Journal of Advanced Transportation - Vol. 37. No 3 Sep 2003

Service Effectiveness of PRT vs Collective – Corridor Transport

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Summary

A generalised model is used to provide estimates of overall trip times and speed for conventional corridor-collective transport and PRT. The results demonstrate why traditional forms of transport find difficulty providing an effective service in a city. Short separations between stops are required to minimise walk times but on conventional transport this leads to significant reductions in achievable speed because of the need for frequent stops. It is also shown that there is very little benefit in service effectiveness from LRT/APM/Monorail over buses. PRT is immune to these effects. The present calculations typically show a benefit for PRT of a factor of two or greater in trip time over either bus or LRT/APM.

Introduction

The problems of collective –corridor transport are established. Any corridor can only serve trips which are along that corridor. Collective transport requires both waiting and frequent stops, probably at every stop on the route during peak periods.

PRT systems are projected to have major benefits for city transport because, in contrast to conventional forms of transport, they offer a combination of good accessibility and short trip times. This note seeks to calibrate this projection via numerical calculations.

The model assumed is shown in Figure 1. The corridor transport stops at each of the stops, assumed to serve a square area with side equal to the distance between the stops.

A trip from start at A to destination at B requires:

1.	Walk to station	A-C
2.	Wait for transport	C-C
3.	Stop at every stop	C-D
4.	Walk to destination	D-B

> "You have to go to a place you don't want to go to to get to a place you don't want to get to"

The present model involves an estimation of the times taken for each part of the trip.

2. Average Speed In-Vehicle

It is of interest to start with the in-vehicle speed for the central part of the trip. The results are shown in Figure 2. They are based on a simple Newton's Law calculation of the acceleration – deceleration process from stop to stop. It is assumed that acceleration and deceleration occur at 0.1g and that stops are 20 seconds each. These results parallel results given originally in Hamilton and Nance (1969) and Lowson (1999).

Stop to start times on buses, including door opening, passenger alighting and door closing can be as little as 10 seconds. However passenger boarding normally takes rather longer, especially if there is a need to pay fares to the driver. For light rail times very low stop times are less likely to be achieved since the driver has less direct interaction with the boarding process. Measurements on buses over several routes in Cardiff showed that the average stop time was 23 seconds between 9.00 and 12.00. Other measurements in peak periods showed that average stop times increased to over 30 seconds. Thus it is thought that 20 seconds is an acceptable overall figure. But in any case, modest changes in stop time have little effect on average speed compared to the deceleration acceleration process.

Figure 2 shows the average speed achieved for various stop spacings. It can be seen that high maximum speeds are of little benefit if stops are closely spaced. Under these circumstances, the vehicle merely accelerates to the mid point between the stops and then decelerates without reaching its maximum speed. For 250m stop spacings, the average speed achieved is less than 20 kph regardless of handbook maximum speed.

This corresponds to speeds achieved in practice by buses in favourable conditions. Light rail, or other systems such as monorails and Automatic People Movers (APMs), which have a higher maximum speed, will normally use longer stop spacings, reducing accessibility in order to provide higher average trip speed. Even so it can be seen that the average in-vehicle speeds achieved for 1 km stop spacings is still only 40 kph, ie the same as projected for PRT systems such as ULTra.

3. Walk and Wait Times

Average walk time to the station is dependent on size of the area served by the station, which is in turn dependent on the average stop separation. A simple assumption is that the corridor is serving a “grid” city with all roads laid out at right angles. Although not typical of all European Cities, this offers an acceptable approximation for the purposes of the present estimates.

Figure 3 shows this typical case. A walk from any location to the central station will involve a trip N-S and a trip E-W. Consider a trip starting from any point on the diagonal line. The length of any trip from a point on this line to the centre is L/2 where L is the length of side of the square. But by symmetry since there is exactly the same area on the far side of the line away from the station as on the near side, this line also represents the average trip length.

Thus, the average walk length in a grid route system over a service area of side L is simply L/2. If it is assumed that the walk trip has to be made at both the start and end of the journey then the average distance walked is identically equal to the average stop separation L.

Use of any form of public transport involves a walk at each end of the trip. In typical cases such as shown in Figure 1, the area served by each station can be assumed to be at the centre of gravity of the served area. Thus the average distance from all points in served area at the start to all destination points in the served area at the destination is equal to the station separation. This is an interesting result which applies to a wide range of circumstances; for example, it applies both to grid based and to straight line travel.

