Staged Introduction of PRT with Mass Transit

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Abstract

Personal Rapid Transit (PRT) offers driverless, on-demand and non-stop travel over a network of dedicated guideways separated from other traffic.

During early phases of introduction, many public transport trips require transfers to/from scheduled route services by bus, tram, subway or train. This paper describes a model for trip assignment and mode split estimation in mixed public transport networks. If non-transit modes remain unchanged, changes in transit disutility contain sufficient information to estimate increased transit ridership.

The mixed mode assignment has been integrated in the generic PRT simulator ”PRTsim” and has been applied in a case study of PRT mixed with scheduled bus services in Umeå Sweden.

Results show that the introduction of a first stage PRT network not only attracts trips from car, bicycle and walk to PRT but at the same time attracts more trips to remaining bus services. Full implementation of PRT is estimated to more than double transit ridership.

Personal Rapid Transit

Personal Rapid Transit (PRT) is driverless, demand-responsive individual transport in small vehicles on guideways separated from other traffic. Stations are off-line so that passing traffic is not impeded. Trips are non-stop along the quickest path to the passenger destination. Travelling is private or with chosen company. Guideways are normally elevated but may be at grade or in tunnels as long as they are safely separated from other traffic, pedestrians and animals.

From a service point of view, PRT is similar to taxi although automated, without traffic congestion and at a lower fare. The Swedish term for PRT translates to ”rail taxi”. One PRT-like system with larger vehicles has been in successful operation in Morgantown WV since 1975. During 2010 PRT systems are being installed for public operation at Heathrow airport and in Masdar City, Abu Dhabi. Another PRT system has been contracted for Suncheon City in South Korea.

From a modelling point of view PRT offers much higher level-of-service. Travel times are reduced to about half compared to mass transit. Waiting-times are typically less than one minute and riding-times are short without stoppping. Conventional models for transit which are based on fixed routes and service frequencies cannot be applied to PRT.

This paper deals with the problem of estimating the demand for PRT trips in a mixed network with scheduled services. We then analyse the impact of PRT on mode choice and transit trip-making. As a case study we present possible implementation stages for PRT in the Swedish city of Umeå.

Implementation Strategies

When a new transit mode is introduced into an existing system, it will almost certainly be built in stages. In early stages of introduction only a limited numer of travel relations can be served. Even if the new system offers direct trips within the system, many trips will involve transfers between the traditional system and the new. The advantages of transfer-free trips are limited in early stages while they become more obvious as the system is expanded.

The initial stages of introduction are the most critical with high investment, public sceptiscism and limited benefits. Control system and some other common costs burden the first stage while the benefits in terms of served relations grow exponentially with system expansion.

Careful planning and analysis of costs and ridership is called for in the first stages. Later expansions willl normally offer higher benefits per unit of investment.

The following are some suggested considerations in selecting the first stages of PRT implementation:

• Plan the total system of which the first stage will form a part

• Identify major trip generators/attractors within limited distance to be connected in the first stage

• Include connection points to other transit modes

• Seek support from real estate owners, developers and local businesses

• Avoid ”sensitive” public places such as cultural and historic landmarks

• Avoid narrow streets in housing areas

• Connect stations in a way consistent with the planned total system.

Most of the opposition and debate will be stirred up by the first stage. Later stages have the benefit of public and decision-makers being familiar with the system, its visual impact and level-of-service. Later stages will also be less costly per added km and increase system attractiveness more than proportionally.

Mixed-Mode Transit Assignment

A new assignment model for mixed networks has been implemented in the generic PRT simulator ”PRTsim”. The underlying assumption is that each passenger will choose the route combination that minimizes his or her expected disutility (weighted travel time components). In the new model PRT is introduced as a generalized ”route” visiting all PRT stations with a matrix of travel times for each relation and average waiting-times at each station.

Routes with fixed scheduled can be served by bus, LRT, Metro or train. We will refer to all of them as ”bus” for simplicity.

In the assignment algorithm direct connections using one single bus route or PRT are calculated first. The expected waiting-time depends on the sum of frequencies of acceptable routes and to what degree their time-tables have been coordinated. Combinations of ”routes”, including PRT, are then evaluated with waiting at the transfer plus a penalty for each transfer until no further improvement can be made.

As a result of the assignment, the model produces route link loadings, network flows on bus and PRT, a PRT demand matrix and a matrix of weighted travel times (disutilities) between all transit stops/stations.

The PRT demand matrix is used in the PRT simulation as a basis for dimensioning vehicle fleet and stations, identification of possible bottlenecks, trimming of operational strategies etc.

Improvements in weighted travel times of the combined system of buses and PRT will attract more passengers from other modes (car, bicycle and walk) to transit. In the following section we will estimate these changes in transit ridership.

Elasticity of Transit Demand

So far we have modelled the assignment of given transit trips on different transit modes and routes. With improvements in transit supply we can expect more travellers to change from other modes to transit.

The commonly used choice model for mode split is the so called ”logit” model. The share of public transport z is given by the function

$$z = e^{-x} / (e^{-x} + e^{-y})$$

where x and y are the disutilities or generalized costs of transit and other modes respectively. The disutility is a weighted sum of travel time components, costs and extra penalties for transfers and for certain modes. The disutility of transit has the form

x = (ride-time + w1 * walk-time + w2 * wait-time + tp) * vt + fare + mp

where the weights w1 and w2 of walk-time and wait-time typically has values around 2 to 3. The penalty tp for transfers may be 5-15 minutes for each transfer. vt is the value of time and mp is the mode penalty for public transport versus e.g. car.

Our aim is to estimate the effect of reduced transit disutility (value of x) on the mode share z. The dependence of z on x is an S-shaped function decreasing from 1 to 0 for increasing values of the disutility x, (figure 1).

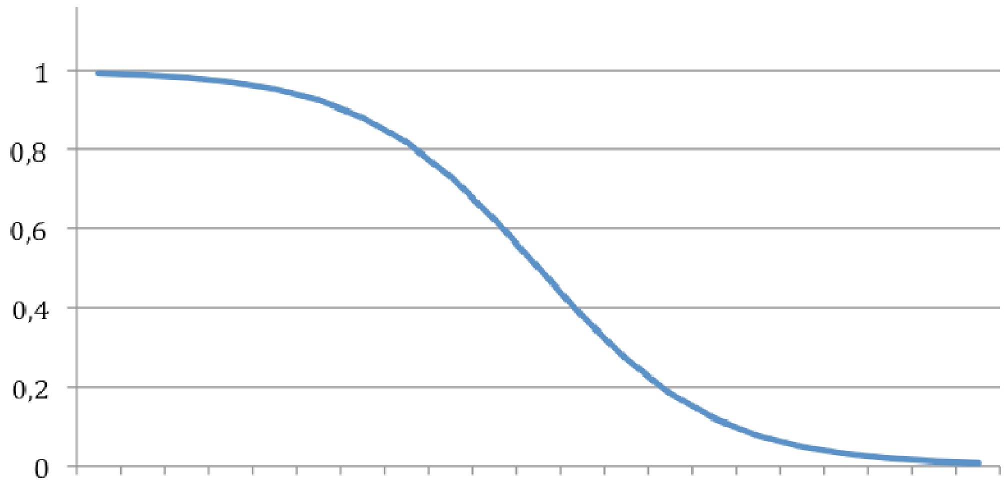

Figure 1. Mode share of transit as a function of disutility (weighted times)

The present mode share and the present travel standard define the position of the curve and where we are on the curve. This means we can calculate ridership effects of improved transit without knowing anything about the other modes, only assuming that they remain unchanged.

