Single direction versus dual direction networks

Summary

This document challenges the ancient wisdom of the PRT community that loops of single direction lines is the proper way to design PRT networks. By comparing three different network layouts based on the same station positions it is shown that a dual direction network gives a much higher quality of service at about the same cost as the single direction network. This result is based on the assumption that a dual idrection line costs 1.5 times as much to build, compared to a single direction line.

Background

The most common way of thinking about PRT network layouts has been as a number of interconnected, single direction loops. Beamways started out with the same idea but when simulating larger networks it soon became obvious that there are substantial drawbacks with single direction networks of loops. For smaller networks the main disadvantage is that the real traveling speed is much lower for a given line speed. For larger networks the main disadvantage is that the capacity is too low. On the positive side a single direction track is of course cheaper than a dual direction track, which makes it possible to install more track for the same amount of money, thus providing better area coverage.

In theory, when looking at a large network of square loops the disadvantage of length is on the order of three sides of the square per trip. With a long trip compared to the square size this does not seem overly problematic. In reality though, most networks are drawn with more organically shaped loops, following roads or other natural rights of way. This leads to designs with multiple stations on one loop side, without any crossings between them. These designs can have extremely large factors of added length.

Method

In the following paragraphs I will describe three versions of a network for the Swedish town of Östersund. Most of Östersund lies on the shore of lake Storsjön, while a part is on the nearby island Frösön. Frösön also has the airport, which is one of the main targets of the PRT system. Östersund town has 45 000 inhabitants.

I first drew a mostly single direction network, although a few links close to the bridge and at the airport were dual direction. This network is seen in figure 1. To make a simple comparison I then made all lines dual direction. The resulting network is seen in figure 2. This network would obviously be much more expensive to build than the original network. But with dual direction or mostly dual direction lines you don't have to build as many lines to be able to go to and from every station. By removing and changing lines to get a more tree-like network most of the advantages of the full dual direction network can be preserved without getting as high a cost increase. An attempt at this type of change can be seen in figure 3. Note that station locations are *not* changed for this network either.

To further reduce cost stations could be placed a bit further apart, and still offer a quicker door-to-door travel time. This way of thinking reduces cost further without increasing the total travelling time compared to the original, single direction network and in addition brings a public health and energy consumption bonus!

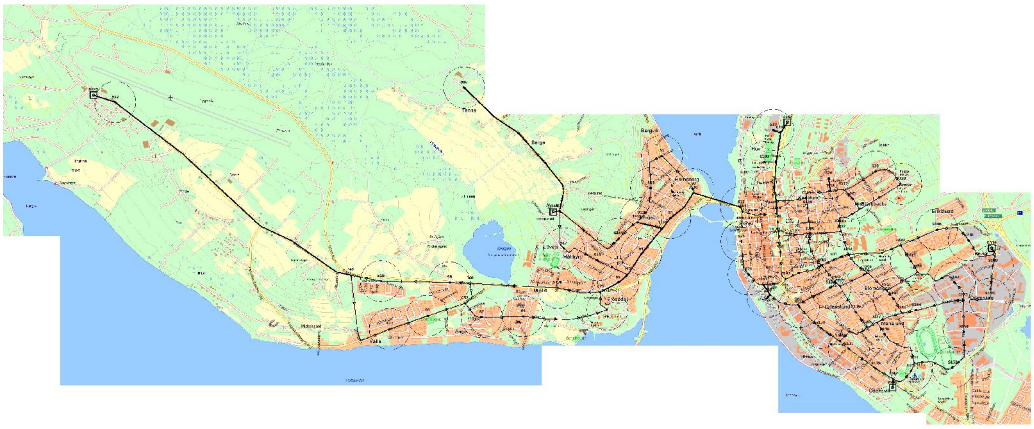

Figure 1, the original, single direction network.

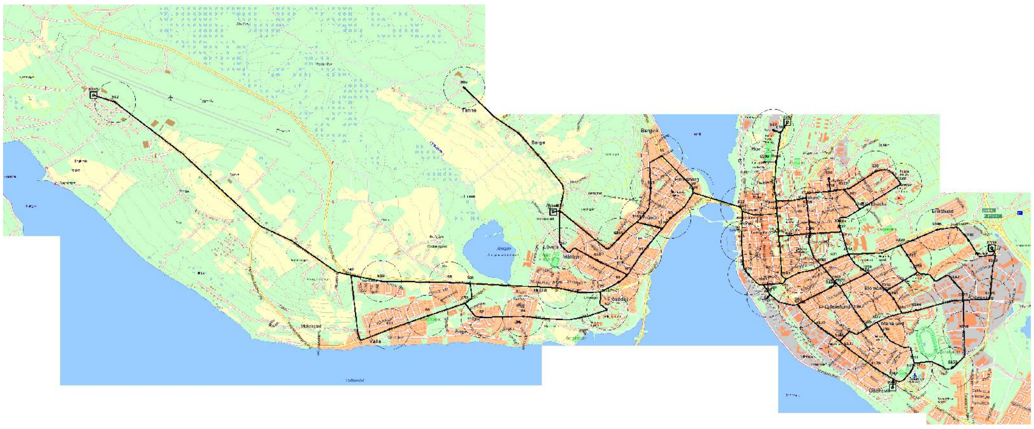

Figure 2, the original network with all lines made dual direction.

