Personal Rapid Transit in Stockholm – Market demand and Economic Appraisal

Author: Mr Göran Tegnér, M. Pol. Sc.
Business Manager Transportation Studies
TRANSEK Consultants Company, Solna, Sweden
Phone: +46-8-735 20 10; Fax: +46-8-735 20 30; e-mail: goran@transek.se

1. ABSTRACT

This research project deals with the problem of introducing a potential demonstration-track in the form of a PRT system somewhere in the Stockholm region. The aim of the study is to find an answer to the following main questions:

i) Which is the best site for such a test-track of a PRT system for Stockholm?
ii) Which is the most probable demand for such a PRT system, and how much traffic would be diverted from the private car and other modes of transport and how much would be newly generated?
iii) Which is the economic viability of such a PRT system in Stockholm in terms of user benefits, system costs and overall cost-benefit ratio?

In order to answer these three highly important and interesting questions, the study is divided into the following major parts - a PRT Market Demand Analysis; and a PRT Economic appraisal.

The research results and findings were documented in a research report (in Swedish) by the end of 1998. This paper describes the contents of the project, the methods chosen for the analyses, and the results and research findings.

2. Personal Rapid Transit (PRT) – individual trips in public vehicles

Personal Rapid Transit (PRT) offers individual trips in public vehicles – a competitive alternative to the most popular mode of urban transport – the private automobile. PRT is developed to offer some of the advantages of the private auto:
+ It departs on demand without any timetable.
+ It runs the quickest path without any stop and without any transfer.
+ It offers a private trip alone or together with passengers of your own choice.

At the same time one would like to avoid some of the major disadvantages of the private auto:
- Noise and exhausts.
- Congestion and accidents.
- Parking demand.

PRT is a system of small, automated vehicles on their own guideway that is demand-responsive and offers a direct trip to the destination without any stop en route.

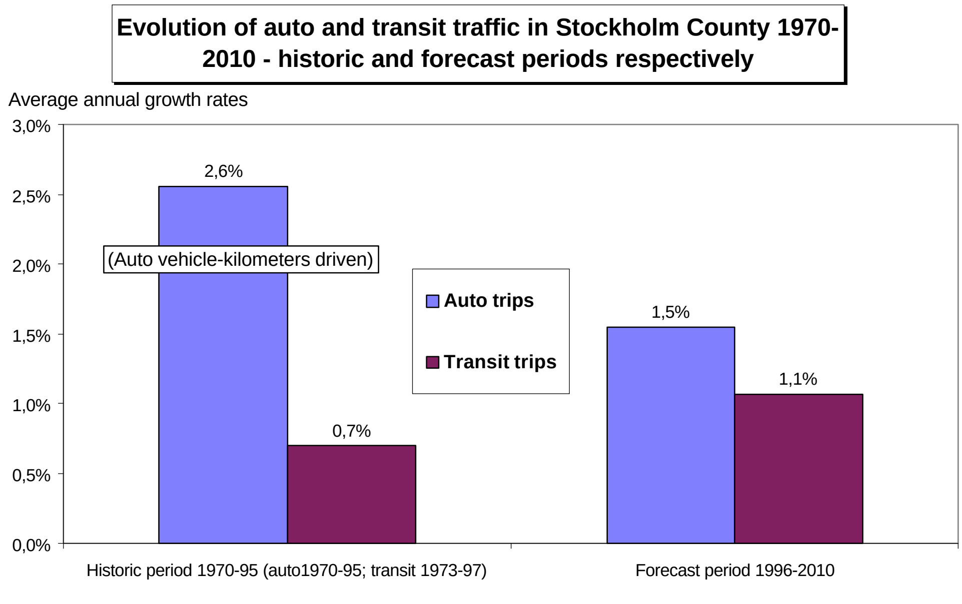
The PRT solution with many small vehicles can be derived from many different perspectives:

- The trip maker should not wait for the vehicle to come – the vehicle should wait for the passenger
- If one does not force several passengers to travel together, there is no need for large vehicles. The load will resemble that of a taxicab.
- The track should not be larger or more expensive than what is needed. The track cost increases with the weight of the vehicle. One has to distribute the weight. A car with 4 passengers every second gives the same capacity as a traditional train every 15-minute with 1,800 seats.
- The stations should be short. This will be possible with a constant turnover of vehicles and travelers, i.e. dense departures with small vehicles.
- If the vehicle is driven automatically, the only reason for large-scale vehicles falls short. The passenger service governs the traffic performance, not the driver cost. Small vehicles demands a very dense traffic, which means that vehicles are not allowed to stop for boarding and alighting on the main track from capacity reasons. Also, unnecessary stops for service reasons should be avoided. Therefore, all PRT systems are designed with stations located on sidetracks.
- Short time slots between vehicles do not allow switches on the track; this would be too time-consuming. Instead the vehicle chooses its route through fixed switches.

- Acceleration and deceleration does not allow standing passengers. Therefore the system is designed to carry seated passengers only. Guaranteed seating capacity also contributes to the attractiveness of the system. Wheel-chair passengers are foreseen to be able to travel in all PRT-vehicles.
- A PRT ride without a stop between origin and destination station is not only comfortable and convenient. The energy consumption is less than one fourth of that of an automobile.

3. The long-term evolution of auto and transit traffic

Transek Consultants was commissioned by the Regional Planning and Urban Transportation Office, Stockholm County Council to investigate the long-term evolution of auto and transit traffic (Ref. 1, 2, 3 and 4). The estimated auto traffic production in terms of vehicle-kilometers has increased by 88 % between 1970 and 1995 or by 2,5 % annually. The corresponding transit ridership, estimated through ticket sales records, is estimated to have increased by 18 % or by 0,7 % annually between 1973 and 1997. The imbalance of modal development, both in the retrospective and in the forthcoming period is shown below:

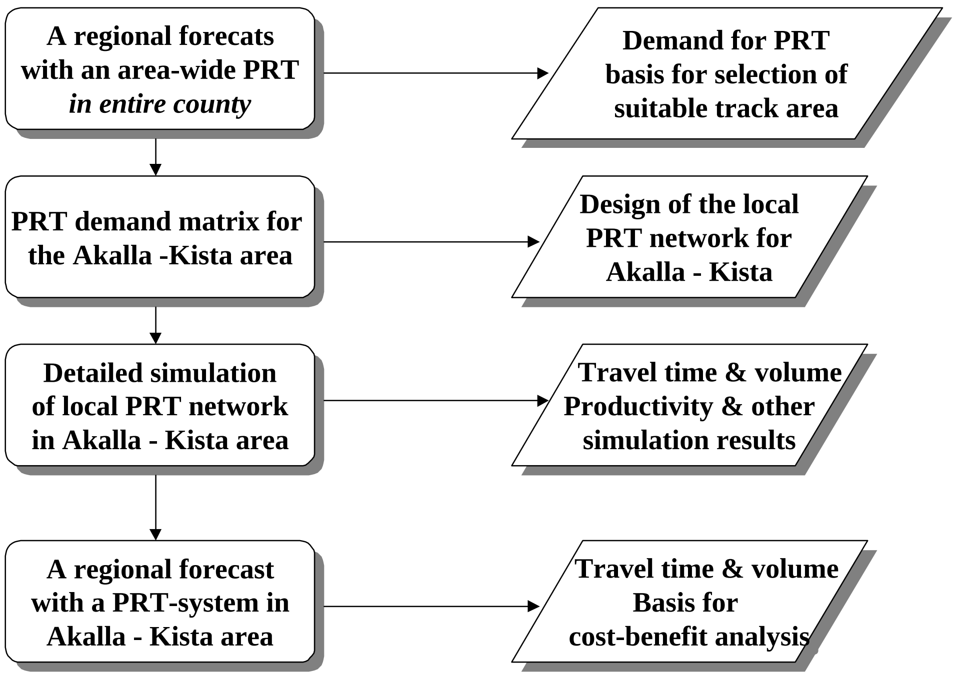


Our conclusion from this observation is that the present type of transit systems (bus, metro and commuter rail) is insufficient in its performance to attract new travelers to cope with the self-service system of the automobile. There is a strong need for a high-quality performance transit system – such as PRT – if the urban transportation problems of too low efficiency, too high accident rates and environmental air pollution should be curbed.

