RIDERIDESHARINGSHARING METHODOLOGY FOR INCREASING PERSONAL RAPID TRANSIT CAPACITY

Submitted: July 24, 2011
4,378 words + 3 figures and tables = 5,128 words

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ABSTRACT

Personal rapid transit (PRT) systems are comprised of small, driverless vehicles carrying passengers between stations on dedicated guideways. Originally envisioned to operate at very short headways (a second or less between vehicles) and to provide non-stop service, initial systems are operating at higher headways of around three or more seconds. The resultant reduced capacity has prompted the question of ridesharing to be raised – even if it requires some or most passengers to no longer receive non-stop service.

Large PRT systems with many origins and destinations have been thought not to be conducive to ride sharing. This paper presents a ridesharing methodology (where passengers are encouraged to share rides despite not knowing each other and/or not having the same destination) that is applicable to any PRT system with more than about ten stations. The methodology is simple to implement and has sufficient flexibility to accommodate changing demand in each station (e.g. morning peak, off-peak, evening peak, late night, etc.).

The paper provides sufficient information and analysis to describe the ridesharing methodology and demonstrate its functionality. It finds that vehicle occupancy (and therefore system capacity) can be substantially increased over a fairly wide range of demand levels both between and at stations. The purpose of this paper is to indicate the preliminary viability of the postulated concept and encourage further analysis and research.

INTRODUCTION

Personal rapid transit systems were first envisioned over sixty years ago. The concept of small vehicles carrying individuals or small groups to their destinations non-stop and at high speeds was very appealing. After many false starts, two small PRT systems are now in public service (*1, 2*). When operating at speeds above about 30 mph (48 kph) these systems are limited to headways (time between vehicles) above about two or three seconds (depending on the emergency deceleration rate used) if they are to comply with the so-called “brick wall” stopping criterion. While many believe this criterion should not to be applicable to PRT, until sufficient proof is available, most installations are anticipated to be required to comply with it. This criterion originated in the railroad industry and requires that a following train should stop without colliding with a preceding train if the preceding train were to instantaneously turn into a stationary brick wall.

Limiting a system capable of operating at one second headways to a two or three second headway effectively reduces its capacity by a factor of two or three. While capacity is not a significant problem for the two systems referenced above, a number of PRT systems are under consideration or being implemented in India where capacity is deemed to be an important consideration. Ridesharing, where passengers are encouraged to share rides despite not knowing each other and/or not having the same destination, provides a means of restoring capacity to systems operating at higher headways. It could also boost the capacity of systems with very short headways. In addition, it has the potential to reduce fares and/or per passenger operating costs of a system.

Ridesharing can be encouraged in PRT systems by simply charging for rides on a per-vehicle basis. Thus anyone wishing to share a ride could offer to share the vehicle (transportation pod or T-pod) and the cost with another party at the station. However, this voluntary ridesharing solution can be seen to quickly break down as the number of destination stations increases and it becomes increasingly difficult to locate other passengers with the same destination.

Figure 1 depicts an area served by a PRT system with four hundred subzones each containing at least one station. It is clear that, with so many destinations, a passenger departing from one station would have to wait a long time for one other party (let alone three)

