PERSONAL RAPID TRANSIT AS FEEDER/DISTRIBUTOR TO RAIL

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ABSTRACT

Efficient feeding/distribution systems around train stations are important to attract train passengers. This would be a suitable application for Personal Rapid Transit (PRT). This paper suggests layouts and operations strategies for transfer stations between PRT and heavy rail. Ticket handling can be avoided by combination with the train fare. Ride sharing can be encouraged by destination signs. The catchment area which can be efficiently served is related to the interval between trains. The capacity of station and guideway can be further improved by coupling PRT vehicles in the station and decoupling them as necessary en route. Applications in Sweden are illustrated using the PRTsim software. In one case outgoing PRT vehicles were loaded to 78 %.

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ACCESS TO TRAIN STATIONS

Many countries have invested in heavy rail for commuter trains, regional and inter-regional trains. Very large investments are being planned for high-speed rail in America, Europe and Asia. For these investments to be economically and socially viable it is necessary to bring passengers to and from trains by convenient and attractive feeder/distribution systems. The door-to-door trip needs to be competitive to the private car. Not only the train portion of the trip but also the first and last miles need to be attractive with fast and convenient transfer arrangements.

Train stations are spaced far apart in order not to slow down the train trip. Commuter trains typically stop every 3 kilometers while high-speed trains may run 150 kilometers or more without stopping. It becomes crucial to enlarge the effective catchment areas around train stations.

Train stations attract development, typically in all directions around the station. Feeding a station with bus services requires several bus lines to cover a passenger catchment area with reasonable walking distances to bus stops. The frequency of service on each line should be synchronized with the frequency of train services. Frequent bus services on parallel lines may be uneconomical.

Buses will typically make many stops on the way to and from the train station. There is a risk that a combined bus and train trip would not be competitive enough to attract car owners to use public transport.

APPLICATIONS FOR PRT

FIGURE 1. PRT vehicles from ULTra, Vectus and 2getthere

Personal Rapid Transit (PRT) is individual public transport on demand. Driverless vehicles run on guideways separated from other traffic. Stations are off-line so that passing traffic can be non-stop. While the concept is not new, only recently have commercial suppliers entered the market, such as ULTra, 2getthere and Vectus. Vehicle capacity ranges from 4 to 6 seated passengers (figure 1).

PRT offers zero or short waiting and typically travel speed twice that of bus. Although the investment is relatively high, it is only a fraction of the investment for light rail and the operations cost is lower than any other public transport *(1).* The main hurdles for PRT implementation are believed to be the visual intrusion of guideways and the lack of operating experience.

It is generally considered that early implementations of PRT systems are most suitable for:

- landside transportation around airports
- circulation to and within shopping areas
- university and hospital campus areas
- feeding/distribution around rail stations
- local transport in new cities

This paper explores the suitability of PRT as a feeder/distributor to rail stations.

CONNECTING MASS- AND PERSONAL TRANSIT

The paradigm of mass transit is about bunching people so that they can be transported in large units by a single driver. In contrast, PRT is designed to serve individual travel demands as they emerge. Trip assignment on mixed networks with mass transit and PRT is treated in *(2).* Combining these two modes is a challenge, especially serving large bunches of arriving passengers in small vehicles without excessive waiting.

PRT stations are typically small since only few people wait at any one time. And stations need to be small to fit in the urban street-space. At a train station quite a lot of passengers can arrive from the same train wanting to continue by transit.

We are faced with two problems: 1) finding space for the PRT station and 2) taking care of large numbers of passengers within a short time.

STATION LAYOUTS

All rail station platforms need to be as long as the longest stopping train regardless of passenger usage. PRT stations, in contrast, can be tailored to the demand at each station. When connected to a heavily used rail station the PRT station needs to accommodate a large number of empty vehicles waiting for the train.

Ideally a PRT station track (unidirectional) would be located on the train platform allowing cross-platform transfers from either side. The passing PRT track need not be brought to the train platform. PRT access and exit ramps would pass over the train catenaries (figure 2).