4. PRT in Stockholm – an efficient and sustainable transport system

The purpose of this chapter is to illustrate the *area-wide* potential of a high-level-of-service transit system in terms of generalized travel times and market shares – in comparison to the more traditional transit modes, such as bus, commuter rail and subway. A second purpose of this exercise is to form a basis for the selection of the best site for a PRT demonstration track in the Stockholm Region. Therefore, a PRT trip demand analysis has been carried out for the entire Stockholm County Area (population; 1,775,000 inhabitants in 1998), with the simplified assumption that a PRT-station would be (theoretically) available in every traffic zone (1,043 zones) and running on the present major road links in the network. The existing transit modes are assumed to prevail. The demand procedure is summarised in figure 2.

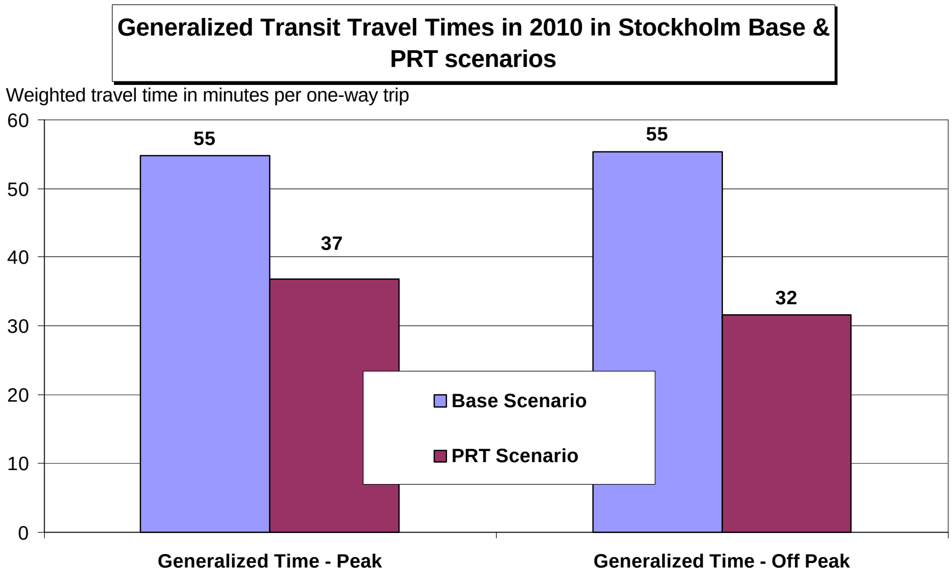
PRT demand in four steps



This formed a basis for considerations of the best suitable location for a PRT demonstration track.

The major changes in the generalized travel times that could be achieved by the PRT system, are mostly a dramatically reduction in the waiting and transfer times, compared to the present day modes of mass transit.

As the PRT system operates as an automated and a demand responsive system, the time spent waiting for the vehicles, does not differ at all between peak and off-peak time periods; this being the opposite for today's' manually driven fixed line service. Thus, the major travel time gains with PRT will occur during the off-peak period. The weighted generalized time[1] is calculated to be reduced from almost one hour (55 minutes) in the base scenario to a little more than a half-hour in the PRT scenario. (Figure 3)