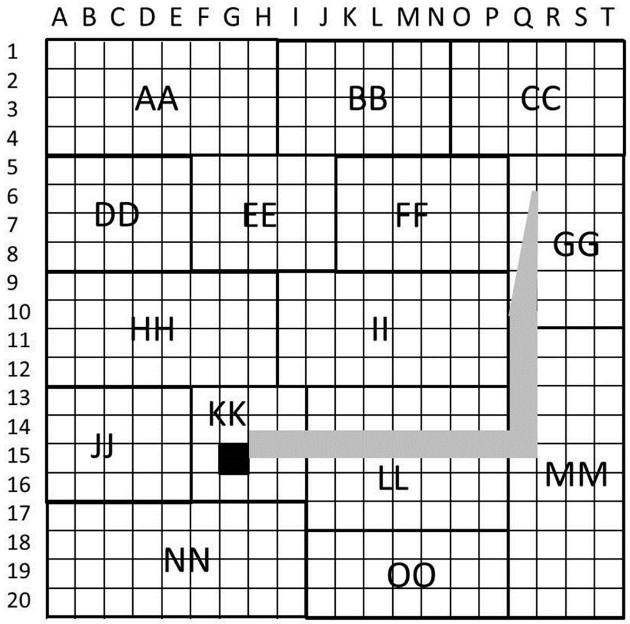

Figure 1. Service area divided into 400 subzones and 15 zones

to show up with the same destination. Thus ridesharing on a large system has previously been thought to be impractical (*3,4,5*). The purpose of this paper is to indicate the preliminary viability of the postulated concept and encourage further analysis and research.

RIDESHARING FACILITATED BY FIXED ZONES

The grouping of subzones in larger areas, designated as zones is deemed to provide a viable means of implementing ridesharing. In the ridesharing methodology described here one option is to divide the service area into a number of zones. While the methodology is not very sensitive to the size and shape of zones, it is thought to work best with approximately 10 to 20 zones. In the example depicted in Figure 1, the four hundred subzones are grouped into 15 zones. For ease of clarification, the subzones are designated by a letter column and a numeral row and the zones are designated by single sets of double letters.

Figure 2 depicts a PRT station in subzone G15. This figure represents a station in a suburban setting, during the morning peak hour when most passengers are using the PRT system to leave for work elsewhere. Passengers entering the station can purchase a ticket and/or orient themselves by using the system map. They will need to decide if they want to share a ride (pay per passenger) or travel exclusively in a vehicle dedicated to their use (pay per vehicle). If they choose pay per vehicle they will proceed to the lane so marked, process their “premium fare” ticket and enter the desired destination on the ticket kiosk. Within a minute (typically) they will be instructed to enter a vehicle parked in a lane where the electronic display is indicating “pay per vehicle” as well as their chosen destination. The vehicle will take them to their chosen destination nonstop. While they will pay a higher fare than that for a shared vehicle, the passenger receives private, point-to-point service. Note that paying per vehicle permits the traveler to take along as many companions, having the same destination, as will fit in the vehicle and could thus result in less cost per passenger than paying the reduced “pay per passenger” fare.

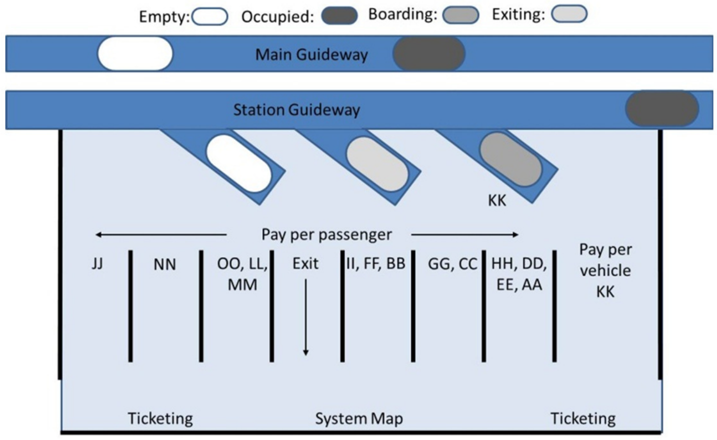

Figure 2. Station during the morning (outbound) peak

If a passenger chooses to share a ride (pay per passenger) they will proceed to the lane displaying the zone of their destination station (possibly along with other zones). They will swipe their ticket and enter their destination station before being allowed to enter the lane. Once the predetermined number of passengers (usually equal to the vehicle capacity) has entered the lane, or a predetermined amount of time has elapsed, they will be allowed to proceed to and board a vehicle, when available. If a vehicle is not immediately available, they may have to wait a while longer. Their vehicle will be designated by a variable message board over the station bay displaying the same zones as their lane was displaying or the destination stations selected by members of the group. Once all passengers are aboard, the vehicle will proceed to the designated zone(s) where it will drop each passenger off at their pre-selected stations using an optimized route. Thus the vehicle will usually be full for that portion of the trip to the designated zone(s) and (on average) half-full for the portion within the designated zone(s).