Since the relation is non-linear it is not possible to use a fixed elasticity for ridership effects of improvements. Each OD relation is at a different point with a different elasticity. For large improvements we must take the curvature into account. The resulting method is referred to as ”arc elasticity”.

Mode Penalties

Most people choose car over transit to a higher degree than can be explained by differences in travel time and travel cost. Model calibrations in Sweden indicate that most people are willing to pay about 2.5 € extra for a car trip versus a bus trip even if time and other costs were equal. This constant (mp) is included in the Logit choice model.

Before PRT has been implemented in urban applications it will not be possible to estimate its mode penalty. The question is whether travellers perceive PRT as a small demand-responsive bus or as a car on guideway. Interviews with a number of prospective passengers indicate that PRT is perceived as half-way between car and bus, indicating a mode penalty around 1.2 € versus car.

For trips which were previously made by bus and now entirely by PRT the change in mode penalty is included in the change of service. Trips using both bus and PRT are assumed to be associated with the same mode penalty as for bus.

Application in Umeå

Umeå is a city in the north of Sweden with 112 000 inhabitants. Eight bus routes (figure 2) cover a 44 km network. Bus routes offer service every 15 to 30 minutes and carry 8 % of all trips in Umeå. Remaining trips are 57 % by private car, 19 % by bicycle and 16 % walking.

A recent study by WSP and this author (Tegnér et al 2009) outlined a PRT network (figure 9) to be introduced in stages. The existing bus services in Umeå, if remaining unchanged, are estimated to attract 4 000 passengers during the morning peak hour in the year 2020. No decision to implement PRT has been taken so far.

Next mixed-mode transit assignment by PRTsim is used to calculate individual travel paths and travel times. Arc elasticity is applied to each OD relation to estimate ridership in each stage of implementation. The new travel demand is then again assigned to the mixed-mode transit network.

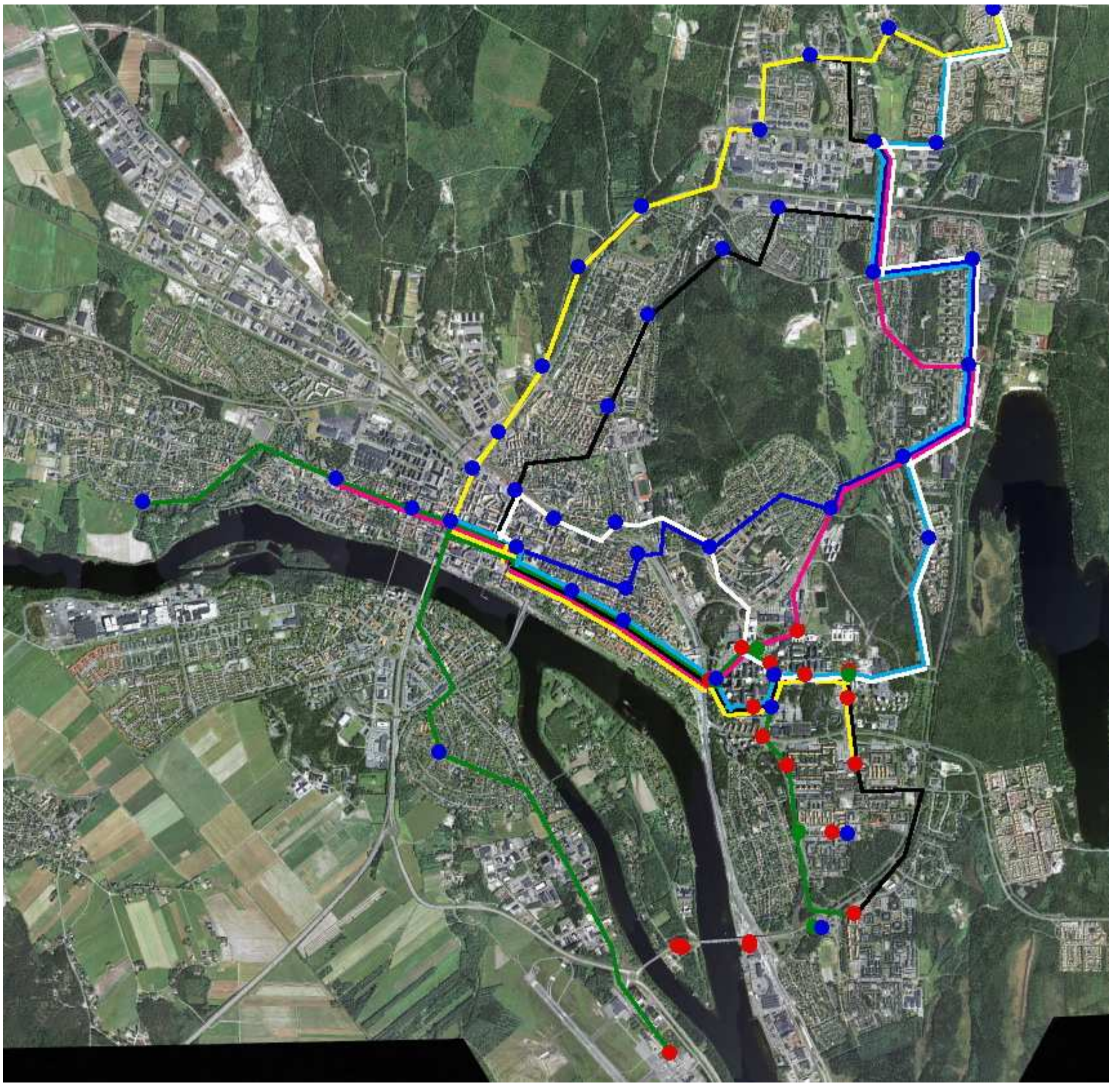

Figure 2. Present bus routes in Umeå

The flow of passengers on the bus route network as assigned by PRTsim is shown in figure 3.