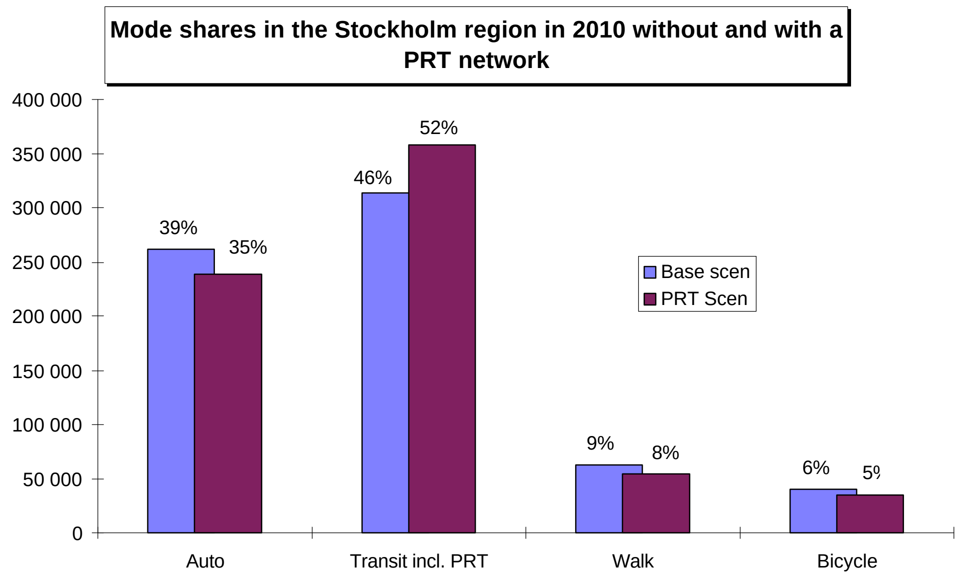


If an *area-wide PRT system* would be introduced in all Stockholm region, a substantial modal shift from the auto mode (-4 % units) would occur; also a slight shift from the walk and bike modes towards the transit modes, including the new area-wide PRT-system.

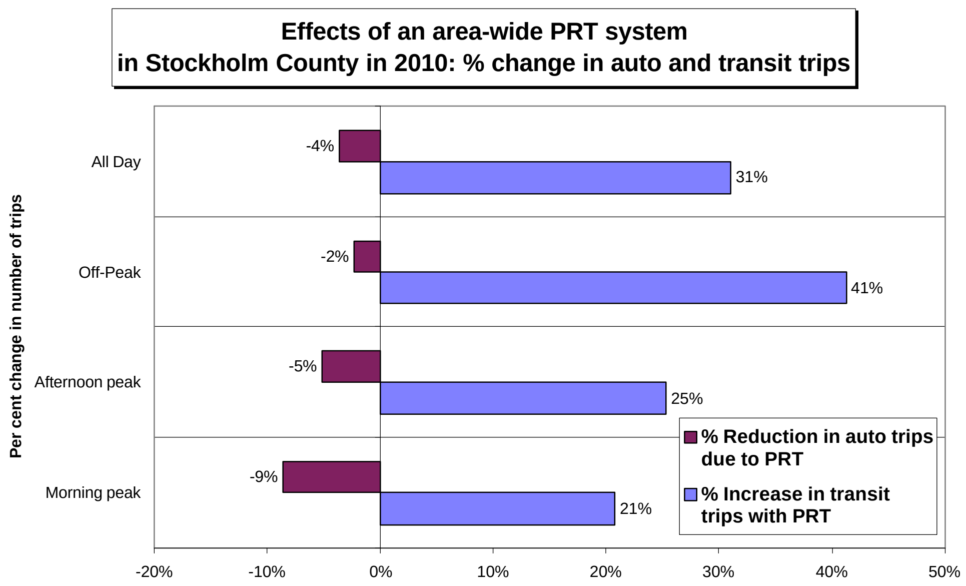
---

[1] The weights are 2 for the walk, wait and transfer travel time and 1 for the in-vehicle travel time (see Reference 6).

The transit modal split is estimated to augment from 46 to 52 % by the new PRT system, i.e. a 13 % growth in market share:



The number of auto trips is calculated to be reduced by 9 % in the peak period, with its dramatic and positive impacts in terms of reduced congestion, air pollution and road traffic accidents. Transit trips – including the new PRT mode – is forecast to expand by almost one third (31%) during all day, and by 41 % in the off-peak period:



5. The demand for PRT-trips in the Akalla – Kista area

The choice of the most suitable location for a potential PRT demonstration track is based on at least six various criteria:

- Areas (in fact origin-destination pairs) with a generalized time elasticity with respect to the demand for transit trips(numerically) above –2.0 and a minimum number of transit trips
- Areas with a travel time relationship between the transit and auto mode of three or more and a minimum number of transit trips
- Areas with an even distribution of peak and off-peak trips and a minimum number of transit trips
- Areas with a high traffic load and a minimum number of transit trips
- Areas with a high load of estimated PRT trips per track-kilometer
- Robust areas with a combination of high densities in the number of:
  - Occupied residents per square kilometer
  - Work-places per square kilometer
  - Household income potential per square kilometer
  - Privately owned automobiles per square kilometer.

