Personal Rapid Transit Study in Gothenburg, Sweden

BO BLIDE

The Gothenburg Traffic Authority found that new traffic policy goals identified during recent years are very difficult to achieve by conventional public transport techniques. Consequently new system concepts must be studied. Personal rapid transit (PRT) is one of them. The PRT project in Gothenburg, Sweden, was initiated in 1991. After prestudies an enlarged study, which is described, was started in summer 1992. The object of the study was to investigate whether PRT could take over as the only public transport system and replace the present system (light rail and buses). The work concentrated on four parallel activities: (a) design of a PRT track network covering a major part of the city and the central parts of two adjacent communities, (b) establishment of the travel demand in the area (trip matrices), (c) development of a control system suitable for a large PRT system, and (d), development of a simulation program for the analysis of PRT system functions, with special emphasis on operational strategies, travel standard, capacity, productivity, and resources needed. The approach to the problem and the techniques used and developed in the study are described. The result of the study is that it appears theoretically possible to operate very large PRT systems. The system studied in Gothenburg includes 700 track km (counted in single tracks), 650 stations, and 17,000 vehicles. One question still to be answered is whether it is possible to attain satisfactory reliability for all the components involved.

Gothenburg is Sweden's second largest city, with 433,000 inhabitants. Including the suburbs, the population is 730,000. The present public transport system is a mixed light rail-bus system with nine tram lines and 30 bus routes. The number of daily trips by public transport in the city is about 300,000, including trips by passengers who transfer from regional bus and train services. Up to 65 percent of public transport operations in the city are financed by local taxes.

During recent years new traffic policy goals that are practically impossible to realize with a conventional public transport system have been identified. Consequently new system concepts must be studied. Personal rapid transit (PRT) is one of them.

STUDY OBJECTIVES

The PRT project in Gothenburg was initiated in 1991. After prestudies an enlarged study, which is described in this paper, was started in summer 1992. The object of the study has been to investigate whether PRT could take over as the only public transport system and replace the present system (light rail and buses).

MODEL CONCEPT

According to a decision by the Traffic Committee of Gothenburg the model PRT concept should be a system of cars with rubber wheels on elevated tracks. In some sensitive parts of the city, mainly in the central area, it is anticipated that tunnel solutions must be discussed.

Gothenburg Traffic Authority, Box 2403, S-40316 Gothenburg, Sweden.

TRAVEL DEMAND

Trip Matrices

The calculations of travel demand were based on existing public transport trip matrices and existing statistics concerning car travel (area-area matrices).

The information was translated into station-station matrices for the alternative PRT networks studied. Matrices have been prepared for the time periods 0600 to 0900, 0900 to 1500, and 1500 to 1900 hr. The statistical material also made it possible to study shorter time periods, down to 30 min. For the capacity tests of the networks the half-hour of the morning and afternoon peak periods with maximum ridership levels were used.

Figure 1 shows the distribution of the present public transport ridership between 0500 and 2200 hr on a half-hour basis.

The share (in percent) of the maximum hour and half-hour in each time period is (a) time period—0600–0900, 0900–1500, 1500–1900; (b) maximum hour—50, 22, 34 percent; and (c) maximum half-hour—30, 11, 17 percent.

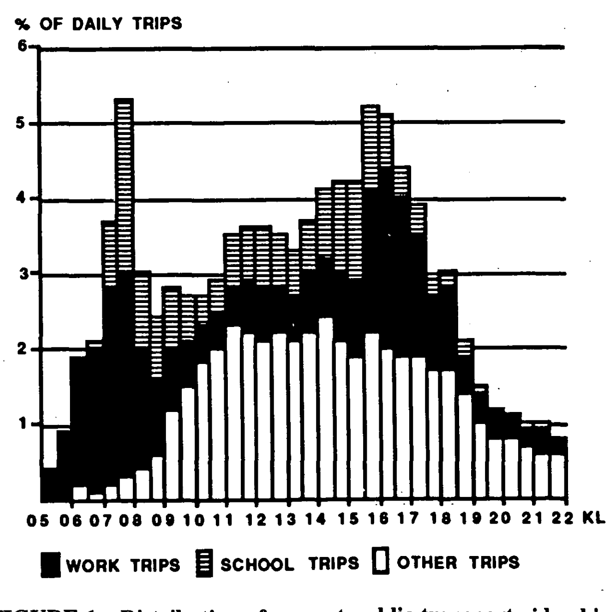

FIGURE 1 Distribution of present public transport ridership between 0500 and 2200 hr on half-hour basis.