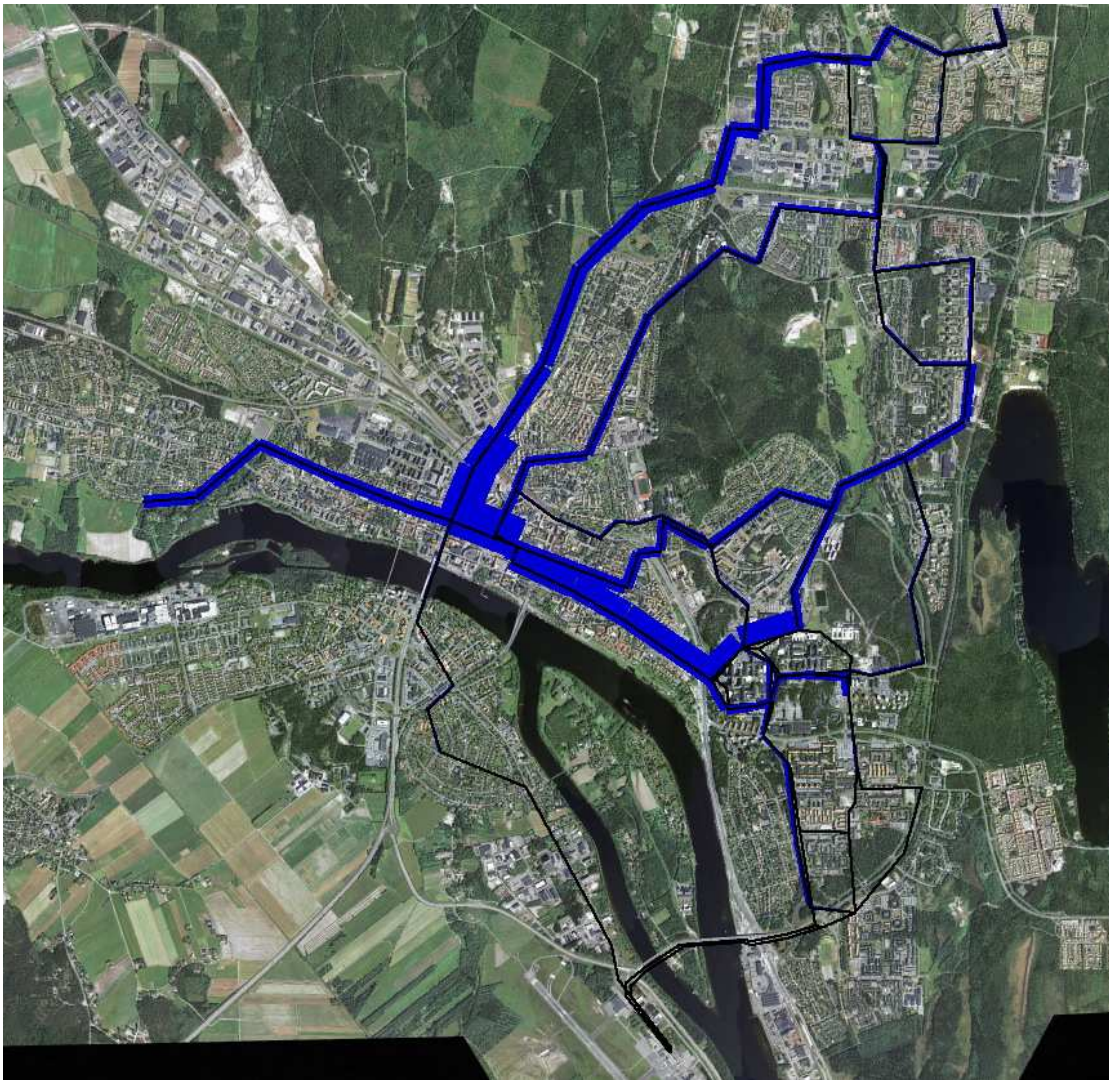

Figure 3. Modelled flow of bus passengers in the morning peak hour 2020

In order to define the first stage of implementation some candidate trip attractors/generators can be identified as in figure 4. The city center was deferred to a later stage in order that citizens first would get to know the system in less sensitive areas. As can be seen in the figure, bus services do not carry many passengers in the candidate areas. Most of the trips in the student/university/hospital areas are by foot and bicycle. The airport is remarkably close to the city and most airport trips use private cars or taxis.

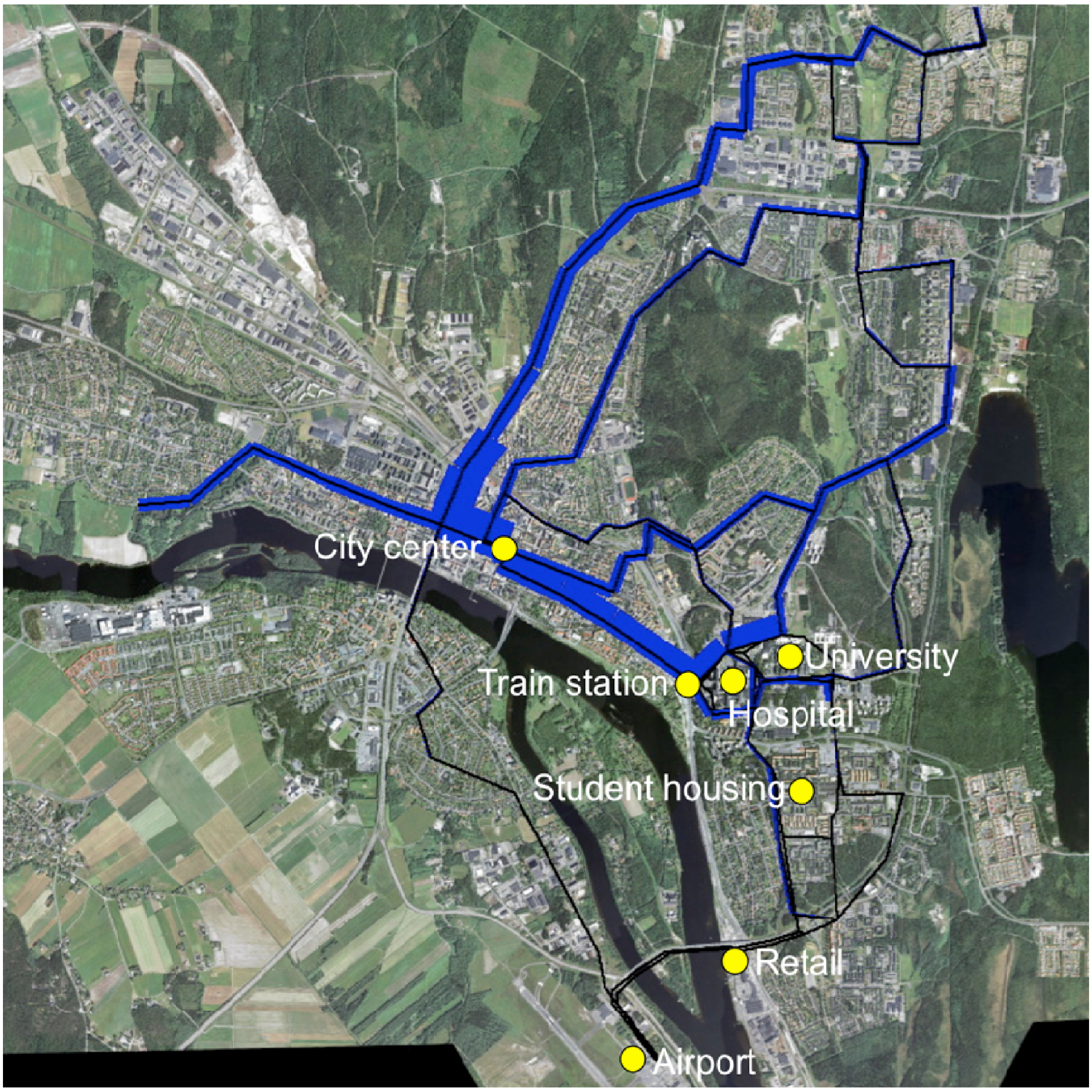

Figure 4. Candidate areas to be served by PRT in stage 1 (with bus passenger flows)