Since, under the above fairly general assumptions, the average distance between start and destination is simply the station spacing, the walk required to get to and from the station is an overhead. Although some walks are in the direction of travel, others are in the reverse direction, while half of all walk distance is normal to the direction required. This overhead adds to the average time taken for travel, but not to the distance usefully travelled.

If it assumed that passengers will walk to the downline station where this provides a net benefit in travel time, there is a small modification to the above argument. This is illustrated in the second diagram in Figure 3. Suppose that the blue line indicates the boundary between the locations where it is preferable to walk to the upline or downline stations. Then on the boundary the journey time via either station is the same, either by walk directly to the downline station, or by walk to the upline station and in-vehicle travel to the downline. This can be expressed algebraically as

$$T = (L/2 + x)/W = (L/2 - x)/W + L/V$$

Where W is the walk speed and V in the vehicle speed (which should include the effect of stops).

This gives $x = L/2 \, . \, W/V$

The effect is that the area served by any station is displaced upline. Under the present grid city assumptions it can be seen that the additional walk time to be added on for upline passengers is balanced the reduced walk time to be added for the downline. Thus the average walk distance to the station remains the same. However, the area served has been displaced upline by x. Similar arguments apply to the passengers arriving at the destination, who can choose to get off one stop early. Thus at the destination, the area served is displaced downline by x. This means that the average distance between origin and destination served by a station pair a distance D apart increases to D + 2x, ie to

$$D + LW/V$$

This only makes a small difference to the numerical results, but is included for completeness.

In practice bus or other journeys will use variable spacings so that the relations above will not apply exactly. However, it appears to offers an acceptable first approximation for the walk distance required. Walk times can be found directly from the walk distance by assuming an average walk speed, taken here as 4.8 kph ie 80m/min the average walk speed recommended by the Confederation of Passenger Transport.

In addition to the walk time there is also a wait time. For the present calculations, this has been assumed to be 5 minutes. This would imply a service frequency of 10 minutes, only occasionally provided by conventional transport.

Finally, a typical trip length must be assumed. For the purposes of the present comparisons, this has been taken to be 8 km, corresponding to the average trip length in the UK. As noted above the average separation of origin destination pairs served by stations 8 km apart is equal to $8 + LV/W$. The total time is the time taken in-vehicle plus the walk overhead at both ends of the trip, plus the wait time. The average speed is found by dividing total distance by total time as defined.

4. Results Including Walk and Wait

Figures 4A and B give the results of these fuller calculations. The two Figures show results for bus and light rail respectively. For the bus case, an average in-vehicle speed of 30 kph has been assumed. This is a reasonable assumption for achieved in-vehicle speed in a city where the bus is obliged to stop regularly at pedestrian crossings, traffic lights etc. The second case shows the results for a higher speed service assumed here to be 80 kph. This is a somewhat generous figure to represent light rail, monorail or APM. This figure also provides an indication of the possible effects of priority bus lanes, or guided bus, which could provide increases in in-vehicle speed for buses.

The results in both Figures 4 are presented in terms of average speed achieved against stop spacing. The top curve gives the speed achieved in-vehicle, and is essentially a replot of the 30 kph results from Figure 2. At high stop spacings, it is possible to achieve high in-vehicle speeds, approaching the maximum speed of the vehicle being considered. However, the addition of walk and wait elements to the journey reduces overall trip speed considerably.

As might be expected that the best overall speed for the journey is achieved when stop spacings are short and the amount of time spent walking to and from the stop in is minimised. It can be seen that for the bus case this provides an optimum stop spacing of around 0.5 km. This is quite close to the average stop spacings used by buses in city operations, although typically closer stop separations (and thus lower average speeds) will occur in the city centre.

For the Light Rail/APM model, the optimum stop spacings are also found to be around 0.75 km. The higher speed of the vehicle means that a higher proportion of the time is spent in the walk for the optimum case.

However the most striking feature of these graphs is the low average speed achieved, for the bus this is 14.0 kph and for the Light Rail/APM 17.4 kph. This is because the length of time in the walk part of the trip forces the systems to work at short stop spacings for which the in-vehicle speed is of little benefit. The small improvement in average speed offered by the far higher maximum speed of the Light Rail/APM case is striking.[1] It is also noteworthy that these average speeds are virtually identical to the average speeds achieved by cars in peak periods. This speed is achieved on the corridor, which itself only serves a limited proportion of the trips desired. It is not surprising that current forms of public transport have little attraction compared to car transport.