Maybe, the most important criteria above all, are the support from local authorities. By coincidence, most of the areas selected according to the above mentioned six criteria, are also preferred locations by the local municipalities:

- Handen Center
- Järfälla-Kista-Akalla-Häggvik
- Karolinska Institute & Hospital-Solna-Sundbyberg
- Sigtuna - Arlanda - Märsta
- Skärholmen-Kungens kurva-Huddinge C-Huddinge Hospital
- Södertälje Centre
- Upplands-Väsby

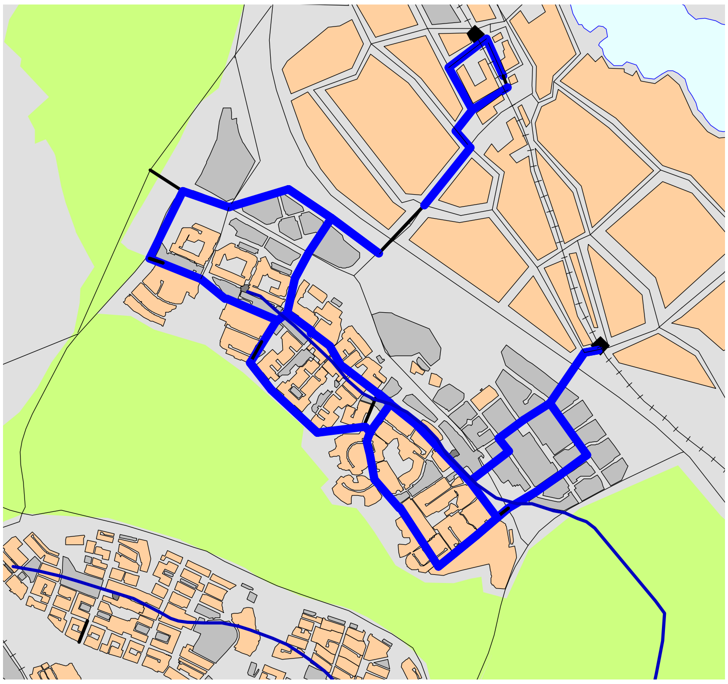
A corridor from the cities of Sundbyberg – Solna – Karolinska and the northwestern part of the inner city have been excluded due to political and visual intrusion points of view.

The major results for the studied PRT network alternatives are shown below

Indicator/ Network alternative	**Kista**	**Kista-Helenelund**	**Akalla-Husby-Kista**	**Akalla-Husby-Kista-Helenelund**	**Akalla-Husby-Kista-Helenelund-Sollentuna C**
Track lenght, km	9	11	18	20	28
Number of stations	9	10	19	20	26
Vehicle fleet size	31	38	82	121	275
PRT Trips per day	2 750	3 460	6 125	7 460	12 735
Daily trips per track km	305	315	340	375	455
Average trip length in peak	2,3 km	2,6 km	3,0 km	3,6 km	5,8 km
Average trip time in peak	4,1 min	4,6 min	5,2 min	6,1 min	9,9 min

The structure of the entire network examined is shown below:

The PRT networkfor Akalla-Kista-Helenelund-Sollentuna C



The results indicate that the number of daily trips per track-kilometer increases as the network size augment from 9 to 28 kilometers. This is an indicator of the cost-benefit ratio, as the number of trips is associated with user benefits, and track size with its costs.

6. A Stated Preference Study on PRT comfort and convenience

A Stated Preference survey was carried out with the aim to investigate the willingness to pay for PRT comfort and convenience factors, such as:

- In-vehicle travel time with PRT
- PRT headway
- In-vehicle travel time with bus
- Bus headway

In all 162 persons were interviewed in the Barkarby – Kista area in the northwestern suburbs of Stockholm, of which 50 % were auto drivers and 50 % transit users.

- The result for the onboard travel time as well as for the trip frequency (or headway) showed *no significant* deviation in the travel time component value for a PRT trip compared to a bus trip.
- To have *manned stations* - instead of unmanned stations – has a very high value, 0.50 US$ per trip, reflecting the insecurity of today's mostly unmanned metro and rail stations in Stockholm.
- Travelling 5 meter above the surface with a PRT vehicle, is shown to have a slight negative value of -7 cents per trip.

