The PRT Project
Phase 1 Design & Engineering

ICCS for PRT

Information, Communication and Control System for the JV PRT

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Content

1 Executive Summary

This report describes the information, communication and control system for the planned FlyBy project at Fornebu. The report describes in detail the various requirements for the project. It also recommends a set of solutions for the PRT.

The report is based on the work of several experts, partly working together during workgroups. Other inputs have come from literature available at various sources, both in print and via Internet, where PRT is discussed and presented by several companies and institutions.

Control
For the control system, the report has the following recommendations.

Intelligent guideways, "stupid" vehicles
The control system shall be based on a layered structure where most of the intelligence is built into the guideways, while as little as possible depends on the vehicles. The vehicles are passive devices with motors in the guideways. Most sensors and regulators are in the guideways, while the vehicles only deliver a few of the sensor signals.

Control system
The experts connected to the PRT project recommend point-synchronous control as the best way to handle a system with traffic peaks and network with at least one bottleneck.

A fully synchronous control system has been considered since the PRT Fornebu system is limited in size, but is not recommended for several reasons:

1. We cannot ensure that the destination station has space for entering vehicles
2. A local disturbance would halt the whole system
3. A fallback asynchronous system is needed to handle unforeseen events

Independent vehicle safety control
To ensure personal safety, there shall be an independent automatic vehicle safety control system (AVC). This system shall ensure that direct collisions are avoided, either during an unexpected stop or during merging. The system shall operate independently from the main control system, similar to ATC or ATP systems used by trains.

One part of the system shall be a collision detector in front of each vehicle that starts emergency braking to avoid direct collisions with objects ahead of a moving vehicle.

Communication
For the communication system, the report has the following recommendations.

Passive sensors
Along the guideway there shall be sensors that shall detect any vehicle, where the vehicle acts as a passive device. The sensor shall be able to detect both the presence of a vehicle as well as speed. This is achieved by having a pattern along the vehicle (optical or mechanical).

Data link
There shall be a local data link between vehicles and the guideway. This link shall transfer a limited amount of data between the control system and the vehicle. This information is used for controlled operation of the vehicle, but is not essential for the safety of the passengers. The data link may be based on standard components, but the design will be so that other types of communication using similar components will not normally disturb the link.

Data network
There shall be a common data network throughout the whole PRT system. The network shall transfer data between all local devices and the central control. The network will probably be a redundant fibre network based on standard components.

Communication link
There shall be a general wireless communication link between each vehicle and the central control system. This link shall be used for two-way communication between passengers and a control centre in case of problems. It may also transfer data to an information display in the vehicle.

This link may be based on standard communication equipment such as GSM/GPRS. It is essential to ensure that other users do not block this link during an emergency or other un-normal situation.

Information
For the information system, the report has the following recommendations.

User information
Before and during the ride, the passengers in the vehicle shall have information about destination and expected time of arrival.

At the station, the waiting passengers shall have information about waiting time.

General information
All passengers shall have information about general problems with the system, such as delays because of accidents or too many passengers at some stations

Critical issues
The following items need special attention:

Communication: Sensors and local RF link
These parts of the communication system are very important for the whole PRT system and need to be analysed in detail, in order to ensure that they can be realised as planned. These parts also need to be fault-tolerant.

Basic control system
The basic control system algorithm shall ensure that the vehicles move according to calculated values. Algorithms, controllers and LIMs must be developed and designed so that this goal is achieved.

2 Abstract

The information, communication and control system is an essential part of the FlyBy project.

This report gives a detailed description of the information, communication and control system for the planned FlyBy project at Fornebu. The report describes and discusses the various requirements for the project.

The report is based on the work of several experts, partly working together during workgroups that have been arranged in Oslo during March and April 2003. Other inputs have come from a large amount of literature available at various sources, both in print and via Internet, where PRT is discussed and presented by several companies and institutions.

In Section 1, Executive Summary, there are recommendations for the PRT project at Fornebu

Section 3, Introduction, introduces the PRT project and the scope of work.

Section 4, System overview, explains more about the ICCS.

Section 5, Information, Communication and Control Systems (ICCS), introduces the main principles for design of the systems.

Section 6, Control, discusses the possible control strategies for a PRT system

Section 7, Communication, discusses the communication system needed for PRT

Section 8, Information, discusses the information system for PRT

Section 9, Safety, discusses the very important area of automatic vehicle safety control

Section 10, Recommendations, presents recommended choices for the PRT at Fornebu

3 Introduction

3.1 Subject

The FlyBy project is divided into several subprojects and ICCS is one of them. ICCS means Information, Communication and Control System. In this report, the sequence is changed to Control, Communication and Information in order to show the priority given to the areas.

Safe and reliable control of all vehicles in the system is essential for the whole project. If the system is not safe and reliable, the system is unusable.

Reliable communication is part of the system and some of the communication is essential for safe operation.

The system also relies on various type of information for the users; some of this is essential in case of emergency situations, while other is used for general information and perhaps entertainment.

3.2 Purpose

The purpose of this report is to give a detailed overview over the requirements for ICCS in a PRT project, with focus on the PRT Fornebu project.

3.3 Scope

The scope of this report is to provide enough information for future detailed planning and development of the various information, communication and control systems needed in order to design and build a complete PRT system.

3.4 Structure

The report is divided in two main parts. Section 1 to 5 gives an introduction to ICCS for PRT, while section 6 to 8 gives a detailed description of the various systems and their modules. Section 10 presents the conclusions, with a table of requirements and recommendations.

4 System overview

PRT systems are still considered as outsiders in the transportation field. Well-known suppliers of buses, trains and trams dominate the market. This has had a long-term influence on the technology and design philosophy. It also has an influence on safety requirements. It has therefore been necessary to analyse and discuss PRT in detail in order to find how PRT systems can be made safe, reliable and cost-effective so that they can operate in a world dominated by more traditional transportation systems.