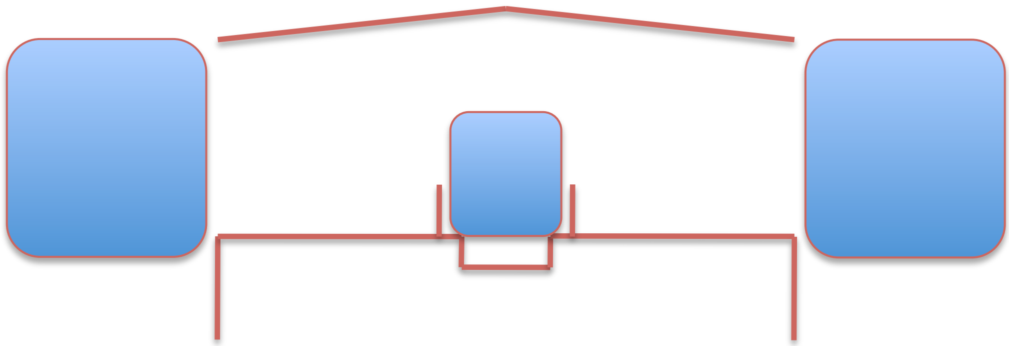

FIGURE 2. PRT on a train platform

The width of existing train platforms has been dimensioned (at least in Sweden) with regard to the number of passengers and the speed of passing trains. If the width of the platform does not have room for a PRT track then it is suggested to use the free space above the length of the platform (figure 3).

FIGURE 3. PRT station over a train platform (source: WSP)

The linear space on or above a rail platform is appropriate for linear PRT stations with vehicles parking in line on the PRT station track. This layout has also been shown analytically *(3)* to be the most efficient in terms of station throughput per unit space. The calculation was based on distributions of boarding- and exiting times observed at Heathrow.

Commuter trains around Stockholm are up to 214 m long and that is also the length of the rail platforms. A PRT station track of that length (excluding entry and exit ramps) can hold about 60 PRT vehicles with 3.6 m spacing.

Over a large train terminal with many platforms it may be possible to build a crossing double-track PRT station with an escalator from each platform (figure 4).

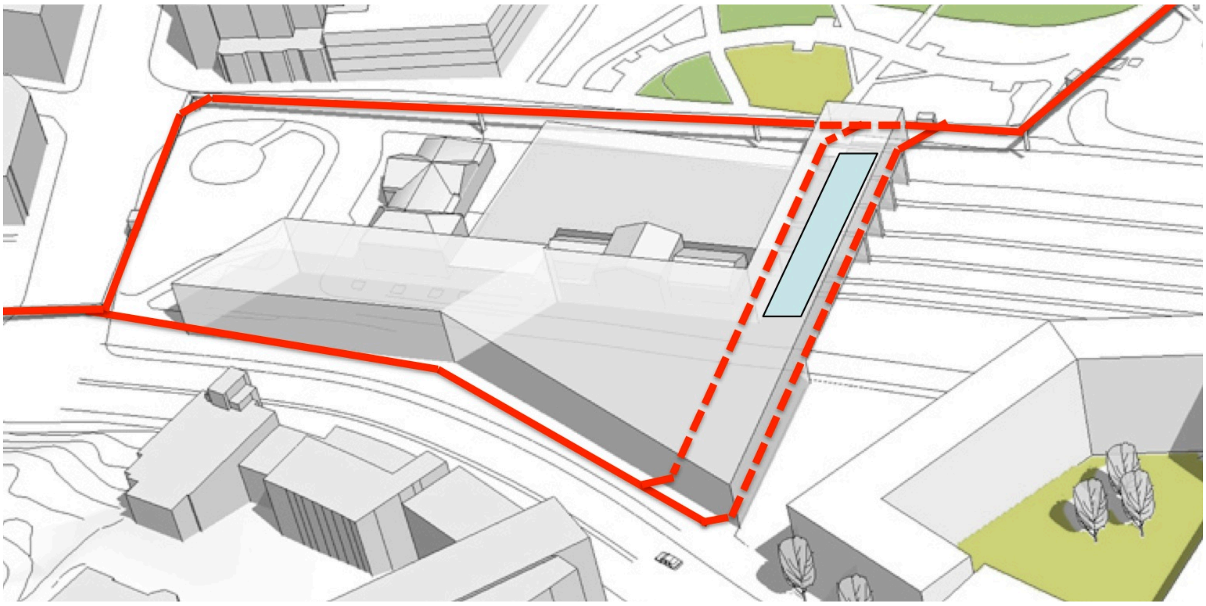

FIGURE 4. PRT station across a rail terminal

VEHICLE SCHEDULING

With trains we know when they are scheduled to arrive. By communication with train control we may know also about train delays. If we know five to ten minutes in advance when a train is expected to arrive, that is enough time to direct PRT vehicles to the train station.