Increased Public Transport Ridership

A citywide PRT system should be able to cope with a considerable increase in public transport ridership in comparison with the present ridership. There can be various reasons for such an increase.

- Improved travel standard makes today's public transport riders travel more.
- Better level of service attracts a portion of the present car riders, especially for origin-destination combinations for which present public transport services are poor.
- Car riders are "forced" to leave their cars by traffic policy measures, such as high parking fees and road pricing.
- A change of the "global" conditions for car use, such as supply and price of fuel.

In the study described here an expansion of public transport ridership is created by a transfer of car riders from the car trip matrices to the matrices containing the present public transport trips. The matrices are prepared on a station-station level for the PRT system.

The transfer of car trips has not been made evenly for all origin-destination combinations, because the present modal split is not the same for the central area and the rest of the city. In the city as a whole 25 percent of the trips made are by public transport, but for the central area the figure is considerably higher (55 percent). By testing the capacity (in percent) of the PRT system the transfer was accomplished in a stepwise manner as shown in the in-text table.

Transferred Car Riders	*Central Area (percent)*	*Other Trip Combinations (percent)*
Step 1	10	24
Step 2	20	48
Step 3	30	72

In Step 3 almost 60 percent of the car riders during the morning peak period was transferred, corresponding to an 80 percent increase in the number of public transport riders. The simulations indicated that the PRT system could cope with this situation. The figures on the performance of the system refer to Step 3, which is believed to cover the transfer potential of people attracted by the high standard of the new system and people forced to use the new system by traffic policy measures that are already available or being discussed.

TIME GAPS

The possible minimum time gap between two cars is a basic factor in the design of a PRT system and for the calculation of its capacity. The time gap is defined as the shortest possible time distance between two cars that can be allowed if Car 2 in Figure 2 should be able to stop without any car damage or personal injuries if Car 1 comes to an abrupt stop.

The time gap depends on the following factors:

- In what way Car 1 stops.
- Time it takes to inform Car 2 of the stop.
- Time it takes for Car 2 to evaluate the information and to give braking order.

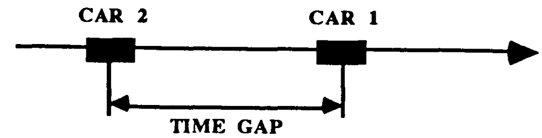

FIGURE 2 Time gap.

- Time it takes for the brakes to work to full effect.
- Time for deceleration to a standstill.

Of these time factors the last one is by far the longest.

Concerning the way in which Car 1 stops, two cases have been studied: (a) the car is brought to a brick-wall stop, (b) the car completely breaks down, slides along the track, and stops as fast as friction allows. Assuming an operating speed of 13 m/sec and a maximum deceleration of 6 m/sec^2 the minimum time gap is 1.6 sec in Case a and 0.8 sec in Case b. In simulations of the system an average speed of 10 m/sec (36 km/hr) has been used to compensate for lower speeds at curves and switches.

A special risk case arises if a car is brought to a stop according to Case b and finally stops at a merge point where two track links meet. In this case a special detecting system in the track is needed if the time gap of 0.8 sec is used.

The choice of time gap depends, however, not only on technical factors but also on psychological ones. To what extent are people prepared to ride in automatically guided vehicles at the actual speed and distance gaps? No such studies have been done within the framework of the present study. It should be observed, however, that the construction time for a system of the actual size is long, and is probably the time before the minimum time gaps must be used. Therefore there will be time for people to get used to the new situation.

In the evaluation of the capacity and travel standard of the PRT system the effects of both time gaps were studied.

OPERATIONAL STRATEGIES

A strict PRT operation means that the passenger rides directly from start station to the destination, alone or with the company he or she chooses. It was estimated that the average number of people per car in peak hours would be 1.25, the same as in private cars today. This implies a poor use of the car and track network capacity, especially considering that, on average, less than 50 percent of the cars in the system is running with passengers. The others are either on their way to a new mission or are waiting at stations or depots.