4.1 Standards

Most standards that are relevant to transport systems are based traditional transportation systems, such as trains or trams. When we are going to introduce PRT, we will have to analyse current requirements and market expectations and ensure that a PRT system will fulfil these requirements and demands, even if a PRT system in many ways is a very new and different transportation system.

It is especially important to ensure that all safety related issues are addressed so that PRT can document to be as safe or safer as current transportation systems

4.2 Methodology

PRT systems have been discussed and analysed for several decades, still only a few test tracks and small systems have been built. PRT therefore mostly exists on paper. It has been necessary to analyse various sources of information from many PRT projects to understand the background and intention for PRT. Later, several experts have discussed several aspects of PRT in order to focus on the requirements for a PRT system.

4.3 Testing

The PRT project plans to test their PRT design on a special test track before building a full-scale system. The purpose of the test track is to be able to test the various elements of a PRT system. In parallel with a test track and some vehicles, there will be built parts of the information, communication and control system. It is especially important to test the basic elements in the control system in order to ensure that PRT will be a safe transportation system.

5 Information, Communication and Control Systems (ICCS)

The information, communication and control systems are all needed in order to operate the PRT system safe and efficiently. In our study, we have focussed on the basic functionality and discussed how this can be achieved with low complexity and high reliability.

Some basic design criteria have become important during the study:

- Intelligent guideways, stupid vehicles
- Local control of vehicles
- Independent automatic safety systems for vehicles (automatic vehicle control, AVC) in order ensure safe operation

Several other criteria have been discussed and should be mentioned as basis for future development of the PRT system:

- Safe headway versus speed
- Safe headway versus complex control system
- Speed versus capacity
- Speed versus curve radius in populated areas
- Bottlenecks in the system that has an influence on efficiency
- Integration of stations in existing buildings
- Easy user interface avoiding the need for learning to ride the PRT system

Designing information, communication and control systems for PRT is a multi-discipline task, requiring input from many different fields. It has therefore been important to have close contact between several experts in order to achieve a good overall view of the requirements for a PRT system.

In section 6 to 8, the control, communication and information system is explained in detail. The sequence is deliberately changed in order to show that control is the most important part, while information is less important for safe operation of the PRT system.

6 Control

The control system for PRT is an essential part of the PRT system for several reasons. If the control system fails, we may kill or injure people. Less serious consequences are reduced capacity, delays and increased wear, leading to less satisfied passengers and unsuccessful operation of the PRT.

This section explains various parameters of the control system.

The independent automatic safety system is described in section

6.1 Strategy

As described earlier, there is a lot of information available about PRT systems, including control systems.

An important issue for PRT control system is the type of control philosophy one should choose. Two main classes exist: synchronous and asynchronous control. In addition, some subclasses exist. Details about the classes, their advantages and limitations are discussed in articles and books about PRT. In this report, section 6.2; we will mainly give the conclusions and recommendations.

6.1.1 Modularity

It is a part of the design philosophy to make a control system that is made up of several small modules in order to achieve the following:

- Redundancy
- Reliability
- Capacity
- Scalability

Some of the modules may be made uniquely for the PRT, while other parts may be based on standard open technology.