Passenger arrivals by train are fairly regular from day to day and week to week. After some weeks of operation we can have reasonably good statistics of passengers deboarding from each train, how many of those wish to continue by PRT and the number of vehicles needed to carry them to their respective destinations.

For the distribution of train passengers the system needs to call empty vehicles to meet the train. For the collection of passengers it is up to each passenger to plan their departure in time to catch the train.

CATCHMENT AREA

The combination of distribution and collection is particularly attractive when the loop time out and back in to the station is just under the interval between trains. The longer the interval between trains the larger catchment area can be efficiently served during the interval.

Total travel time by PRT to one rail station in Swedish Umeå is illustrated in figure 5. People in the yellow and green areas can reach the rail station in less than 10 minutes (including walking up to 400 meters and waiting). With 20-minute train frequency PRT vehicles would have time to distribute, collect and return for the next train. Larger areas can be served but need more vehicles.

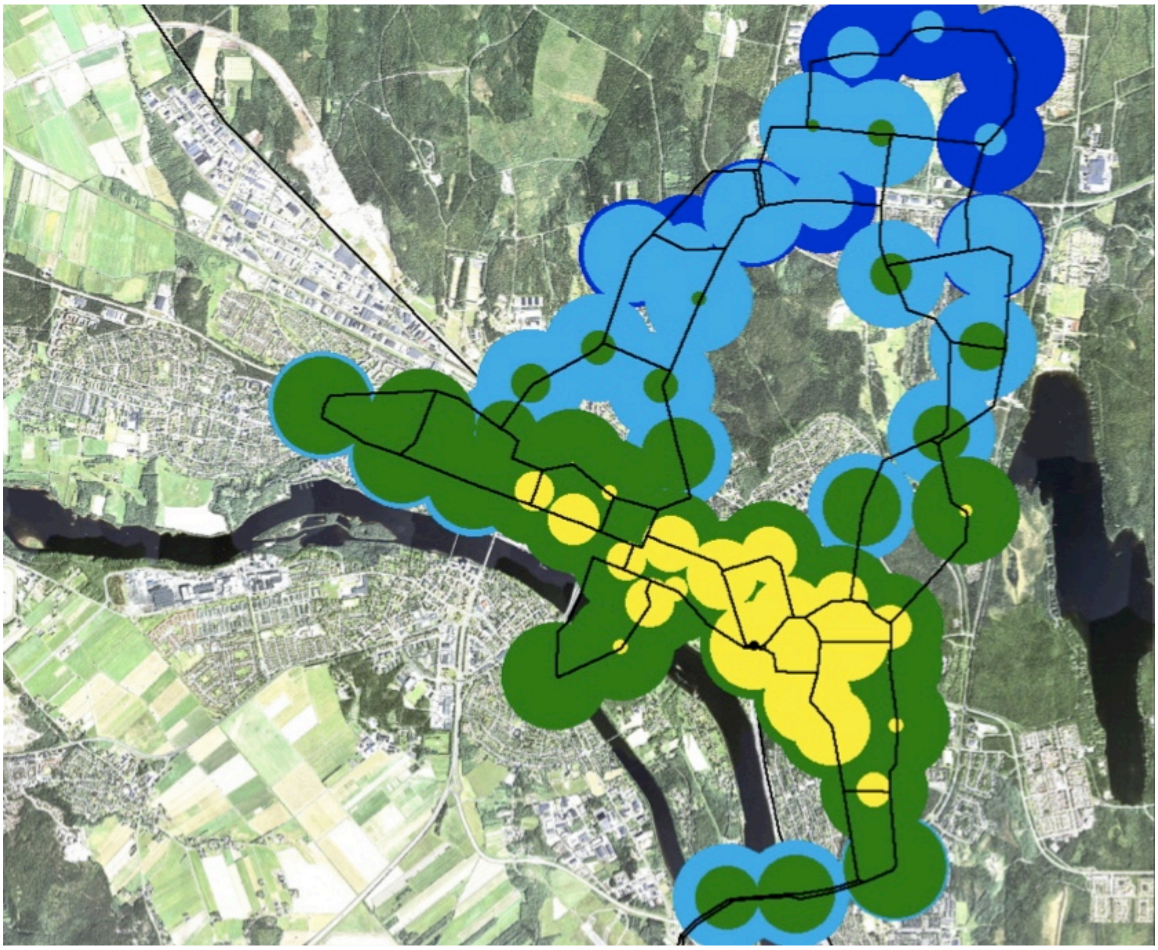

FIGURE 5. Travel time by PRT (walk+wait+ride) to a rail station in Umeå within 5-10-15-20 mins (yellow-green-cyan-blue)

High-speed trains would have longer intervals between arrivals and a PRT system could serve a larger catchment area between train arrivals.