It was found to be important to increase the occupancy of the cars, at least in the morning and afternoon peak periods, to increase the ability of the system to cope with a growing number of passengers.

An increase in the occupancy requires an organized coordination of trips. There are two main ways of doing that: (a) route operation and (b) ride sharing.

Route operation was abandoned at an early stage. The important quality of direct trips would require a great number of routes even if a considerable portion of the trips would still be strictly PRT. Furthermore the route network would have to be changed several times during the day because of variations in travel patterns.

A more flexible way to coordinate trips would be through some sort of organized ride sharing. Ride sharing between prechosen pairs of stations was found to have little effect. The same arrangement for groups of stations had a better effect on car occupancy but had two disadvantages: (a) there would be several intermediate stops for many passengers and (b) the prechosen groups of stations would have to be changed a number of times each day because of the varying travel pattern. Instead it was decided to test a more dynamic type of ride sharing that is more flexible and better exploits the possibilities of a modern control system.

A station is used for ride sharing if the number of incoming passengers is at least two per minute. Passengers with destinations likely to result in ride sharing wait for a certain maximum time, in the present study 3 min, before their car arrives. Then the car leaves whether fellow passengers have arrived or not. The matching of passengers is based on the first passenger's destination order. Other passengers are accepted if they have the same destination or a shorter or longer trip in the same direction. In the present study "the same direction" means that no passenger in a ride-sharing group has a destination that results in more than a 30 percent detour for anyone. The simulations indicate that this detouring possibility will be used to a fairly low degree.

Ride sharing is arranged only from one and the same station, which means that the passenger "knows" the company he or she is going to ride with from the start and there are no unpleasant surprises en route. Moreover tests with a pick-up-en-route strategy showed little effect on average car occupancy.

With this type of ride sharing it was possible to increase the average car occupancy from 1.25 to 1.90 (52 percent) in peak hours, which leads to a 30 to 35 percent decrease in the size of the car fleet needed.

In Figure 3 the trip from Station 0 to Station 1 is initially booked. A new passenger to Station 2 is accepted if Station 2 is close to the route between Stations 0 and 1 (within the small oval in Figure 3). Alternatively a passenger to Station 3 can be accepted if Station 1 is close to the direct route from Stations 0 to 3 (within the large oval in Figure 3). The ovals represent a 30 percent increase in the riding time compared with that of the shortest route.

Assume that the trip to Station 2 is accepted. With two destinations locked (Stations 1 and 2), a third station can be accepted according to one of the following examples.

Points 0, 1, and 2 are now given. Station 4 can be accepted if it is close to the route between Stations 0 and 2. Station 5 can be accepted if it is close to the route between Stations 2 and 1. Station 3 can be accepted if Station 1 is close to the route between Stations 0 and 3 (Figure 4).

Matched passengers are gradually grouped until they fill up a car or until the first passenger has waited for 3 min.

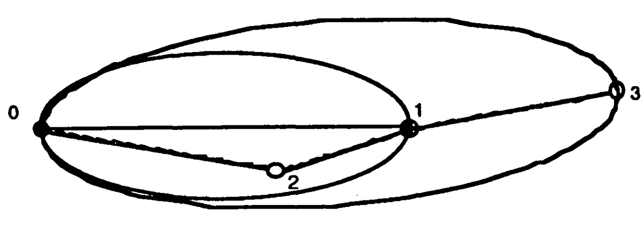

FIGURE 3 Ride sharing.

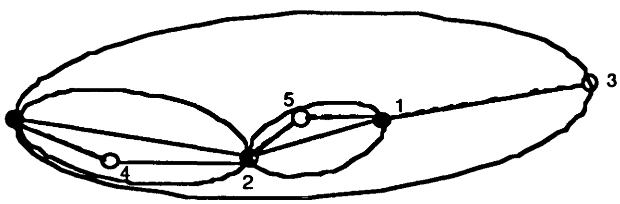

FIGURE 4 Extended ride sharing.