5. Comparison with PRT

Finally these results are compared to a PRT model. ULTra has been taken as the base for this comparison. This operates at a maximum speed of 40 kph. More importantly, it does not have to stop at the stations since, as with all PRT, these are off-line. For ULTra, it has been anticipated that station spacings would be about 0.5 km, but it would be reasonably straightforward to shorten this separation to 0.25 km if required. The same walk time assumptions have been made for PRT as for the previous cases. For ULTra most passengers

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[1] Doubling maximum speed again to 160 kph (or indeed again to 320 kph) provides no benefit. The maximum achieved overall speed is 17.5 kph.

will have a zero wait time, but a total additional time of 30 seconds to include both wait and boarding has been assumed for the purposes of these calculations.

The comparison is shown in Figure 5. For Bus/LRT these figures correspond to the same data as presented in Figs 4, but now presented in terms of trip time. It can be seen that PRT can typically offer around a halving of average trip time. These calculations refer to uncongested conditions. In congested peak periods the average speed of buses, and cars, will reduce further, while PRT will continue to be offer the same level of service.

However the key issue is that the overall trip time for small stop spacings by conventional transport is unacceptably high. Small stop spacings are necessary to provide good accessibility, so that the basic nature of the corridor –collective service leads to major transport inefficiencies.

For bus, and particularly for Light Rail/APM/Monorail there is pressure to choose larger stop spacings to provide shorter trip times at the expense of accessibility. In the case of PRT in-vehicle speed is independent of the stop spacings selected. Thus in areas such as a city centre it is straightforward to provide closer stop spacings for better accessibility with no loss of transport effectiveness in terms of total delivered trip time.

Conclusions

Analysis of the service effectiveness of conventional corridor collective and PRT transport systems using a typical 8 km trip with walk wait and in-vehicle travel has shown that

For conventional transport

1. Achieved in-vehicle travel speeds are controlled by station to station separation.
2. High maximum speeds offer no benefit to in-vehicle speed at the small station spacings necessary to provide good accessibility.
3. Inclusion of representative walk and wait travel times shows that minimum overall trip times are achieved with modest station spacings (0.5-0.75 km).
4. Maximum achieved speed for the complete trip in any case studied was 17.5 kph, little more than buses.
5. Higher speed forms of conventional transport such as Light Rail, APM or monorail offer little benefit over buses.

For PRT

6. A benefit of around a factor of two is provided over the best trip times achievable by conventional corridor-collective transport.
7. Additional improvements in accessibility can be provided via closer station spacing with no penalty in trip time.

Acknowledgments

I would like to thank Jerome Rapin for making measurement of times on buses and Hugh Collis for helpful comments on the draft. This work has been partly supported by the EC under the Cybercar contract and by the EDICT project under the City of Tomorrow program.

References

Hamilton, W.F., and Nance, D.K., (1969) "Systems analysis of urban transportation" Scientific American Vol 221 No1 pp19-27
Lowson, M.V (1999) "Personal Public Transport" Proc Instn Civ Engrs Transp 1999 135 Aug 139-151

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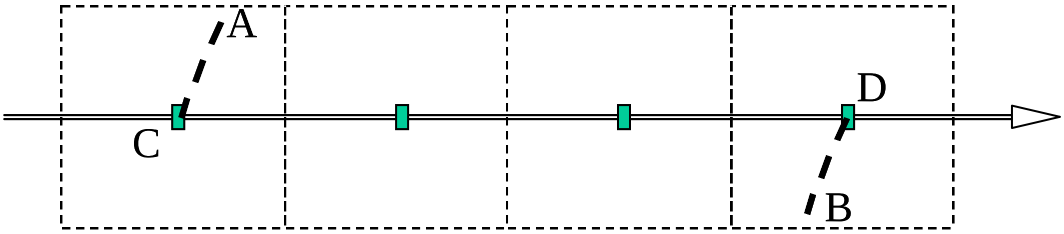