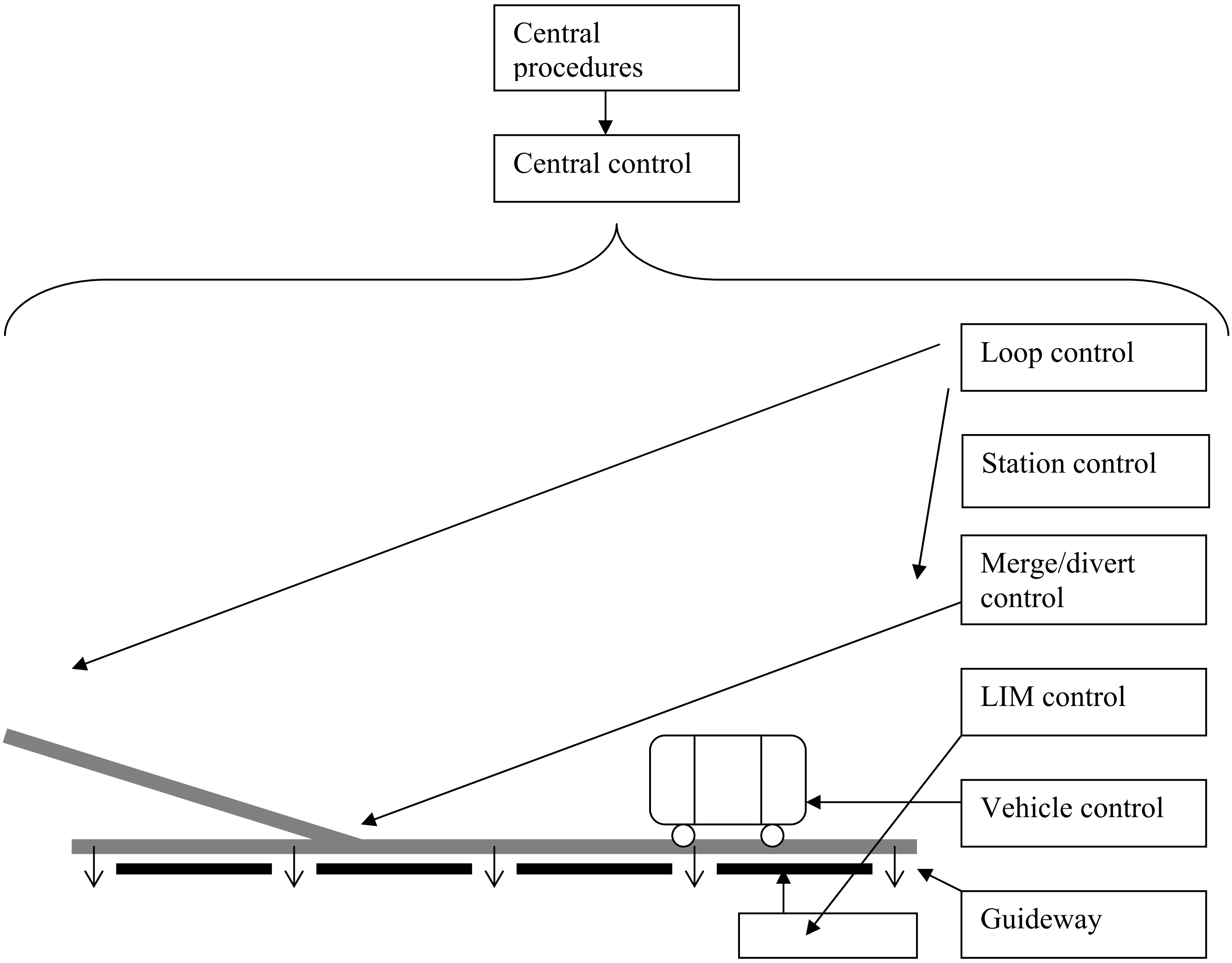
6.1.2 Centralised control

Part of the control system will be centralised, no matter what type of control strategy that is chosen. This central part will include the following areas:

- Fleet management
- Statistics
- Emergency
- Operating centre
- Maintenance
- Demand forecasting from ticketing system

The design of the control system is based on a layered structure, as shown in the figure.

- Guideway sensors
- Vehicle control
- LIM control
- Merge/divert control
- Station control
- Loop control
- Central control
- General procedures: Emergency, traffic planning, maintenance



6.1.3 Critical system

The control system is a critical system, because it directly has an effect on safety for passengers. Since the system is critical, it is also important to identify if the system is built of existing or non-existing parts. The PRT roughly consists of three elements, guideway, stations and vehicles.

Guideway

The guideway shall be made as a ”smart” guideway. This means that we plan to move as much functionality as possible from the vehicles down into the guideway. The reason for this is safety; we do not rely on wireless communication between vehicle and guideway in order to have safe transportation.

The main control parameters for a vehicle in the guideway are:

- Safe headway (measured in time or distance)
- Variable safe headway, depending on speed (reduced at lower speed)
- Vehicle ID
- Vehicle position
- Vehicle speed
- Vehicle standstill
- Normal braking/deceleration
- Acceleration
- Merge and split control

Stations

The part of the control system related to the stations covers the following areas:

- Ticketing
- Procurement: paying with cash or cards, several types
- Automatic or manual payment
- Separate destination inputs and berths
- Permanent or temporary destination berths
- Information about destination
- Platform doors, control of doors
- Ordering of empty vehicles when needed or anticipated

Vehicles

As explained earlier, the vehicles shall be as stupid as possible. This means that they shall not be part of the drive or ordinary control system. This in turn means that the vehicles become low-cost, low-weight and easy to service.

There still are some areas that need to be controlled in the vehicles. The vehicles also need to supply and receive some information to and from the control system, especially in the case of an emergency situation.

- Vehicle identification
- Switching
- Un-normal heating, in wheel bearings or cabin
- Door lock
- Speed detection
- Loaded/empty detection

6.1.4 Non-critical Off-the-Shelf Systems

There are several non-critical systems that can be bought from different suppliers. We just briefly mention them here, with some comments.

- Back Office, storing all information about ticketing and use of vehicles
- ERP, enterprise resource planning, not discussed further
- CRM, customer relation management, not discussed further
- Maintenance, perhaps combined with Back Office, a system for cost effective maintenance of vehicles, guideway and stations
- Climate control, in each vehicle, complete module, typically from the car industry
- Entertainment, optional, may include Internet and advertisement

6.2 Requirements

The control system shall ensure that a vehicle goes from start to destination without any problems, via the shortest route without delays and with almost constant speed. In order to achieve this, it is possible to use some control principles, with different key principles.

Control systems for PRT have been discussed and developed during several decades and a lot of information about control systems is available. One result of this work is that some philosophies and “brand names” have established themselves. We shall briefly present and discuss some of them here. Prof Ingmar Andreasson has given a more detailed description and analysis in his report “Control Strategy”. This report also describes other elements as merging and dynamic routing of vehicles.

6.2.1 Synchronous control

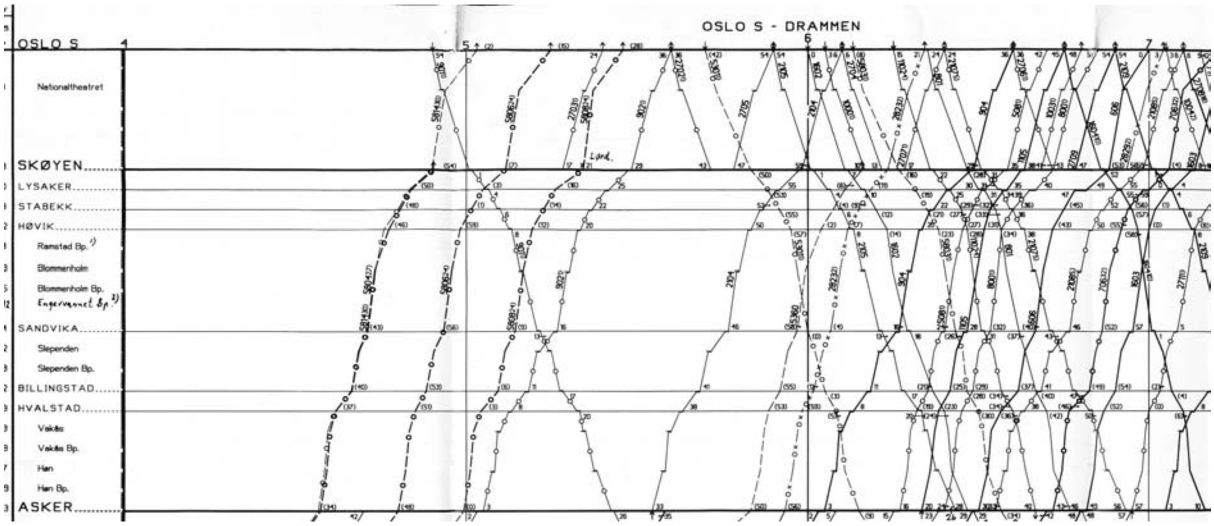
One basis for PRT is that is shall be personal (P), similar to driving a taxi or a personal car. Therefore it is a bit surprising that a synchronous control system for a long time has been seen as efficient for PRT, since a synchronous control system takes full control of all vehicles and any event in the PRT system.