EMPTY CAR HANDLING: DEPOT SYSTEM

The handling of empty cars is one of the big problems in a large PRT system. In the initial computer simulations of the Gothenburg system it became clear that the stations would not be able to house all their needed empty cars without becoming unacceptably large. Therefore special depots for empty cars were introduced at strategic locations in the network to (a) secure the provision of empty cars to subareas in a way that gives short and "guaranteed" waiting times and (b) work as buffers for empty cars to minimize the sizes of the stations. For a more detailed description of vehicle distribution see the paper by Andréasson (this Record).

CONTROL SYSTEM

Four control system principles have been studied and compared: synchronous control, asynchronous control, quasisynchronous control, and point-synchronous control. The characteristics of the four control system principles are briefly described.

Synchronous Control

- A car does not start its transport mission until a time gap is available and booked the whole way (through all the switches) between the start station and the destination.
- The search for and booking of time gaps must be made in a central computer, which then updates booking tables for each switch. The supervision of time gaps and cars is made via the communication system between local systems and the cars.
- The cars are driven at a speed that must be coordinated and synchronized with the generated time gaps.
- In case of disturbances in the system all cars must stop and wait for a replanning of routes and time gaps.

Asynchronous Control

- Each car in the system is allowed to adjust its running according to events that occur en route. The cars can, within certain limits, accelerate and decelerate as traffic conditions demand. The cars behave like cars on a road system.
- A transport mission can start without the whole route to the destination being planned and clearance through all switches secured. Continuous route choices are made during the trip.
- During capacity disturbances in the track network either queues are allowed to be formed or the control system gives the cars alternative routes without disturbing the reliability of the system.

Quasisynchronous Control

- The generation of time gaps is made at a central level, but the assignment of time gaps is made locally (at switches).
- A transport mission starts as soon as a time gap is available at the start station.
- The cars operate at a constant speed, which must be the same as and synchronized with the time gaps. At merge conflicts or disturbances the cars are allowed to back a distance corresponding to a multiple of the time gap.
- At disturbances in the system queues may develop, but redistribution of routes can be made. Queues can be organized at time gap or shorter distances.

Disadvantages of Synchronous, Asynchronous, and Quasisynchronous Controls

Synchronous, asynchronous, and quasisynchronous controls were found to have disadvantages when applied to a large PRT system. The synchronous control is very rigid in its operation, centralized, and sensitive to disturbances (each disturbance has a significant consequence on the operation). The use of asynchronous control carries the risk of congestion, which is difficult to control. Quasisynchronous control corresponds best to the demands of a large system, but it demands the synchronism of time gaps, which complicates the control at switches.

Point-Synchronous Control

It was decided to try to combine the advantages of the three types of controls in a new one: the point-synchronous control. The following principles from the other types of controls were chosen:

- Synchronous control: the assignment of time gaps and an even speed at switches to provide high capacity.
- Asynchronous control: simplicity, in which each car controls its own speed; decentralization, in which all decisions are made in cooperation between the car and the following switch; robustness, in which disturbances are dealt with locally without central replanning; and flexibility, in which rerouting can be made continuously.
- Quasisynchronous control: time gap assignment for the next switch and methods for giving priority and for the continuous choice of routes.

The point-synchronous control principle can be said to be asynchronous control with adaptation to locally created time gaps at switches. The speed is adjusted by the car for arrival at the next switch at the right time and the right speed, just as a pedestrian advances toward a self-revolving door.

SIMULATION SYSTEM

The purpose of the simulation studies was to evaluate different track networks, control principles, and operation strategies. The evaluation included several aspects: (a) travel standard, (b) capacity, (c) productivity, and (d) resources needed.

For simulation results, see the later section System Analysis. For a description of the simulation system see the paper by Andréasson (this Record).

RELIABILITY

Extensive automation of different functions in society has been going on for a long time. Automation as such is consequently not an unknown concept. There have been a number of applications with automated vehicles in the industrial sector for more than a decade. In the public transport area there are well-tried automated systems for rail-bound vehicles as well as buses.

None of these systems, however, has anything like the complexity of a large PRT system in the number of possible origin-destination combinations, the number of switches, and the number of vehicles.