The first stage of PRT introduction is illustrated by the red network of figure 5. It is a subset of the final system in figure 9 with 11 kms guideway and 16 stations. All bus routes were kept unchanged although they could have been cut short within the area served by PRT.

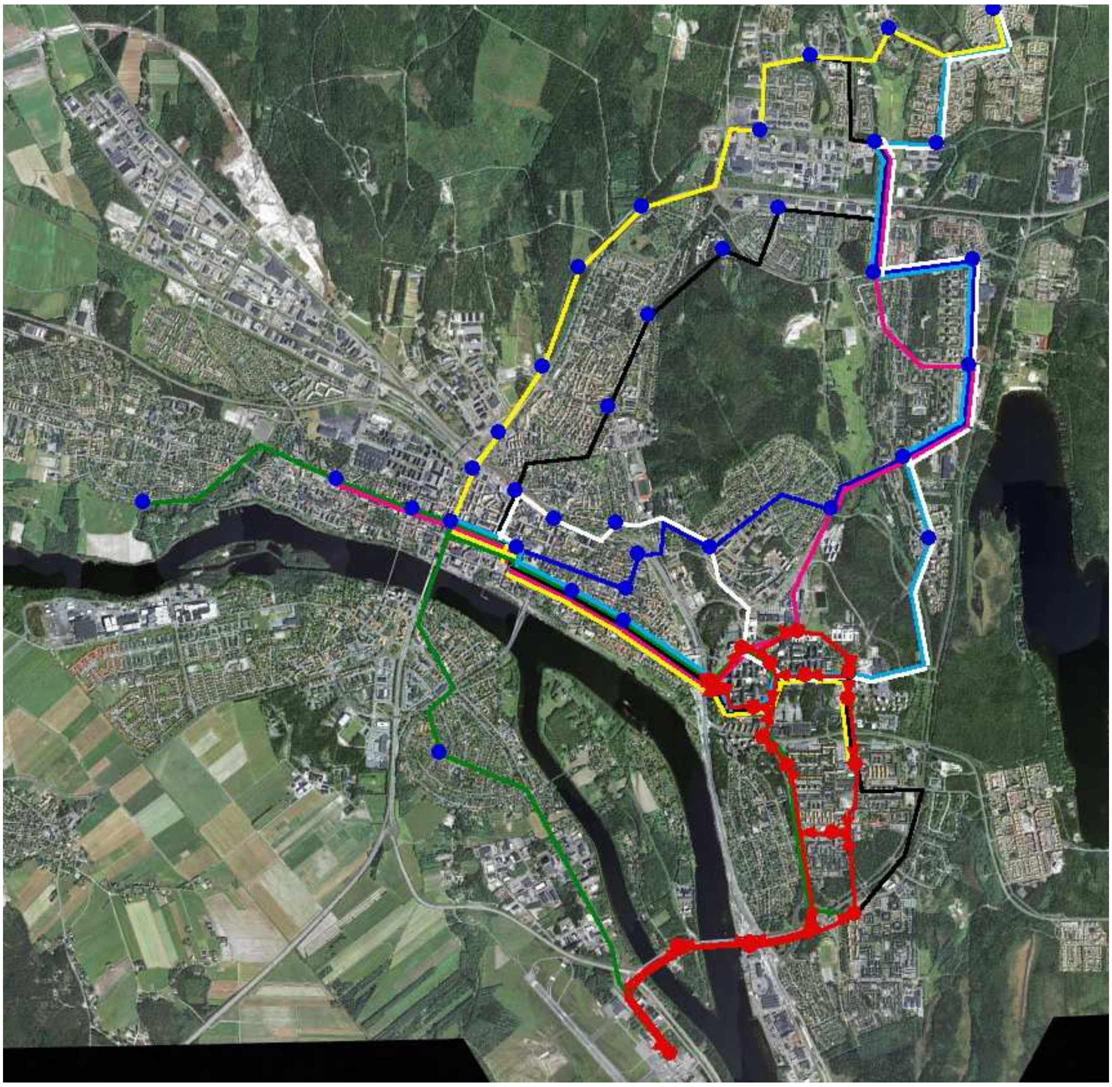

Figure 5. First stage PRT network (red) with existing bus routes

Figure 6 shows the flow of passengers on bus routes and on the PRT network. 100 PRT vehicles for up to 6 passengers would be needed to offer average waiting-times around 1 minute.

Although the stage 1 PRT network covers only 25 % of the bus network, PRT would increase total transit ridership by 30 % during the peak hour and take over practically all trips within its served area. Comparing the PRT passenger flows of figure 6 with the bus flows of figure 3 it becomes clear that new transit trips have been diverted from car, walk and/or bike in the PRT area. Most of the PRT trips involve transfer to/from bus causing a 20 % increase in bus ridership. Diversion of trips to transit, more than compensated the ”loss” of bus passengers to PRT. The remaining bus trips became shorter since almost half of all bus passengers in Umeå would use PRT for parts of their trips.