Figure 1 Area Served by Corridor Transport

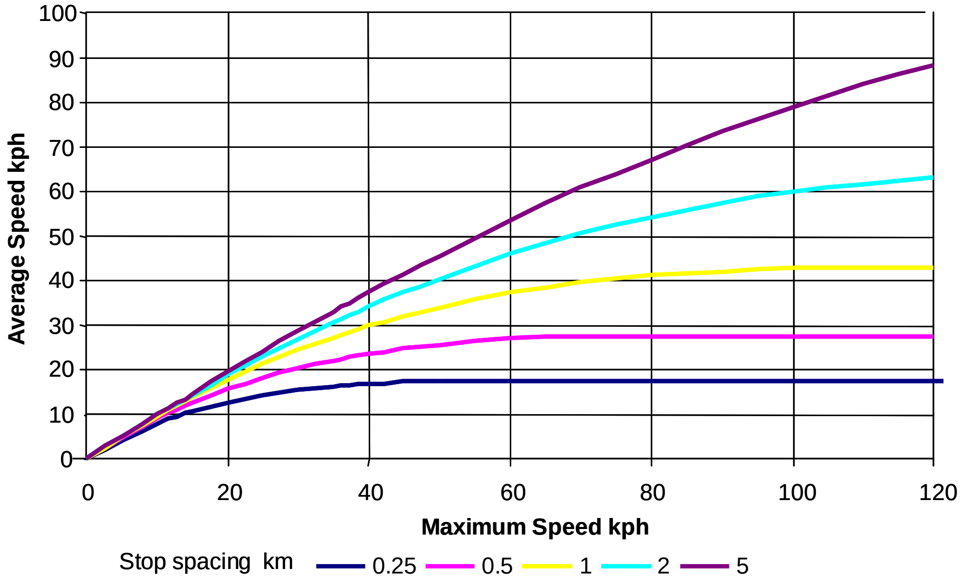


Figure 2 Average Speed in-Vehicle Against Maximum Speed for Various Stop Separations

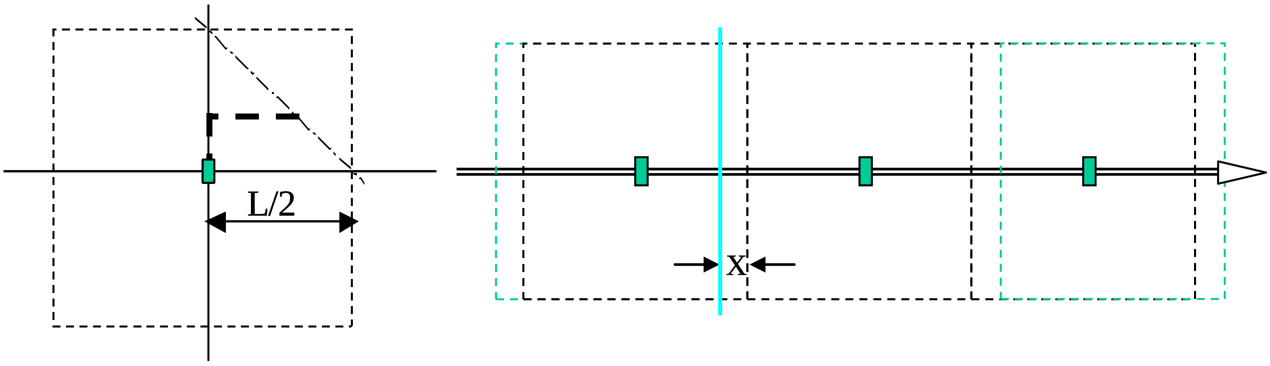
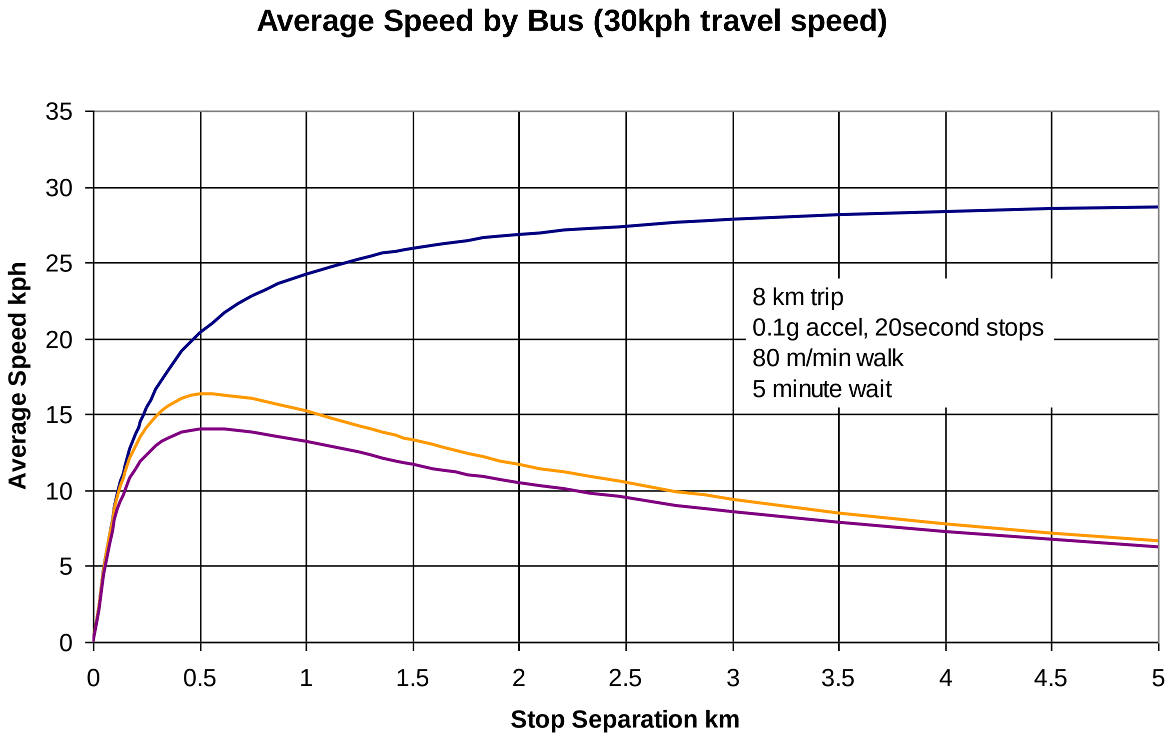