When reading the section System Analysis one should bear in mind that the results are based on simulations that presume 100 percent reliability for all components. Even if the control system can deal with disturbances in the operation, a PRT system of the actual dimensions will demand reliabilities of both vehicles and other installations that are greater than those of today's vehicles and systems.

NETWORK STUDIES

Network Design

A combination of two network models has been in the design of track networks, the spider net model and the grid network, both of which are in general use in traffic planning.

The spider net model is generally used to design plans for the main arterials for car traffic in a city. The model has the advantage of easing traffic pressure on the central area and of creating direct connections in tangential travel combinations.

The grid model is used mainly in older parts of cities that were designed in blocks and with little thought of the larger travel needs of the inhabitants. For both car and PRT traffic the grid model has the advantage that the corridors are easy to arrange for one-way traffic, which can provide higher capacity, simpler intersection design, less space demand, and lower costs.

To exploit the economic and space-saving advantages of the grid model, it was used in the central area of the city and in some residential and industrial areas according to the principle described below. The major configuration of the citywide track network follows the spider net model. The network for the final simulations is shown in Figure 5.

The network has the following dimensions:

- 728 track km (counted in single tracks and including station and depot tracks).
- 391 stations (654 station directions; see later for information concerning stations).

Capacity

The theoretical capacity of a track link at a speed of 10 m/sec is, if all time gaps have one car, 2.250 cars/hr at a time gap of 1.6 sec and 4.500 cars/hr at a time gap of 0.8 sec.

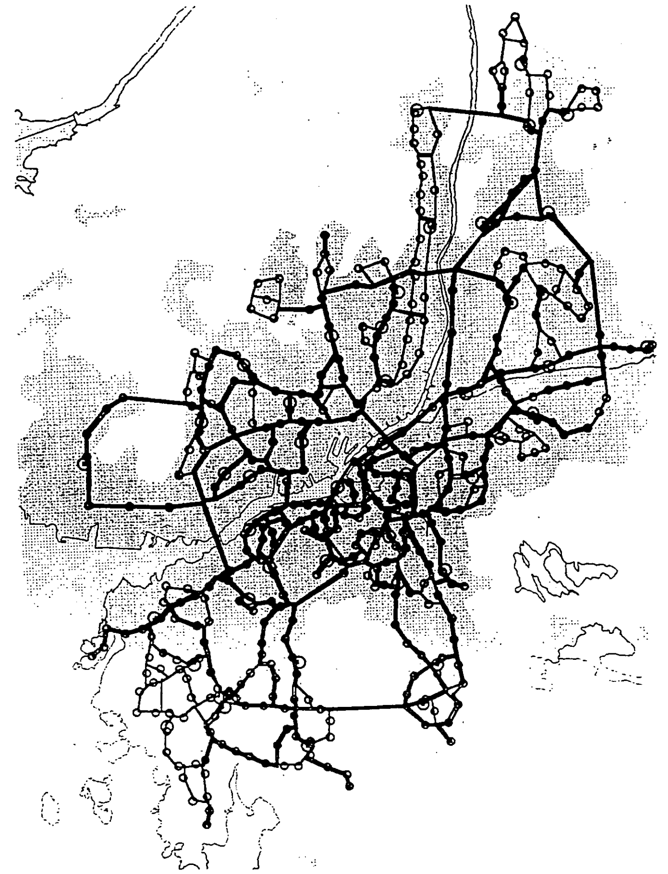

FIGURE 5 PRT network in Gothenburg study.

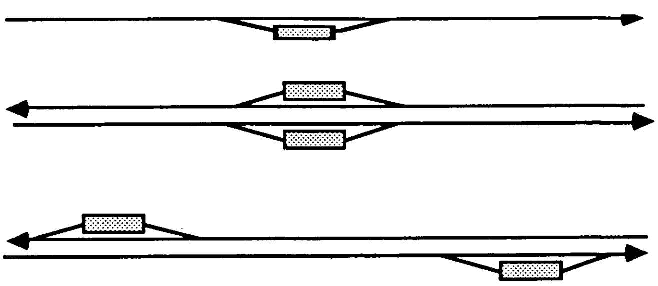

FIGURE 6 Off-line stations.