TICKET HANDLING

With large groups of passengers wanting to be served within a short time it would be impractical to have each one of them order PRT tickets. It is recommended that train tickets include adjoining PRT trips so that no transactions are needed at the transfer station. Also we cannot assume that other train stations where passengers may have started their trip have PRT ticket machines. How then do we get to know passenger destinations?

One possible solution would be to have passengers enter destinations after boarding a PRT vehicle. However this would slow down station throughput and passengers entering the same vehicle may have diverse destinations. We also want to facilitate ride sharing beyond people already knowing each other (many regular commuters recognize passengers with the same destination).

RIDE SHARING

Users of mass transport are used to sharing vehicles. Experience from the Heathrow PRT system shows that people are willing to share, they even do it spontaneously without being encouraged to *(4).* A combined ticket for train and PRT can be offered with the condition that ride sharing will apply whenever possible.

The PRT concept was designed for individual trips or trips with chosen company. Without sacrificing the level-of-service with non-stop trips on demand, it is sometimes possible with ridesharing to increase vehicle load as well as guideway capacity with a smaller vehicle fleet. Ride sharing is only needed at peak demand and this is also when the conditions for sharing are favorable.

Reference *(5)* calculates analytically the potential for ride sharing under some simplifying assumptions such as Poisson arrivals and all destinations being equally probable. One of the conclusions is that waiting time increases with the number of destinations. Bunched arrivals such as from trains are more favorable by increasing the chances for matching without waiting. Sharing is also improved when some destinations are more probable than others. Vehicles to popular destinations allow high sharing while the opposite is true for unfrequented destinations.

Reference *(6)* analyzed various forms of ride sharing in PRT vehicles. The most efficient strategy for ride sharing applies to passengers with common origin and common destination. While multiple destinations would help to fill vehicles and increase departure capacity, the extra time for multiple stopping would reduce vehicle productivity and increase travel times.

In PRT stations with ticketing the system would know at each time how many passengers wait for the same destination. Without ticketing at a train station we have to rely on statistics from previous days.

SIGNAGE

Destination signs on or above each vehicle help passengers to share vehicles. Based on statistics of historic vehicle destinations an appropriate number of vehicles can be signed for the expected destinations. Additional vehicles can be unsigned for passengers with unexpected destinations.

Vehicles signed for various destinations are spread over the length of the station platform so that passengers would never have to walk far to a vehicle with their destination.

If, by mistake or otherwise, passengers with the wrong destinations or with different destinations enter a vehicle, this would still not be a problem. That vehicle would serve one destination after another, the only disadvantage being an extra stop and perhaps a detour.

TIME TO DEPART

In normal (small) PRT stations the station throughput is often limited by the time to let passengers off and on. Slow boarding passengers in front vehicles may hinder the departure of vehicles behind. Measurements at Heathrow *(4)* indicate that boarding time variations for 4 passengers are not more than +/-10 %.

If the train-PRT station has separate levels for the two systems, passenger arrivals to PRT will be dispersed. Fast passengers will pick the front vehicles if in a hurry so that slow boarding passengers become less of a hindrance. In simulations all passengers show up at the same time and boarding times of different vehicles are independent.

At a long PRT station the time to clear the station may be limited by the exit capacity to the main track. With little passing traffic on the main PRT track the time to clear is determined by the minimum safe headway between vehicles. With 3-second headway it would take some 3 minutes to clear 60 PRT vehicles from a station track.

With 4-passenger vehicles the theoretical station clearing capacity is 240 passengers in about 3 minutes. Depending on the distribution of destinations the average load in practice may be 3 giving a clearing capacity of 180. Some PRT vehicles can seat up to 6 passengers thus increasing station and exit capacity.

