in Neustadt/Saale, Germany; entry restricted gate, which is actively opened by the bus. *(VDV "Stadtbussysteme in kleinen und mittelgroßen Städten")*

separate spaces, indiscriminate parking is discouraged.

Examples:

- Croydon, George Street.
- Karlsruhe, Linkenheim.
- Leith Walk "greenway", Edinburgh.

"Head start" traffic signalling and lane arrangements

This technique is used to give priority in two ways:

1. So that public transport gets away first or is in a prime position if stopped at a road junction.
2. In a traffic lane shared with other traffic the public transport is in front of other traffic and therefore not delayed by it.

The second method usually requires the first to exist to make it work.

Traffic lights with special signals for public transport should be used on street track in order to give priority. It is not possible to use the same signals if priority is required because this would cause confusion and introduce serious hazards. Public transport vehicles need to be equipped in such a way that they notify their approach to traffic lights sufficiently early to avoid the vehicle having to stop at traffic lights. This can be achieved by means of an induction loop set into the roadway that picks up a signal from the vehicle.

Kerb guided busways have been designed in Leeds so as to give buses using them priority at roundabouts, by means of pre-signalling, lane location, the position of pedestrian crossings and stop lines. Note that left hand running applies in the UK and right hand running in other North Sea Region countries.

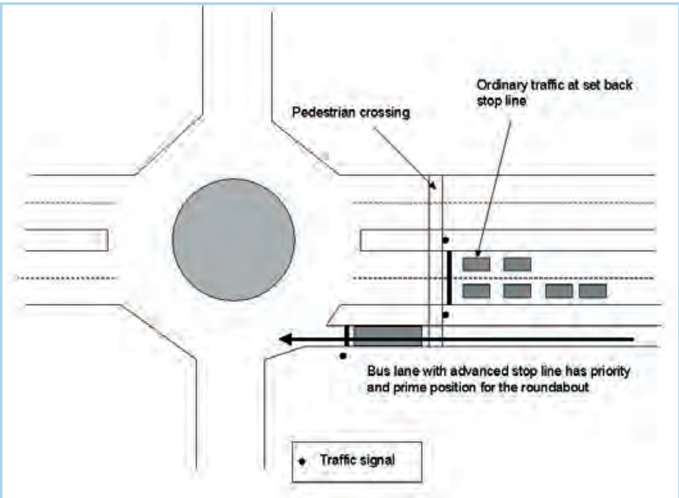
The great advantage of giving public transport the leading position in a line of traffic is that it provides high quality priority without the need for separate lanes, saving cost and roadspace and providing a good solution for medium and small cities.

There has been a lot of discussion in Germany[71] about the merits of the two methods of achieving priority: i.e. via providing exclusive road space, or traffic signal priority allowing public transport to run in front of the queue. One issue in Germany is that funding was at one stage available for infrastructure but not for traffic signalling, so the former solution tended to be adopted. While separate lanes may seem ideal where there is room for them, they do have a number of important disadvantages:

- They take up road space that could be used for other purposes. This is especially important if the public transport flows are light compared with other traffic.
- Access to stops cannot be direct off pavements unless "gutter running" is used, which restricts other road traffic using the lanes alongside the pavement, including for waiting and parking.
- It may be necessary to remove mature trees and landscaping in order to create the alignment.
- Pedestrians and cyclists will have to cross extra "traffic" lanes, introducing further hazards.
- Stops will require more space for platforms, access etc.

The following factors need to be considered when giving public transport priority within a shared traffic lane:

- The section that public transport enters first must not have tail back traffic in it.
- Other ways of causing congestion, e.g. parked vehicles causing an obstruction, must be avoided.
- Vehicles entering from side roads or parking areas may need to be signalled.
- There must be no room for private transport to overtake public transport within the shared lane itself, for example when the traffic stops behind the tram or bus while it sets down and picks up passengers.
- The entry and exit areas have to permit clear through flow.
- The tail back behind the public transport vehicles must not be such that it causes downstream congestion.
- All public transport vehicles using the priority routes must be fitted with appropriate technology in order to be able to take advantage of it.



Leeds, Kerb Guided Bus Priority at roundabouts. *(Interfleet)*

This approach is also of interest when different operators share infrastructure, as is the case for UK bus systems.

Example:

- Leeds, Scott Road Guided Busway.

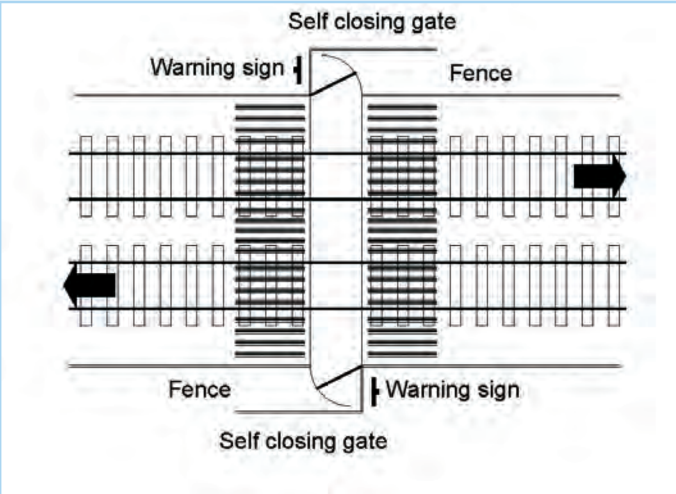
Vehicle recognition/charging

The track circuits at the end of a segregated track tramway, where it joins a street tramway, can be used to tell control that this is a tram and therefore not subject to a charging regime. A control centre will know where a tram is. Equivalent systems for busways would include:

- Induction loops – with or without signal from vehicle.
- Magnetic sensors that detects a specific pattern of disturbance in the earth's magnetic field.
- Beacons.
- Remote sensing.

Direct methods of monitoring the specific positions of vehicles include:

- Digital cameras linked to image sensing/number plate recognition.
- Global Positioning information collected by the vehicle and transmitted to control.



Z-gate. (Interfleet)

- Direct input by the driver.

Some detection systems can be used to operate bus gates. Systems can distinguish between vehicles running late against those running on time or early. This allows the priority to be adjusted accordingly.

Vehicle recognition can be used as an alternative method for controlling access to lanes. One option would to be to have an open access to a segregated lane fitted with vehicle recognition so that a bus gate or other barrier only activates when an unauthorised vehicle is detected. Traffic can return from the barrier into the main traffic flow when it activates. This would be a suitable solution where the number of public transport vehicles is high and the amount of abuse is low, giving three important advantages:

1. The entry to the segregated lane can be approached at speed.
2. Public transport vehicles can follow each other closely.
3. The bus gate would need to be operated relatively infrequently.

The alternative is not to have a bus gate or barrier, but to deliver a fixed penalty to anyone who misuses the segregated alignment.

This technology could also be used so that bus lanes may only be used by the buses used by "authorised" operators. This could be of interest in the UK, where most bus services are deregulated and so any bus only infrastructure has usually to be made available to all bus service operators, regardless of whether they have paid for it or not.

Example:

- Arriva, Kent. First GPS bus control system in the UK.

5.1.3 Priority for cross traffic

Footpath and cycleway crossings

The methods used at footpath and cycleway crossings will depend on the nature of the busway or tramway line that exists and the number of pedestrians and cyclists crossing. If this is segregated track, the crossing needs to be clearly marked as such and if the public transport operates at higher speeds (> 40 km/h) should be divided off using "Z-gates" or similar.

The "Z-gate" uses fencing so that the pedestrian is directed towards both the warning sign and the direction in which a tram might be approaching. This can be emphasised by making the crossing diagonal so that as the pedestrian comes to the second track he is looking in the direction that a tram would approach from. He has to make a positive effort to open the gate as a further aid to recognising potential danger. A central refuge between tracks might also be provided, subject to there being adequate space for sufficient numbers of people.

In cases where the passenger transport operates as part of the street environment, special measures are only necessary where pedestrian / cyclist numbers are higher. In this case pedestrian/cyclist crossing lights should be installed indicating approaching buses or trams. Physical barriers are not practicable in a generally pedestrianised environment.

Numerous examples of pedestrian crossings will be found on all existing systems.

Road crossing Design

The speeds shown here refer to the speed of the public transport route.

< 30km/h inside a built up area: Driving on sight will usually be adequate. An example might be a tramway passing along a pedestrian street where there are minor side roads giving a cross traffic flow. Traffic signals will be required where the cross flow has priority over the pedestrian movement.

30–50km/h within a built up area: Crossings should be treated as standard road intersections with integrated traffic lights for both the public transport and other road traffic. Public transport should have priority. It is possible to fit trams and guided buses with automatic train stops to mitigate against the risks associated with the drivers passing a traffic signal at danger.

Speeds 50–80km/h. Either open crossings with traffic signals or as for speeds above 80km/h. The treatment will depend on local circumstances and the safety requirements of each country.

Speeds > 80 km/h and all totally segregated track in suburban areas. This should be treated like a railway crossing and the crossing traffic should be closed off the track by barriers or other measures when trams or buses are approaching. The railway crossing requirements of each country provide a reference.

Traffic signals for priority at road crossings

City wide traffic signalling systems can give appropriate levels of priority to public transport at traffic intersections. Perhaps as much as 70–80% of all journey time losses within urban city centres are due to waiting time at traffic lights, if there is no priority.

Within smaller cities a balance needs to be struck between giving public transport priority and avoiding general traffic disruption. But the case for public transport having priority, even if it is a relatively low investment bus based system, is strong because the reliability of interchange between less frequent services is more critical. So a missed connection may add 30 minutes to a public transport journey for the gain of just a few minutes for a private car given priority at traffic lights. Another issue is the fact that a public transport user will experience both at stop and in vehicle delays if the service is unreliable.

Public transport services may only pass through junctions relatively infrequently, and in these cases the object should be providing signals at green for a sufficient period at the right time.

- Regular cycle patterns are not appropriate.
- It is necessary for public transport to make a “demand” for a break in the regular pattern.
- Overall planning of the junction is important, including pedestrian movements.

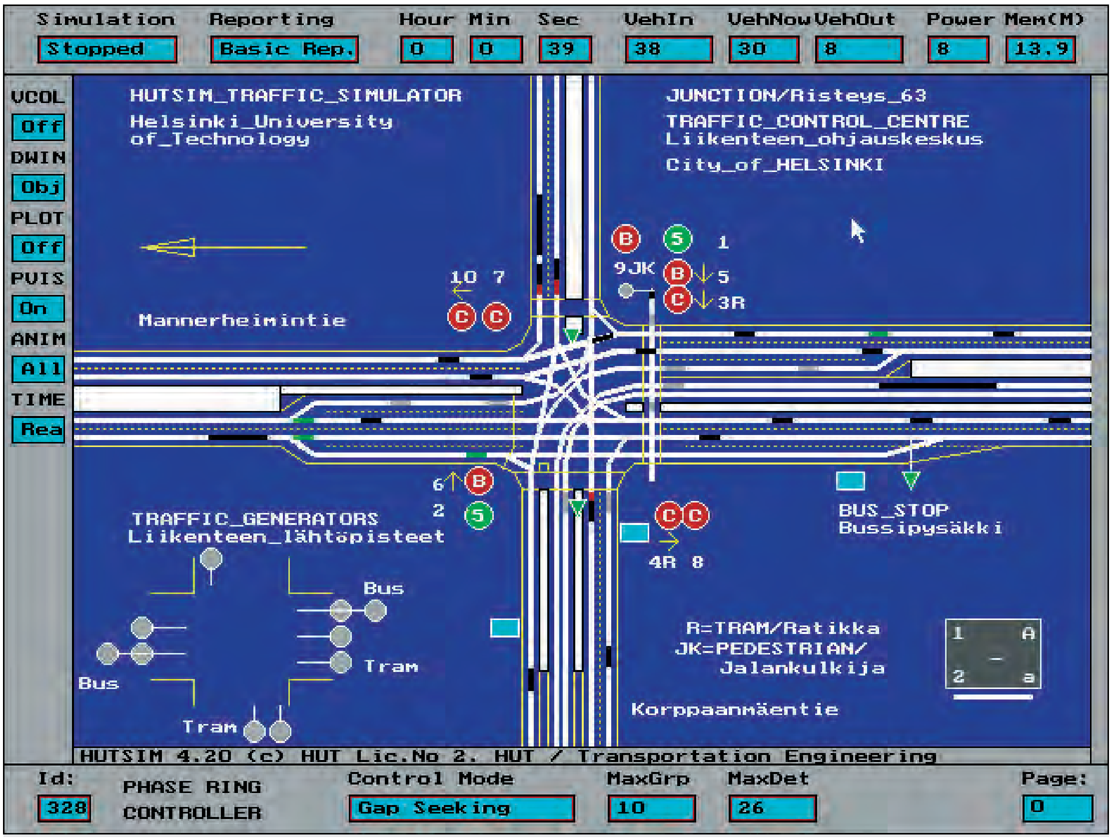
To implement the principle of maximising signals at green it is necessary to have a centralised control system of which there are a number available. It is also essential to provide some means whereby public transport vehicles can be distinguished from other traffic.

Modern systems are “intelligent”. Priority is only given when needed. Arguably they can be better for private traffic than less sophisticated traffic signalling in the past, where public transport had no priority but private cars could also be held up for no reason.

Examples:

The City of Gothenburg now operates an absolute priority strategy for its trams at traffic signals. The KOMFRAM AVL system is used for detection of the trams well upstream. Dedicated loop detection is located typically 100–150m before the intersection and at the intersection exit to terminate the priority actions.

The new control scheme reduces the delay in the network by 8–20%, compared with the priority system that depended on the traffic conditions. The priority functions increase the delays for the private vehicles. However, if the public transport vehicle is weighted as 10–15 private vehicles the priority could be justified. The increase in capacity achieved by the new control scheme could be used to increase the number of priorities or to reduce the delays for the private vehicles. Emissions and fuel consumption drop by 4–6% with a delay-minimising cost function, which contributes substantially to the environmental



The user interface of Traffic Simulator HUTSIM developed by the Helsinki University of Technology.
(Helsinki University of Technology)

and energy-saving objectives. Finally, also “Green waves”, (whereby public transport is presented with a series of green lights) can be created if the weightings are set appropriately.

Helsinki University of Technology has developed a new approach to studying the problem of providing public transport priority without unduly disrupting other traffic. The basic idea is to combine a microcomputer and a real signal controller to a traffic simulator system called HUTSIM. The microcomputer simulates vehicles and detectors and transmits traffic data to the controlling processor. The controller simulates traffic signals and sends the status of each signal head back to the microcomputer. Traffic functions just as it would at a real junction, but can be monitored in the office environment.

Bus detection is fundamental to any bus priority function. Earlier designs of fixed detectors have several technical shortcomings, not least a high need for maintenance and poor accuracy at detecting all buses.

A new technology called low-power-radio communication will be tested in Helsinki. All traffic signals on one bus route and one tram route will be installed using these detectors. All junctions along the routes will be installed with bus and tram priority functions.

An extensive study of traffic signal priority methods was carried out in 1998[143]. Details were obtained on more than twenty different Selective Vehicle Priority systems that have been developed and implemented in many schemes around the world. These have been used to give priority for buses, trams/Light Rail and emergency vehicles.

Bus priority systems were found to be the most common.

Very few of the selective priority systems developed did more than provide an opportunity for intervention by the local controller on detection of a vehicle requiring priority. Notable exceptions are the UTOPIA system in Turin and PRODYN in Toulouse. In both of these adaptive Urban Traffic Control (UTC) systems Automatic Vehicle Location (AVL) is used to continuously track public transport vehicles. Predictions of delay to the public transport vehicles are used when optimising the signal settings.

- **Extensions**, where a green is extended to allow the priority vehicle through the junction,
- **Recalls**, where a stage giving green to the priority vehicle is brought in early,
- **Queue jumping**, where a special stage which gives priority vehicles a chance to start ahead of other traffic is triggered,
- **Queue management**, where queues of traffic are cleared to allow the priority vehicle a clear run through a junction,
- **Triggering green waves**, where a progression through a series of junctions is triggered by the arrival of a priority vehicle.

Many of these interventions are made directly by the local controllers on the street and no attempt is made to compensate non-priority vehicles for the extra delay incurred by the passage of the priority vehicle. More recent schemes however attempt to take some compensatory actions. These usually result in lost green time being returned to phases where it has been cut, in the cycle following the passage of the public transport vehicle.

The study also found that schemes had been developed to be selective about giving priority in congested conditions. Priority is not given if it would cause any arms of the junction to become over-saturated; resulting in queues that would not be cleared. Limits can also be placed on how often priority requests are allowed, to avoid continual shortening of opposing phases.

Some of the methods were only able to provide the information that a priority vehicle has been detected, whilst others were able to also provide extra information about the priority vehicle which can be used to make priority requests more selective. The most common use of this information is to determine whether a public transport vehicle is adhering to its schedule and to only give it priority if it is running late. Conflicts, where public transport vehicles on different routes at the same junction both request priority at the same time, can also be resolved by giving first priority to the vehicle with the most passengers or the vehicle that is most behind schedule.

It was also common to have a combined public transport and emergency vehicle priority system, where emergency vehicles get a higher level of priority than public transport vehicles. In this case there is a need to discriminate between the two different classes of vehicle.

One final method, which is not really a priority method but which employs the same technology, is used where a public transport stop is close to a junction. A special signal at the stop is used to provide advance notice of an upcoming green signal at the junction so that the public transport vehicle can leave the stop and be sure it will not be held up as it passes through the junction. This means that the public transport vehicle only waits at the stop, where it can pick up passengers, rather than at the signals where it cannot.

5.1.4 Safety issues

This report only considers safety issues associated with normal operation. Issues such as the failure of traffic signals are not covered.

A conflict, i.e. a collision or potential collision between vehicles or between vehicles and pedestrians and cyclists, is the main hazard to be considered.

Conflicts can happen at crossings, access to stops and at changes in alignment. Specific problems may occur at entry points and where there is parallel separation of traffic lanes. They will also occur as the result of the mixed use of traffic lanes.

Conflicts at crossings
Safety measures will depend on the speed, intensity and type of traffic flows:

- The extreme cases of this are pedestrians crossing tram tracks or a bus route in a pedestrian street on one hand and a high-speed segregated line with grade separated crossings at the other.
- For low intensity crossings a warning sign may provide basic protection whereas at higher intensity traffic signals may be necessary.
- The relative speed of crossing traffic is also an issue.

The fundamental requirement is to raise and concentrate the attention of the user on the potential of crossing traffic.

Methods used include the arrangement of pedestrian and cycle crossings as described previously, the use of islands and short barriers to keep traffic separate at stop positions and providing traffic light timings that do not keep traffic waiting for no apparent reason.

Access to stops
There is a special problem associated with any stops used on a system where the priority lanes can only be accessed by crossing other traffic lanes. The same measures can be used as mentioned earlier for pedestrian crossings but a more rigorous approach needs to be considered because people may behave recklessly when running for a bus or tram. Two methods are available to reduce this risk; both associated with the use of traffic signals at the pedestrian crossings associated with the stops:

1. The public transport vehicle arriving at the stop would not leave until there had been a green light phase on the pedestrian crossings.
2. The light should be green and stay green as long as a public transport vehicle is approaching and boarding and alighting is taking place.

These measures can be incorporated in traffic light control schemes, although this is not easy to do.