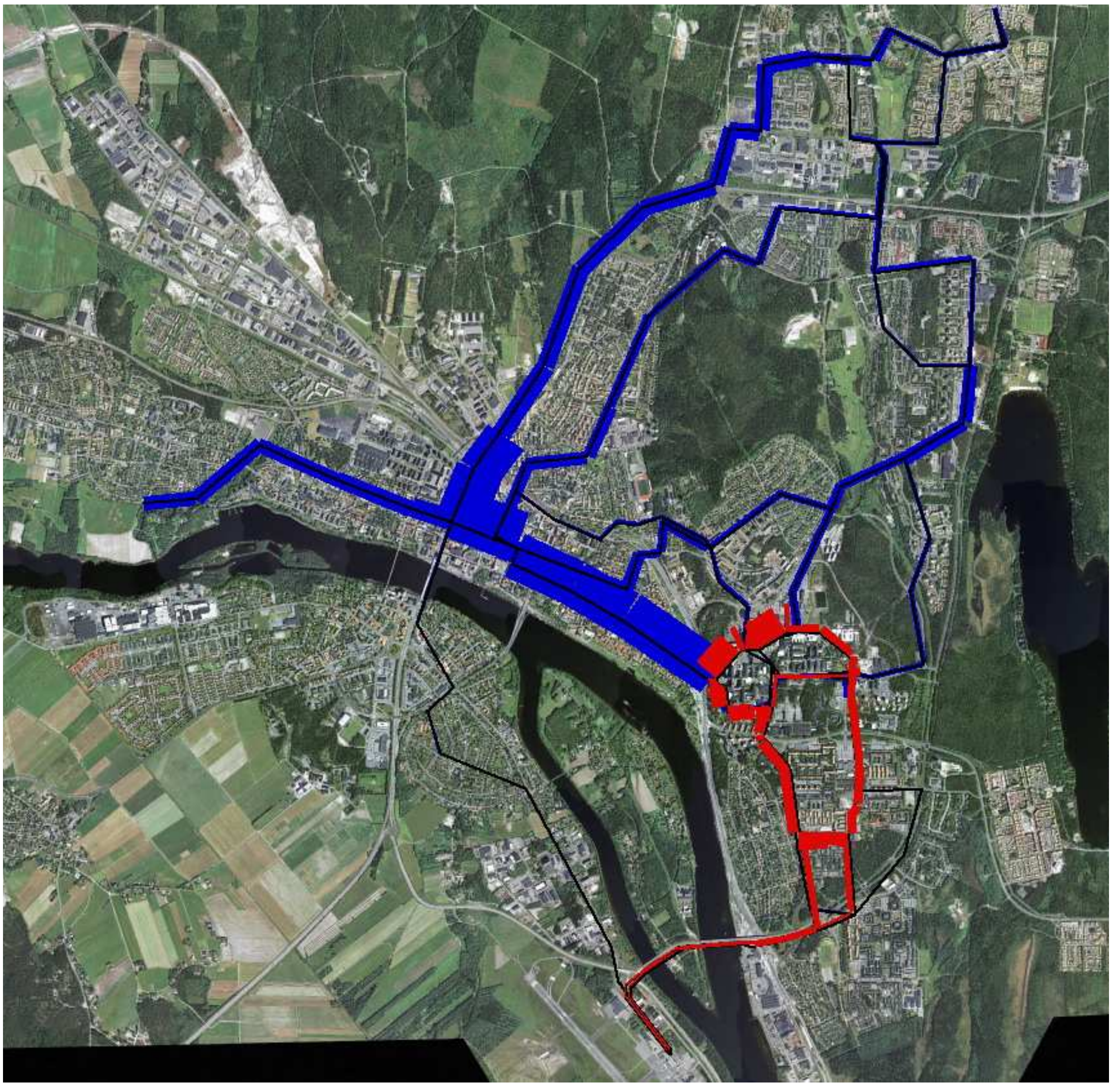

Figure 6. Passenger flow on bus (blue) and PRT (red) in stage 1

The second stage of PRT introduction is illustrated in figure 7. The PRT system now covers two thirds of the bus network with 28 kms of track and 37 stations. The bus routes have been maintained in the analysis although they could be cut short where they overlap with the PRT network.

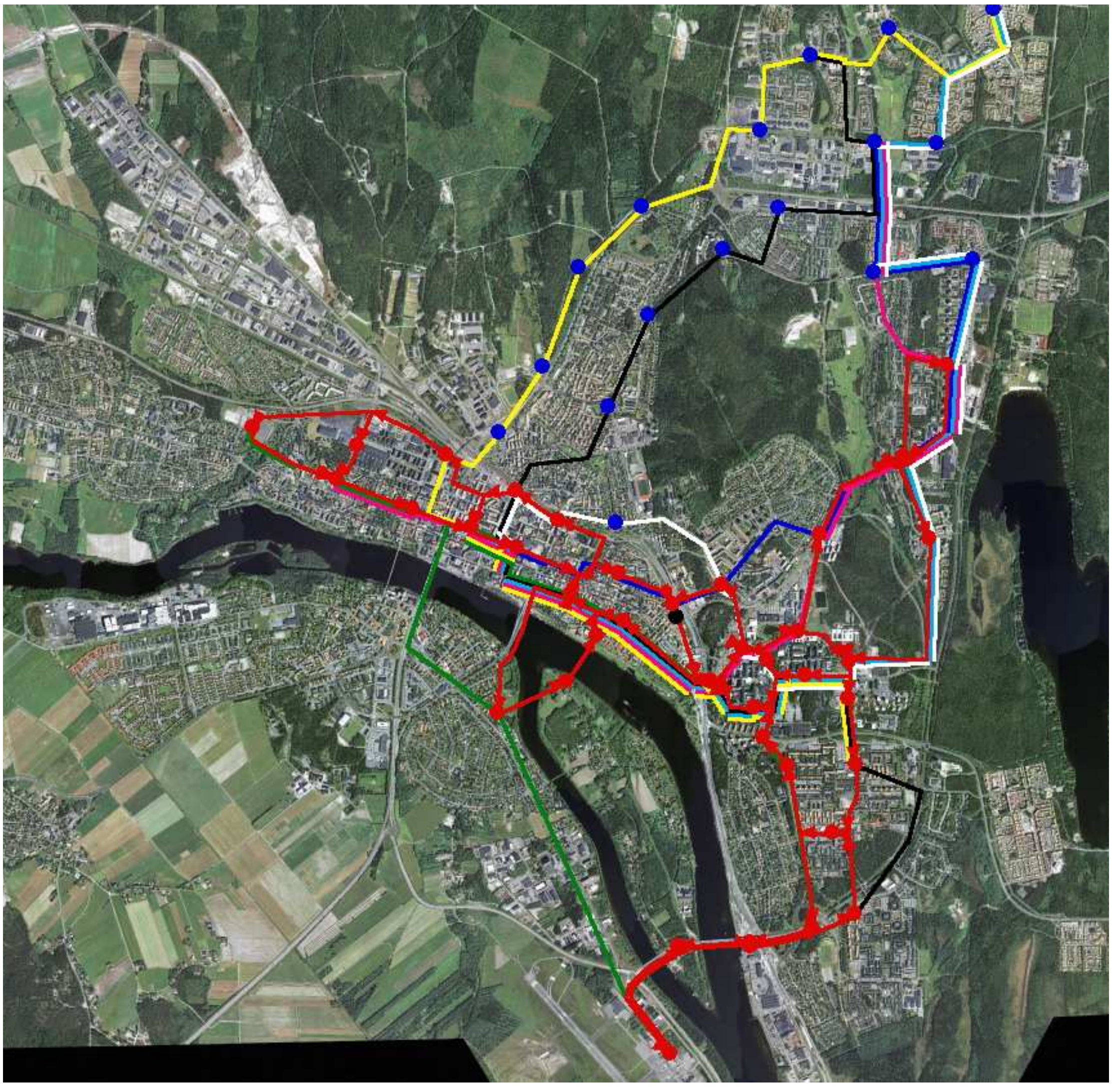

Figure 7. Second stage PRT network with bus routes

The improved level-of-service is estimated to attract more than 90 % more passengers to transit than the original bus network. Bus services would lose 17 % of its original passengers. 700 PRT vehicles would be needed to offer waiting-times around 1 minute. Resulting flows of passengers are shown in figure 8. Notice how bus passengers near their destination in the city prefer to continue the last bit by bus rather than transferring to PRT.