If the expected number of passengers from one train is greater, there can be a ramp of waiting PRT vehicles ready to enter the station platform once the first set of vehicles have left.

COUPLED PRT VEHICLES

PRT systems can ensure safety by either keeping a safe distance between vehicles or by running them together as one unit *(7).* The existing PRT systems could, if they wanted to, implement coupling of their vehicles with minor development efforts. The coupling can be mechanical or by control.

While coupling en route would be considered unsafe (although quite possible as demonstrated by Matra-Aramis), uncoupling can be safely made in diverges by vehicles switching in different directions. Uncoupling vehicles run close together into a diverge as long as they overlap laterally.

It is suggested to couple vehicles in stations before departing and to switch apart en route for different destinations. Platoons or vehicle trains can be of any length (with restrictions on ordering) with safe distances before and after each train.

Vehicles can break out from a train as long as it does not create an unsafe gap. Hence one or more vehicles can break out from front or rear but generally not from in-between (unless the created gap is longer than the minimum safe distance).

At transfer stations between train and PRT we can control the ordering of destinations signed over vehicles. The sequencing can be made such that trains can be safely split successively along their routes.

In most cases a sufficient increase of capacity can be achieved by coupling vehicles only in pairs, and pairs can always be safely split regardless of destinations. Pair coupling would almost double the exiting capacity of a station.

During the collection phase the departure rate from each pickup station is relatively low which is less favorable for sharing, but on the other hand a larger percentage of the departing passengers have the same destination (the rail station).

Coupling of vehicles in stations is possible whenever more than one vehicle is ready to depart regardless of destinations. The need for coupling is largest in the busiest parts of the network, normally close to the rail station. As long as we do not apply coupling en route, the benefits of coupling are highest during distribution.

While pair coupling has been verified in PRTsim, we have not simulated longer trains of PRT vehicles.

DIMENSIONING

A typical commuter train may take 1000 passengers, typically commuting to a large city. Very few of the intermediate stations have more than 200 passengers board or disembark from one train.

Not all disembarking passengers will wish to continue by PRT. Some have their destinations within walking distance from the train station, some will have a bike or a car at the station, some will be picked up and some will take a taxi or a rental car. Only in rare cases will it be necessary to have more PRT vehicles waiting for one train than can be accommodated along the length of the train platform.

APPLICATIONS

We have analyzed potential PRT networks in Sweden feeding and distributing to/from commuter train stations.

A proposed PRT network for Upplands Vasby *(8)* is shown in figure 6 with PRT links shown in red and commuter rail in blue. 2000 passengers would arrive by PRT from the east side to the rail station during the morning peak hour to catch the commuter train towards Stockholm or Uppsala. Simulation of ride-sharing in PRTsim resulted in an average load of 3 passengers on 6-seat vehicles arriving to the station. Ten vehicle berths would be needed along a linear platform. Another PRT station on the west side of the railway had 400 arriving passengers during the same hour.