Changes in alignment
A change in alignment, e.g. from segregated alignment to a street running alignment, can be considered as a "one-sided" crossing or as an entry point issue (see below.)

Entry points
This refers to the possibility of unwanted traffic entering a priority lane, either by accident or design. The report has mentioned various ways of preventing or discouraging it. Some of the safety aspects of these measures are considered here.

Three situations are likely:

1. Entering at the entry point to the priority lane.
2. Taking the wrong lane at a crossing; quite likely where traffic is turning.
3. Crossing from an adjacent parallel lane by penetrating the separation.

There is a clear distinction between the first two and situation 3. In the latter case the other traffic has to make a conscious decision to switch lanes, whereas in the first two cases the problem is likely to arise from a genuine mistake. Abuse and mistakes are much more likely to occur if the priority lane is not well differentiated and the surface can be used by other traffic. An "unfriendly surface " or some physical separation will be effective in situation 3 but less so in situations 1 and 2 because it will be too late by the time the confused motorists encounter it. What is required is some form of effective advanced warning. Some examples are effective measures are given here:

Entering at the entry point to the priority lane: Sheffield Supertram uses a track base that appears as a wide concrete path within the traffic lane. When the system opened it was found that motorists tended to follow the concrete track base rather than the traffic lane and ended up on ballasted

Use of signs in Croydon. *(Interfleet)*

Crossing markings, Amsterdam. *(Rob van der Bijl)*

track where the tramway left the road. To overcome this, Sheffield put a tarmac surface over the track in advance of the point at which the track left the road so that motorists took notice of traffic lanes.

Clear signage is advisable. In Nottingham use is being made of a standard traffic sign that is circular, light blue and shows a white tram within a white border. This means "Tram only" but the comment has been made that people are unfamiliar with it and react better to red prohibitive signs. These signs have been used in Croydon. The use of the sign is enforced by using two signs, the addition of the word "only", as well as lane markings, that include the words "Tram Only".

Taking the wrong lane at a crossing: This is more likely where the crossing has the form of a large open "square". Providing and maintaining very clear lane markings as well as good signage can alleviate it. Amsterdam provides an interesting example, even though the road surface is very busy with markings, the clearest are those that keep the general traffic off the tram track.

Penetrating parallel separation (Crossing from adjacent traffic lane): In general both abuse and misuse will be reduced according to how clear the border is and how difficult it is to cross it. Ways of doing this were discussed earlier.

The enforcement of lane markings using ribbed surfaces and cats eyes can be a cost effective safety measure.

Barriers that allow traffic to pass through at slow speed are a safer measure where access is allowed, e.g. to delivery bays and parking areas. In such situations the driver of the public transport vehicle must be aware of the possibility that traffic could enter the lane in this way and he should be driving with appropriate caution.

Mixed use of traffic lanes

Safety depends on the speed, intensity and type of traffic flows. In this case clearly the onus for safety is a joint one and the regulations that apply to trams and buses treat them as "highway vehicles" specifically to cover this situation. In planning terms there are hazardous situations to avoid:

- Opposing traffic on the same lane

- Cycles and trams – although some mix is inevitable where the tram is in general traffic.
- Pedestrian and cyclists on lanes where the traffic speeds exceed 30km/h.

Safety policy

The safety of priority measures needs to be considered in the context of the safety of the system as a whole. A risk assessment, based on the number of occurrences of each type of accident and its severity in similar conditions elsewhere, should be carried out and sensible mitigation measures introduced. It is important not to overburden public transport systems within smaller cities and towns with safety measures appropriate to main line railways, where there is no case for doing so.

5.1.5 Specific issues

Grade separation versus level crossings

Grade separation should only be considered for public transport systems in a street environment when intersection capacity would not allow a level intersection with traffic lights and public transport prioritisation. Light Rail and tramway grade separation examples are common and bus tunnels do exist, for example in Helsingborg and Lund, Sweden.

Such a solution may make public transport too expensive in small to medium sized cities and should be avoided if at all possible.

Passenger access to stops and platforms

In situations where grade separated crossings between platforms are required for safety or operational reasons they will need to be provided with lifts or ramps to provide access for the mobility impaired. Such solutions are very expensive when compared with simple level crossings, however, and should be avoided if at all possible in the context of smaller cities and regions.

The measures described above should be designed into systems in order to avoid problems where passengers can cross on the level.

Route through roundabouts

At roundabouts it is appropriate to distinguish between "standard" buses and high quality public transport (trams, Light Rail, busways on segregated sections etc.)

It is also important to distinguish between "standard" roundabouts, with a radius of 10m or more, and "mini-roundabouts" with a radius of about 2m. In the latter case all buses will probably need to be able to pass through the centre island, as is the case with all larger vehicles.

Standard buses can generally use the same infrastructure that is provided for other road traffic. Thus for buses, the route should be made around the roundabout rather than through it.

On the other hand, high quality public transport, especially trams and Light Rail, sometimes cannot go around a roundabout due to technical limitations (curve radii etc.) Also, for these vehicles, acceleration will be insufficient for the quick entry needed to allow for good transition through a roundabout. Additionally, vehicle lengths can be too long to keep a roundabout operating anyway.

Trams and high quality public transport therefore need to cross through the middle of a roundabout, making use of traffic lights to provide separation from other traffic and priority. When a public transport vehicle approaches, other traffic must stop to allow it to pass through the centre of the roundabout.

A Swedish study has recommended that the lanes across the roundabout need to be at least 6m wide for buses and should not use "deterrent surfaces" to provide priority because of the discomfort to passengers and possible safety hazards[88].

Similar principles can apply to "mini-roundabouts"(defined as one where the centre island is 2m radius or less), which are too small to hold a tram or bus in the centre and it may not be possible for trams and buses to navigate the tight curves that these introduce. In these cases it is also possible to provide traffic signalling to warn other road users that private transport will take a different course. This has been done by using traffic signals that are green when there is no public transport present and

Cars wait on a roundabout at traffic signals for a tram to cross in Nordhausen. (Axel Kühn)

amber when there is. There are examples in Stavangar, Lyons and Orleons.

Mini-roundabouts need to be designed so that public transport can cross them. This should be true of any roundabout with a radius of less than 10m, although an alternative is that buses might be able to "skim" the edges[88].

Examples:

- **Jönköping,** Sweden. Bus routes pass through roundabouts.
- **Katowice,** Poland, trams on several routes cross a roundabout on the northern edge of the city centre. The tramways on the approach to the roundabout are on a reserved track in the median strip of dual carriageways. There is a tram stop in the centre of the roundabout accessed by pedestrian subways. Bus services go around the roundabout with other traffic. It is planned to replace this arrangement by grade separation as part of an effort to increase highway capacity.
- **Krakow,** Poland. Tramways pass through roundabouts as do buses in some locations. Traffic signals are used to prevent conflicts.
- **London.** Buses use Tyburn Way at Marble Arch. Marble Arch is on a large gyratory roundabout. Tyburn way allows them to cut off a corner. It is an exclusive bus lane used for through Park Lane to Oxford Street services and is also used as a holding area for terminating buses.
- **Wolverhampton,** UK. Midland Metro crosses centre of a roundabout on the edge of the town centre.
- **Nordhausen,** Germany. Traffic signals are used to prevent conflict on a roundabout where public transport passes through.

Avoiding over-use by priority traffic

If public transport traffic on a priority lane gets so high that the vehicles allowed on these sections experience traffic jams themselves then clearly the value of priority is lost.

In this case then the public transport vehicles with the lowest priority need to be taken out of the system. These could be taxis for example.

Also, to ensure that jams don't occur in the most sensitive city areas, intelligent traffic management systems (i.e. traffic control systems) should be used to ensure that waiting areas are used where space is still available, i.e. some way from the centre.

An example of where this problem occurs is Oxford Street in London where the traffic is reduced to a crawl even though it should only be buses and taxis. It should be noted however that these tend to be problems for large cities, not for medium sized towns.

Enforcement of priorities

Fines and enforcement need to be balanced to ensure sufficient deterrence from the illegal use of lanes restricted to public transport use. There is relatively good respect for the law in the North Sea Region but only a few individuals who are unaware of restrictions or flaunt them are sufficient to cause significant disruption. If enforcement is ineffective then separation of the lanes by physical barriers may be the only remaining option. Segregated track systems can usually be designed to prevent abuse.

Priorities at intersections should be provided by traffic lights that react to public transport vehicles. Motorists ignoring traffic signals is a major concern

Platforms used in Dresden both by tram and bus.
(Axel Kühn)

Combined bus and tram stops in Dresden.
(Axel Kühn)

creating significant risks and the penalties will be severe. Use of traffic lights as a method of enforcement is therefore likely to be effective.

Dual use of stops by buses and trams

This can be a good solution for easy transfer between the different modes. It also can make public transport more effective because a person who could make a specific journey either by bus or tram does not need to make a decision in advance about where to wait, and gets an overall better service. It is easier to achieve if buses and trams have the same floor height. In this case, a special kerb (e.g. Dresden kerb) needs to be devised which takes into account the local dimensions and conditions of the two systems.

Where vehicles have different floor heights, two possible solutions exist:

1. If the height differences are only small, then small adjustments might be made.
2. Where the differences are too large, two different platform heights can be used, one stop being right after the other. The two sections of platform should be joined by a ramp.

One disadvantage is that the width of land required for a mixed system may be wider than for a tram only alignment, where buses are not guided. So while a dual track tramway might make do with 6m, shared use with buses might increase this to 7m, even if the buses move at slow speed. This will also impact on stop design; the platforms will need to be wider apart.

Examples:

- Dresden, Germany
- Aachen, Germany

The kerb stone abuts the tram rail and also has a profile that retains the tyre. By this means the relationship between the platform edge and the vehicle is the same for either a bus or a tram.

5.1.6 Priority strategy

It is important to give high quality public transport services priority over individual traffic in order to help to promote a sustainable mobility in the future. Only public transport systems with priority will be able to deliver journey times that are competitive.

Public transport priority is an essential characteristic of any modern traffic signal control system. However, very limited information is available on the impacts of different priority functions on delays and fuel consumption of buses, trams and especially other vehicles.

A priority system that makes best use of resources and available road space is best suited to the needs of small and medium cities and regions.

Priority measures also affect other road users and a balanced approach is essential. The object should be not to cause dis-benefit to other road users but to benefit the community as a whole.

Priority solutions must cover the "difficult" as well as the "easy" locations. An example of a difficult situation would be narrow intersections with extensive conflicting movements in historic town centres. Strategies for remedies in such situations include:

- Diverting unnecessary (through) traffic right away from the location.
- Queue re-location: holding traffic at points upstream of the intersection to prevent congestion at the junction itself.
- Banning certain turns (perhaps just to non-public transport vehicles.)
- Closing certain streets (legs of the junction) entirely, or to non public traffic, thus forcing through traffic to take alternative routes.

In many cities the centre can be made a traffic free zone. In this case if public transport is allowed to penetrate the centre it will not need extra space to provide "exclusive lanes", since it will be the only motorised traffic there.

An effective priority system has to address both the "cross traffic" and "linear traffic" issues.

Public transport timetables need to be optimised to make the best use of priority measures. In particular scheduling must be used so as to prevent bunching so that public transport vehicles do not block one another.

A car user will experience delay as in vehicle time, whereas a public transport passenger will experience delay both in vehicles and at stops if services are unreliable as a result of congestion. This fact needs to be considered in the decision making process, although motorists may not appreciate this.

The intelligent application of modern technology will give public transport fast journey times without restricting general traffic more than necessary.

Modern traffic signalling control systems are "intelligent". Priority is only given when needed. Arguably they can be better for private traffic than less sophisticated traffic signalling in the past, when public transport had no priority but private cars could also be held up for no reason.

Sophisticated software is now available that facilitates planning of overall transport within cities, including the effects of priorities for public transport. A good overview of some typical products is available[130].

If bus stops are provided on heavily used priority lanes, especially where trams use them as well, then buses must have separate bays to pull into.

Kerbside bus lanes are common because they are inexpensive and easy to introduce. But they command little respect from other traffic and require constant policing. Non-respect of median and contra-flow bus lanes is much less[73].

Success depends on co-operation and joint work of transport, planning and traffic interests within a city or region.

For the applications being considered it may well be more effective to use traffic signal priority in a street environment in some situations than to separate public transport from other traffic.

Priority can be applied to buses and therefore is a very good solution for medium sized cities where they play a major role in public transport.

Where there is extensive priority, the efficiency of bus transit systems can equal that of Light Rail systems[73].

Physical segregation is not easy to justify unless there are 20 or more public transport vehicles per direction per hour. At lower frequencies, traffic signal priority is the only sensible option.

5.2 Shared track

5.2.1 Legislative and safety experience

TramTrain

The introduction of lighter vehicles on heavy rail infrastructure basically follows the same principle in all countries that have so far introduced such systems: The new system has to be at least as safe as a system solely based on heavy rail rolling stock.

After the introduction of the first TramTrain line in Karlsruhe, for which approval had been given on a strictly technical basis, there was a discussion about introducing both TramTrain systems and lighter DMU vehicles on a wider basis. Therefore a safety assessment was made based on the following question:

"What would have happened if a Light Rail vehicle had been involved in this accident instead of a heavy rail vehicle, and would the accident have occurred at all?"

The basic result was that the operation of Light Rail vehicles under certain conditions was at least as safe as the existing heavy rail operation. Statistically some accidents would be more serious due to lower passive safety of the Light Rail vehicles. On the other hand fewer accidents would happen thanks to the higher tramway deceleration capabilities.

As the outcome of the risk and safety assessment the German ministry of transport issued a "Light Rail vehicle regulation" (LNT-Richtlinie), which defines the conditions under which the operation of Light Rail vehicles on heavy rail infrastructure is allowed:

- Maximum speed of Light Rail vehicles 90 (100) km/h.
- Braking capabilities according to tramway regulations.
- Automatic train protection (ATP) is required on all vehicles and on the lines on which they operate.
- Operational issues need to be addressed within local operator regulations.
- Up to 80 km/h maximum speed heavy rail infrastructure may be used without major restrictions; between 80 and 160 km/h permission is possible with limits; no Light Rail operation on heavy rail routes with a maximum speed of >160km/h.
- Lines operated by Light Rail may not be used for shunting.

No serious accident has occurred to date on railway infrastructure in Germany, as a result of operating TramTrain systems, since its wider application in 1991.

TrainTram

To date such applications have only been carried out in Germany (e.g. Zwickau) and there are no guidelines laid down in this area. In Germany, rail vehicles operated on the street have to comply with BOStrab regulations. Where this is not possible, special permits have to be obtained by the safety agency responsible for the operations.

For the vehicles in question this meant that they were:

1. Equipped with brakes with braking rates more typical of trams and speed restrictions to comply with BOStrab braking regulations.
2. Equipped with indicators, brake lights and rear-view mirrors for the same reasons.

The vehicles had a special permit for on street operations, as their width of more than 2.65 m was outside BOStrab limits.

If such a system was to be introduced a similar approach could be applied in the North Sea region countries. If possible, segregated track sections should be used, to avoid conflicts between car traffic and the wider heavy rail vehicles. Also, it may be possible to use more narrow heavy rail vehicles for operations of this type (e.g. GTW 2/8 Seetallinie.)

TramMetro

To operate these vehicles on light metro systems it is generally advisable for them to meet as many light metro system requirements as possible. In Germany, LRV, tram and light metro systems are all operated under the BOStrab framework and therefore the systems cannot be completely different in terms of safety philosophy. In the UK railway safety principles are also applied to tramways, and light metros will be treated as railways. Where such legal frameworks are not in place, some general recommendations can be given:

1. LRVs and trams operating on light metro systems need to fulfil the same fire safety standards as light metro vehicles. This may include the additional requirements for tunnel running. It is also important to point out the future development of Euronorm prEN 45545 "Fire safety on rail vehicles", which may make some changes to the fire safety standards in future.
2. Generally, LRVs and trams should also fulfil the same crashworthiness requirements as the light metro vehicles. In most cases, the same crashworthiness static strength loadings should be required. However, it is necessary to point out that higher loadings will make LRVs and trams, especially low floor variants, far heavier. Also, higher static strength does not imply higher passenger safety. If the vehicle structure does not crumple during a crash, all acceleration energy will be imposed on the passengers in the vehicle. Therefore it may be advisable in some cases to go for collapsible structural elements, both for financial and passenger safety reasons. Buffer heights may well be an issue.

MetroTrain

From a legal point of view, this example is to be considered the same as operating TramTrains, LRVs and trams on conventional railways. This is because it involves vehicles with less passive safety (crashworthiness) but higher active safety (braking performance), operating on infrastructure in conjunction with vehicles with higher passive but lower active safety. Sunderland provides an example.

5.2.2 Areas of application

This topic considers in what circumstances a medium size city or region (100,000 population upward) would be likely to introduce a shared track solution as part of a solution to its transport problems.

TramTrain

Usually TramTrain systems are based on one or even two existing systems. In Karlsruhe the tramway and the railway both existed before TramTrain operation was introduced, the vehicles and the arrangements at the junctions between the systems were developed. Saarbrücken was different in that no tramway system existed and the parameters could be chosen freely. It is obvious that under these circumstances it was much easier to build a new TramTrain system.

The size of cities or regions that typically adopt this solution is usually between 200,000 and 500,000 inhabitants and not 100,000. Smaller cities generally are less likely to introduce a new tramway system and this makes the adoption of a TramTrain solution less likely, although some smaller ones will already have tramways.

For larger urban areas TramTrain services can close orbital gaps in a network that is otherwise radially orientated (for example Paris.) If the following conditions exist, TramTrain solutions might still be applicable for medium size cities:

- Both a local railway system and a tramway already exist. By connecting both systems, synergy effects will be realised, existing railway and bus services can be replaced and the new TramTrain system provides a better overall efficiency.
- An under-utilised railway line already exists on a route that would work well as a Light Rail system and the costs of TramTrain operation plus new tramway sections and any additional stops are justified.
- If there is no tramway network, an alternative might be to convert disused railway infrastructure into tramways (e.g. old industrial and harbour side tracks) so that only short newly built tramway sections may be necessary. This option has been studied in various locations, including Trieste.
- Ideally local railway services and inner city bus services can be replaced (and resources saved) by an intelligent TramTrain operation. Larger investments might be justified in this case, but in smaller cities the demand is usually too low to

cover the larger part of the operational cost. This can differ however with local circumstances.

- In all circumstances where existing "heavy" infrastructure is used, it is important to consider the location of this infrastructure in terms of the envisaged combined system. This means considering demand potential in relation to the specific route dictated by the location. The question has to be raised why the existing railway does not perform well and how introducing a TramTrain system will improve this. On one hand the railway may "by-pass" urban centres, on the other hand it may pass through them but not have any local railway stations to serve them.
- TramTrain systems have captured up to a third of the overall demand (modal-split) in a corridor under ideal conditions (many stops, good coverage, high frequency, replacement of local bus service by the TramTrain service, long travel times by car, etc..) Under normal conditions it is more likely to perform like a Light Rail system.
- Although a system might initially work very well with, say, a city centre tramway section and TramTrain operation along existing railways, it may be more expensive to extend this to suburbs where there is no rail infrastructure available and the city centre section may need duplication if capacity issues then arise.

TrainTram

In Zwickau the tramway and railway system already existed and it was necessary to create a junction between the two. Here however the existing tramway was metre gauge and so it was necessary to convert the shared section to mixed metre and standard gauge. In general there will be a railway but no tramway and this concept can be applied as a way of bringing the railway into town.