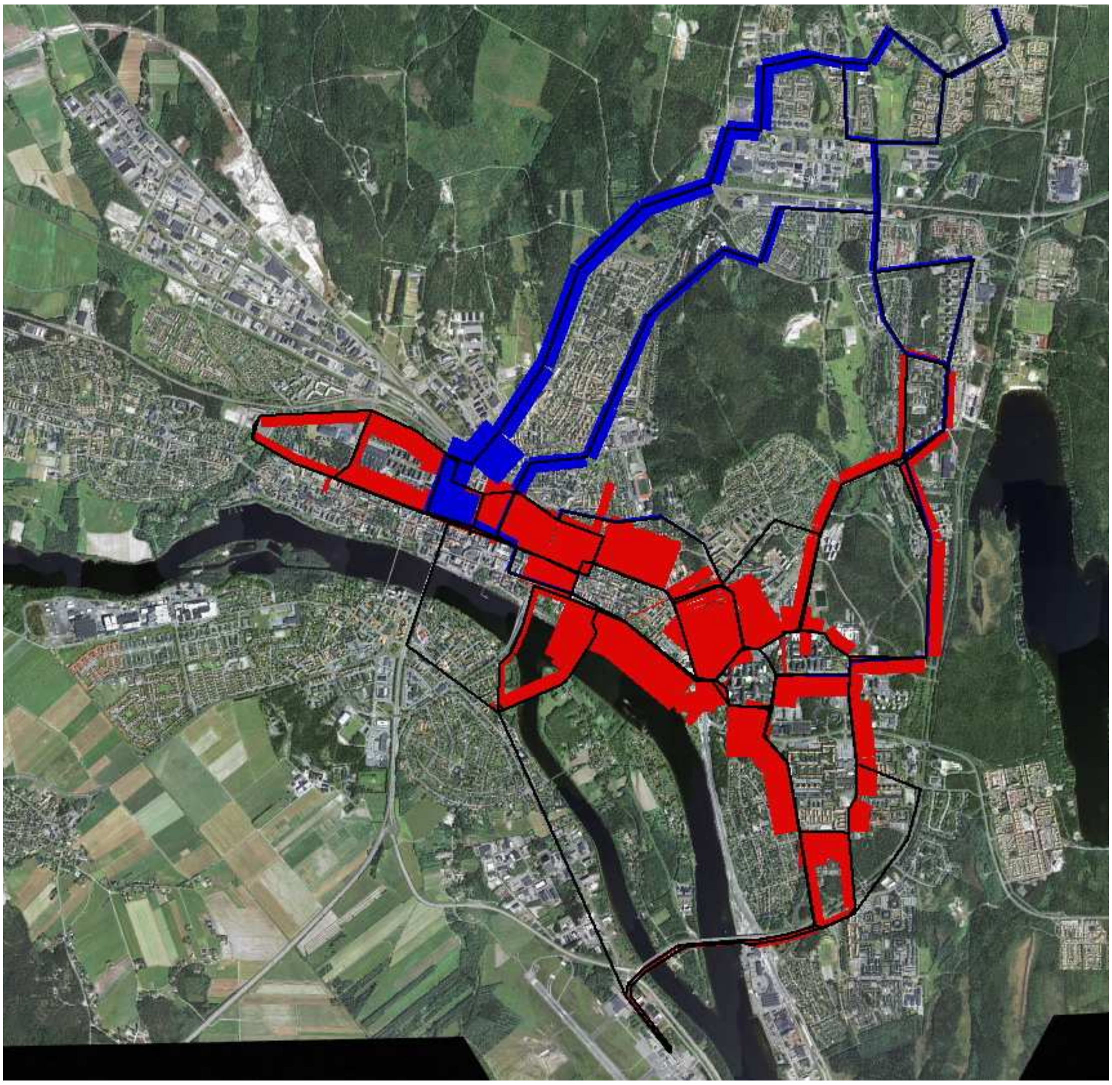

Figure 8. Passenger flow on Bus (blue) and PRT (red) in stage 2

In the final stage all local buses would be replaced by a PRT system with 47 kms track and 54 stations (figure 9).