The central controller arranges a central time, with time slots (for instance one second time slots). All events are synchronized with this central time. Before a ride starts, the whole ride is planned by the synchronous control, including time slots for merging and arrival at the destination station. The ride will only start if there is free space (time slots) through the whole line where the vehicle shall go, from start to goal. The synchronous control system therefore tries to establish an “ideal world” where all rides go perfect, with no delays or problems.

A railway timetable is an excellent example of a synchronous control system, where some of the limitations are easily visible (see the copy of the timetable):

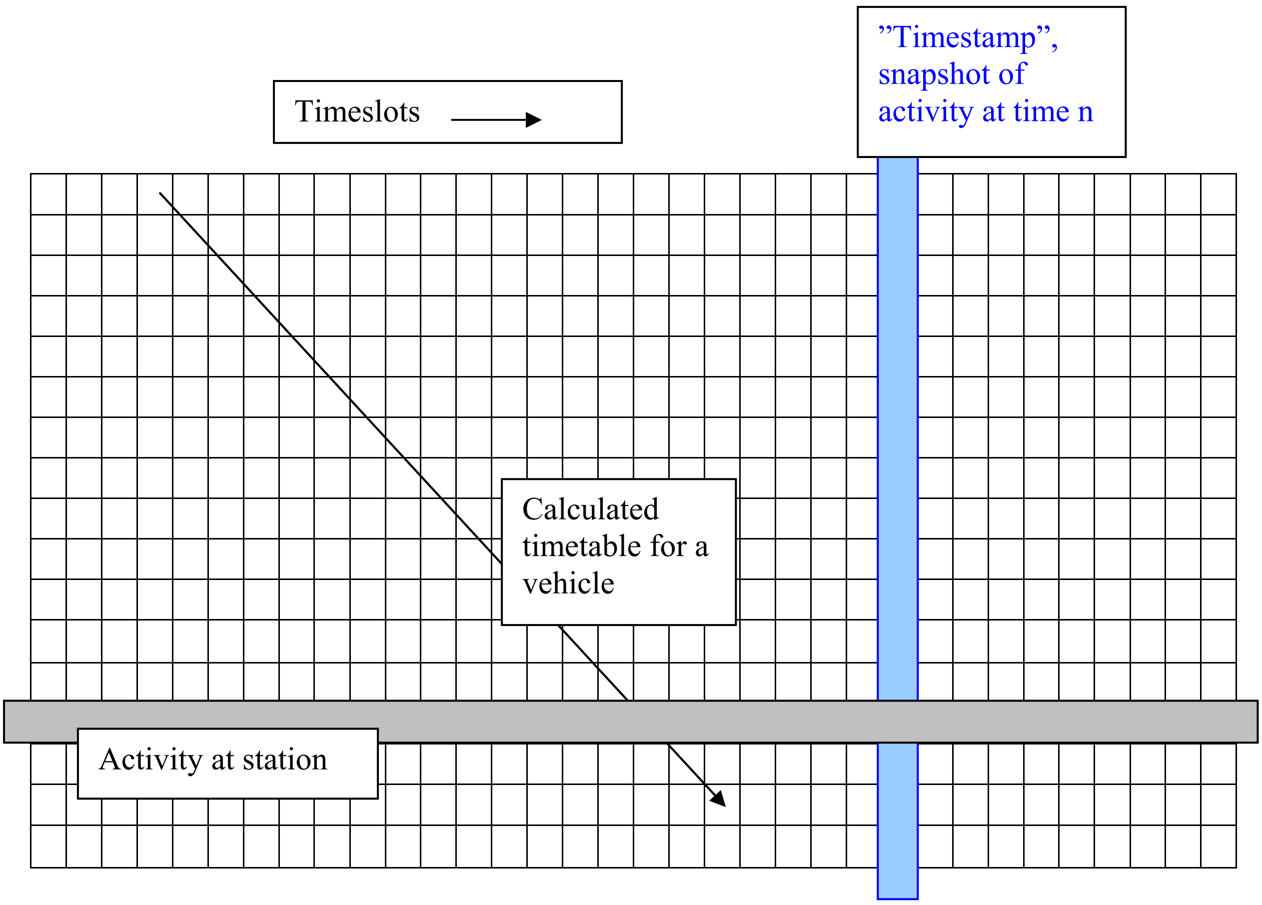
- All rides are planned 3 – 6 months ahead
- All trains must have almost the same speed
- No changes are possible
- Single failures lead to severe problems
- Capacity can not easily be increased
- The timetable relies completely on timeslots

The figure shows the timetable for trains west of Oslo, towards Lysaker and Asker, spring 1998, mornings between about 04:00 to 07:00. It is easy to see increased capacity up to the limit about 06:30. All trains must follow the same speed, even if they shall not stop at all stations.