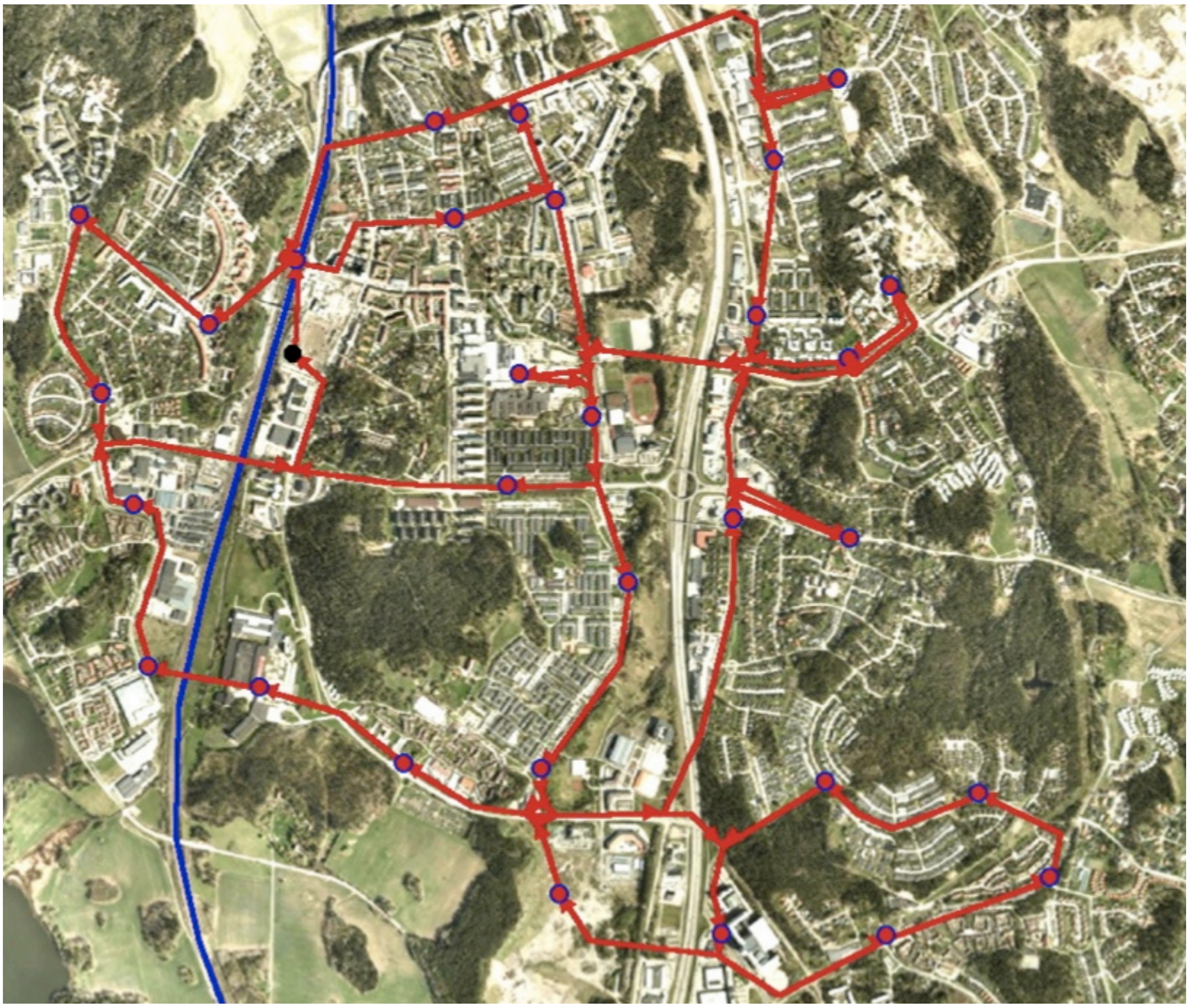

FIGURE 6. Proposed PRT network feeding to commuter train in Upplands-Väsby

Another network for Eskilstuna (figure 7) was planned for a combination of 10 bus routes and one PRT loop with 100 vehicles feeding to the rail station. Assignment to the combined network resulted in 3500 passengers arriving to the station by bus and 860 by PRT during the morning peak hour.