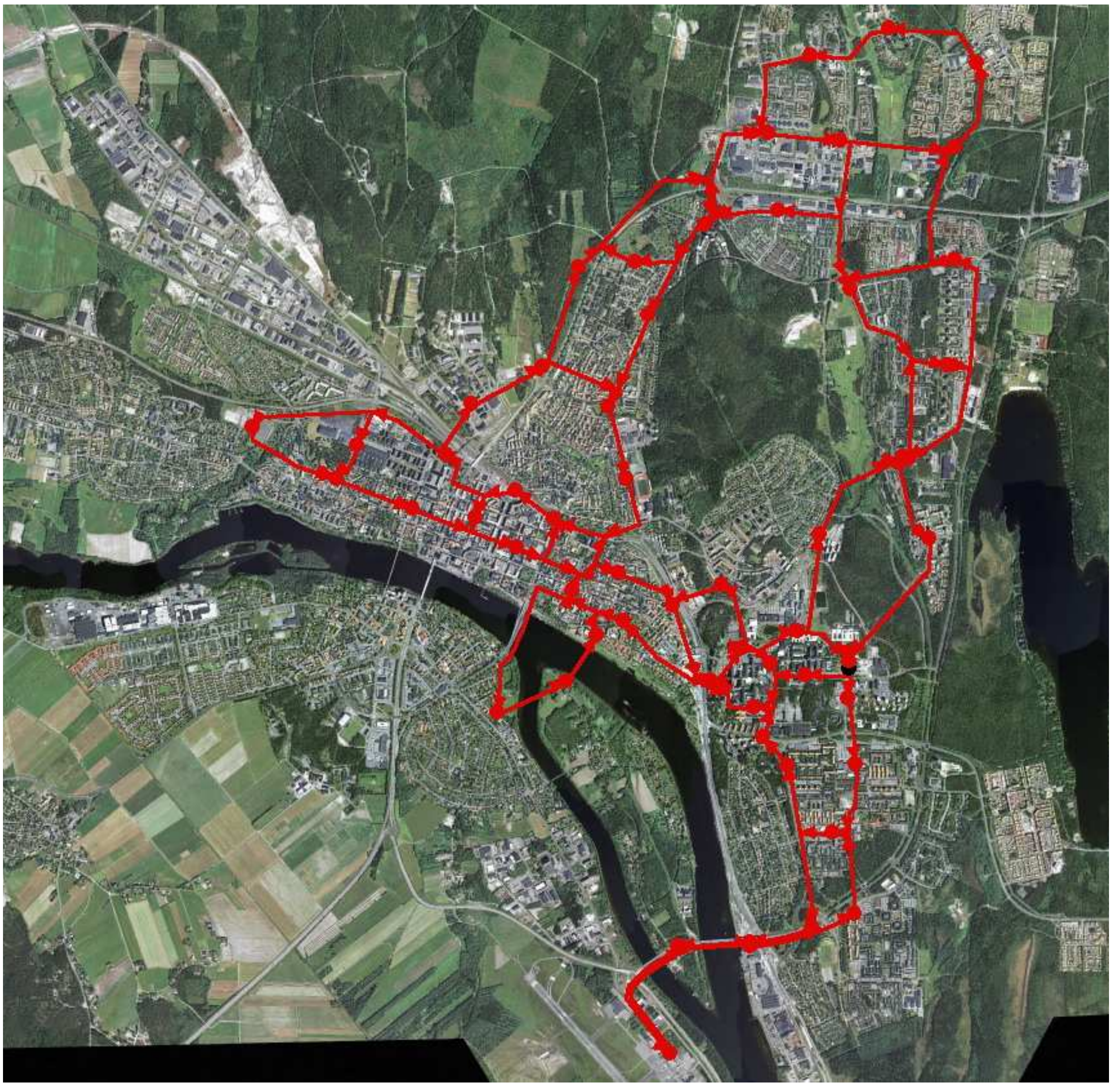

Figure 9. Final PRT network with 47 kms single guideway

Arc elasticity calculation estimates 9 450 PRT trips during the morning peak, requiring 900 PRT vehicles. Replacing buses by PRT would then have more than doubled (+135 %) transit ridership. Passenger flows on the PRT network are illustrated in figure 10. The increased transit ridership occurs in the newly served peripheral areas which are now offered the same level-of-service as the central city.

The arc elasticity model estimates changes in mode choice (diverted trips) but does not estimate new trips induced by the improved level of service. In that respect our calculation are conservative.

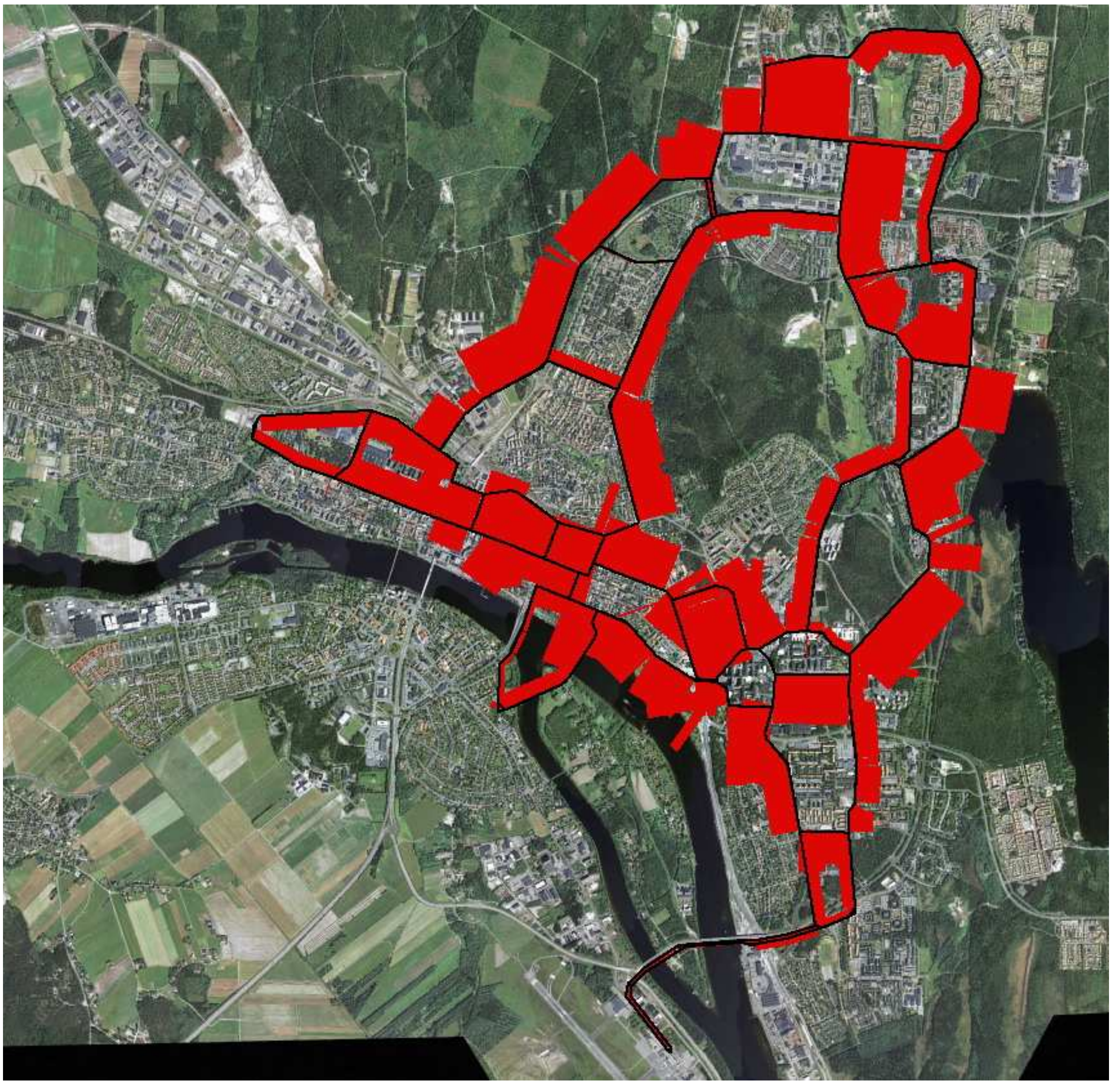

Figure 10. Stage 3 PRT passenger flows during the morning peak

Cost Efficiencies

A simplified investment calculation for each stage was based on the assumed unit costs of table 1.

Table 1. Assumed unit costs for PRT

Single guideway+foundations	5.5 M€/km
Control+depot+commissioning	5 M€
Station including off-line track	0.8 M€
Vehicle	0.075 M€

With these assumptions the total cost for each stage comes out at 7.2-7.5 M€ per single guideway km.

Approximate investment and ridership for each stage are summarized in table 2.