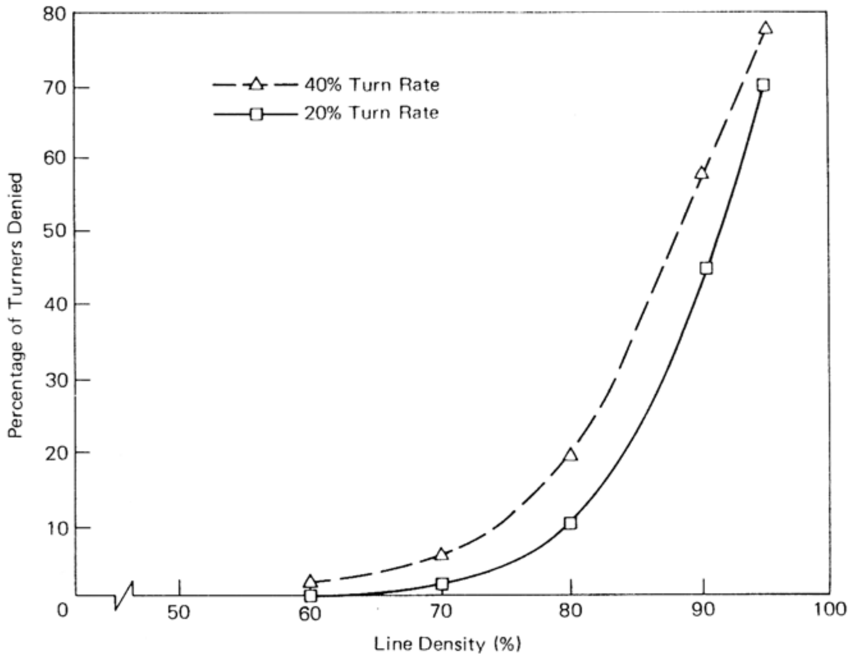
Timetable for trains Oslo – Asker, spring 1998, time from 04:00 to ca 07:00

For a synchronous PRT system, a similar timetable will have to be set up. It may look like the next figure, where x is the time slot axis and y is the guideway with stations.



Example of timetable in a synchronous control system

Experience has shown that the "ideal world" is not always possible to achieve. If there are bottlenecks in the system, or generally too many passengers, the whole system will slow down or perhaps stop completely, because the synchronous control cannot find openings (time slots) for the vehicles through the system. If a single vehicle breaks down, then the whole control system and the timetable collapses. A synchronous control system therefore works best when only part of the maximum capacity is used, typically up to only about 65%; see copy from "Fundamentals of Personal Rapid Transit":



The figure shows capacity problems in merging when more than 60% of the time slots on the main line are occupied.

This knowledge has led to discussions about other types of control systems, where the limitations of the synchronous control system are handled in a better way.

6.2.2 Quasi-synchronous control

The purpose of the quasi-synchronous control is to reduce some of the negative effects of a synchronous control. With quasi-synchronous control, a ride may be started even if the whole ride is not ready and reserved. Conflicts may therefore occur at merging points. Moving some vehicles back one or more time slots solves these conflicts. Vehicles may also not be allowed to turn where planned, because the route is crowded.

6.2.3 Asynchronous control

Asynchronous control means that driving is more similar to driving a personal car. Each passenger is allowed to start without knowing if it is possible to reach the destination directly. An asynchronous system is more similar to driving a personal car, where one has to accept crowds and queues. The purpose of the asynchronous control is to have a decentralised system, which is flexible and robust towards disturbances.

6.2.4 Point-synchronous control

Ingmar Andreasson and partners in "Logistikcentrum" have announced local synchronous control as a good compromise for PRT control. Ingmar Andreasson and partners call it "point-synchronous control system" and describes how they seek to combine the best ideas from the synchronous and asynchronous control strategies.

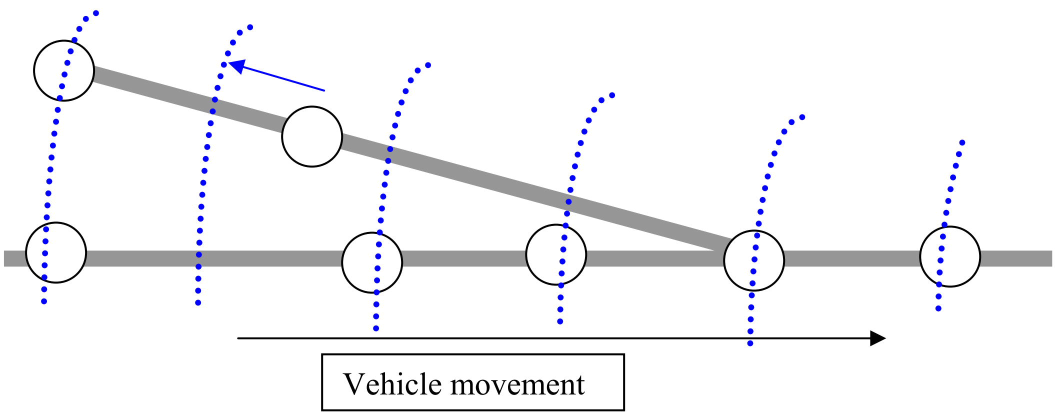
From a synchronous system they use:

- Time slot allocation
- Equal speed for all vehicles in the area

From an asynchronous system they use:

- Each vehicle is in charge of its own speed control
- All decisions are decentralized so that they are between a vehicle and its predecessor
- Robustness so that local disturbances are solved locally
- Flexibility so that route decision can be modified

In a point- or local synchronous control system, all vehicles close to a merge point are allocated time slots so that merging can occur without any problems. Some vehicles may have to slow down in order to fit into their allocated time slots, but this can be done in a controlled way. The drawing illustrates the task.



Merging with local synchronous timing control

6.2.5 Merging rules

Any type of control system needs to handle merging according to a set of rules. The most important rule is that safety must be assured, no accidents shall happen. This is achieved by making enough safe headway for each vehicle as they meet in the merging point. Other rules to decide upon are:

- Give priority to lines with queues
- Allow vehicles to leave a station, with a certain priority
- Priority depends on how long a vehicle has been waiting
- Merge closer to vehicle in front with lower speed (same headway in time)
- Reduce speed locally in order to gain space for all vehicles

6.2.6 Dynamic Routing

In a complex network, it is possible to have dynamic routing, where routing depends on several factors. Often, the central computer can decide routing principles that are not obvious for a single passenger or a local zone controller. Important parameters may be:

- Optimised from the system point of view
- Avoid queues
- It's better to wait in a station than in a car on the line

6.2.7 Platooning of empty vehicles

Platooning of vehicles is a phrase that has become part of the PRT vocabulary. Platooning of PRT means to ride several vehicles very close, shorter to safe headway, for instance bumper to bumper. The purpose of platooning is to save space and increase capacity.