TrainTram is a newer concept than TramTrain and is likely to have more potential applications in smaller cities and regions. This is because it is more likely to achieve a step change in local transport provision with less infrastructure and hence less cost. The TrainTram may be part of a regional service rather than a separate operation, so the costs involved in extending an operation will be minimal and the number of people who can benefit will be greater. A short extension to some networks can make a big difference, and using tramway infrastructure could be the only practical and viable solution in some cases. For example there are many cities where the railway station has several local rail services but is at the edge of town so it is not convenient for local journeys. It is unlikely that extending the railway is possible because of the built environment and an underground line would be prohibitively expensive. A tramway extension for TrainTram use could make a significant difference to the value and use of the rail services.

TramMetro

In the small city context this is only likely if the light metro already exists. Extensions to the Light Metro may not be affordable whereas a tram solution might be. The TramMetro approach would allow the system extensions to be built with tramway infrastructure but retain through running, to the advantage of the user and making the investment more effective.

If the original light metro had tunnels and conductor rail electrification this will technically constrain the options for the tramway extensions, as discussed later.

TramMetro may be a solution for smaller cities and regions that are close to an urban area with a light metro. It would be an alternative to creating a totally separate system and give benefits to the wider region.

MetroTrain

In general the same criteria apply as for TramTrain, the difference being that it is even more unlikely that a small city or region would build a new light metro system.

Sunderland is interesting in that the new light metro section between Sunderland City Centre and South Hylton was built as part of the Sunderland Metro "MetroTrain" operation, which in turn was an extension of the Tyne and Wear Metro. It is unlikely that a separate Light Metro or Light Rail system would have been built on this route in the city had not the MetroTrain project happened.

Smaller cities and regions that have existing local rail services could see these replaced by extensions of light metro systems from neighbouring larger cities. In some cases it would be necessary to apply MetroTrain principles because although the passenger services might be totally replaced by metro there may also be freight operations, which mean that the route must remain as a railway. There is a similar example in the UK at the moment, where there are plans to extend the Mersey Electric services, which is effectively Liverpool's "Underground", over the Bidston–Wrexham railway, replacing local trains but still accommodating freight services.

5.2.3 Barriers to implementation

Most newly proposed public transport schemes face certain barriers against their introduction. However, with a shared track system, the number and magnitude of such barriers tends to rise. This is the case because:

- New and seemingly unproven technology is generally greeted with more reluctance by all stakeholders
- Resistance of some larger rail administrations to the introduction of TramTrain and MetroTrain services.
- Shared track operates in two "worlds", thus having to fulfil requirements placed on it by both of these worlds (heavy and Light Rail or metro and tramway.) This can introduce complex legal, technical and organisational requirements

In order to introduce a successful shared track system these barriers need to be overcome. This report identifies those barriers that have been encountered by existing or planned shared track systems and indicates possible solutions or counteractions to overcome such barriers.

While the four different types of track sharing defined by HiTrans have to be considered, it should be pointed out that a proposed system would face a rising number of barriers as the differences between the systems to be connected rise. This means for example, that a system where a link between a tram and a light metro scheme is proposed, the difficulties are likely to be less than when proposing the connection between a 160 km/h mainline and a tram.

Political and cultural barriers

1. Lack of a co-ordinating organisation Any public transport scheme that needs to be put in place under the control of different organisations will be difficult to implement. Unfortunately, when considering some shared track solutions, this is very likely to be the case. For example the planning authority for tram and metro operations are usually based with the city or region, while planning for heavy rail is done at a national or, as in Germany, state level. For TrainTram, the "main line" railway will need to establish good relations with a local authority that will be involved in approving a tramway extension and the scheme will have to be compatible with the latter's transport and planning policies.

As it will usually be impossible to implement a joint planning authority, it is important to involve all stakeholders as early as possible in the planning process. This will allow everybody to bring in their opinion but also give the project leverage should opposition be encountered elsewhere, because consensus among these stakeholders has already been reached.

A further possibility is to include the scheme in a package, basically ensuring that all stakeholders find something they want within it.

If all this fails, offering financial or other compensation to opponents of the scheme may be considered as a "last resort" measure.

2. Resistance of heavy rail operators or national railways National railways or other railway operators and infrastructure companies or even existing public transport operators may be opposed to a TramTrain or MetroTrain project because they fear:

- That their market share will diminish
- The necessary adaptations to infrastructure will disrupt operations

- Including TramTrain or MetroTrain services on an already busy line will reduce reliability or force them to give up train paths that they are using themselves, reducing their own access to the network.

To counter the introduction of the system they may even put pressure on the infrastructure owner (possibly in the same holding company as the operator) to demand prohibitively high access charges.

Possible solutions are to:

- Include the operator as early as possible in the planning stages
- Raise awareness that the introduction of TramTrain or MetroTrain services usually increases patronage of the whole public transport system including "classic" rail services
- Prove that TramTrains and MetroTrains are not an operational risk (e.g. by visits to existing systems or introducing trial operations with hired vehicles)
- Ensure that contracts with the operator allow for change, such as the introduction of new services
- Give the operator the possibility to participate in the shared operations (e.g. joint venture with local public transport company, public tender of the TramTrain/MetroTrain operations.)
- Compensate for any actually incurred losses (but only after losses have been proven by the operator, as patronage may actually rise due to TramTrain/MetroTrain introduction.)

Technical Barriers

1. Ease of access to the system Providing easy access to a public transport system is a topic that has become more and more important in the last few years. This includes not only the access to the system itself, but also a whole range of related issues such as availability of up to date passenger information etc. While these are all important problems, they are not intrinsically related to shared track but to all transport systems. General access issues are covered previously and this section only considers aspects that are specific to shared track.

For shared track systems, the main difference compared with other forms of public transport systems, in terms of access, is associated with the access to the vehicle from the platform. Here differences in platform height and the distance between vehicle and platform need to be considered. If one of the two systems to be connected is not yet in place (as was the case in Saarbrücken for example) the best way forward may be to choose the prevailing platform height on the existing system as a standard for the new system.

However this may not be possible when both systems to be connected already exist. In this case some adaptation of the infrastructure on the existing systems will be necessary in order to provide full access for all (e.g. Kassel.)

2. Power supply systems The supply of traction energy to the shared track operation vehicle has to be considered for each specific application. Therefore, the options outlined here and the solutions proposed can only be a first review of options. Experience of each solution varies and so there may be a level of technical risk associated with some of the options.

Generally it can be said, that for trams, Light Rail and light metro the following options for energy supply are currently in use or proposed:

- 750 V DC or 1500 V DC from overhead wires.
- 750 V DC or 1500 V DC from third rail (only for fully segregated systems such as underground light metros etc.)
- Diesel traction, a proven technology now being developed for use on tramways.
- 750 V DC from power supply underneath the vehicle (e.g. Bordeaux), an option where there is currently no technology with long term experience of reliable and safe operation.

For heavy rail systems the following options are typical:

- 750 V DC, 1500 V DC from third rail
- 3000 V DC, 15 kV AC or 25 kV AC from overhead supply
- 750 V, 1500 V DC from overhead line (if only small, Light Rail type vehicles are to be used)

- Diesel engine
- Other on-board power source (some options may be unproven technology)

It has to be pointed out that the use of high voltage (15 or 25 kV AC) on reserved track sections of Light Rail and Light Metro systems do not bring significant savings in vehicle terms, as a transformer still has to be carried on the vehicle. Therefore, unless only very short sections of the overall system will be within street sections, the use of high voltage is not advisable.

In the German city of Nordhausen the Combino Duo operated from 1st May 2004 in two different power modes. This hybrid LRV is able to run under a normal 750V dc overhead wire in the city. For the non-electrified narrow gauge tracks in the region (Harzer Schmalspurbahnen – HSB) it is equipped with a 190 kW diesel engine. Performance in the diesel-mode is inferior to the electric one. The diesel engine is a standard car engine. It remains to be seen how long this can last under everyday operations. It reminds one of the "petrol-electric" trams that operated in the UK and elsewhere in the early twentieth century and were never that successful, although the technology was then in its infancy. Development might overcome these problems by using a turbo-generator linked to energy storage. This might allow a small clean engine to be used with energy storage providing electric traction quality acceleration performance and also the ability to run short distances without overhead wires or the engine running. Such "low emission" hybrids may also be acceptable in cities and towns where a new tramway is provided as part of a shared track route, so that the cost and impact of the tramway is reduced by not providing overhead electrification.

Only a few of the theoretically available power supply options have been used. When pursuing shared track solutions it is always necessary to remember that these may require technically complex solutions. If possible, existing technology should be employed unless this is absolutely impossible. If new technology is needed, thorough testing and a development of solutions in close co-operation between manufacturer, operator and promoter should be the aim.

3. Safety systems (signalling, train protection etc.) Safety is a key consideration when introducing shared track schemes.

It is necessary to ensure that the envisaged system is at least as safe as a system, that would not incorporate shared track elements.

To do this it is necessary to ensure that both active (in this case reaction time to safety commands, brake performance etc.) and passive safety (crashworthiness etc.) are the same as for the separate systems. However, this would require the lighter system's vehicles to have buffer loads equivalent to those of the "heavier" system involved. Therefore this option is only achievable where two relatively "light" systems, such as light metro and tram, are to be combined. It would be impractical to raise the buffer load of TramTrain vehicles to the standard UIC value of 1,500 kN, and this can be true for MetroTrain vehicles as well. Therefore complementary measures have to be taken to raise active safety to counterbalance the lack of passive safety.

This would typically mean:

- Use of ATP equipment with automatic train stop on the "heavy" system (This does not rule out existing simpler signalling on the "light" system such as line of sight operation.)
- TramTrain and MetroTrain vehicles need to be capable of using the radio equipment of the railway system (If this is not in place yet, the introduction of a standard European GSM-R system would be advisable.)
- TramTrain, TrainTram and MetroTrain vehicles need higher deceleration capabilities than railway vehicles (e.g. in Germany braking capabilities of 2.7 m/s_ are required as for all Light Rail operations)

If possible (e.g. when one of the systems does not yet exist) the communication systems should be reduced to only one system. If this is not feasible, the shared track vehicle will have to carry both systems.

4. Wheel-rail-interface The track gauge needs to be the same. Flange back to back distances also have to be the same, at least in any areas where wheels are "checked", for example in track switches and crossings.

Mixed gauge track is a possibility but is only economic over short sections.

If one system is to be converted to the gauge of the other system then the new gauge should be the standard 1435mm.

Gauge changing mechanisms would introduce considerable cost on the vehicle; maintenance cost and cost for the changing device itself.

Two separate wheel-track systems can be distinguished:

- Heavy rail type systems adopting UIC specifications
- Light Rail type systems adopting BOStrab or other national Light Rail specifications.

Legislative and organisational barriers

1. Access of LRV to heavy rail infrastructure When access to heavy rail infrastructure needs to be planned for a TramTrain or MetroTrain scheme, the operator of the TramTrain, if it is the operator of a small tram, Light Rail or metro system, may be at a serious disadvantage. The network owner may not be willing to allocate timetable slots for short distance operations, which could reduce line capacity for more profitable services.

Possible solutions to this problem will differ from country to country. Where the market is dominated by one large national railway operator that also owns the infrastructure, it may be possible for that operator to also operate the TramTrain or MetroTrain system direct, thus avoiding problems with the infrastructure owner.

In other cases, some direct political action may be necessary to put pressure on the infrastructure company. This will still depend, however, on what value is ascribed to "local" as distinct to regional, long distance and freight railway services.

In the long run, a European solution may be reached that would require infrastructure owners to prefer those operations that yield the highest benefit to society. This might favour these types of shared track operations.

2. Missing common European standards Common European standards for shared track operations currently do not exist. Those countries having national regulations in place also have operational shared track schemes or systems nearing operation. Countries that do not have such regulations still lack such systems.

Therefore, in the long run, common European shared track regulations should be put in force, drawing from the experiences made by all countries with operational TramTrain schemes as well as from the German Light Rail vehicle regulations (LNT-Richtlinie.)

In the medium term, it would be advisable for the North Sea region to introduce its own set of shared track guidelines, again drawing from the Light Rail vehicle regulations (LNT-Richtlinie) and experiences in other countries, thus ensuring compatibility with a future European standard.

In the short term, cities and regions in the North Sea region that want to introduce shared track services should strive to use as much experience from existing systems as possible, possibly including application of the Light Rail vehicle regulations where appropriate in order to:

- Not re-invent the wheel
- Be able to use economies of scale by manufacturers
- Have the advantage of "proven technology", which will also help in terms of gaining approval.

3. Selection of operators When introducing new shared track services it may be difficult to select the new operator for the system. If two systems that are to be connected already exist, then introducing a new operator would mean involving a third operator with both existing ones. This will clearly lead to organisational problems.

However, as European legislation requires new operations to be tendered, the solution of giving the new system to one of the existing operators or to a joint venture of both may not be possible.

To achieve a maximum integration of the new scheme, selection of operators needs to be discussed and the legal possibilities should be evaluated. Existing operators should be invited to bid in open tender for the shared track operations.

4. Infrastructure ownership A shared track operation will often involve using infrastructure that is not owned or controlled by the operator.

The easiest solution could be the ownership of both infrastructures by the shared track operator. However, this is only possible when the vehicles that operate the shared track service use this infrastructure almost exclusively.

In most other cases, some form of access to another infrastructure has to be achieved. This can be through some form of partnership agreement. In this case, the new operator would, for example, pay a smaller than normal lump rental sum to the infrastructure owner in recognition of the need to carry out some of the maintenance activities itself. An alternative possibility would be the standard "access" case, with the new operator paying access fees for each of its trains operated on the infrastructure that is not owned by himself. The first of these options would allow the shared track operator to have some measure of influence on the infrastructure cost on the section that it does not own.

5. Rolling stock ownership This factor is mainly driven by the economic implications of rolling stock ownership as discussed below.

Economic barriers

1. Cost of rolling stock The cost of rolling stock is a significant issue in any public transport scheme. However, with shared track operations it becomes even more important because:

- Due to the lack of European standardisation, most shared track vehicles may only be usable on one specific system.
- Adaptation of the vehicles to infrastructure conditions on two systems increases vehicle cost.
- Vehicle fleet sizes are generally too small to achieve economies of scale.

If a shared track scheme is to be tendered, ownership of the vehicles by the local authorities and lease to the operator should be considered. This would have the following advantages:

- The number of bidders will increase, as vehicle procurement has no longer to be included.
- Smaller bidders will also compete, as their disadvantage in vehicle procurement against large operators is no longer an issue.
- Operators can now enter this market, which they would not if vehicles had to be procured by themselves, and these vehicles could only be used on the one system

Private vehicle leasing companies may not want to enter this market because:

- These vehicles can only be used on one system
- A resale of the vehicles or lease to other systems will not usually be possible

Public-private partnerships including private leasing companies should be considered, but have to be discussed with local circumstances in mind.

Other barriers (not solely applicable to Shared Track)

There are many other barriers opposing the introduction of public transport systems, such as:

- Availability of public funding for infrastructure and operations.
- Space allocation in the city.
- Prioritisation of public transport.
- Lack of public support.
- Need for provision for future developments that never actually occur.

While these issues all have to be kept in mind, they are not specific to shared track and therefore will not be dealt with in more detail in this report.

5.2.4 Shared track strategy

The decision making process for determining if a shared track application is appropriate is similar to that for any public transport, in terms of demand, public and political support, overall costs and benefits etc., however there are a few "special" factors to consider, for example:

- Demand patterns will be influenced by where stations are already sited or new stops can be feasibly created. The location of existing infrastructure to be used (railway, tramway, metro etc.) is more important than with a system based on new infrastructure.
- Would should detours from an existing route, using some infrastructure be cost effective?
- Can two systems be connected and interoperate efficiently and effectively?
- Are there savings to be made by replacing an existing costly service by the new service?
- What will happen if the system needs further extensions later, will this be feasible, will it add disproportionate cost?
- Will the use of special shared track vehicles offer wider potential advantages elsewhere or later?
- Technical, operational and institutional issues about what may be a novel approach.
- Risk issues associated with not having control over parts of the infrastructure.
- Conflicting uses for the infrastructure, either now or in the future.
- Capacity and other restraints imposed on existing users of the infrastructure.

5.3 Designing bus infrastructure for tramway conversion

5.3.1 Bus conversion situations

Before proceeding it is important to consider the possible situations in which conversion might occur. The types of busway that might be converted are:

1. A bus lane, used by unguided or guided buses (other than mechanical guidance systems) in a street used by other traffic.
2. Guided Light Transit, in a street used by other traffic.
3. Guided Light Transit on its own right of way.
4. Kerb Guided busway.
5. Other reserved track busways.

These might be converted to:

I. A street tramway.
II. A reserved track tramway or Light Rail line.
III. A shared track railway.

Case III would only perhaps occur if the alignment of the busway had previously been a conventional railway, and is a special case.

The conversion situations that are feasible and worth considering further are shown in the following matrix, they are identified later by letters A–G, allowing cross references back to table 17:

5.3.2 How the situations might arise

There is strictly only one situation in which bus infrastructure might be designed for tramway conversion i.e. when a busway is converted that was designed with this eventuality in mind. If the eventuality was never considered, so that the design did not take account of it, then the issues raised in this report are not directly relevant.

The most usual reasons for building in the potential for conversion are:

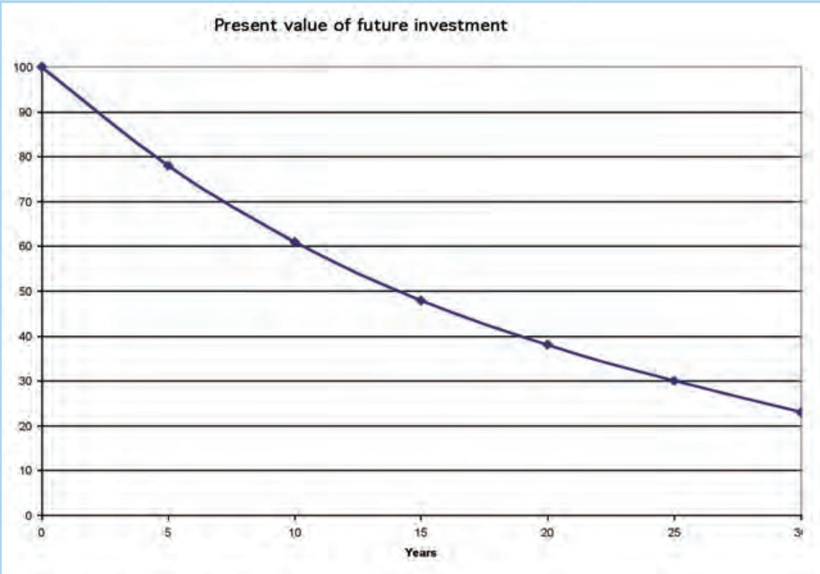
- The route may have sufficient traffic potential to justify Light Rail in future but not at the time of construction.
- The route exists in an area where a Light Rail/ tramway/shared track network exists or is being developed and the route, or part of it, might transfer to that network in future.
- The busway has made use of the old infrastructure of a former railway and the possibility of restoring a rail service has to be retained.

The extent to which one builds in conversion potential will vary with these options, likely timescales and probabilities. The only way to resolve this is to undertake a business case assessment based on the present value of future investment, taking into account probabilities, as discussed further in section 8.1. It should not be assumed that the measures listed below are essential in every case.