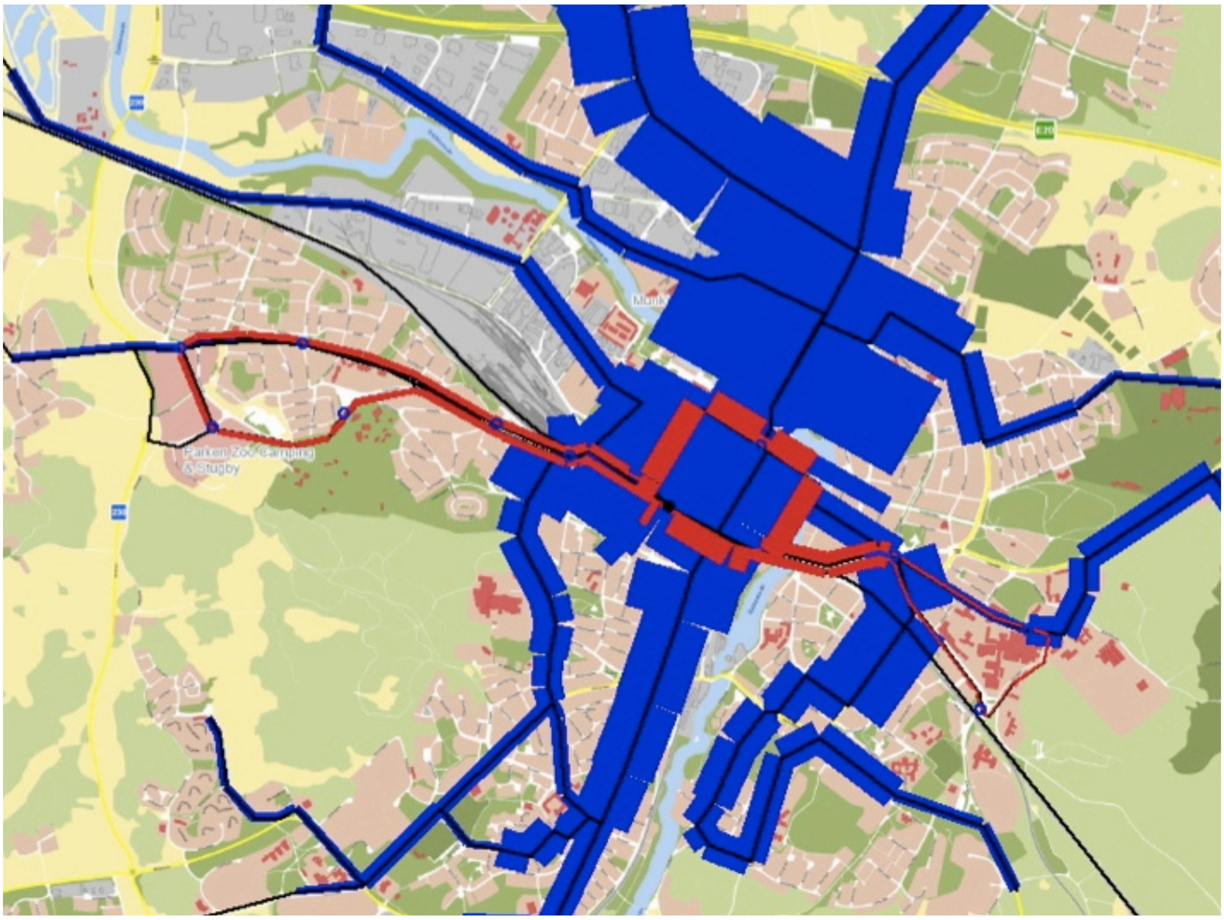

FIGURE 7. Passenger flows on bus (blue) and PRT (red) feeding to train in Eskilstuna

We also designed a PRT network to distribute passengers from three commuter rail stations in Södertälje *(9).* 130 passengers were distributed from one train stop to 28 destinations. 8 of the destinations attracted 80 % of the demand and the most popular destination attracted 22 %. Passengers traveled together with random group sizes averaging 1.5 passengers. Groups with common destination shared vehicle to the extent possible without braking up groups. As a result departing vehicles had average 3.9 passengers out of 5 places (78 % occupancy). The occupancy is limited by combinations of groups not filling a vehicle and by passengers to one destination not being a multiple of vehicle capacity. In reality, although not modeled, further reductions may be caused by passengers not finding or not reaching a vehicle with their destination before it departs.

In the animation snapshot in figure 8 the train is just arriving and empty PRT vehicles are waiting at the station.