The main challenge with platooning is to ensure passenger safety, it must not be possible that passengers may be killed or injured because of crashes or emergency braking.

For the PRT Fornebu project, analysis so far has been that platooning with passengers should not be allowed, since the potential passenger risks are not fully analysed.

Platooning with empty vehicles has been considered, and the following observations seem relevant:

- Make sure that the vehicles are empty
- Empty vehicles may run slightly faster than vehicles carrying passengers

Platooning of empty vehicles seems to be important and effective for PRT Fornebu since the main bottleneck in the morning peak is towards Lysaker with many empty vehicles returning as well as loaded vehicles with destination at Lysaker.

6.3 Control system, comparison

In order to compare the control strategies, the following table was made in order to do a fair comparison and to evaluate the situation at Fornebu.

The table indicates the well-known limitations for a synchronous control system. For the Fornebu PRT system, our discussion has shown that these limitations are not necessarily very important. The main potential problem with the PRT system at Fornebu is the bottleneck related to the station at Lysaker. Changing to an asynchronous or point-synchronous control system does not seem to reduce this problem, since merging into the Lysaker station shall be locally synchronous anyway. Still, a point-synchronous system may have a more "graceful" decline in efficiency compared to a synchronous system; which may collapse more abruptly, needing special procedures for restart. Asynchronous or point-synchronous systems handle this problem much better.

The reasons for considering a synchronous control system at Fornebu are:

- The Fornebu project is small, with only about 250 vehicles and few loops
- There is only one real bottleneck, the Lysaker station
- With one merge controller for traffic into this bottleneck, Lysaker, we are very close to controlling most of the network with synchronous control anyway
- Computers are now so powerful that it is not difficult to have a simple yet very effective centralized control system.

Parameter	Sync.	Quasi - sync	Async	Point - sync	Fornebu
Clock	Central	Central	NA	Local	
Speed	Fixed	Fixed	Variable	Variable	Little problem at Fornebu
Timeslots	Fixed	May change	Free	Local control	
Schedules	Planned ahead	Planned ahead	No	No	
Central computer	Yes	Yes	No	No	Little problem at Fornebu
Pre-booked rides	Necessary	Necessary	Not needed	Not needed	
Change of destination	Not possible	Not possible	Possible	Possible	To be decided
Merging	Easy	Easy	Variable	Easy	
Sensitivity to errors	High, no easy restore	Better	Good	Good	Bottleneck near Lysaker
Sensitive to full stations	Critical, need longer stations	Less critical	Acceptable	Acceptable	Bottleneck at Lysaker and Telenor
Flexibility	Low	Better	High	Highest	
Scalability	Low				No problem now
Capacity	Max 65%, no room for expansion	Higher	Higher	Highest	Little problem at Fornebu?
Platooning	Not possible	Possible	Possible	Possible	Recommended
Cost	Lower, (less than 10%)	Low	Higher	Higher	

A comparison of PRT control strategies

It has been suggested a set of simple design rules for a synchronous system, including merge and divert control.

The potential weak points of a synchronous control system are:

- Very sensitive to single errors
- Heavy delays in case of problems at a station or a vehicle
- Difficult to handle unexpected rush traffic, may need system restart procedure

As explained in section 7 Communication, all relevant information about vehicles is available everywhere in the system, due to the communication network. Therefore it is easy to change the control system into other versions if the PRT system is expanded, other design parameters change or if experience shows that it is an advantage to redesign the control system

The conclusion regarding control system, reflected in the design parameters, is that we continue with the evaluation of a point-synchronous system.

6.4 Infrastructure

The infrastructure will be described in other reports; here are only discussed items of interest for information, communication and control systems, ICCS.

6.4.1 Guideway

The guideway shall be as intelligent as needed in order to run the vehicles as planned. The current idea is to have sections of about 3-meter length, where each section contains:

- One LIM (linear motor), custom version of standard products
- One sensor for passive detection of vehicles, existence and speed, perhaps a custom version of a standard product

The guideway shall also carry the data network that has connection with all parts of the PRT system. The data network will be made of standard components.

It is yet not decided how maintenance data from the guideway can be used as input for the maintenance and service of the PRT system.

6.4.2 Station

The station is a very important part of the PRT system since it is the first part of the PRT seen by the passenger. All stations must be carefully prepared to ensure that the passenger gets relevant information before the ride. This includes ticket machines, ticket validation, and general PRT information with map of the area and platform guidance to the nearest vehicle or to the right vehicle for ride sharing.

Most of the components for the ICCS at stations can be standard components.

6.4.3 Vehicle

As mentioned earlier, the vehicles shall be as “stupid” as possible. Still, the vehicles need an internal controller to take care of some functionality. The most important is the passenger safety, see section 9.

We have identified the following areas for vehicle control:

- Vehicle identification
- Switch control
- Passenger detection (weight, IR)
- Door control, mechanical, from station, emergency
- User interface: alarm, panic button
- User two-way audio communication
- Braking, emergency and parking

7 Communication

The communication system is a vital part of the PRT system. Without communication, the system stops operating. There will be several communication systems, serving different purposes.

7.1 Strategy

The strategy for the communication is to provide safe and cost-efficient communication between all PRT modules. The general control strategy is to have intelligent guideways and stupid vehicles. One reason for this is to have as little as possible communication between vehicles and the guideways in order to improve safety.

7.2 Requirements

There has been developed a set of requirements for the various parts of the communication system, depending on the area of use.

7.2.1 Control data

- Vehicle ID and speed information, from vehicle to guideway
- Destination station and route, from station to vehicle
- Vehicle weight and passengers present, from vehicle to guideway

7.2.2 Passenger data

- In vehicle: GSM/GPRS link for audio and video
- In station: Similar data link

7.2.3 To/from external actors

- Police
- Fire Dept.