Besides, the following types of *attitudinal* questions also revealed some interesting results:

- On the question: ”I am uninterested in PRT, as it has a negative visual intrusion (makes the city look more ugly)”, only 25 % agreed. Therefore, visual intrusion does not seem to be a major drawback for PRT.
- On the question: ”I am uninterested in travelling by PRT if I have to share my trip with other passengers in peak hours”, only 13 % seem to think this might be any problem. More than two thirds of the respondents denied this would be a problem.
- Of all respondents, about half of them felt insecure travelling in a driver-less vehicle, of which 15 % had a very strong expression against it; while 30 % declared this was no problem. This shows there is a need for more information to the customers of this new kind of driver-less transit service (which is not in operation anywhere in Sweden so far). Professor Elsa Rosenblad's focus group interviews in Gothenburg show that this fears for automation disappears after a proper information about it (Ref. 5).
- On the question: “ I feel unsafe travelling 5 meters above the ground”, only 20 % confirmed this negative statement. As many as 60 % expressed their view, this was no problem to them. As the average monetary value was slightly negative, we conclude that there is a minority with a very strong negative feeling for going elevated (there is no such transit system in Sweden except for ski lifts).

- The last question was “If a PRT system would be built between Barkarby and Kista, how often could you imagine to go with it”? Almost 65 % or two-thirds could imagine going by PRT regularly or sometimes and only 16 % answered ‘seldom’ and just 3 % said ‘never’. These positive results are well in accordance with the research findings from Professor Elsa Rosenblad’s study in Gothenburg (Ref. 5).

7. A Cost-benefit Analysis of a PRT network in the Akalla-Kista Area

Several cost-benefit analyses have been carried out for the five various PRT-networks (described in section 4 above). Our findings reveal that the best cost recovery is obtained for the largest PRT network, i.e. the Akalla-Husby-Kista-Helenlund-Sollentuna network.

Investment cost data were obtained from Raytheon’s PRT2000, and from two conceptual Swedish systems - Swedetrack’s FlyWay (a suspended PRT system) and SkyCab (a supported system). A high (0,24 US$) and a low (0,17 US$) operating cost per passenger-kilometer is also associated with the US PRT2000 and the two Swedish conceptual systems, respectively.

The analysis is carried out over the calculated economic lifetime of the PRT project, 60 years. In our recommended cost-benefit analysis procedure, we consider higher values of time, comfort, safety and environmental impacts over the total time span for the project. This is related to the assumed average long-term economic growth rate of 1-2 % annually (GNP or household disposable income per capita). A present value and related annuity benefits and costs are then calculated.

As a consequence of these assumptions, the first year’s benefits from the PRT project will increase over time due to the fact that the travelers will evaluate the benefits at a higher value each year, as prosperity grows in the future years to come. As a sensitivity analysis we have also calculated the benefits without an adjustment of the behavioral values over time (not presented in this paper). The table below shows that a PRT demonstration network in the presented Akalla – Husby – Kista –Helenelund – Sollentuna area of Stockholm would be economically viable and well justified in the low cost alternative. The cost-benefit ratio is calculated to be 1,5, which means that one dollar spent on PRT in this area yields one dollar and 50 cents in total benefits. Even the more expensive Raytheon PRT 2000 system would yield 70 cents per spent US dollar at its full-calculated price.

With a 25 % reduction (covering engineering, construction, management, administration, start-up and testing[2]), also the PRT 2000 system would balance benefits and costs (benefit-cost ratio equals 1,0).