Table 2. Investment and ridership in each stage

	Investment	Peak hour passengers
Stage 1	85 M€	2530
Stage 1+2	240 M€	6480
Stage 1+2+3	375 M€	9450

Summary of Results

The introduction of a small 11 km PRT network complementing the 44 km bus network, is estimated to increase total transit ridership by 30 % and bus ridership by 20 %, see table 3 and figure 11 below.

The second stage PRT system is estimated to increase transit ridership by 90 % and reduce bus ridership by 17 %.

The area-covering PRT system is estimated to attract 135 % more passengers than the original bus system. The transit share of all trips would then go up from 8 to 19 %.

Table 3. Ridership effects in each stage

	Bus	Bus and PRT stage 1	Bus and PRT stage 2	PRT stage 3
Bus only passengers	4 000	2 710	1 190	
Bus&PRT passengers		2 090	2 120	
PRT only passengers		440	4 360	9 450
Total passengers	4 000	5 240	7 670	9 450

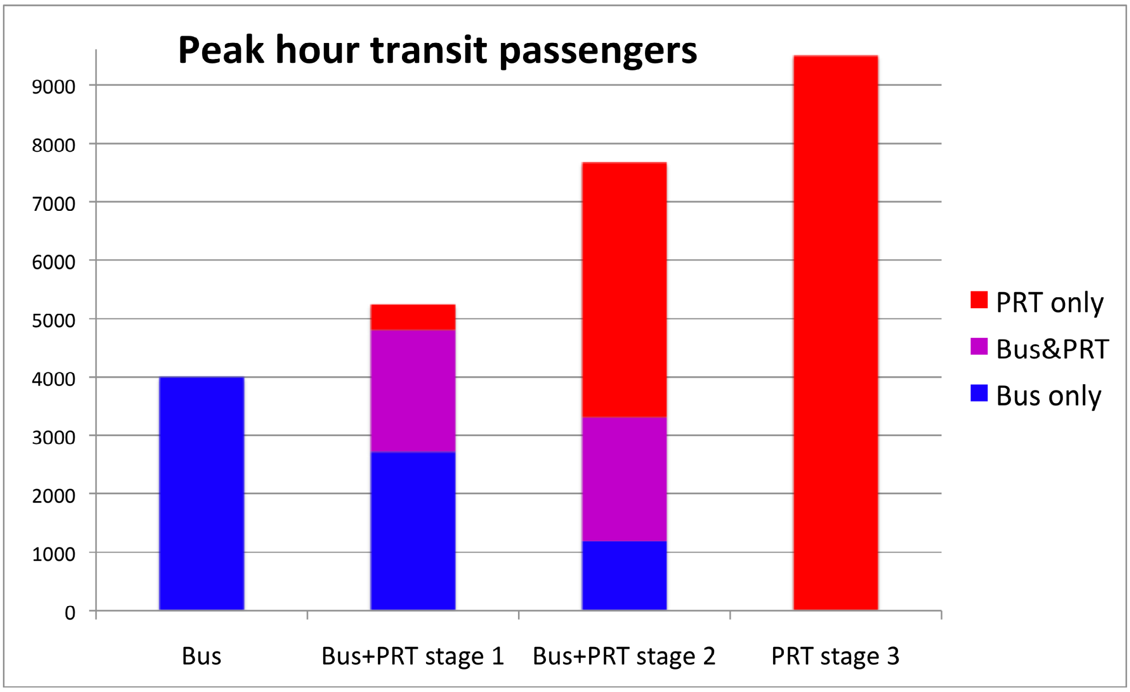

Figure 11. Ridership effects in each stage of PRT introduction in Umeå

Investment and ridership for stage 1 and 2 relative to stage 3 are illustrated in figure 12. PRT ridership is very near proportional to the PRT guideway length and cost of each stage. This may not generally be the case and is a consequence of a good selection of stages.

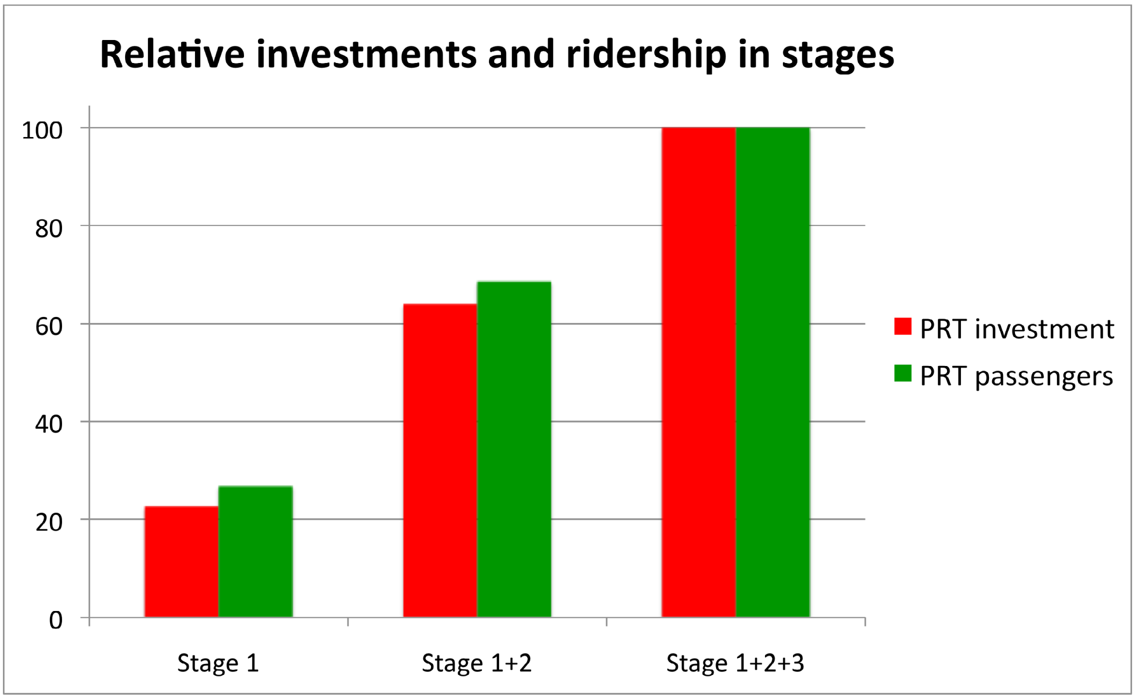

Figure 12. Relative investment and ridership for each stage

Conclusions

• Initial stages of PRT introduction need especially careful planning and analysis

• PRT and mass transit need to function together

• An assignment model for mixed (mass and PRT) transit modes has been introduced and demonstrated

• Ridership effects of transit improvements can be estimated by arc elasticities as long as competing modes remain unchanged

• In good applications initial stages of PRT can be equally cost effective as full PRT networks

• Transit ridership in Umeå is estimated to increase by 135 % (from 8 to 19 % of total trips) if local bus services are replaced by PRT.

References

Tegnér, G., Andréasson, I. et al, *Förstudie av spårtaxi i Umeå*, WSP, Stockholm, 2009.