The simulation, however, used the possibility that empty cars could be run with a shorter safety distance between them. This resulted in link use of up to 2.800 cars/hr in the 1.6-sec time gap case. The capacity of a track link depends on the percentage of empty cars in the flow and in which order they arrive (the possibility of forming platoons). The greatest benefit of this type of operation is reached when both capacity demand and empty car percentage are highest in the central area.

STATIONS

Design

There are two main types of stations: on-line stations and off-line stations. On-line stations have the disadvantage that cars stopping at the station delay other cars. They can only be used on links with very low traffic flows or as cul-de-sac stations on links with no other stations. In the Gothenburg system practically all stations are off-line (Figure 6).

In two-way track sections the two station directions can be split up, which means that the station pattern is better at covering the area and implies shorter average walking distances. In contrast to route traffic a PRT system offers a direct trip from all station directions even if the riding time is a bit longer from the most unfavorable direction. It is the passenger's choice whether he or she wants to walk or ride longer (Figure 6).

The principal function of an off-line station in the Gothenburg study is shown in Figure 7.

The standard station has one entrance from and one exit to the main track. The station has an arrival zone, an empty car buffer zone, and a departure zone. The car buffer zone is installed to provide as short a waiting time as possible. The number of empty cars in the zone should correspond to the car consumption during a time period equal to the running time from the nearest car depot. If the station is used for ride sharing it should be provided with an extra exit track as shown in Figure 7.

With ride sharing, arranged according to the principles described in the section Operational Strategies, cars can use the arrival zone of a station and continue to the main track without being delayed by the car buffer zone or disturbing the operation at the departure zone. This additional exit also has the function that arrived and emptied cars can easily be sent away if the buffer zone is full.

Capacity

The capacities of the stations and the main tracks should harmonize to take care of the forecasted number of passengers.

There are no empiric figures concerning the maximum capacities of PRT stations. In different papers it has been assumed that one car could depart every 10 sec. To be on safer ground preliminary capacity calculations were carried out. They indicate that a station where three cars can be boarded simultaneously could send away at least 500 passengers per hour.

SYSTEM ANALYSIS

Simulations and analyses of the PRT system of the four loading cases presented in the section Travel Demand were performed.

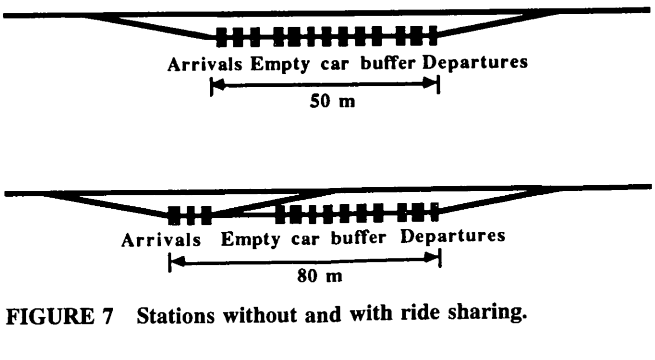

FIGURE 7 Stations without and with ride sharing.

The performance figures presented refer to the highest-load case. Simulations were made for both the 1.6- and the 0.8-sec time gaps.

TRAVEL STANDARD

The travel standard that a PRT system can offer is a crucial factor in the evaluation of the system. It should motivate the costs and other efforts connected with its realization.

The concept of travel standard has many components. Concerning most of the components PRT is superior to conventional public transport. A few important ones follow.

- *Travel time.* The travel time is shorter because of 100 percent direct trips, shorter trip lengths, higher average speeds, and the complete absence of disturbances from other traffic.
- *Headway.* The concept of headway does not exist in a PRT system. Instead there is a waiting time for an ordered car that is considerably shorter than the average waiting time in the present public transport system. The so-called hidden waiting time often discussed in connection with conventional public transport disappears completely.
- *Transfers.* The transfer frequency is 0 percent.
- *Punctuality.* The concept of punctuality does not exist because there are no timetables.
- *Comfort.* All passengers are seated.