Another possibility is to construct a section of route initially as some form of "dual system" that might only be used in the first instance by one of the modes. This might occur for example where a

Table 17 Bus to tram conversion options matrix

Convert to option: / From option:	I **Street tramway**	II **Reserved track LRT**	III **Shared track railway**
1. Bus lane	This is equivalent to building a new tramway.	Not practical.	Not practical.
2. GLT in street	Situation A	Not practical	Not practical
3. GLT reserved track	Not practical	Situation B	Situation E
4. KGB	Not practical	Situation C	Situation F
5. Reserved busway	Not practical	Situation D	Situation G



Present Values expressed as a percentage of Future Cost for 30 years at a 5% interest rate. *(Interfleet)*

busway was being built through a tunnel that would also be used later by a planned tramway. In this case the tramway would only be partially built initially and when it was eventually opened the route would still carry bus traffic as well. Examples of this are discussed later. The issues that dual use introduces will tend to be specific to the application and are not considered in this report.

5.3.3 The obsolescence issue

Light Rail and tramway technology does not stand still. For example if one had planned a tramway 20 years ago it would have been reasonable to assume that vehicles would have a floor height of 450mm, whereas the standard now is typically 300–350mm. This would have had far reaching consequences on system design.

Improvements to traction systems, track construction, electrification would also occur within this timescale. New regulations will arise and fashions that influence system design features will change.

For all these reasons it could be a mistake to build too much "convertibility" into an initial system. The recommendations that we have made in the previous section reflect this.

5.3.4 Cost implications

There are four basic types of costs that a system might incur initially in order to permit conversion later.

1. Costs that need to be incurred so as to ensure that conversion is feasible eventually, for example:
   – Ensuring that space is available for the depot, eventual full sized stops, signalling, and changes to the route.
   – Design work.
   – Compromises in the alignment design in terms of gradient, curvature etc.
   – Obtaining authority for eventual conversion.
   These costs must be incurred if the decision is made to make the route "convertible".
2. Negligible costs associated with system design that may save costs when the route is converted ("passive provision".)
   These costs should be incurred if the decision to make the route convertible is made.
3. Costs that will definitely need to be incurred at the time of conversion.
   These include laying track, providing new signalling, overhead electrification, route detours, new stops.
4. Costs that it might be worth incurring in order to save costs later. These should be kept to a minimum because they are wasted if conversion never actually occurs.

In order to decide which type 4 costs are worth incurring at the outset it would be usual to apply the following method. This should be performed for each individual feature identified during the design process.

Step 1: Estimate the "Future Costs" i.e. the costs of carrying out the work in the future. As well as the work itself one needs to include costs associated with disruption and loss of traffic during an extended closure period.

Step 2: Multiply this by a factor that represents the probability that this work will ever occur. So for example if the probability is assessed at 50% then the Future Cost is halved. We call this the "probabilised" value.

Step 3: Determine the Present Value of the Future Cost based on a typical interest rate and when it is anticipated conversion might occur.

One should go ahead with any work where the cost is less than the Present Value of the work performed later. In marginal cases one might need to consider risks in more detail and also the availability of funding now and in the future.

Two examples are given here in order to illustrate this:

1 Should services be diverted before a GLT route is built if it is eventually to be converted to Light Rail?

For this example the following statistics are assumed to apply:

- The cost of diverting services is 1million euro per km (reserved track, off street route.)
- The system is 20km long with 10km of GLT track.
- The GLT system will be carrying 20 million passengers per year after 10 years, generating revenue of 50c per passenger i.e. 10 million euro revenue per year.
- The system will need to close down for 6 months longer, when it is converted if services are to be diverted later.
- There is a 50/50 chance of the conversion occurring after 20 years.

Calculation:

Costs to be incurred at conversion:	
Diversion of services (1 million x10)	€10 million
Loss of revenue (0.5 x €10 million)	€5 million
Total	€15 million
Current value (assuming 5% interest)	€5.7 million
Probabalised (50%)	€2.9 million
Investment required now to avoid this cost:	
Diversion of services (€1 million x 10)	€10 million

Since €10 million is significantly more than €2.9 million it would not be worth diverting services when the initial system is built.

2 Should a bridge on a busway be built high enough for Light Rail electrification?

For this example the following statistics are assumed to apply:

- A new bridge over the route is being built. It will cost €2 million or €2.1 million if Light Rail clearance is to be provided.
- To replace and reconstruct the bridge later to Light Rail clearance will cost €2million, but this will not extend the time required for conversion of the system as a whole.
- It is planned to convert the route in 5 years time but there is a 10% chance that this will not happen.

Calculation:

Costs to be incurred at conversion	€2 million
Present value (assuming 5% interest)	€1.56 million
Probabalised (90%)	€1.4 million
Investment required now to avoid this cost:	
Diversion of services (€2.1 –€2 million)	€0.1 million

Since €0.1 million is significantly less than €1.4 million it would be worth providing clearances when the initial system is built.

In this case it would still be worthwhile even if the conversion did not take place until significantly longer than the planned 5 years.

The optimum time to convert a system will depend on other factors including vehicle life. Whereas ordinary buses might be deployed elsewhere, a specialised fleet of guided buses or GLT vehicles might only be worth replacing when near the end of their life.

Another key issue is the availability of capital at the early stage of a project. It may make commercial sense to build conversion features into the initial system in terms of payback but the investment may not be available. This may be true, for example, where the expected traffic relies on development of an undeveloped area.

5.3.5 Experience

There are actually very few known examples of systems being built for eventual possible conversion. See table 18.

Table 18 Examples of conversions

Situation	Conversion from	Conversion to	Examples
A	GLT in street	Street tramway	None
B	GLT reserved track	LRT reserved track	None
C	KGB	LRT reserved track	None
D	Reserved busway	LRT reserved track	Amsterdam, Brisbane, Seattle, Pittsburgh, Rouen
E	GLT reserved track	Shared track railway	None
F	KGB	Shared track railway	None
G	Reserved busway	Shared track railway	None

Amsterdam

An express bus route known as Zuidtangent was opened in 2002 to link Haarlem with Schiphol Airport. It consists of a busway and bus lanes with some tunnel and elevated sections. All the busway sections have been designed for conversion to Light Rail, while some of the bus lanes in Haarlem will become tramways.

In 1998, HTM, the transport company of The Hague, made an offer to build Zuidtangent as a Light Rail system. The proposal was rejected because the regional authorities placed emphasis on speed of implementation.

The current system is 24km long, with 16 stops. Further extensions are either under construction or planned, to Amsterdam (Bijlmerstation), Ijmulden and Ijmeer. These will increase the length to about 40km and add 6 further stops.

It is a well designed system in an architectural and image sense, and has won international awards. It one of the most extensive busway projects in the world. It has "Light Rail" quality with distinctive stops, priority and modern information systems.

It is operated by Connexxion using 33 VanHool 18m low floor articulated buses, with 45 seats and room for 90 standees. Daily ridership figures of 125,000 have been reported.

The system has achieved high standards in terms of accessibility for all.

The only feature known to have been included to allow conversion to Light Rail is the provision of adequate clearances, including for overhead in tunnels. No provision appears to have been made in the busway surface for future rails or for electrification.

The platform height used (300mm) would be suitable for Light Rail but this is measured from the road surface, which suggests that conversion would involve substantial reconstruction. Platforms are between 23 and 30m in length. The lane width of 3.5m would be adequate for Light Rail.

Brisbane

Brisbane is developing an elaborate busway system with reserved roadways and distinctive stations based on a similar one developed in Ottawa.

The feasibility of making the SouthEastern Busway suitable for Light Rail conversion was discussed and the Inner Northern Busway has been designed to be convertible. The measures incorporated have included:

- A Faraday cage (A method used to reduce earth leakage problems on electrified systems. A steel mesh is laid below and either side of the tramway track, embedded in the roadway.)
- A vibration mat installed on section close to a hospital.
- Slots in the road surface for future rail.
- A short branch provided in a tunnel so that a Light Rail junction can be built there without impacting on the tunnel wall.
- Negative cant has been eliminated in the design.

Seattle

The city has a network of trolleybus routes. In the 1980s a bus only subway with underground stations was built in the downtown area. Tramway track was laid into the roadway.

The city now has a Light Rail project; the route will use the tunnel. The following works will be necessary:

- Replacing the rails, providing improved insulation.
- Providing new overhead.
- Raising platforms.

This is a good example to show how, even when provision is made for later conversion, the original installation may prove to be technically obsolescent by the time it is needed.

Pittsburgh

The Port Authority of Allegheny County operates four busways:

- The South Busway (6.9km); opened in 1977, with 8 stops served by 16 routes. This includes a shared Light Rail and busway tunnel.
- The Martin Luther King, Jr. East Busway (10.9km); opened 1n 1983 and served by 36 bus routes feeding into it. A 3.7km extension opened in 2003.
- The West Busway (8km); opened in 2000 is an exclusive route with 6 stations.
- The North Hills Busway (9km.); opened in 1989, this is a road that functions both as a busway and a High Occupancy Vehicle (HOV) lane.

The South Busway used old tramway infrastructure and therefore would be potentially easier to convert to Light Rail than a purpose built busway. On the other hand some bridges would need replacing, as they are no longer adequate to bear the weight of modern LRVs.

The Authority claims that the other busways were designed for conversion to Light Rail and this is a long term objective. However it is clear that the Light Rail/Busway issue is a very contentious political one in the area, with allegations that poorer districts are being provided with low cost bus rapid transit with all the environmental disbenefits of diesel buses. In view of this it is not clear to what extent Light Rail conversion potential was built into these busways and it may be a political statement rather than technical reality. From an extensive study of literature it would seem, that the only measures included in the design were clearances, alignment parameters and bridge strength.

The West Busway cost $326.8 million to build in 1994. This included the cost of enlarging the bore of an old railway tunnel to take buses, at a cost of $33.3 million. Prior to building the East Busway extension, an engineering study was carried out by Otak. This estimated the cost of converting the existing busway to Light Rail and building the extension as Light Rail would be $401 million, whereas the cost of simply extending the busway would be $62 million. Otak also estimated that these works would have taken 10–15 years to implement. These figures suggest that very few “conversion features” can have been built into the original busway.

Charlotte–Mecklenburg, North Carolina, USA

In 2001 plans were discussed for building two busways that might be upgraded to Light Rail later. The measures to be provided were:

- Alignment/bridge/gradient and curve standards applicable to Light Rail.
- Buried conduit for future cables.
- Dual use bus and tram stops.

The authority was being advised by a consultant who had worked on the Ottawa Busway, and also, possibly, on the Brisbane schemes. So there may have been transfer of the principle from that application.

Rouen

The Rouen “metro”, a Light Rail system opened 1994–8. The Civis optically guided bus has recently been introduced on two other routes. It is reported that provision has been made for eventual conversion to Light Rail.

Edinburgh

A guided bus system known as CERT (City of Edinburgh Rapid Transit) was planned in detail to connect the city to the airport and other developments in that area. It was designed to accommodate future conversion to tramway. The project has now been abandoned and the corridor is now planned to be served by one of the three lines of the Edinburgh Light Rail system.

The measures that CERT planned to include to allow conversion to tramway were:

- Vertical curvature was limited to 500m.
- Stops were designed to be 65m long.
- Alignment allowed for future stops that might be served after conversion.
- A 6% maximum gradient was used rather than 10%.
- Cant and transition were not optimised because of uncertainty about future tram designs.
- 4.6m clearance was provided under structures.
- Bridges were designed for Light Rail loadings and future track ballast.
- The concrete re-inforcement was formed into continuously welded panels so as to create a Faraday Cage.
- The CERT control room would also be suitable after conversion.
- All stops would have been designed to provide access for the mobility impaired.
- Pedestrian crossings on the busway at stops would have also met HMRI requirements for tramways.

The following features, required for busway operation, would have been suitable for tram operation:

- Maximum speed 50km/h.
- Minimum curve radii of 150m.
- CERT would have passed through the middle of the one roundabout at Gogar using traffic signals.
- Slope of trackbed.
- Priority.
- Car parking provision.

The following features would not have been provided until after conversion:

- Formation width increase from 6.2 to 6.55m, to allow a 0.75m central reserve for traction poles.
- Protection at bridges over the route from overhead electrification.
- Strengthened bridge parapets.
- Diversion of certain services.
- Sub-station sites.
- Platforms for trams (busway platforms would have been 180mm high.)
- Architectural brief for redesigned stops.
- Depot, including land.

CERT would not have involved:

- Electrification (as a busway)
- Re-use of any railway infrastructure.
- Tunnels.
- Signalling (other than traffic signals.)

Consideration was given to providing slots for rails in the road surface but this was seen as too restrictive and costly. Instead the busway was designed assuming that the rails would be laid on the top of the busway surface.

Dual systems

During the 1980s a metre gauge tramway in Essen was converted to KGB operation but this was done in such a way that trams could still use the route. The KGB operation was subsequently removed and replaced by buses on conventional roads when further capacity was required for the trams.

In Mannheim a kilometre of tram route was converted to dual KGB and tram operation to allow buses to access the tramlines and avoid a congested section of roadway.

There are many examples of bus and tramway systems sharing the same infrastructure, good examples being Oslo and Oberhausen.

5.3.6 Bus to tram conversion strategy

The conclusions of this topic are:

- It is possible to construct busways so as to facilitate their conversion to Light Rail or shared track routes later. The most likely scenario might be the conversion of a conventional unguided busway, although conversion of GLT and KGB is also possible. Guided bus systems that use electronic, optical and magnetic guidance can be considered to be "unguided" in terms of infrastructure issues related to conversion.

- Converting a bus lane in a street to a tramway is not significantly different to building a new tramway.
- The shared track option might occur where an old railway has been converted to a busway and is later converted to mixed railway and Light Rail operation. When this occurs it may be necessary to increase the structure gauge (e.g. clearance under bridges) for re-use by rail because any "grandfather rights" to use restricted clearances may have been lost by virtue of the break in rail use (this would also apply if the route was converted back into a railway.)
- There have been two examples of mixed tram and KGB operation (Essen/Mannheim) that prove some of the engineering issues. In both cases the tramway track was metre gauge.
- The possibility of conversion might restrict alignment options and restrict curves and gradients.
- It is better to plan for Light Rail to cross through the centre of roundabouts. Busways should either do this initially or revert to unguided mode and join the traffic at roundabouts.
- The distance between the centres of parallel tramway tracks may need to be closer than the centres of the busway lanes that they replace.
- Different considerations apply to reconstructing old structures initially; for example where old railway infrastructure is being used rather than building new structures for the initial system.
- If a busway is converted to Light Rail or shared track there may also be costs associated with making connections with an existing tramway, Light Rail or railway network.
- If it is planned to convert a GLT line to Light Rail later and it is found worthwhile to divert the underground utilities before the GLT system is built, this will tend to eliminate most of the claimed cost advantages of using GLT.
- Overhead electrification, signalling, signage and platforms suitable for Light Rail are not worth providing until conversion occurs. If a busway is using overhead electrification (trolleybus technology) then it is relatively simple to convert it for Light Rail use.
- If a busway is converted to Light Rail it may make more sense to convert it to diesel tram operation rather than incur the high costs of retrospective electrification.
- Long term conversion potential needs to be authorised at the time of the original system. This introduces risks for the initial system but avoids high costs that might arise in the period before conversion occurs and the possibility that development might block the scheme.
- Space must be available for features not required on the initial system, such as larger stops, more parking space, signalling, substations and depots.
- Technical obsolescence is a problem for "advance works", and this is demonstrated by the one system that made early provision, i.e. the Seattle busway tunnel, where the rails installed 20 years ago will now have to be replaced before the tunnel can be converted for Light Rail use.
- We propose that decisions on the extent to which a system should be engineered initially to facilitate conversion later should be based on breaking the design into cost elements and then considering the probabalised present value of future investment. This implies that design and some other work on the future system is required in order to identify these requirements at the initial stage, once a decision to make it convertible is made.
- It may be advisable to obtain authority for the eventual system at the same time as it is obtained for the initial system, but this introduces risks for implementing the initial system, including legal and planning complications. The legislation in some countries may require fresh applications to extend the time that powers or planning permissions exist. This introduces a risk that such consent might not be given at a future date.
- There are very few examples of systems designed for later conversion.

Quite a lot of information exists on the "before and after" effects of implementing the new technical solutions described in this report. The exception is the new guided bus modes for which there is no significant operating experience. We are very aware of what these results are and have access to them. One problem is isolating the effect of specific features. For example when the Karlsruhe-Bretten Tram Train operation was commenced and the Leeds Superbus service was initiated each experienced traffic growth but were part of a series of measures so it is difficult to know how much this was actually due to the specific technology change. However more applications are coming on line and by comparing results in similar locations it is now possible to begin to identify which cause is responsible for which effect. Interpreting the results of such experience is more important than repeating them and the context of the system being described also needs to be clearly understood.

The issue of what features actually make public transport effective is very important in the context of considering alternative technical options that actually might share some of these features. For example in a city where the tram system has ticket machines at stops but people pay the driver to use buses, what would be the effect of putting ticket machines at bus stops?

Our analysis therefore considers the features that are the "building blocks" that form high quality public transport systems of different types, as well as the overall performance of individual systems and networks. Our belief is that this provides important guidance on what features will suit specific applications and in turn identify the technology to be used.

In order to do this we have studied the output of the other strands and used this where appropriate. This includes the recommendations of Strand 2 work on effective networks.

Where possible, under the main headings of patronage, land use and urban design, we have further sub-divided discussions under the following headings:

- Vehicles
- Infrastructure
- Regulatory issues
- Platform/accessibility

An overall assessment of the effectiveness of each technical solution follows.

In considering the costs of shared track systems we have considered TramTrain rather than the wider shared track possibilities (TrainTram, MetroTrain and TramMetro.) These can be considered in each case as a combination of two systems. The overall cost and effectiveness of a given shared track system will be very dependent on the proportion of infrastructure of each type that it contains. So the approach should be to consider the sections of the system with different infrastructure separately. This is also applicable to TramTrain where the proportion of tramway/Light Rail running to railway running is outside of the approximate range 10–30%, or where no additional stops are opened on the shared section of railway. See table 19.

Table 19 Infrastructure cost assumtions for shared track

Shared track mode	Split into	
TramTrain	LRT	Modern Multiple Unit
TrainTram	LRT	Modern Multiple Unit
MetroTrain	Light Metro	Modern Multiple Unit
TramMetro	LRT	Light Metro

6.1 Effects

6.1.1 Patronage

The diagram shows the maximum capacities that each of the technologies can reasonably achieve based on conditions that are appropriate to medium size cities in the region, based on a 5 minute service interval. Capacity is the total number of passenger places per hour per direction and assumes "trains" of coupled vehicles where appropriate.