7.2.4 Maintenance data

- Not yet decided

7.2.5 Emergency data

- Not yet decided

7.3 Infrastructure

The communication system consists of several layers of networks. We have identified the following layers:

Passive sensors

Along the guideway there shall be proximity sensors that shall detect any vehicle moving on the track straight above. The vehicle shall be assumed to be a passive device. The sensor shall be able to detect both the presence of a vehicle as well as speed. This is achieved by having a pattern along the vehicle (optical or mechanical). The pattern can be on the LIM plate, on the vehicle body or on the antenna for the data link.

Data link

There shall be a local data link between vehicles and the guideway. The data link shall provide a low data rate two-way communication between vehicle and guideway. The data rate is very low, typically 150 bits in a package, which has to be repeated a few times per second.

This information is used for controlled operation of the vehicle, but is not essential for the safety of the passengers. The data link may be based on standard components, but the design will be so that other types of communication using similar components will not normally disturb the link.

Data network

There shall be a common data network throughout the whole PRT system. The network shall transfer data between all local devices and the central control. The network will probably be a redundant fibre network based on standard components. The network will probably be located in the guideway structure. The redundancy should include protection against a direct break of the cable somewhere in the guideway.

Communication link

There shall be a general wireless communication link between each vehicle and the central control system. This link shall be used for two-way communication between passengers and a control centre in case of problems. It may also transfer data to an information display in the vehicle.

This link may be based on standard communication equipment such as GSM/GPRS. It is essential to ensure that other users do not block this link during an emergency or other un-normal situation

8 Information

The information system provides control information between all elements that are part of the control system.

The system also provides user information to all passengers using the PRT system. In addition, the users may receive entertainment, advertisement and general information about other areas than the PRT

8.1 Strategy

The strategy for the PRT information is to make sure that the control system works as planned.

In addition, the passengers shall receive the most relevant information for the ride. Later, the system may be expanded to cover other areas.

8.1.1 Maintenance data

Information in the PRT system is more than passenger information. The system shall also deliver vital information about the operation of the PRT system. Maintenance data is essential in order to run the PRT in a safe and a cost-effective way.

8.1.2 Emergency data

The PRT system shall be planned for safe operation. In order to achieve this, the system must be able to handle emergency situations in a controlled way. The information system plays a vital part here. There is need for various types of information:

- The central control shall have information about all vehicles and their status
- Passengers shall have information about the status and what they should do
- Service personnel shall have information about status in order to handle unexpected situations in the best possible way

8.2 Requirements

8.2.1 Guideway

In the guideway, we shall have the following information:

- LIM: speed regulation, voltage and frequency
- LIM: Controlled acceleration and retardation
- From Vehicle: Detection and speed

8.2.2 Station

At a station, the passengers need information about ticketing. After they have bought a ticket, the destination needs to be brought to the vehicle, either manually or automatically. The use of proximity cards may ease this operation.

Ridesharing needs to be informed about in order to achieve a high load factor in the rush.

At the station, the waiting passengers shall have information about estimated waiting time. All passengers shall also have information about general problems with the system, such as delays because of accidents or too many passengers at some stations

The vehicle needs to receive information about destination and how to get there, in order to control the switch correctly.

During the ride, the passengers shall receive information about their destination and expected arrival time. There may also be announcements and advertisement on the display.

The passengers shall have the possibility to change destination or to stop at first possible station if they change their mind, feel unwell or have other reasons for ending their journey immediately.

During the ride, all passengers shall have general access to any available mobile network, like GSM/GPRS or WLAN. The use of these systems is not controlled by PRT, but it may be used in the future for personal information to passengers about price, capacity or delays in the system. Mobile phones with short-range links like Bluetooth may also be used to pay for tickets.

8.2.3 Vehicle

The vehicles shall be able to deliver the following information:

- Vehicle present, vehicle ID
- Vehicle speed
- Vehicle stopped
- Passengers present or empty vehicle
- Vehicle destination
- Vehicle weight
- Doors locked or unlocked
- Seat belt detection, if provided
- Fire alarm
- Smoke alarm
- Temperature in cabin
- Temperature in critical parts, like wheel bearings
- Air gap between LIM and LIM plates

8.2.4 Training of passengers

For the passengers, we are considering the following type of information

- Signs, both static and electronic
- Vehicle information display

In the introduction phase, there is need for more detailed information, mainly by manual assistance.

8.2.5 Control Centre

The control centre needs to handle a lot of information about the vehicles and the passengers.

- ID and position of vehicles
- List of employees at PRT
- Internal video cameras

In an emergency, the control centre handles:

- Emergency calls from passengers, both in vehicles and at stations
- Audio communication with passengers
- Stop requests from passengers in vehicles
- Sensor information about emergency situations
- Contact with external actors: Police, fire department

8.3 Infrastructure

The infrastructure for the information system is not yet fully planned. Some of the information system is based on the communication system described in Section 7. This network (probably a standard 100 Mbit/s net) will have a capacity high enough for handling static information to all vehicles and stations.

Part of the information system, like the vehicle two-way communication, see section 7.3, will be based on GSM. It is assumed that capacity in the PRT area is so good that the system will not be blocked even during an emergency.

9 Safety

It is vital that the PRT system is as safe as any other public transport system available. It is also essential that the passengers judge the PRT system as safe. The consequence of this is that the PRT system shall be built according to the latest safety regulations. It shall also be based on knowledge from other similar systems, like driverless metros.

9.1 Vehicle safety

Personal safety in the vehicles has been discussed. It is essential that the passengers can have a safe ride, even in the case of an emergency situation.

- During a normal ride, acceleration and retardation shall be so smooth that no passengers are hurt.

- All passengers shall be seated during the ride. Seatbelts are an option, but they will not be compulsory, only with an information sign and perhaps a warning light.