The travel standard components mostly used in traffic planning are travel time and trip length, the first as a good measure of the "travel sacrifice" of the passengers and the second as a measure of the "traffic work" and a base for the calculation of energy consumption. Both components are easy to quantify and are thereby useful instruments in a comparison with other types of public transport systems.

Comparison with Present Public Transport System

Table 1 shows the average travel time (excluding walking time, which is estimated to be the same as that in the existing system) in the PRT system outlined here compared with that of the present public transport system (light rail and bus). For the present system the figures represent an average for the morning period from 0600 to 0900 hr, whereas the figures for the PRT are valid for the half-hour of the same period in which ridership is at a maximum. No transfer penalty has been included in the calculations for the present system.

The detailed presentation below refers to the half-hour of the morning peak period in which ridership is at a maximum. The same observations for the afternoon peak period are then provided.

TABLE 1 Average Travel Time in PRT System Compared with That in Present Public Transport System

System	Riding time	Waiting time	Transfer time	Total	%
Present, real time	17.3 min	5.1 min	1.9 min	24.3 min	100
PRT, real time					
0 car riders 2)	10.3 min	1.5 min	0 min	11.8 min	48
30/72 car riders	11.2 min	1.5 min	0 min	12.7 min	52
Present, weighted time 1)	17.3 min	10.2 min	3.8 min	31.3 min	100
PRT, weighted time 1)					
0 car riders 2)	10.3 min	3.0 min	0 min	13.3 min	42
30/72 car riders	11.2 min	3.0 min	0 min	14.2 min	45

1) Riding time weight 1, waiting and transfer times weight 2.
2) Concerning car riders see Travel Demand

Trip Length

The average trip length is 6.7 km at a time gap of 1.6 sec and 6.4 km at a time gap of 0.8 sec. This is because of the higher capacity use of the network at the longer time gap, which leads to a more extensive rerouting (bottlenecks). Some of these bottlenecks could be removed by a more carefully detailed design of the network. There was, however, no time or reason for such a detailed study.

In the present public transport system the average trip length is 7.2 km. The difference is an effect of the spider net model used for the PRT system (see the section Network Studies), whereas the present system is radially oriented.

At this point it should be observed that the present public transport riders are mainly riding in the travel combinations where public transport provides good service. A major part of the transferred car riders would have considerably longer trip lengths in the present public transport system.

Travel Time

As shown in Table 1 the travel times of the present public transport riders would be reduced by more than 50 percent in a PRT system. For the transferred car riders the travel times would not be as short as they are today by car, but PRT would be a fairly acceptable alternative.

Waiting Times

The waiting times at stations are approximately the same in both time gap alternatives (1.5 min). Part of the waiting time is needed for the short walk from the ticketing machine to the departure point. The average waiting time includes the somewhat longer waiting times for some of the ride-sharing passengers. Some 99 percent of the passengers have waiting times shorter than 4 min.

Delays

At high capacity use of the system queues can develop at certain merge points. This is observed by the control system, which reroutes the traffic around these points. In the simulation, however, this does not happen instantaneously and certain delays can arise before the queue has disappeared. In a full-scale control system the rerouting can be accomplished more quickly, which will reduce delays. The average delay because of speed adaptations at switches is small, less than 1 minute in both time gap alternatives.

The maximum delay, which happens to a very limited number of passengers, is also small in the time gap alternative of 0.8 sec and is probably even smaller outside peak hours. In the time gap alternative of 1.6 sec the maximum delay was found to be more than 5 min in the highest loading alternatives, but it involves a limited number of passengers. The maximum delay depends on the bottleneck effects discussed and it is possible to reduce this by a more detailed network design. It indicates, however, a rather large sensibility for disturbances, as is the case in a car traffic system with a high capacity use.

Capacity

The system can cope with the high travel demand without any inconveniences other than the maximum delays presented. The number of passengers at the stations at the end of the half-hour in which ridership is at a maximum corresponds to a normal inflow, and the passengers will have the same waiting time as the average. With the present daily variation of traveling the PRT system could provide more than 600,000 trips per day.

Productivity

Fully 40 percent of the passengers in the half-hour in which ridership is at a maximum are ride sharing, which results in an average car occupancy of 1.9 persons.