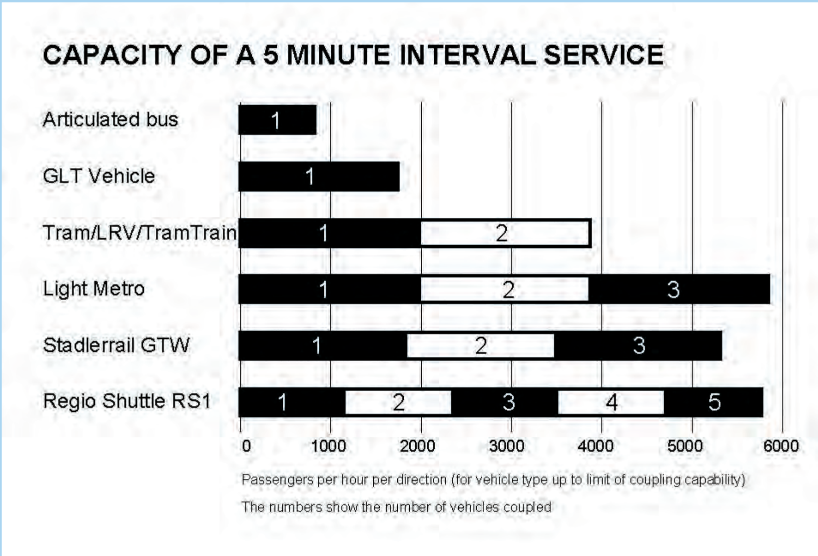
These figures are based on vehicle capacities given in Chapter 4. It should be noted that higher capacities are possible, rail routes can operate at 2–3 minute intervals and bus routes at 1 minute intervals. Also even higher capacities are possible when routes are combined over short sections. For example signalled rail services can operate 2 minutes apart, trams driving on sight down to about 50s apart (For example Karlsruhe Kaiserstrasse) and buses about 20s apart. However at these service levels, speed is restricted, reliability is poor and stop times become critical.

A factor of 0.65 has been included above to allow for the fact that peak capacity is rarely fully taken up (because people tend not to crush up unless necessary) and it is inefficient to operate fully loaded. One also needs to allow for daily and seasonal fluctuations and sudden surges in demand.

The importance of this diagram is that one needs to choose a technical option where the capacity matches the demand. Because even though the cost per seat of an option may be less it is the cost per passenger kilometre carried that actually matters.

Table 20 illustrates the points made above, based simply on operating costs taken from the table in section 8.3. It assumes a LRV of 250 capacity costing €7.5 per km to run and a bus capacity of 100 costing €3.7 per km to run.

If one had calculated these figures for a given service then one might conclude that it would always be cheaper to operate a bus than a tram. But this overlooks the fact that particular modes may attract more customers than others, so for example in the case shown here the bus would actually be more expensive if the LRV were attracting more than twice as many passengers.



Capacity of a 5 minute interval service. *(Interfleet)*

Table 20 Cost per passenger carried

Average passenger load	Cost per passenger carried (Euro cents/km) LRV	Bus
100	8	7
80	9	9
40	19	9
20	38	19
10	75	37

It has been suggested that the "breakeven" in overall cost terms between Light Rail and bus solutions is at about 2000 passengers per hour per direction[15]. A five minute interval, which is typical for "rapid transit", suggests an average loading of 2000/12 = 166, which is probably very high for all but exceptionally busy corridors in a medium sized city.

Promoters of schemes will usually be seeking a "step change" in patronage of public transport in the area served in order to justify the investment. This section of the report examines how the different technologies vary in this respect. This can best be considered by looking at reported "before and after" effects. Some problems have to be admitted however:

- The methods of measuring change may not be consistent.
- There are many examples of some types of system and only a few examples of others.
- There is not much experience of some of the newer technologies.
- System performance varies for many other reasons than the basic technology choice.
- Other contributing factors and influences.

For these and other reasons the data that follows can only be an indication. We have not carried out any original research in this area so are dependent on the accuracy of the reports used.

The tables that follow cover each of the technology options in turn and give some published results under the following headings:

- Country
- City
- Population of city/region (million) e.g. 0.5/1 = city of 500,000 in a region of 1 million.
- Name of system
- Route length
- Year opened
- Passengers carried (per year in millions)
- Passengers carried per route km
- Other performance indicators/notes

In each case where there is a lot of choice we have selected European examples that we consider are typical of what might be achieved in future.

The figures in the tables are mostly "snapshots" in that they show recent statistics for one year. A few figures have been included to indicate growth and also a table that shows patronage growth on new UK LRT systems (table 27)[46].

The data was prepared to show the difference between predicted and actual but this is an issue of the accuracy of the prediction methods, not always of the technology itself. Some more examples of predicted versus actual are shown in the tables. There is some evidence that methods might have improved, or be more cautious now, in the UK. The new Nottingham system is carrying 25,000 passengers per day, three months after opening; it was predicted to carry 30,000 eventually.

Some growth trends can be recognised when schemes are implemented:

- An initial surge in new off-peak traffic for leisure, shopping etc., based partly on novelty and the fact that people can easily change their travel habits for these activities.
- A slower take-up of modal transfer and peak hour traffic. This is probably due to the fact that people need to change places of employment and residence before some of the impact is felt. They may also be slower to change travel habits, especially if more cost is involved.
- Initial growth to a peak followed by gradual decline. This was experienced by longer established new systems such as Nexus and the Light Rail and busways of Pittsburgh. It can reflect general decline in public transport use and the effect of economic factors.

Revenue

The relationship between patronage and revenue is not straightforward. There will be a relationship between patronage and fares, so the success of a scheme in terms of attracting customers and achieving modal shift depends on the level of support that governments and local authorities are prepared to give.

In the tables above we have shown passenger

Table 21 Light Metro patronage

Country	UK	Netherlands	Germany
City	Newcastle	Utrecht	Hannover
City Population (million)	0.281	0.25	0.517
Region Population (million)	1.1	na	1.124
Name of system	Nexus	Sneltram	Üstra
Route length (km)	59	22	110
Year Opened	1980–4, short extension 1991	1983	1975 (expanding)
Passengers carried (million)	37	13	94 (1)
Passengers carried per route km (million)	0.63	0.59	0.85
Other performance indicators/ notes	Data excludes Sunderland Metro	–	(1) Our estimate for 2001. Part of a wider tram and bus system.

Table 22 Light Rail patronage

Country	France	UK	Germany
City	Strasbourg	Croydon	Freiburg
City Population (million)	0.25	0.522	0.208
Region Population (million)	0.46	6.3	0.298
Name of system	Strasbourg Tramway	Tramlink	Freiburg Public Transport
Route length (km)	25	28	27.5
Year Opened	1994/2000	2000	(extended original tramway from 14km, 1983–1997)
Passengers carried (million)	43	19	67 (including bus network)
Passengers carried per route km (million)	1.72	0.68	Probably >2
Other performance indicators/ notes	Public transport use in Strasbourg increased from 40–60.1 million per year from 1992 to 1998. Tram passengers from 18 million in 1997 to 35 million in 2002. 1n 1991 17,000 passengers used the bus route replaced by the tram, increased to 55,000 by tram in 1997 and 100,000 in 2002 for same line A. 122% coverage of operating costs.	Passenger numbers are 76% of prediction. Modal shift from cars accounts for 19% of users. 4% reduction in road traffic flows. 6% reduction in car parking.	Modal split change: Year 1982 1999 Walk 35% 22% Bike 15% 27% Tram / bus 11% 18% Car 39% 33% 30,000 daily car trips replaced by tram/bus.

Table 23 TramTrain patronage

Country	Germany	Germany	Germany
Route	Düren-Heimbach	Freidrichsdorf-Brandoberndorf	Kaarst-Mettmann
Name of system	Dürener Kreisbahn Rurtalbahn	Hessische Landesbahn	Verehrsverbund Rhein-Ruhr (Regiobahn)
Route length (km)	30	37	34
Year improved	1993	1993	1999
Passengers carried (million)	0.5	2.6	4.42
Passengers carried per route km (million)	0.02	0.07	0.13
Other performance indicators/ notes	Traffic increase of 123%	Passenger numbers are 10 times what they were in 1992	Year / Service gap (min) / Passengers per day (Mon–Fri) 1998 / varied / 512 1999 / 60 / 5200 2002 / 20 / 17000

Table 24 Multiple Units patronage

Country	Germany	Germany/France
City	Karlsruhe	Saarbrücken
City Population (million)	0.271	0.196
Region Population (million)	0.581	1
Name of system	Karlsruhe Verkehrsbetriebe (Karlsruhe-Bretten line)	Saarbahn
Route length (km)	25	26
Year Opened	1992	1997–2001
Passengers carried (million)	3.64	12.3
Passengers carried per route km (million)	0.15	0.47
Other performance indicators/ notes	Daily passengers Before conversion 2500 1992 7500 1996 12200 2004 17000	Modal shift is 22% for public transport in the city. In the region, public transport has risen from 6–13% while car usage has dropped from 69–65%. Daily passengers Original estimate 19000 Actual 1997 25000 1999 29000 2003 40000

N.B. It should be noted that the reason that the Saarbrücken figures are higher than the Karlsruhe ones is because the latter includes the new urban city centre tramway, whereas the latter figures are for the suburban TramTrain route only.

Table 25 Guided bus patronage

Country	UK	France	Netherlands
City	Leeds	Caen	Eindhoven
City Population (million)	0.7	0.117	0.205
Region Population (million)	2	0.202	
Name of system	Superbus, Scott Hall Road	TVR	Phileas
Route length (km)	6km of which 1.75km is guided (one way)	15.7	15
Year Opened	1995–8	2002	2003
Passengers carried (million)		23 (including bus network)	3.5 predicted
Passengers carried per route km (million)		0.085 (whole network)	0.23
Other performance indicators/ notes	25% increase in bus route passengers, of which 6% might be due to technology	TVR Guided trolleybus system	-

Table 26 Quality Bus patronage

Country	Sweden	Ireland	Canada
City	Jönköping	Dublin	Ottawa
City Population (million)	0.118	1.028	0.35
Region Population (million)	0.26	1.113	0.724
Name of system	CityBus	Quality Bus Corridors	Transitway
Route length (km)		30	56 (exclusive busway plus bus lanes)
Year Opened	1996	1996–9	1973–1996
Passengers carried (million)	11.5 (total bus network)		60
Passengers carried per route km (million)			1.08
Other performance indicators/ notes	5% passenger growth on routes in first year, 100% in 2 years. Public Transport share in city increased from 19–22% in this period. 66% of new users had used car previously.	30% passenger increase, rising. 60% of new users had used cars previously. 16% total car to bus modal shift. Up to 10,000 cars less on the roads per day.	About 75% of all public transit use in Ottawa is via the Transitway. Total "track" length of bus routes is 2633km. Total public transport use declined by 15.7% 1986–1997 but since then has increased by 24% (i.e. higher than 1986)

Table 27 Patronage of new UK Light Rail systems

System	Expected annual patronage	Patronage in first full year	First full year	Patronage 2002–3	Average growth per year
Sheffield	22	6.6	1995–6	12	12%
Midland Metro	8	4.8	1999–2000	5	1.3%
Croydon	25	15	2000–1	19	13%
Manchester 1	12	11	1993–4	19 (both)	5% (max)
Manchester 2	6	3	2001–2		

Figures are in millions of passenger journeys.

numbers. The distance each passenger travels is also important since some systems will have fare zones or distance based fares. Passenger kilometre figures are also a useful measure, especially if one is comparing converting a railway to Light Rail, where one might expect typical journeys to be much shorter.

A good example of how this has worked is in Croydon, where although the system has been reasonably successful in attracting passengers the revenue has been below expectations. This is because the take-up of the London Transport Travelcard, which is valid on the trams, was greater than expected. Croydon is now seeking to correct this by revising the fare structure.

Quality systems can justify high fares but the important thing is to ensure that the public can actually appreciate and experience this added value. One reason for the poor performance of the Sheffield Supertram in early days was that the higher fares were based on faster journey times, overlooking the fact that the higher frequency of bus services meant that it was quicker to use buses on a "turn up and go basis". This was compounded by the fact that bus and tram stops were separated and people soon realised that they were better off waiting at a bus stop, so trams got no customers even if they did turn up first. The subsequent increase in passenger numbers in Sheffield was associated with a substantial cut in fares, among other factors.

Other issues affecting patronage and revenue
Technology choice is only one of many factors that contribute to patronage and revenue, some examples of this being:

- The significant growth in Freiburg was associated with pedestrianisation, traffic management, provision of cycling facilities and the introduction of simpler more attractive public transport fare offers, as well as extensions to the existing tramway.
- Only 6% of the 25% growth in traffic on the Leeds Superbus route is thought to have been due to the change in technology. Other factors were new buses, better service and promotion.
- The significant increases in passenger numbers on the Karlsruhe-Bretten route and the various improved rail services were in the context of including these services into Verkehrs Verbund coordinated public transport systems with through ticketing etc.

Dramatic "before and after" figures associated with improved rail services need to be tempered by the very poor performance of these routes before improvement. These routes are still carrying fewer passengers than successful urban Light Rail systems.

Light Metro and Light Rail are generally carrying a much higher number of passengers, than the bus based and improved rail options.

A very exhaustive study by Carmen Hass-Klau and others[7] has concluded that it is not the mode that matters but the political commitment to an overall strategy of reducing car use in urban areas. It concluded that any mode can secure expanding demand if a high density and high quality service is provided and if complementary measures are vigorously implemented.

The same report found that transfer figures from car to public transport rarely exceed 20% for Light Rail, with all bus-based options being much lower (Dublin was an interesting exception at 16%.) Such transfers are short term and difficult to measure in a consistent way. A key issue, the report pointed out, was the existing level of public transport use. World cities like London and Paris, with high existing use of public transport will not see as high modal shifts when new schemes are implemented as a small city that previously had only a modest bus service.

6.1.2 Modal Shift

Modal shift is the transfer of patronage from one mode to another when a new system opens, as distinct from really new "generated" traffic. This usually falls into two main categories of interest, i.e. modal shift from car, which should have a positive benefit and modal shift from other forms of public transport, which in some cases may cause problems. If an existing public transport service loses traffic then it may well become more costly to provide for the residual users. In addition modal shift will not give any significant advantages especially if the buses etc. that lose traffic continue to operate.

Modal shift from car is usually an objective for quality public transport systems. It is a factor that will justify investment because it leads directly to reductions in congestion, energy usage, pollution and accidents and improves quality of life. In general relatively high modal shifts are expected for more expensive rail based systems e.g. 10–20% to justify their cost, whereas less ambitious figures are expected for bus-based systems (e.g. 2–3% anticipated for the proposed Cambridge-St.Ives Guided Busway in the UK.)

One also needs to distinguish between short term and long term effects. Modal shift tends to be a "one-off" event, so for example if car traffic had been growing it may continue to grow at the same rate but from a reduced initial point.

It is accepted that rail based systems tend to be more effective than bus based systems in terms of achieving modal shift from private cars[7]. The same qualities that attract the car user will also have two other important effects:

- They will abstract traffic from existing bus services
- They will generate new traffic.

These issues may or may not be seen as a problem, depending on the objectives of the transport authority.

Another related factor is that where the quality of one public transport corridor is significantly improved in a city, the usual experience is that public transport in the city generally experiences an increase in ridership and modal shift from car, without any quality change on other routes.

6.1.3 Other important criteria

Apart from passenger numbers and modal shift, the following factors are usually assessed as part of a cost benefit analysis for assessing the effectiveness of different public transport options:

- Accessibility
- Environmental impact
- Safety
- Integration
- Economic development stimulus

As a measure of how effective these other criteria might be it is worth considering the position statement of the UITP European Committee published 25/9/2003, which considered safety issues:

"The Road Safety Action Programme should include *modal shift to public transport* as a key strategy. It is to be noted that the estimated direct and indirect cost of road accidents is €160 billion. This is more than three times the total turnover of the road passenger transport industry in 1999 (€53 billion.) Thus a modest saving in accident costs would, if properly applied, provide funding for significant public transport improvements."

There may be others, depending on local situations and transport policy, but the above list tends to cover the principal areas of interest.

This is a very complex area and the issues involved cannot be adequately dealt with in a report of this scale. The rest of this section of the report is a simple exercise intended just to give an indication of the effectiveness of the different modes and how one might start to assess them in terms of these other criteria. In reality it is impossible to generalise in this way, so what follows needs to be considered purely as an "illustration"; it is not definitive.

Our method was to rank the technical options (Rank 1 is best) according to the five criteria listed above in very general terms. Unlike passenger numbers and modal shift, it is less easy to quantify these criteria, but we have noted below where this has been done. In general, however, decisions will be made on a ranking basis, possibly associated with a weighting derived from how important these criteria are in a given locality. The ranking and the importance of the ranking will therefore vary from place to place and we can only discuss general trends here. For convenience we have summarised the results of this exercise.

Accessibility

Rank 1: Light Rail, tram and continuous guided bus.

Modern systems achieve level access with virtual gapless boarding, direct from the street. Systems can generally penetrate areas that are not as accessible nowadays by private car (e.g. tramways through pedestrian streets.)

Rank 2: Light Metro/Tram Train

Level access also possible but stops will not be as accessible.

Rank 3=: Multiple units

Reasonably good access to vehicles but stops may not be ideally situated.

Rank 3=: Bus systems including non-continuous guided bus.

Stops will be well located, networks tend to be denser, but level access cannot be guaranteed.

The distinction between the last two is difficult in general terms, so we have ranked them equal for this exercise.

High quality access, in the sense of ease of access in and out of vehicles and movement within vehicles, will generally only be provided on new systems. Older systems are typified by high steps, wide gaps at platforms and other features that create a barrier for passengers with restricted mobility and cause problems for everyone.

Environmental impact

This subdivides into specific issues, e.g. noise, air pollution, and visual intrusion. In Germany values have been assigned to vehicle emissions that allow this aspect to be quantified.

Strand 3 has looked at urban design issues, many of which are environmental issues, and has produced a list of topics under which this can be considered. We have used this checklist as a basis for considering what impact each of the selected Strand 4 technologies will have on urban design.

Rank 1: Light Rail, TramTrain, tram and guided bus (all electrically powered)

Noise problems tend to be local and can be mitigated. Pollution is low; engines are not running when the vehicle is stationary. Overhead wires create visual intrusion but careful design, or the future use of ground level electrification (as in Bordeaux) can reduce this.

Rank 2: Light Metro and multiple units (all electrically powered)

Likely to be more intrusive in terms of noise and visual intrusion, although this is offset by the fact that systems will not be in the street. Electrification may be from conductor rails that are less visually intrusive.

Rank 3: All non-electric systems, off street.

Emissions and noise become more significant.

Rank 4: All non-electric systems on street.

Emissions and noise are closer to people.

Hybrid solutions have value in mitigating effects in specific local circumstances. It should be noted also that emission standards for buses, in terms of noise and gases, have been improving significantly.

Safety

As with risk assessment, it is possible to quantify by multiplying the number of instances of accidents by the costs to society of dealing with them.

Rank 1: Light Metro and multiple units

Very high "railway" safety standards apply throughout.

Rank 2: TramTrain and Light Rail.

Street running increases the number of accidents.

Rank 3: Tram and guided bus.

The higher accident rate associated with a higher proportion of street running than for other rail systems.

Rank 4: Bus.

Experience shows that rail based urban transport is at least twice as safe as bus systems[15]. On the other hand another reference from the UK suggests that rail and bus fatalities have been on a par in recent years in that country[14]. We have based our analysis on the former.

Integration

Integration can be "measured" in various ways and unlike the other criteria is often "manageable" by design and the application of information systems and ticketing regimes rather than by choice of technology. The following ranking assumes that any system can be integrated in ticketing and "identity" terms but this might not be the case in specific applications. The criteria we have used are based on typical practice for interchange arrangements and that the new system is the one that adapts to provide them.