- Airbags have been discussed, but are not recommended so far, because of low speed and passengers facing each other.

- The side doors shall be locked during the ride. Emergency exit shall be possible through the front or rear window and onto the guideway.

- The vehicle shall be made of non-combustible material. There will be one or two batteries on board, but except from that; the passengers must bring something flammable on board, like paper or clothes in order to start a fire. There shall be several heat and smoke detectors on board, in the passenger cabin, close to the batteries and technical equipment and at the wheel bearings. A fire extinguisher may be installed.

- In case of emergency, there is an alarm button to warn the control centre, which may have two-way contact with the passengers. The vehicle may automatically go to the next station, which is less than one minute away.

9.2 Automatic vehicle control

In case of emergency, the vehicle will do controlled emergency braking with the mechanical braking system in the vehicle. Emergency braking is controlled from an independent vehicle control, operating independently of the normal control system. This is equivalent to the philosophy for ordinary trains, which have automatic braking when a red light is passed without stopping; or if the speed is too high. Such systems are often called ATS, ATC or ATP.

For PRT, this system shall have two main tasks:

1. Avoid collision with a vehicle ahead
2. Avoid collision with another vehicle at a merge point

Input for these two situations come from different sensors.

1. Collisions with a vehicle ahead are avoided with a distance measurement system, probably self-contained, based on radar, light or IR technology.
2. Collisions at merging are avoided with help from an in-track control system.

The design of these systems has not started, but some design parameters are studied.

Head-on anti-collision radar systems are available for some cars, like Lexus or Mercedes. The purpose of these radars is to avoid coming too close to cars ahead on highways. Price for such radars are quoted at between 1500 and 2000 US$ (Mercedes). The system needed for PRT does not need the range for car systems, which need to cover more than 100 to 150 meters ahead, in speeds up to more than 150 km/h. A PRT system only needs to work within a range of 20 to 30 meters. Speed is seldom above 60 km/h, even during an emergency (downhill, motor or brake failure). A possible problem is curves, with radius down to 40 meters. At 20 meters distance, the guideway is ca 5 meter off the centreline, so the beam from the radar should have a horizontal opening of ca +/- 5 meters at a 20-meter distance. The radar would then be very sensitive to all kind of fixed objects close to the track, meaning that the radar would start emergency braking too often. This calculation shows that is not trivial to design a good anti-collision system.

A simpler anti-collision system could be based on the guideway sensors and count the number of "free" sensors ahead of the vehicle. Let us assume that safe headway always shall be more than 3,5 seconds at 10 m/s, 35 meters, or at least 10 3-meter sections. If the number of free sections starts to drop below 10, then speed should be reduced similarly.

9.3 Station safety

Passengers at stations must be safe at all time. Safety is ensured in several ways:

- All stations are open
- The stations are built of non-combustible material
- Evacuation of the station area is easy
- At the main stations with a lot of passengers, the guideway is protected with platform doors
- In case of emergency, all passengers receive relevant information

10 Recommendations

Information, communication and control cover a large area. The following table summarizes the recommendations in this report.

10.1 Table

Area	Recommendations
Control	**Intelligent guideways, stupid vehicles** The control system shall be based on a layered structure where most of the intelligence is built into the guideways, while as little as possible depends on the vehicles. The vehicles are passive devices with motors in the guideways. Most sensors and regulators are in the guideways, while the vehicles only deliver a few of the sensor signals.
	Control system The experts connected to the PRT project recommend point-synchronous control as the best way to handle a system with traffic peaks and network with at least one bottleneck. A fully synchronous control system has been considered since the PRT Fornebu system is limited in size, but is not recommended for several reasons: 1. We cannot ensure that the destination station has space for entering vehicles 2. A local disturbance would halt the whole system 3. A fallback asynchronous system is needed to handle unforeseen events
Comm.	**Passive sensors** Along the guideway there shall be sensors that shall detect any vehicle, where the vehicle acts as a passive device. The sensor shall be able to detect both the presence of a vehicle as well as speed. This is achieved by having a pattern along the vehicle (optical or mechanical).
	Data link There shall be a local data link between vehicles and the guideway. This link shall transfer a limited amount of data between the control system and the vehicle. This information is used for controlled operation of the vehicle, but is not essential for the safety of the passengers. The data link may be based on standard components, but the design will be so that other types of communication using similar components will not normally disturb the link.
	Data network There shall be a common data network throughout the whole PRT system. The network shall transfer data between all local devices and the central control. The network will probably be a redundant fibre network based on standard components.
	Communication link There shall be a general wireless communication link between each vehicle and the central control system. This link shall be used for two-way communication between passengers and a control centre in case of problems. It may also transfer data to an information display in the vehicle.

	This link may be based on standard communication equipment such as GSM/GPRS. It is essential to ensure that other users do not block this link during an emergency or other un-normal situation.
Info	**User information** Before and during the ride, the passengers in the vehicle shall have information about destination and expected time of arrival. At the station, the waiting passengers shall have information about waiting time.
	General information All passengers shall have information about general problems with the system, such as delays because of accidents or too many passengers at some stations
Safety	**Independent vehicle safety control** To ensure personal safety, there shall be an independent automatic vehicle safety control system (AVC). This system shall ensure that direct collisions are avoided. The system shall operate independently from the main control system, similar to ATC or ATP systems used by trains.
	One part of the system shall be a collision detector in front of each vehicle that starts emergency braking to avoid direct collisions with objects ahead of a moving vehicle.
Critical	**Critical issues** The following items need special attention: **Communication: Sensors and local RF link** These parts of the communication system are very important for the whole PRT system and needs to be analysed in detail, in order to ensure that they can be realised as planned. These parts also need to be fault-tolerant. **Basic control system** The basic control system algorithm shall ensure that the vehicles move according to calculated values. Algorithms, controllers and LIMs must be developed and designed so that the goal is achieved.

This table summarizes the recommendations from this report. The ICCS report will be input to a summary report “Overall System design” which presents an overall view of the PRT system.