The number of passenger and car kilometers is practically the same in the two time gap alternatives, 1.6 and 0.8 sec. The number of empty car kilometers is about 45 percent of the total.

The number of transport missions per car hour in the period in which ridership is at a maximum is slightly more than two, which indicates that each car carries out 20 to 25 missions per day and serves 35 to 45 passengers per day.

Resources

The car fleet needed for the operation in the half-hour of the morning period in which ridership is at a maximum is 15,000 cars with the time gap alternative of 0.8 sec and 17,000 cars with the time gap alternative of 1.6 sec.

Depots

The PRT system has been provided with 45 depots for empty cars (see the section Empty Car Handling). The depots have the following functions:

- To secure the provision of empty cars to subareas in a way that gives short and guaranteed waiting times.
- To work as buffers for empty cars to minimize the sizes of the stations.

The sizes of the depots needed vary between 50 and 250 cars, depending on the size of the subarea (number of stations) it must serve. A more sophisticated control system in which not all empty cars must go via a depot should bring down the depot sizes.

Altogether the depots can house about 7,000 cars, which means a total track length of 25 km.

Stations

The 654 stations (one directional) are of various sizes, depending on the different needs for empty car buffers. Only 9 percent of the stations demand a car buffer of more than 10 cars. A detailed study of the depot function would probably reduce the size of the largest stations to this figure or less.

Night Storage of Cars

The outlined depots can house about 40 percent of the car fleet and the stations can house about 30 percent. The other 30 percent must be stored somewhere else at times when the PRT system is closed or is seldom used. The most economical way of doing this is to use the track sections in the network. Such sections can be one direction in two-way track links that are closed in a way that travel is not affected except for longer trips, because of rerouting around them. The track length needed for 5,000 cars is about 20 km, which can easily be found in the network.

AFTERNOON PEAK PERIOD

Travel times and trip lengths during the afternoon period are practically the same as those during the morning period.

The waiting times, both the average and the maximum, do not show any differences between the two time periods, nor do the delays because of high capacity use.

Ride sharing is somewhat higher in the afternoon period, probably because a higher percentage of the passengers will have their start stations in a concentrated central area. The average occupancy of the cars is, however, the same as that in the morning period because of the lower concentration of passengers at the rest of the stations.

Also in the afternoon the travel demand can be accommodated without any passenger queues at stations at the end of the peak hour.

The percentage of productive cars is the same as that in the morning period.

The number of transport missions per car hour in the afternoon peak period is slightly lower than that in the morning peak period.

The same total car fleet was used for the simulations in both time periods.

CONCLUSIONS

The following conclusions drawn from the studies presented in this paper and the discussions during the work can be made.

- A PRT system provides a travel standard that is clearly superior to a conventional public transport system. The travel time (excluding walking time) would be reduced by 50 percent or more. Walking times are estimated to be the same as those in the present system.

This superior travel standard is also created for origin-destination combinations in which the public transport service presently is poor, which makes PRT an acceptable alternative to car riding even if today's car travel times cannot be provided on all trips.

- A PRT system that covers most of the city can be given a capacity that allows an increase in public transport ridership by up to 80 percent, corresponding to a transfer of close to 60 percent of the present car riders in the city during peak hours.

This is estimated to cover the possible transfer of car riders because of the attractiveness of the PRT system and the number of people who can be encouraged to leave their cars by present or future traffic policy measures.

- A PRT system with the characteristics described above is large. It includes some 700 track km and more than 600 stations. As a comparison, the total length of the present tram and bus routes is about 600 km and the number of stops is somewhat greater than 600.
- The realization of such a system is expensive, because an automated system demands an infrastructure of its own that is completely separate from that for other traffic.
- A large PRT system will demand a high degree of reliability of all the components included, hardware as well as software. Estimation of the possibility of reaching the necessary reliability demands extensive studies and full-scale tests.
- The architectural aspects of the PRT system have not been studied in detail. Discussions, however, point to the difficulty of using elevated tracks in the central area of the city. Tunnels may have to be considered.
- From a land use point of view the effects of an increased and more evenly distributed accessibility are of a long-term nature.
- Present knowledge is not sufficient to implement a PRT system large enough to function as the only public transport in a city. An immediate decision is not necessary, however.

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