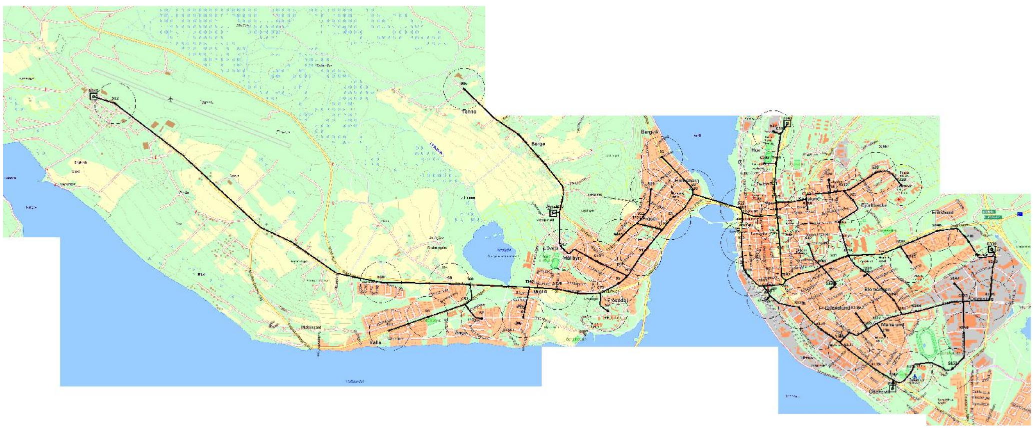

Figure 3, the reduced network, with routing optmized for dual direction lines.

Results

The follwing table summarizes the results from simulating the three networks using BeamEd's simulator. The line speed was set to 54 km/h (15 m/s) and the headway was 1 s. The simulation ran for one rush hour with a grand total of 6700 trips.

Measure	Single direction	Dual direction	Dual, reduced lines
Number of stations	57	57	57
Number of 3-way intersections	36	36	28
Number of 4-way intersection	5	5	3
Total line length	55 km	55 km	44 km
Total beam length	81 km	134 km	105 km
Weighted beam len	75 km	107 km	83 km
Normalized infrastructure cost	100%	143%	111%
Straight mean trip	3300 m	3300 m	3300 m
Real mean trip	6100 m	4200 m	4400 m
Mean speed along line	36 km/h	41 km/h	40 km/h
Mean speed compared to straight line	20 km/h	32 km/h	30 km/h
Mean line load	1230 v/h	475 v/h	622 v/h
Max network use	31%	11%	15%
Number of vehicles	2000	1200	1300
Percentage empty trips	42	35	37

Percent empty km	18	16	16
Total km per trip	9,4	5,5	5,9

Out of all of these values the following may warrant further explanation:

Weighted beam length: Length of single beams + 1.5 * length of dual beams. It has been noted in several reports that dual direction lines cost about 1.5 times more than single direction lines.
Nomralized infrastructure cost: Weighted beam length in percent of the single line system's cost.
Straight mean trip: Mean length as the bird flies of all simulated trips.
Real mean trip: Mean length of all simulated trips as traveled.
Mean line load: Mean load of all lines in vehicles/hour.
Max network use: Total guideway length compared to headway induced vehicle spacing. 100% means that the guideway is filled with vehicles at minimum distance. Normally you can't rely on figures higher than 35% as some parts of the network will be more densely used than others.
Number of vehicles: The number of vehicles available to the simulation. The count has been selected to be as many as needed to not get short in supply during simulation, but not more.
Percentage empty trips: Count of empty trips as a percentage of full trips.
Total km per trip: Includes full and empty km to perform one full trip.

Conclusions

When comparing the (mostly) single direction network with the entirely dual direction network the immediate conclusion is that the investment is 43% higher for the dual direction network. There are however large gains in lower number of vehicles required and shorter trip lengths. The mean travel speed for the dual direction network is also significantly higher than for the single direction network, which will attract a higher ridership. Also note that the network usage figure of 31% for the single direction network is dangerously close to the overload limit of around 35%. Finally the redundancy in the network is much higher in the dual direction network which improves the availability of the service.

Looking at the third network we notice that by reducing the number of thru-lines we can reduce the cost to almost the same as the single direction network while almost preserving the quality of the full dual direction network. With the increased revenue thanks to the higher attractiveness and the reduced cost of the shorter trip lengths and reduced vehicle count and smaller depot size it is highly probable that the optimized dual direction network is the most economic alternative from a operator's standpoint. If the increased benefit for the environment (by reducing car traffic more) and for the citizens (by higher travel speeds) are taken into account the optimized dual direction network is by far the b est of the three networks investigated here.

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