Summary result: Benefit – Cost Analysis of PRT in Akalla-Kista-Helenelund-Sollentuna

Cost item; Annual Costs, MSEK[3]	**FlyWay**	**PRT 2000**	**PRT 2000 (less 25% overhead)**
Capitalized Investment costs	63 (investment: 1,885)	152 (investment: 3,428)	116 (investment: 2,628)
Annual Operating costs	81	133	106
Cost of public capital; shadow price	33	65	51
VAT tax burden	53	105	82
TOTAL ANNUAL COSTS	**230**	**455**	**355**
Benefit item; Annual Benefits, MSEK[4]	**FlyWay**	**PRT 2000**	**PRT 2000 (less 25% overhead)**
Transit travel time gains, incl. .PRT	178	178	178
Ticket revenues, incl. less public capital	26	26	26
Traffic safety gains from less auto trips	48	48	48
PRT Comfort & Convenience gains	42	42	42
Less congestion due to less auto traffic	21	21	21
Health and Environmental gains	24	24	24
TOTAL ANNUAL BENEFITS	**339**	**339**	**339**
NET BENEFITS (Benefits – Costs)	109	-116	- 16
BENEFIT/COST ratio	**1,5**	**0,7**	**1,0**

A PRT System in the Akalla - Kista area of Stockholm would yield a wide range of positive and desired impacts:

- Travel time and comfort and convenience gains for PRT users
- A modal shift from auto to transit (including PRT) modes of transport
- Traffic safety gains
- Eased congestion from less auto traffic
- Health and environmental gains.

---

[2] These figures are based on the SeaTac study: Personal Rapid Transit (PRT) Feasibility Project-Executive Summary and Technical Appendices, City of SeaTac, August 1997)

[3] One million Swedish Crowns roughly corresponds to 125,000 US$ (exchange rate 1 SEK = 0,13 US $)

[4] One million Swedish Crowns roughly corresponds to 125,000 US$ (exchange rate 1 SEK = 0,13 US $)

From the analysis, one could estimate the maximum investment cost per system-kilometer for a PRT network of the relevant size to be about 115 MSEK/km (corresponding to 15 million US$ per track-kilometer). The desired minimum peak load should amount at least 500 passengers per peak hour and track-kilometer.

From our area wide PRT demand study (section 3 above), we have indicators of the cost-benefit ratio for 14 potential areas within the Stockholm region. As a rough estimate we have used the number of daily trips per track-kilometer. Bearing in mind, that this is just a crude indicator of economic viability, one could however conclude that there might be at least six potential areas, with an even higher possible return in terms of social net benefits over costs:

These areas are in order of cost-benefit ratio:

- Odenplan - Karolinska Institue & Hospital - Solna
- Bergshamra - University of Stockholm - Odenplan
- Solna Center – Sundbyberg
- Solna Center - Bergshamra
- Barkarby – Akalla.
- Södertälje C

Our recommendation is therefore clear – a PRT system for Stockholm provides such a broad range of desired qualities, that it should be given highest priority in research, development, testing and demonstration for implementation in the Stockholm Metropolitan area.

8. References

1 Tegnér, G. ; Loncar-Lucassi, V., (1997) "Demand for Road Use, Accidents and their Gravity in Stockholm: Measurement and analysis of the Dennis Package". Transek AB, Stockholm, 18 p.

2 Tegnér, G.; Loncar-Lucassi, V. (1997) "Time-series Models for Urban Road Traffic and Accidents in Stockholm". Paper presented at the Aalborg University, Denmark.

3 Tegnér, Göran B., Loncar-Lucassi, Vesna M. (1997): "An Analysis of Urban Road Traffic Safety in Stockholm - The use of aggregate time-series models with the TRIO programme". Proceedings, the European Transport Forum Annual Meeting, 1-5 Sept, 1997, London.

4 Tegnér, G; Loncar-Lucassi, v; Nilsson, C., TRANSEK Consultants; and Holmberg, I., Gothenburg University, Department of Statistics, School of Economics and Commercial law, (1998) “The Demand for Public Transport Trips in Stockholm County – a two-stage aggregate, non-linear time-series model. Paper presented at for Economics and Institutions of Transport, May 25th - 27th, 1998, Borlänge, Sweden.

5 Rosenblad, E., (1997) “Spårtaxiresenärer – brukares möte med ny teknik”, (in Swedish), CTH Rapport 1997:10, Chalmers Tekniska Högskola, Göteborg, Sweden

6 Tegnér, G., (1997) “Market Demand and Social Benefits of a PRT System: A Model Evaluation for the City of Umeå, Sweden”. Infrastructure, Vol. 2, No. 3, pp. 27-32, 1997, John Wiley & Sons, Inc.