Figure 3 Diagrams showing walk trip length


Average Speed by Bus (30kph travel speed)

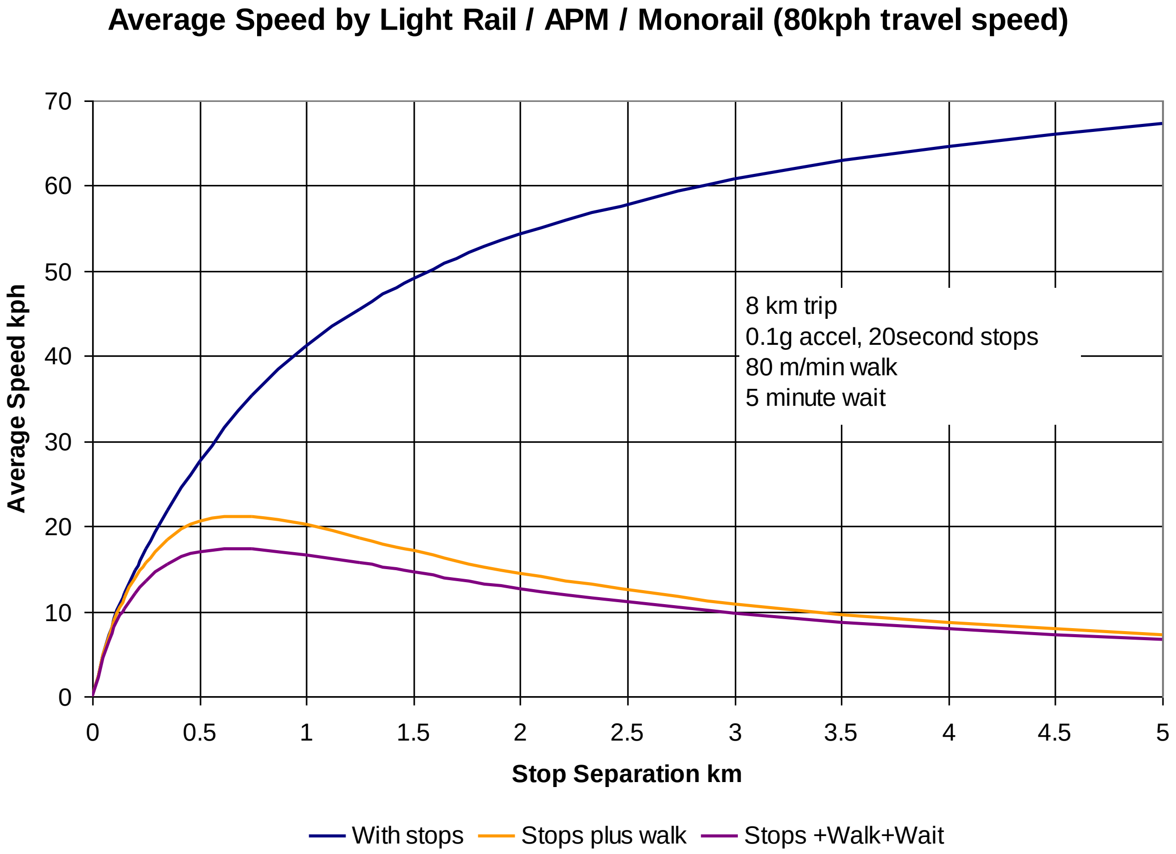

Average Speed by Light Rail / APM / Monorail (80kph travel speed)