Rank 1: Light Rail, tram, guided bus

Easy level interchange is possible, both with other routes and with other public transport. Tram and bus stops can be shared. Stops will be easily identified and the same platform or cross platform interchange is typical.

Rank 2: Bus

Although the same quality of interchange is possible, facilities tend to be less obvious and a change of vehicle often involves a walk between stops.

Rank 3: Light Metro

Interchange between routes will be well designed but may involve a change of level and more walking. It may not be possible to integrate stops well with existing public transport foci.

Rank 4: Tram Train

This lies between Light Rail and multiple units, as a "mixed" system. In practice TramTrain projects in Germany have achieved high levels of integration, but this is a management process rather than an inherent feature of the technology.

Rank 5: Multiple Units.

There is likely to be little if any scope for integration because the existing rail route is being used. Interchange will often involve a change of level, if only to cross the railway to reach a bus stop. The restrictions imposed by railway timetables will also tend to create problems for passengers due to missed connections.

Economic development stimulus

The importance of these criteria will vary widely. It can be quantified, although not fully, figures used include:

- Number of new jobs created in an area.
- Square metres of land developed.
- Change in land values.

Strand 1 has considered the application of land use planning as a means of increasing public transport patronage. In this case we are considering the issue the other way around, "What impacts on land use do specific types of public transport have?".

The impacts have long been recognised. Classic examples repeated all over the world that are relevant to HiTrans being:

- Market towns and villages around cities growing as dormitory suburbs when suburban railway services and later suburban railways were introduced.
- Expansion of urbanisation beyond historic city centres, usually associated with alleviation of

overcrowding in inner areas, as tramways developed and allowed longer urban journeys.

- The growth of vast metropolitan areas of linked communities made possible by electric railway and tramway systems.
- Expansion beyond the urban area with low density housing as motor buses and trolley buses were perfected.
- "Ribbon development" along inter-urban bus routes.
- Long distance commuting as rail service improvements are made.
- Re-development and rejuvenation of areas with poor access made possible by new public transport systems.

From this it is clear that people "balance" the possibilities that come into being when improved public transport is introduced. They balance the "cost" versus the "benefits". "Costs" will include actual fares, journey time, remoteness from their homes, places of work etc.; benefits will include a better quality of life with more room, healthy conditions and more recreational facilities. Land use changes partly because this creates a demand and partly because property speculators recognise and develop the housing and other facilities required. In a few cases the transport companies who promoted such schemes also undertook the development.

It is also clear from the above that different transport technologies also create different types of development and this in turn arises from the specific characteristics of each one.

Development can be categorised in different ways, but perhaps a key parameter is density. Dense development tends to be linked to higher income as in city centres and business districts and to higher rents and income from services in residential districts.

In order to serve dense development a public transport system must have a relatively high capacity, so one can expect higher capacity systems to be more likely to generate higher density and higher value development. Table 28 summarises the likely impact on land use of the various technologies being considered in Strand 4. Note that in this table "severance" refers to the creation of difficulty for people wishing to cross the route (usually pedestrians), with a damaging effect on community life.

To support these views the following evidence of previous studies is worth quoting in full[95]:

"Does investment in transport have a significant impact on urban development? And if so by how much? Previous research finds it generally difficult to judge regeneration impact, but broadly suggests:

- **Heavy Rail:** regional impacts in terms of the potential (re) distribution of development. Can work in favour of urban cores rather than exurban areas where combined with other strategies, e.g. TGV in Lyon and Lille (Bannister,2000)
- **Light Rail Transit:** investment appears to have an impact on local urban development (Hack, 2002 and Ryan, 1999.) However, most research studies experience difficulties in quantifying how much development is directly caused by the transport project in question, relative to other planning policies or general economic market conditions.

Why is there more impact reported for some schemes than others, e.g. development around some Light Rail stations, and in some cities, than others?

- Urban Light Rail tends to relate directly to development that can take direct advantage of it, and a number of supporting measures need to be in place, such as the availability of attractive development sites, supportive planning policies and strong local economies (Hall and Hass-Klau, 1985.)"

We have identified what we would expect to see happen for each of the reported technologies in terms of change in land use, we have also collected some information from systems worldwide to see if this does actually happen. See table 29.

Phase 2 of Manchester Metrolink provides a good example of how the benefits of public transport improvements cannot be separated from other factors. The Lowry Centre is only indirectly served by Light Rail yet extensive development has taken place there despite the fact that a short branch line to it was authorised but has not been built. Clearly other

Table 28 Impact on land use

Technology	Vehicles	Infrastructure	Regulation	Accessibility	Impact on land use
Light Metro	High capacity trains	Wider station spacing, park and ride sites	Limited scope for new lines, difficult in urban areas without high cost	Easy access, attractive, might cause severance (1)	Dense development around new stations in previously undeveloped areas. Low density residential development accessed from park and ride.
Light Rail/ Tramway	Intermediate capacity	Varying stop distances, park and ride	Restricted application but tramway sections facilitate serving urban centres.	Very easy access, very attractive, few severance problems (1)	
Guided busway	Low capacity	Varying stop distances, flexibility to serve wide area. Some technologies unsuitable for town centres.	Difficult to get effective priority off main route	No more attractive than buses at the outer ends. Causes severance if kerb guided.	Could stimulate low density development. Might encourage certain types of commercial development.
Busway	Low capacity, unattractive?	Varying stop distances. Very flexible. Park and ride option.		Generally poor	
Heavy Rail	High capacity	Too inflexible to serve many locations, basic network only. Park and ride can be included.	Very difficult to create new lines, some scope for improved service on existing. Funding may be available as part of a wider area "package".	Quality can be improved but access to stations is an issue. Not as convenient as other urban transport.	Dense development around stations but only if other stations serve market well. Strong commuting value creating distant local centres.
TramTrain	High capacity	Mix of LRT and Local train characteristics, according to route	Relatively difficult to implement at present in some countries because it is a new type of application that does not match existing regulations.	Very easy access, very attractive, few severance (1) problems on tramway sections	Dense development around stations in previously undeveloped areas. Low density residential development accessed from park and ride. Strong commuting value creating distant local centres.

Table 29 Examples of land use impacts

Country	City / System	Type	Required land use changes
UK	Croydon	LRT	Increased retail turnover through increased catchment area. Within Central Croydon property values increased by 4% compared with adjacent areas not served by LRT. Industry boost by enabling employees to access workplaces more easily. No clear views on property values generally . Provided qualitative benefits to residents of New Addington, a remote London suburb previously only accessed by buses via poor quality roads. By the end of 2003 the inward investment in the area was estimated at £1.5 billion.
Germany	Hannover	Light Metro	High degree of co-ordinated land use and transportation planning at a regional level.
Germany	Karlsruhe	LRT and TramTrain	Any relationship between land use and rail services on a regional level occurs more as a result of planning than of market forces. Substantial rise in property prices around stations on the initial TramTrain route Karlsruhe-Bretten.
UK	Sheffield	LRT	Development along Line 1, which was a deprivation area has happened but was slower than expected. The out of town Meadowhall shopping centre at the outer terminus pre-existed LRT but has seen it as vital to ongoing commercial success and has made financial contributions. The decline of the city centre, partly caused by Meadowhall, seems to have been arrested. 1600 jobs created.
France	Lyon	LRT	The value of social benefits, regeneration etc, were seen as more valuable than transport benefits.
UK	London Docklands	Light Metro	Made high density development of small land areas separated by water possible. Highly successful in this respect. One of the busiest and most prosperous office areas in the world.
UK	Manchester	LRT	Regeneration of Eccles. High quality development at Salford Quays including leisure and shopping facilities. Evidence of the "unlocking" of otherwise unattractive redevelopment areas. See note below.
France	Nantes	LRT	25% of new office development since 1985 has taken place within LRT served corridors. No observable property price aspects.
France	Grenoble	LRT	Large number of service based businesses have developed in tram served corridors. Property prices and residential development increased as construction begins but diminish after 3/4 years. Rental prices have not increased significantly.
France	Strasbourg	LRT	Retail growth in city centre with lease prices increase. This was also perhaps due to simultaneous pedestrianisation. House prices are 7% higher in areas well served by public transport. Little impact on office and commercial land use otherwise.
Australia	Adelaide	Guided Bus	Poor performance and possible mis-reporting of positive results. No studies but minor positive impact on city centre and development of the Modbury Suburban Centre seems to be a result.
UK	Leeds	Guided Bus	No studies but minor positive impact on city centre seems to be a result.
UK	Oxford	Quality Bus	Growth in urban commercial and retail activities linked to improved public transport provision with traffic restraint.

Table 30 UK NAO views on the regeneration and social exclution values of Light Rail

System	First year of operation		2003
Manchester Phase 1	1993	Poor*	Poor*
Sheffield	1996	Poor	Moderate
Midland Metro	2000	Poor	Moderate
Croydon	2001	Moderate	Good
Manchester Phase 2	2001	Moderate	Moderate

*The report pointed out that regeneration was not a scheme objective.

factors have provided this stimulus.

The National Audit Office in the UK summarised their views on the value of Light Rail in terms of regeneration and social exclusion, i.e. "The impact of Light Rail on regeneration and social exclusion has not been fully evaluated". See table 30.

Experience in North America has been more positive. A review[10] stated that the uplift in land values there has been reported as typically being between 5 and 10% for residential and 10 and 30% for commercial.

In general rail based systems are considered to be much more effective, and the generally accepted theory is that this is due to their "permanence" and the fact that they demonstrate a commitment in investment terms. People can locate businesses, homes and associated facilities with confidence once a fixed route system is installed. The more expensive and visible the system, the more likely this is to happen. Improving local railways will tend to have less effect because areas around stations are more likely to be developed already and the relatively low investment might not be seen as "permanent". These considerations have given the ranking we have proposed.

Table 31 Overall assessment of relative effectiveness

Effect	Improved rail	Light Metro	LRV	Tram	Tram Train	Guided bus	Bus
Attracting patronage (1)	2	1	1	2	1	2	3
Modal shift from car	2	1	1	1	1	3	4
Accessibility (2)	3	2	1	1	2	1/3	3
Environmental impact (3)	2E,3N	2E,3N	1E,3/4N	1E,3/4N	1E,3/4N	1E,3/4N	4
Safety	1	1	2	3	2	3	4
Integration	5	3	1	1	4	1	2
Economic development	4	1	1	1	2	3	5

Notes:
1. Based on overall results of known systems.
2. Guided bus ranking depends on whether continuous or not.
3. E = Electrified, N = Non-electrified. Non-electrified options are further sub-divided according to whether street running or not (street running/non-street running.)

Overall summary

From the conclusions of this section it is possible to give a very simple overall assessment of overall effectiveness of the different modes as discussed in this report, using the same ranking process where 1 is best and 4 is worst, table 31.

The table gives a very rough guide to the relative value of each mode.

Light Metro systems show a high score but will not achieve the accessibility or low environmental impact of Light Rail or tramways. They are also difficult to integrate, due to lack of flexibility in route choice and the distance of platforms from public roads.

Light Rail systems come out best, provided they are electrified. They are less safe than reserved track rail systems but the level of safety achieved is usually perfectly acceptable.

Trams will be almost as effective as Light Rail but slightly less attractive due to lower performance standards and potentially less safe due to more street running. But in many cases they will be found as acceptable, both to safety authorities and the public.

TramTrain scores well but is restricted since by definition it is using existing infrastructure, so is less attractive in terms of integration and potential for stimulating new economic development than a Light Rail or tram system with a free choice of alignment.

The use of new rolling stock on existing railways will only be of marginal benefit in comparison with new built rail systems but could be expected to attract more modal shift than bus based systems. This option scores lowest of all in terms of integration because existing stations may not be very user friendly and not easily accessed from the road network.

Guided bus systems are considered to be less successful in attracting patronage or achieving modal shift than rail based systems. They can achieve equivalent levels of accessibility, low environmental impact and integration however. They will be seen as less safe and less likely to attract economic development.

Conventional bus networks score badly but can achieve reasonable integration; they clearly have value as feeders in less important corridors.

It must be stressed yet again that this general assessment will not always apply. Local circumstances and the objectives of the promoter will alter the ranking for specific applications. An important overriding factor is affordability; will the higher quality systems be justified by the revenue or potential traffic?

6.2 Costs

This section of the report provides a basic method for costing new schemes . The following definitions are being used:

Capital costs
All costs incurred prior to the operation of a new service associated with implementing that service.

Often these costs will be incurred by the scheme promoters and where not may still be treated as an investment. For example, costs incurred by a railway infrastructure owner to permit a new design of multiple unit to operate a new service on their system, might not be paid as a capital expense but will be recovered through track charges. A few costs, for example civic improvements associated with the scheme, would not usually be treated as a cost to the project, depending on local circumstances. Decisions on whether or not to build a system will however depend on such wider issues.

Operating costs
All costs incurred in operating a public service from the date that the service commences.

We provide operating costs on an annual basis (per year.)

These costs will be incurred by the operator, and will be set against revenue. They may also be incurred in part by other parties to the scheme, for example vehicle suppliers may meet maintenance costs for a period, local authorities may maintain infrastructure, for example busways. It is quite common to lease vehicles, but for simplicity we have assumed that such costs are capital and that there are no lease charges. Maintenance of infrastructure may also be contracted out but we have included these costs in operating costs throughout.

Operating costs can often be underestimated. Comparisons can easily be made on relative capital costs, overlooking the whole life cost of a course of action. Some government funding processes recognise this by making money available to fill the shortfall per year rather than through an up-front capital grant.

When the preferred technology option has been chosen it is most important to assess the operating (as well as the capital) costs as accurately as possible. Staffing levels and salaries need careful consideration because of the sensitivity of operating costs to assumptions made here. This will help to establish and maintain the credibility of the new system.

Whole life costs
Capital costs and the sum of all operating costs per year for the lifetime that a service operates, which is usually defined by a concession period. It is typically calculated assuming a period of 30 years for rail-based systems but when different modes are being considered the same period should be used. If buses last 15 years then it would be normal to compare a 30 year rail based option on the basis that a bus fleet will be replaced once during the same period, and so on. The term may also be applied to specific assets such as vehicles, in which case it refers to the total life of that asset, which may be not be the same as a concession period.

Whole life costs should include residual value, disposal costs and the costs of any "make good" requirement in a concession agreement.

Net Present Value (NPV)
The sum of the current costs of all future expenditure during the project lifetime being considered, using a predetermined discount rate, which must be the same for all options.

This is a method of properly evaluating the whole life costs of alternative options where the dates of expenditure vary. The NPV method gives a fair comparison of the costs of alternatives such as tramways and bus systems, where asset lives and operating methods vary.

6.2.1 Assessment Criteria

Accessibility
Overall ease of access, including the ability of the system to reach specific locations where traffic demand exists; walking distances; ease of entering stations

and stops and reaching the platform; and ease of entering, exiting and using the vehicle. High quality standards should apply to enable the system to be used by the whole community.

Environmental impact
All aspects of the impact of the transport system on the local and wider community; including vehicle noise, vibration and pollution, infrastructure appearance, severance and effect on neighbours, power generation, electromagnetic interference, stray current effects etc. This will also consider the impact that a new system might have on historic buildings, sensitive sites, community and commercial activity in general and on other types of traffic.

Safety
Overall safety, not only for people travelling on the system but also staff and the public in general.

Integration
The ease with which the mode can be integrated with other forms of transport, including public and private transport, cycling and walking, in terms of interchange arrangements (linked to accessibility), through ticketing, compatibility, service quality, information systems, combined system management etc.

Economic development stimulus
The extent to which, by its nature, a mode of public transport will stimulate development (residential, commercial, leisure etc.) in the area that it serves.

6.2.2 Calculating costs

This section provides enough basic information for a promoter to make initial assessments of options for a given scheme as follows:

1. For a given route prepare a sketch plan of the alignment, levels and stop locations in sufficient detail to show the parameters that can be costed using the infrastructure cost table, for each mode being considered.
2. Prepare costings for each option using the same table.
3. Calculate the journey time and round trip time using the method proposed below.
4. Determine likely service intervals based on demand and vehicle capacities using the vehicle table.
5. Calculate the fleet size and cost of the vehicle fleet using the same table.
6. Calculate other costs, using the method below, to obtain overall system costs for the options.
7. Develop a notional timetable, which should be as consistent as possible for all modes, in order to calculate vehicle kilometres and hence operating costs.
8. Assume a project life and calculate Net Present Values (NPVs) based on the following elements:
   – Capital cost (one off expenditure) at start of project.
   – Fleet renewal, based on vehicle lives, see table.
   – Operating cost, assumed to be the same per year.
9. This gives a single NPV for comparing each option based on whole life costs.
10. Compare these NPVs against the criteria in the table, modify according to local circumstances and add any other known factors such as likely demand, in order to make the initial assessment of which option is likely to be best.
11. Options can be compared on the basis of costs per passenger carried, costs per car trip saved etc.
12. Finally, consideration should be given to the availability, feasibility, reliability and experience gained with each technology (see Chapter 5.)

Table 32 Infrastructure cost

	Light Rail / Tramway / TramTrain and some heavy rail where noted	Kerb Guided Bus (KGB) / Busway	Guided Bus (excluding KGB) / Quality bus	Unit
Street utility modifications				
Town centre	8.0	1.6	1.6	€million/km
Street	6.9	1.4	1.4	€million/km
Open country	1.7	0.4	0.4	€million/km
Double track				
Simple street	1.7	1.3	1.2	€million/km
Complex street	2.4	2.0	1.9	€million/km
Grassed track	1.6	-	-	€million/km
Grassed track and formation	2.3	-	-	€million/km
Ballasted track	1.2	-	-	€million/km
Ballasted track and formation	1.9	-	-	€million/km
Busway	-	2.0	1.9	€million/km
Railway upgrade (1)		-	-	€million/km
Tram Train operation (2)	1.0–5.0	-	-	€million/km
New railway junction (3)	10–40	-	-	€million
Power supply				
LV Overhead (double track) (4)	0.5	-	-	€million/km
HV Overhead (double track) (5)	0.7	-	-	€million/km
Low power substation (6)	0.6	-	-	€million
High power substation (6)	5–8	-	-	€million
Stops				
Platform (urban system)	60	15	15	€000 Per platform
Platform (railway system) (7)	150	-	-	
Shelter, lighting, fittings	25	10	10	
Footbridge with ramps (8)	300	300	300	€000
Ticket vending machine	20–50	20–50	20–50	€000 Per platform
CCTV/information system	15–20	15–20	15–20	
Traffic priority				
Minor priority (or upgrading)	90	90	90	€000
Major priority	190	190	190	€000
Traffic management	175	175	100	€000 /km
Control Room complete	650	500	500	€000
Depot (new) (9)				
20–50 vehicle system	350–380	150–200	150–200	€000 /vehicle
50–100 vehicle system	320–350	130–180	130–180	

Notes:

1. Applicable to converting a railway to Light Rail or Light Metro, but excludes heavy engineering such as replacement of bridges by crossings.
2. Costs associated with safety measures, changes to signalling, minor infrastructure works, adaptation of existing stations to accept TramTrains. This applies to the former railway sections. We have not included the option of converting an existing tramway for TramTrain operation because the issues are complex and diverse.
3. Applicable to connecting an existing railway to a Light Metro or Light Rail for TramTrain operation, also to a junction in a Light Metro system.
4. Only appropriate for electrified systems, 600-1500Vdc.
5. 15-25kVac on railway lines, where appropriate.
6. Cost include feeders and cables, the method of calculating the number and type of substations is as follows:
   – For all "street based" options assume 1 MW substations, except where there are vehicles operating at intervals of 2minutes apart or less, in which case assume 2MW.
   – For all reserved track and railway options assume 2MW substations.
   – Assume that 1MW substations are spaced 2km apart.
   – Assume that 2MW substations are spaced 4km apart.
   It may be possible to adapt existing substations, for example in a TramTrain scheme. In this case costs will be €2-3 million.
7. A new platform to railway standards, applicable to Light Metro and TramTrain or multiple unit operations on an existing railway (Source: Interfleet)
8. To span two tracks at a stop on a Light Metro or railway (Source: Interfleet)
9. For multiple unit operation an existing railway depot may be used.