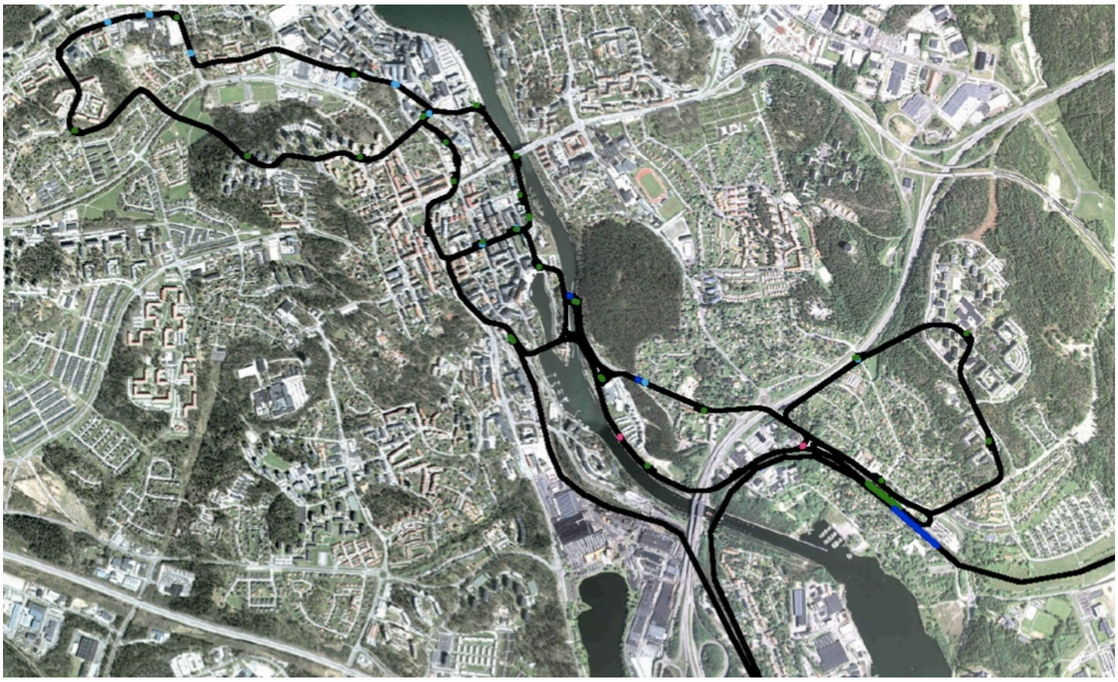

FIGURE 8. Snapshot from PRTsim animation of train (blue) entering Östertälje station with empty PRT vehicles (green)

In the following snapshot (figure 9) the train has just left and 28 loaded PRT vehicles have departed, 12 of them filled with 4 or more passengers (red color). Three empty PRT vehicles are left at the station.

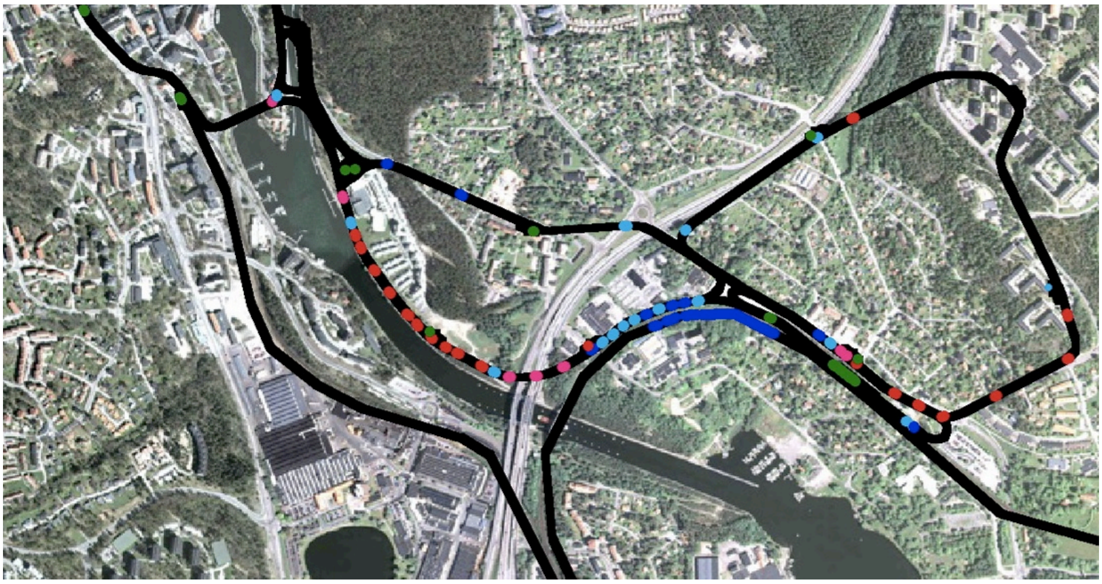

FIGURE 9. Snapshot of animation showing departed train (blue) and PRT vehicles empty (green) and loaded with 1 (cyan), 2 (blue), 3 (magenta) and 4 or more (red) passengers

CONCLUSIONS

- Ridership on rail system may benefit from attractive feeder/distribution systems
- Feeding rail stations is a feasible application of Personal Rapid Transit
- Transfer stations between rail and PRT can be designed to handle peak loads
- Rail fares should include feeding/distribution in order to speed up transfers
- Destination signs may facilitate ride-sharing, thereby increasing capacity
- Coupled PRT vehicles may reduce station clearing time to about half
- With 28 destinations, PRT vehicles from one rail station were loaded to 78 %
- Effects have been verified by simulations in PRTsim

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