Figure 4 Overall Average Speed for Conventional Transport vs Stop Separation

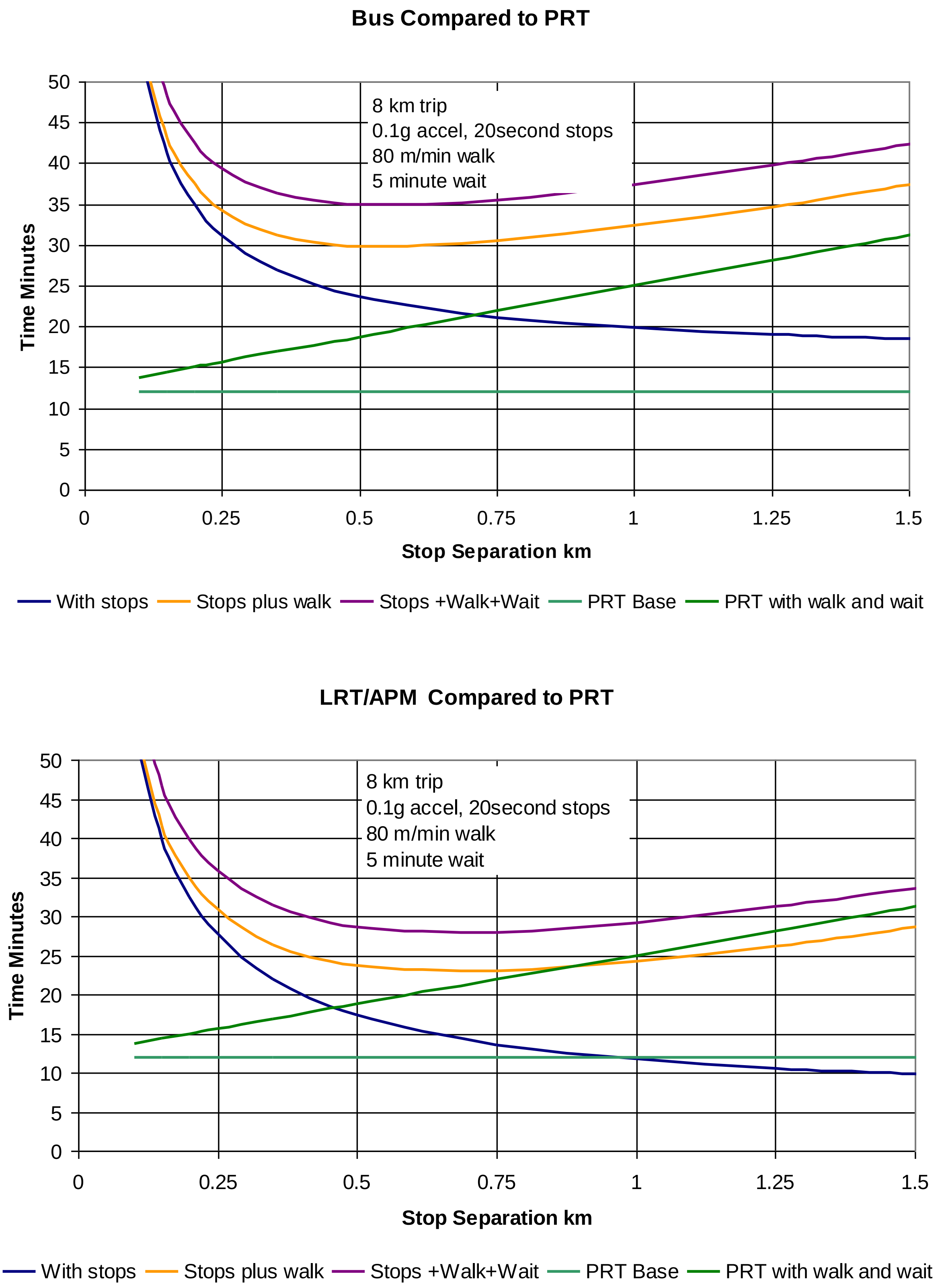


Figure 5 Average Trip Times: PRT Compared to Conventional Transport