Using the above details it is possible to build up an approximate first case for the typical applications that might arise in the medium sized cities and towns of the North Sea Region.

Capital costs of infrastructure
Table 32 includes the basic unit costs that UITP recommends[44] for "Quick indicative calculations" at the start of assessing alternative modes, i.e. they are appropriate for the objectives of this report. They are also consistent with the more detailed UITP cost models .

Table 33 Capital cost of vehicles

Vehicle	Total vehicle passenger capacity	€ million
Light Metro train	440	4.2
Light diesel train (1)	450	2.8
LRV/Tram (30m)	220	2.2
LRV/Tram (45m)	288	3.5
Diesel tram (30m) (1)	220	2.4
Tram Train, 750Vdc (30m) (2)	180	2.0
Tram Train, dual voltage(37m) (dc/ac)	240	3.0
Diesel Tram Train (37m)	240	3.3
Guided Light Transit vehicle (TVR) (1)	143	1.8
Kerb Guided Bus (Diesel) articulated	120	0.5
Kerb Guided Trolleybus articulated	120	0.8
Diesel bus (non-articulated)	80	0.4

Note

1. Very few examples to base cost on. Estimated prices.
2. No actual examples, this is an estimated figure.

Capacities are based on both seating and standing at 4 standees per square metre.

Capital cost of vehicles

Table 33 could be extended but for initial assessment purposes, where the objective is to compare the overall costs of specific modes, the number of options needs to be restricted. Otherwise total system cost figures will be confusing.

The number of vehicles required for a given service is determined from the round trip journey time divided by the peak service interval, plus an allowance for vehicles being out of service for maintenance etc. For the first cut estimate one can use the commercial speeds, which include time spent at stops, shown in the table in 8.3.3. This table shows the time spent at stops as minimal but for some applications dwell time should be extended by adding the product of extra dwell time per stop multipled by the number of stops to total journey time. One fact that might determine this is that the plug doors used on LRVs can take 5 seconds to open and 7 seconds to close. A minimum turnaround at termini of 3 minutes is appropriate for all modes but might be extended where there is a risk of unreliability for any reason and for very long routes (greater than 30km.)

Vehicle capital costs need to be considered in the context of vehicle lives, as will be discussed later.

Other capital costs

There are other costs that need to be added, the major ones being:

- Land (although in some cases these costs may be minimal)
- Site clearance
- Park and ride car parks
- Streetworks, signs, signalling
- Significant engineering costs for special features, such as a tunnel under a river. Usually it will be possible to get a "first cut" estimate of such works from civil engineers.
- The costs of obtaining legal and planning approvals and raising funds.
- Design costs.
- Project management and other management costs.
- Operation costs for testing, commissioning and training, prior to public opening.

With the exception of major engineering works, which should simply be added in, these costs can be covered by adding a percentage at the first stage. The percentage will vary between countries because of the different authorisation and procurement methods. The method we propose is that one should find a recent scheme in the same country, or in a country where conditions are similar, and cost this using the same unit costs to obtain the factor "A". Then

Table 34 Operating costs

Vehicle type	Conditions	€Min	€Max	Source
Light Metro train	Large system size (>40 vehicles)	9.0		Nexus
Diesel train	Operated by a regional railway company	10	14	See note
LRV/ Tram/ TramTrain	Small system size (20 vehicles)	6.8	8.7	UITP
	Large system size (>40 vehicles)	5.5	6.6	UITP
	Large size system, two vehicle trains	4.4	5.2	UITP
Guided trolleybus		4.5	5.4	UITP
18m diesel bus		4.0	4.4	UITP
12m diesel bus		2.9	3.7	UITP

Note:
Diesel train costs are based on the figures published by UK Train Operating Companies that predominantly operate trains of this type.
Vehicle kilometres can be calculated from the route length and proposed timetable, with an allowance made for empty running to and from the depot. It is important to match vehicles to demand. Two mistakes can easily be made at this stage:

1. Assuming the same number of vehicles for different modes, calculations need to be based on actual capacity required and a reasonable service level.
2. Not providing enough capacity for the demand required to make the system viable.

A = Actual cost of scheme/Calculated cost of scheme
A can then be applied to a calculation of the cost of the promoter's own proposal:
Estimated cost of proposal = A x Calculated cost of proposal

We believe that it is valid to apply the same factor to alternative technologies since very broadly these extra costs will be proportional to the infrastructure costs (i.e. not the costs of infrastructure AND vehicles.)

Estimates of operating costs
Although it is possible to calculate operating costs for preliminary cost comparisons in considerable detail we advise against this because the results are very sensitive to assumptions made. There are always cheaper ways of operating once one has selected a specific solution, and there is a tendency to underestimate the unexpected.

Instead we advocate the use of "first cut" figures based on actual operating experience. See table 34.

Table 35 Speed matrix

Average speed for given values of average stopping distance and maximal permisable speed

km/h max	30					50						
Length m	**200**	**300**	**400**	**500**	**600**	**200**	**300**	**400**	**500**	**600**	**700**	**800**
Ideal BUS-free flow 0 dwell time	21.1	23.4	24.8	25.7	26.3	23.0	28.1	31.5	34.1	36.0	37.5	38.7
Ideal BUS (full priority +30sec dwell time)	11.2	14.2	16.3	18.0	19.3	11.8	15.8	19.0	21.7	24.0	26.0	27.6
Ideal BUS (full priority +20sec dwell time)	13.3	16.3	18.4	20.0	21.2	14.1	18.5	21.9	24.7	27.0	28.9	30.5
BUS (20 sec dwell + traffic delay 30s/km)	11.2	14.4	16.0	17.1	18.0	12.6	16.0	18.5	20.5	22.0	23.3	24.3
BUS (20 sec dwell + traffic delay 60s/km)	10.9	12.8	14.1	15.0	15.6	11.4	14.1	16.1	17.5	18.7	19.5	20.2
BUS (30 sec dwell + traffic delay 60s/km)	9.5	11.5	12.8	13.8	14.6	9.8	12.5	14.5	16.0	17.1	18.1	18.9
BUS (30 sec dwell + traffic delay 120s/km)	8.2	9.6	10.6	11.2	11.7	8.4	10.3	11.6	12.6	13.3	13.9	14.4
BUS (30 sec dwell + traffic delay 180s/km)	7.2	8.3	9.0	9.5	9.8	7.4	8.8	9.8	10.4	10.9	11.3	11.6
Trolleybus (full prior. + 20s. dwell time)	13.6	16.7	18.8	20.3	21.4	14.7	19.2	22.7	25.5	27.7	29.6	31.2
Trolleybus (20s dwell + delay 60 s/km)	11.1	13.0	14.3	15.2	15.8	11.8	14.5	16.5	17.9	19.0	19.8	20.5
LIGHT RAIL (full prior. 15s dwell time)	15.0	18.0	20.0	21.4	22.5	16.2	20.9	24.4	27.2	29.5	31.3	32.8
LIGHT RAIL (15s dwell + traff. delay 60s/km)	12.0	13.8	15.0	15.8	16.4	12.7	15.5	17.4	18.7	19.8	20.6	21.2
Heavy Rail (full priority - 20s dwell time)												

Journey time calculation
Table 35 shows the average speed in kilometres per hour (km/h) for various modes, based on the average distance between stops, maximum speed for the section concerned, minimum stop dwell times and level of priority. Delay is expressed as extra time per kilometre. This can be determined for routes where priority will not exist, simply by driving along the route and noting the delay at the busiest time of day.

Source: Light Rail Guidelines, Manual, Running Time Model, UITP, August 2003[44].

Example

A city has a 15km route that might be built either as a tramway or diesel kerb guided bus (KGB) system.

		80							
900	1000	*300	*400	*500	600	700	800	900	1000
39.7	40.5	28.3	32.7	35.6	40.0	43.1	45.7	48.0	50.0
29.0	30.3	15.8	19.4	22.7	25.7	28.5	31.0	33.2	35.3
31.9	33.1	18.6	22.5	26.0	29.2	32.1	34.7	37.0	39.1
25.2	25.9	16.1	18.9	21.4	23.5	25.3	26.9	28.3	29.5
20.8	21.3	14.2	16.4	18.1	19.6	20.9	22.0	22.9	23.7
19.6	20.1	12.5	14.7	16.5	18.0	19.3	20.4	21.4	22.2
14.8	15.1	10.4	11.8	12.9	13.9	14.6	15.2	15.8	16.2
11.8	12.1	8.8	9.9	10.6	11.3	11.8	12.2	12.5	12.8
32.6	33.8	19.4	23.6	27.3	30.7	33.6	36.3	38.6	40.7
21.1	21.6	14.7	16.9	18.8	20.3	21.6	22.6	23.5	24.3
34.1	35.3	21.2	25.4	29.2	32.6	35.7	38.3	40.7	42.8
21.8	22.2	15.6	17.8	19.6	21.1	22.4	23.4	24.2	25.0
		19.0	23.1	26.7	30.0	32.9	25.6	37.9	40.0

Key assumtions

1. Curve and gradient impact (to the speed reduction) are not included in speed matrix calculation.
2. Deceleration assumed the same for all modes and traffic conditions (same comfort level) with value of 1.0 m/s2.
3. Acceleration assumed as average for bus 0.7 m/s2, for trolleybus 0.9 m/s2, for light rail 0.85 m/s2 and heavy rail 0.8 m/s2
4. For 200 m. distance between stops are assumed maximum bus speed of 46 km/h and for light rail 49 km/h.
* - For 300 m, 400 m, 500 m maximum achievable speed (can't be 80 km/h) varying from 57 to 77 km/h.

Traffic delays "steps" (30, 60, 120, 180 seconds per km) are selected in accordance with research done by Atkins for A23 Corridor study.

3km of this would be in city streets, 6km on an old railway trackbed and 6 km on a new alignment. The KGB could not run in the city centre streets because of the severance the guidance would cause, so here it would be an unguided bus lane. Major priority measures would be installed including junction re-arrangement at 6 junctions.

Capital costs using the Infrastructure costs table 32 are shown in table 36.

Journey time using the Speed matrix table 35:
Stop spacing = 15/30 = 0.5km
Dwell time 15s (Tram) 20s (KGB) assumed
Maximum speed city: 50 km/h, elsewhere 80km/h

Table 36 Calculation of infrastructure costs

Item	Tramway cost €M	KGB cost €M
Street utility clearance town centre (KGB is a "bus route" in the city centre)	24.00	0
Street utility clearance open country	10.20	4.80
Simple street track	5.10	0
Ballasted track	7.20	0
Ballasted track and formation	11.4	0
Busway	0	24.00
LV Overhead	10.5	0
Low power substations	4.80	0
Stops (30 fully equipped stops)	8.25	6.15
Major priority	1.14	1.14
Traffic management (3km city section only)	0.52	0.52
Control room	0.65	0.5
Depot (based on fleet size below)	3.75	3.57
TOTAL	**87.51**	**40.68**

Average speeds: Tram, city centre (full priority) 27.2 km/h, elsewhere 29.2 km/h
KGB, city centre with 60s/km traffic delay 17.5 km/h, elsewhere 26 km/h.

Journey times:
Tram = ((3/27.2) x 60) + ((12/29.2) x 60) = 31.5 minutes
KGB = ((3/17.5) x 60) + ((12/26) x 60) = 38 minutes

With 3 minute turnarounds, round trip times are 69 and 82 minutes.

The peak demand is 1500 passengers per hour.
The promoter decides that a service of a tram every 8 minutes (capacity = (60/8) x 220 = 1650 or a bus every 4 minutes (capacity = (60/4) x 100 =1500) is appropriate.
This requires 69/8 = 9 trams or 82/4 = 21 buses. With spares the equivalent fleet sizes were assumed as 10 trams and 23 buses at a cost of €22million and €11.5million respectively.

Using the process suggested above the promoter decided to assume that the infrastructure costs should be doubled those calculated above to allow for all capital costs that are not covered. These may have been contingencies, unforeseen utility diversion, electric substation feeders and city centre works.

He worked out a timetable that gave 1.4 million vehicle km per year for trams and 2.8 million vehicle km per year for buses. Using table 34 this gave equivalent operating cost figures of €10.85million and €11.76million per year respectively.

The system was to be let on a concession for 25 years, during which time the bus fleet would need to be replaced once. NPVs were calculated for the two options. The capital costs were shown in year 1 as €175.02million for the tram option and €81.36million for the KGB option. In addition, €11.5million was added to the KGB option in year 13 for fleet replacement. These figures, combined with the operating costs at a fixed rate over 20 years gave NPVs as follows:

- €310million for the tram option.
- €233million for the KGB option.

These final figures were used as the basis for the assessment against net benefits.

Cost indices and Conversion factors

All costs in this report are taken from the UITP Light Rail Planning Guidelines, except where otherwise noted. They have been converted into 2003/2004 values using the following indices.

Original year	Factor to 2003/4
1998/1999	1.13
1999/2000	1.10
2000/2001	1.077
2001/2002	1.05
2002/2003	1.025

All monetary values are given in EURO (€.) Figures originally in other currencies have been converted using the following conversion factors:

Currency	Rate
£ Stirling	0.67
$US	1.26
FFR	6.56
DM	1.96
AUD	1.62

Table 37 **Actual system costs as built**

Year	System	Country	Cost	Units	km	Cost/km € million
1981	San Diego Blue Line	USA	788.52	$US M	40.5	30
1984	Buffalo	USA	760.5	$US M	10.3	101
1986	Portland, Barnfield route	USA	398.64	$US M	24.1	21
1986	San Diego Orange Line	USA	506.69	$US M	34.8	19
1987	Sacramento, initial line	USA	226.71	$US M	29.4	10
1990	Strasbourg routes A and D	France	296	€M	12.6	32
1990	Los Angeles, Blue Line	USA	954.55	$US M	35.4	29
1992	Karlsruhe-Bretten TramTrain	Germany	80	DM M	30	2
1992	Manchester phase 1	UK	145	£M	30.9	9
1992	Baltimore Central Line	USA	424.54	$US M	36.4	12
1993	St.Louis Metrolink	USA	398.27	$US M	30.6	13
1994	Rouen	France	2631	FFR M	11.2	43
1995	Sheffield	UK	260	£M	29	16
1995	Los Angeles, Green Line	USA	980.29	$US M	32.2	28
1995	Leeds Superbus (KGB)	UK	8	£M	5	3
1995	Strasbourg routes B and C	France	248	€M	12.4	24
1996	Ottawa Transitway (busway)	Canada	330	$US M	32	9
1996	Kuala Lumpar	Malaysia	470	$US M	12	36
1996	Dallas, S&W Oak Cliff	USA	300.21	$US M	15.4	18
1997	Amsterdam ring line	Neths.	237	$US M	20.5	10
1997	Saarbrücken (TramTrain)	Germany	420	DM M	44	6
1998	Izmir	Turkey	420	$US M	9	42
1999	Midland Metro	UK	145	£M	20.4	12
1999	Stockholm	Sweden	95.6	$US M	5.6	15
1999	Adana	Turkey	340	$US M	13.3	22
1999	Manila LRT (Light Metro)	Phil.	655	$US M	22.2	26
1999	Salt Lake City	USA	320.22	$US M	24.1	12
2000	Manchester phase 2	UK	150	£M	7.5	32
2000	Croydon	UK	200	£M	28	11
2000	Hudson-Bergen	USA	992.1	$US M	16.1	53
2000	Lyon	France	2300	FFR M	19.5	19
2000	Montpellier	France	2180	FFR M	15.2	24
2000	Nantes Line 3	France	571	FFR M	4.1	23
2000	Orleans	France	1873.5	FFR M	18	17
2001	Brisbane South East Busway	Australia	350	$AU M	16.5	14
2002	Bursa	Turkey	300	$US M	21.5	11
2002	Bordeaux	France	3290	FFR M	22.2	23
2002	Caen (Guided Light Transit)	France	235.5	€M	15.7	15
2003	Barcelona	Spain	218	€M	16.8	13
2003	Bristol bus route 76/77	UK	3.5	£M	16	0.3
2004	Nottingham	UK	220	£M	14	23

6.2.3 Comparison with actual system costs

Table 37 shows the published total costs of systems as built. This data will help with the process described above and also provides an appreciation of real costs. All systems are Light Rail unless otherwise noted. Some caution is needed because for various reasons not all costs may be included in each case.

The final cost per route km is given in € million in 2003/4 prices. It should be noted that published costs might be inconsistent in what they include.

The comparisons in diagram overleaf show how total costs may vary with type of system and geography.

6.2.4 The alternative "World Bank Method"

This method was developed by the bank and is explained in their technical paper No.52[105]. It is designed to compare various road and rail based options on a mutually comparable basis. The basis is the comparison of annualised capital and operating costs. Operating costs are typically assumed to be fixed, during the period being considered. Capital costs are annualised and take into account infrastructure, equipment and vehicle lives. They are based on use of a fixed interest rate.

6.2.5 Improving the process

If the first cut approach shows a wide variation between options this may be sufficient. But if the difference is small then a more detailed analysis may be justified. Four approaches are suggested:

1. Use of the more detailed Light Rail costing model[44].
2. Use of known data specific to the route or of data that will be required as part of a funding application (e.g. the German Standardisierte Bewertung or the UK Department for Transport processes.)
3. An initial feasibility study with a remit to investigate outline costs and benefits.
4. Use of other available cost models, preferably ones that are kept updated.

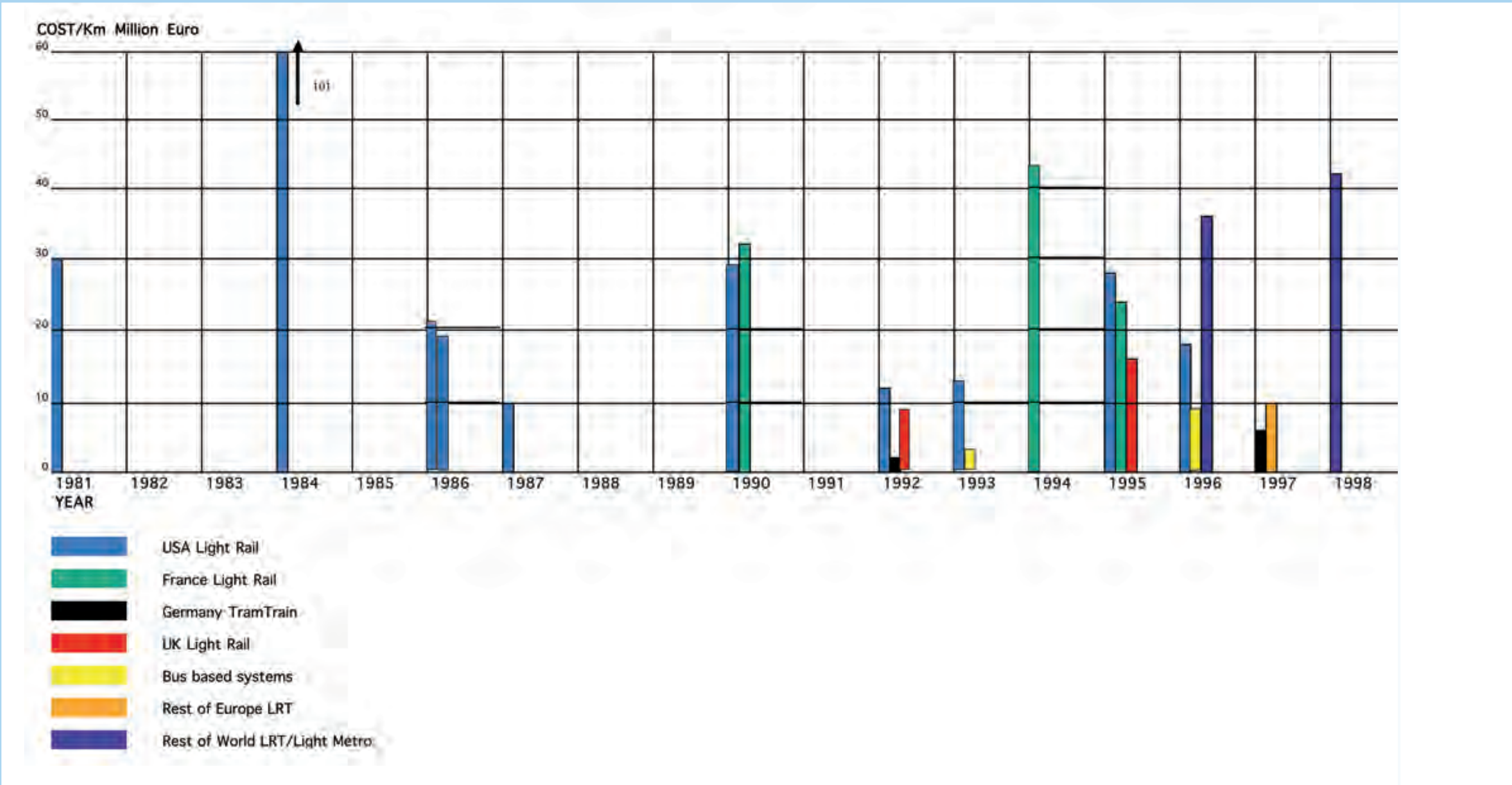
The German Standardisierte Bewertung provides data that can be used to develop the first cut assessment, for example:

- Definition of vehicle lives to be assumed.
- Cost savings from reducing accident numbers.
- Value of reducing pollution.

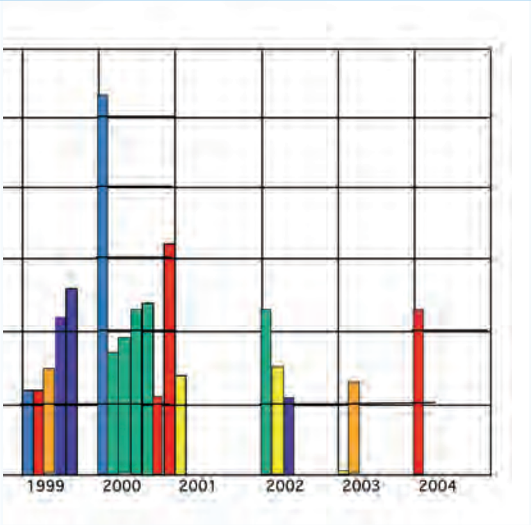
These values apply in Germany but could be adopted for "first cut" assessment in other North Sea countries.

In general, a decision on mode choice will have to be justified during the project life and therefore it is very important to have examined all possible options to an appropriate level of detail. The methods proposed in this paper may not match those required for this purpose by government agencies in certain countries; they are intended purely for "internal" decision making.

The effectiveness of planned public transport systems can also be evaluated by participating in a benchmarking process. There are initiatives underway at a European level and a good starting point is the "best transport" web site that will be available in future as a data source[122].



Capital costs per route km.


1999
2000
2001
2002
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2004

7 Guidelines

7.1 The challenge for smaller cities and regions

This final section of the report provides basic "strategic" guidelines to supplement the more detailed guidance given on best practice in the rest of the document.

For smaller cities compared with larger cities the following facts are important:

- Existing public transport may be poorer quality.
- There may be less control over policies that could be important for success.
- There may be less political interest in initiatives to achieve regional, national and Europe wide objectives.
- There may be less money available.
- The maximum potential demand may be low.
- There is more likely to be under-utilised infrastructure and space.
- There may well be an abundance of land for development.
- The impact of a new public transport system may have more "image" effect.

From this it is clear that the choice of technology will be influenced by different factors than in larger cities and that the "balancing" that is necessary between costs and benefits will be different as well. This means that very effective public transport systems (in terms of local objectives) might be implemented using relatively simpler technical solutions, for other reasons than just lower demand. Systems can also be more effective if they are an integral part of local planning.

7.2 Basis of the technology choice

Light Metro
Light Metro systems typically provide inner city or short distance suburban transport with closer station spacings than conventional suburban rail and some metros. Peak loadings are likely to be relatively heavy and the capacity will be between that of metro and Light Rail systems. It is unlikely that new Light Metros would be built in smaller cities but such communities may be served by extensions reaching out from larger neighbours.

Suburban and rural heavy rail with multiple units
The operation of existing or new railway services using multiple units is a possibility where a railway exists and can be improved in this way. It may be necessary to provide additional stops and an improved service. There is a fine balance between cost effective use of existing railway infrastructure and the high costs associated with expanded heavy rail service. Where simpler operating methods, direct local management and promotion of the services and integration with local transport networks can be achieved, it is possible to provide a very useful and attractive service.

Light Rail
New systems typically provide inner city or short distance suburban transport with closer station spacings than conventional suburban rail or metros (including light metros.) Peak loadings are likely to be relatively heavy and the capacity will be between that of light metro and bus based systems. The key feature is making use of street running to gain access to major traffic sources at an affordable cost.

Shared track
This will only be implemented where at least one type of system already exists, i.e. railway, metro, Light Rail, tramway. Shared track can be used so that a new system or route can make some use of this existing infrastructure, to improve an existing system by extending it using different infrastructure (usually TrainTram, i.e. the extension of a railway using a tramway) or simply linking two systems together. In each case the characteristics of the system will be a combination of the types of technology so merged. TramTrain, TrainTram and in future any TramMetros will generally have the key Light Rail/Tramway characteristic of providing direct access to major traffic sources. The usual objective of shared track is to provide high quality service at significantly less cost.

Guided bus
Guided bus systems have been seen as an alternative to Light Rail and could fulfil a similar role. However some of the applications to date have been modest enhancements of existing bus routes, or single routes; only now are extensive systems being developed. A key issue is the fact that guided buses are automatically "dual mode", i.e. they can operate both on and off the guideway. This can be seen as a significant advantage but recent thinking has tended the other way, and we are seeing new systems being developed to be 100% guided, which also allows use of longer unit formations. Guided busways can have Light Rail characteristics and be applied in similar situations. Overhead electrification is an option, using trolleybus or duobus technology. Four other key issues are:

- Doubts about the practicality of some new technologies and whether or not the public will see them as an acceptable alternative to Light Rail.
- The unsuitability of KGB for street operation in pedestrian areas.
- The reluctance to convert railways to guided bus because of the barrier this imposes on future potential rail development.
- The possibility of introducing a guided bus system as a first stage in building up traffic to justify a later Light Rail scheme.

Quality bus corridors
Quality bus corridors can include well-engineered private roadways with substantial stations. Such systems can be expensive and will take up significant road space within an urban environment. They are

Table 38 Performance against specific requirements

Requirement	LRT or Guided bus on own track	Guided bus partly on own track	Bus
Capacity	Best	Medium	Worst
Performance	Best	Medium	Medium
Environmental Impact	Best	Medium	Medium
Cost	Worst	Medium	Best

more suited to outer suburban areas with low density development.

The more typical European quality bus systems are normally limited to provision of better than average quality passenger waiting environment, with well-lit shelter and high quality information (possibly in real time), linked with priority and some segregation. The most common form of priority on a Bus Quality Corridor is a bus lane in the same direction as the general traffic flow.

Bus lanes do not necessarily need to run the full length of the quality corridor, but may be restricted to short sections as required to bypass any congestion. A short section of priority lane or bus gate (banned entry) may suffice to keep traffic out of a particular road, or to enable buses to bypass a queue on the approach to an intersection.

Quality bus corridors may not be as effective as, say, Light Rail but can provide significantly improved service for public transport users and an attractive alternative to private car use. As well as being intrinsically cheaper they can be implemented more easily, usually without legal powers, and be built up gradually as demand grows and funding becomes available.

UITP have recently proposed a simple matrix to help promoters determine which of some of the modes considered here are appropriate in different circumstances[182].

It is based on the principle that the selection of mode depends on key requirements. We have used the matrix as the basis for table 38.

7.3 Selected topic – priority strategy

High quality public transport services require priority over individual traffic. Only public transport systems with priority will be able to deliver journey times that are competitive.

Priority measures also affect other road users and a balanced approach is essential. It is possible not to cause significant disadvantages to other road users while benefiting the community as a whole through providing improved public transport. The intelligent application of modern technology will give public transport fast journey times without restricting general traffic more than is necessary.

Success depends on co-operation and joint work of transport, planning and traffic interests within a city or region.

Physical segregation is not easy to justify unless there are around 1000 public transport passengers in any one direction per hour. Below this figure, traffic signal priority is the only sensible option.

7.4 Selected topic – building busways for eventual conversion

It is possible to construct busways so as to facilitate their conversion to Light Rail or shared track routes later. The most likely scenario would be the conversion of a conventional unguided busway. The possibility of conversion might restrict alignment options and restrict curves and gradients. Long term conversion potential ("passive provision") needs to be planned and authorised at the same as for the original system. Space must be available for features not required on the initial system, such as larger stops, more parking space, signalling, substations and depots.

We propose that decisions on the extent to which a system should be engineered initially to facilitate conversion later should be based on breaking the design into cost elements and then considering the probabalised net present value of future investment. This implies that design and some other work on the future system is required in order to identify these requirements at the initial stage, once a decision to make it convertible is made.

There is very little experience to go on.

7.5 Effects

7.5.1 Patronage

The selection of the overall technology used only plays a relatively small part in the overall effectiveness of a system in attracting passengers. The measures needed to make a system effective, such as traffic management, complementary urban planning, assigning priorities and marketing are more important, and these will only happen if the political commitment exists. The qualification to this statement is that the technology must be suitable for and have the capacity to cope with the demand over the whole project life.

Another factor that has a significant effect on patronage is the inclusion of any system into a city-wide or regional ticketing system with through ticketing and common fares. This is independent of overall technology although some ticketing systems are easier to incorporate within specific technology mode choices, either because of the details of the technology or because of legislation in the country concerned.

In general new Light Rail systems are carrying more traffic per route kilometre than any bus-based system in Europe, although parts of large bus networks might exceed this. The amount of traffic is also much higher than has been carried on modernised rural railways. The implications of this are that for smaller traffic flows, such as would be found in smaller cities, solutions based on bus based options or improved local rail services could be adequate.

There is little experience of guided bus systems to go on and no European city has an extensive network as yet.

It is important to consider how patronage might vary with time. The rates at which it builds up vary and a "steady state" may never be achieved. These issues are important when considering what is affordable because of the effect on the cash flow aspects of any projects.

High step changes in patronage can be achieved by improving local railways at relatively low cost where the current traffic levels do not match "latent" demand.

7.5.2 Modal shift

When a new service is introduced the modal shift from car is unlikely to exceed 20%. This may not reduce the growth rate of private car traffic but may mean that traffic will be lower than it might have been for a period of years. This applies to the route itself; actual modal shift within a wide region may be very small because the corridor only represents a small proportion of total traffic.

Bus based options are usually significantly less successful in achieving modal shift than rail based ones.

7.5.3 Revenue

High patronage does not necessarily mean high revenue; relationships are complex and are determined by local policies and circumstances.

If a high fare is charged then it is vital for success that a premium service is provided, that both matches demand and provides the travelling public with an experience in which they can appreciate the higher quality in terms of higher speed, comfort, reliability, accessibility etc.

7.5.4 Development and land use

The relationship between providing improved public transport and consequent land use changes is not a simple one. The effects vary, but in general experience suggests that land use is stimulated by public transport investment.

Historically, providing different types of urban public transport has had a significant impact on land use in city regions and towns and this can be seen repeated many times. However in these days, when transport is dominated by private road vehicles, significant land use change can only be expected where public transport remains effective in attracting a large section of the transport market. This is clearly an important clue as to how much effect on land use each of the technical options will have.

One relationship is likely to be:

- Positive change in land use is proportional to effectiveness, which in turn is proportional to the combination of capacity and quality.

This seems to be reflected in the examples given where the lower capacity bus based systems are not demonstrating the results of the higher quality rail based ones.

The exception to this (Oxford) demonstrates that bus based systems can be effective providing severe traffic constraint exists. But care is needed here because such constraints, if only through removing road space and on street parking, are also a feature of most Light Rail schemes.

There may be small effects on land use if local rail services are improved by introducing multiple units with improved services and a more positive image. Likely scenarios would be housing development in the communities served, small business and industrial parks being established at stations.

Land has to be available to be developed in the area served. Evidence on land values is very patchy and any effect may even out in time. A further complication is the ability of public transport to "unlock" a potential development site. Docklands Light Railway proved so successful in this respect that the system needed drastic upgrading and has now been augmented by a full metro.

7.5.5 Environmental impact and urban design

The extent to which each technology can contribute to the urban design of a city and in turn affect its image to allow branding and marketing varies considerably.

As discussed in Strand 3, Light Metro, Light Rail and tram systems perform best in this respect. The various bus based options are less likely to, especially if there is no city centre infrastructure other than bus stops. Use of existing railways; either for improved services or shared track service may not have much impact either.

7.5.6 Networks

We have examined the contribution that each technology might make to achieve the desirable network features identified by Strand 2. This analysis proved to be valuable but should only be seen as a broad indication. For specific applications some criteria will have more weight than others. For example the ability to serve weak markets (areas with less public transport demand) will often not be an issue. A balance will always be needed between meeting good network practice and what is affordable.

7.5.7 Overall conclusions

A number of lower cost modes and technologies are both available and suitable for application in smaller cities and regions as a means of creating very effective public transport networks. Some of the technology is still developing (e.g. some forms of guided bus and novel Light Rail) and doubts remain about their value in the longer term. In general however there is probably a much better understanding now of the relationship between mode/technology and the results to be expected and this will include relatively new options such as shared track.

This choice and greater understanding means that promoters can develop really effective schemes to suit local conditions and the HiTrans guidance will help this process as an introduction to these possibilities.

As in larger cities, transport networks will probably comprise different modes and technologies. A medium sized city may in future have a core public transport network on main routes provided by Light Rail, guided bus or quality bus, supplemented by conventional buses in low density traffic areas and perhaps improved service or a shared track service on the local rail network. Ideally the network should be integrated so that the user sees the service provided as an attractive facility providing a simple and reliable method of getting about, rather than as a set of disjointed services using different modes. Cities and regions that are able to take advantage of these principles could see a significant change in how their citizens and the rest of the world sees them. There are now a number of cities in Europe where one of the best known facts about them is that they have high quality public transport systems.

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161 http://www.sias.co.uk/sias/paramics/movies/movies.html, industry website, simulation, various examples are given of priority measures in video clip format.
162 http://www.sitram.net .Mulhouse (France) Tram-Train project web site.
163 http://www.sl.se, AB Storstockholms Lokaltrafik
164 http://www.stadtbus-dormagen.de, Stadtbus Dormagen.
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166 http://www.tfl.gov.uk/trams/. Official TfL web page that gives current data on Tramlink performance.
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169 http://www.tram-train.net, website for marketing of the Mulhouse TramTrain system.
170 http://www.TramTrain.org, web page of the 2002 conference that covered the "Karlsruhe" TramTrain model in depth, following 10 years experience of operating the Bretten line. It also considered future development of the concept.
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173 http://www.uestra.de,ÜSTRA AG, public transport Hannover.
174 http://www.ulev-tap.org. ULEV-TAP (Ultra low emission vehicle - transport advanced propulsion), Siemens AG, CCM, Imperial College, Kiepe, TTK.
175 http://www.uptenergy.com, trackside kinetic energy storage systems, a new option for transit applications.
176 http://www.urbantransport-technology.com/projects/gothenburg/. Various technology initiatives associated with the Gothenburg public transport system.
177 http://www.vdv.de, German Public Transport Association web site with information on their guidance publications.
178 http://www.verkehrsplanung.de/Halle/Bericht.pdf, application of priority measures in Halle with a detailed reference list of German papers.
179 http://www.vogtlandbahn.de, web page of the Vogtlandbahn in SouthEast Germany and the Czech Republic, including the TrainTram operation in Zwickau and details of the rolling stock used with dimensions etc..
180 http://www.westyorkshirebuses.freeserve.co.uk/guidedbuses.htm, details of guided busways in Leeds and Bradford.
181 http://www.zuidtangent.nl.,web page of Zuidtangent (in Dutch.)

8.3 CD-Roms

182 “Innovative guided transport systems on tyres”: UITP International Light Rail Commission CD-ROM. Contact doriano.angotzi@uitp.com.

HiTrans Best practice guide 4
Public transport – Mode options and technical solutions

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HiTrans
HiTrans is an EU sponsored Interreg IIIB (North Sea Region) project seeking to improve public transport in medium sized cities with 100,000–500,000 inhabitants. The full official project title is *Development of principles and strategies for introducing High Quality Public Transport in medium sized cities and regions*. "High Quality" refers to modes that are perceived as offering higher quality than ordinary bus-solutions. However HiTrans also recognises the important role buses will have to play in any medium sized city.

HiTrans is a partnership between

- Rogaland County Council, Norway (lead partner),
- Edinburgh City Council, Scotland,
- Helsingborg City Council, Sweden,
- Jernbaneverket (The Norwegian National Rail Administration),
- NEXUS (PTE of Tyne and Wear), England,
- NSB (Norwegian National Rail Operator),
- AS Oslo Sporveier (Oslo public Transport Ltd), Norway,
- Statens vegvesen (Norwegian public Roads Administration),
- Stavanger and Sandnes City Councils, Norway,
- Sunderland City Council, England,
- Aarhus County Council, Denmark.

For more information on HiTrans, visit www.hitrans.org

HiTrans best practice guides
As part of its activities, the HiTrans partnership has produced five best practice guides:

1. Public transport & land use planning
2. Public transport – Planning the networks
3. Public transport & urban design
4. Public transport – Mode options and technical solutions
5. Public transport – Citizens' requirements.

4

Best practice guide 4
Public transport – Mode options and technical solutions
This guide gives an extensive overview of various options for the introduction of high quality public transport in medium sized cities. Rail-based options range from ultra light rail to heavy rail, with various permutations and combinations such as tramtrains, light metros, metro trains and so on. Cities opting for bus-based transport will have to choose between different forms and combinations of propulsions, as well as whether to use bus only streets, busways, and/or to adopt one of the evolving technologies to guide buses.

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