While this methodology will work well for trips to zones located at a fair distance from the origination station, it is recognized to be impractical for stations located with the same zone and to nearby stations in adjoining zones. The solution for this condition is to permit individuals destined to within-zone and/or nearby stations to travel there nonstop at the same reduced fare as those paying per ride. This can be accomplished by processing these people through the lane for people paying per vehicle but only charging for trips to these destinations at the per-ride rate. In the example illustrated in Figure2, trips to zone KK are handled in this way.

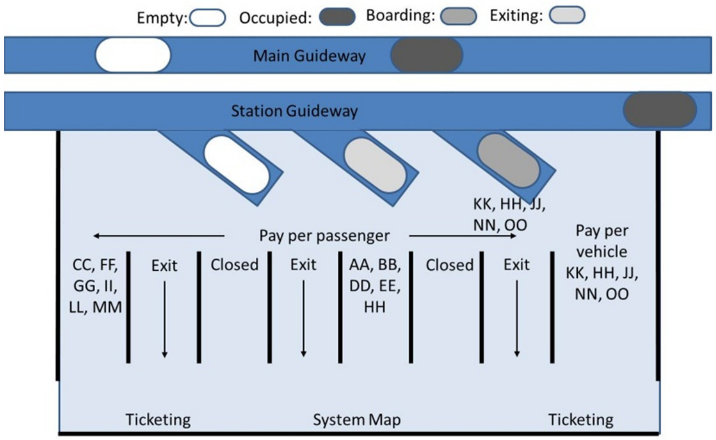

Figure 3. Station during the evening (inbound) peak

Figure 3 depicts the same station reconfigured for the evening (in-bound) peak period. During this period most T-pods arrive at the station full and depart empty. Thus the station needs to be reconfigured to:

- Accommodate numerous passengers wanting to exit the platform
- Facilitate ridesharing among the fewer passengers leaving the station by PRT vehicle.

The reconfiguration is accomplished by altering the dynamic message boards above each lane. Some lanes are converted to exit lanes to accommodate the passengers arriving by PRT and some lanes are closed. The remaining lanes in the pay per passenger area are used to facilitate ridesharing. Since fewer passengers will be looking to share rides, more zones are combined in each lane. The ridesharing that does occur will thus be less efficient than that which occurs during the morning (outbound) peak when many passengers are looking to share rides.

During off-peak periods when demand is low, all pay per passenger lanes not converted to exits could be closed and everyone could use the pay-per-vehicle lane. Fare policies may permit this use at the pay per passenger rate.

Note that, in the description above, the number and size of available zones was adjusted by combining the zones depicted in Figure 1. A potentially better alternative may be to adjust the number of zones and reconfigure each zone to include different subzones. This latter method would be more conducive to dynamically adjusting the zones to meet changing demand patterns. However, it may also be more confusing to passengers who would have to be alert to changes in zone boundaries. A likely solution could be to have a fixed (fairly large) number of zones (say about 30) that are combined as desired on the message board for each lane. This would combine the benefits of reasonable flexibility of destination zones with a fixed zone map. Recognizing the potential confusion that could be caused by variable lane designations, selection of the optimum operational solution must include a confirmation that management of the lanes is readily understandable by passengers at all times.

The described methodology will work equally as well (if not better) at very busy stations which will require additional station bays and entrance/exit lanes. In addition, the station bay configuration, series or parallel (in-line or off-line to each other) should have little impact on the effectiveness of the ridesharing system.

RIDESHARING FACILITATED BY DYNAMIC ZONES

Instead of dividing the service area into predetermined zones, the zones could be dynamically determined by the system in real time. Thus, when a passenger selects a destination, the system could form a zone comprised of all the stations along the route to that destination. Following passengers selecting stations in this defined zone would then join the first passenger on the trip until the vehicle was full or the maximum waiting time for the first passenger had elapsed. Dynamic zones could also be dynamically increased in size if a following passenger had a destination using the same route but beyond the first passenger's destination. The size of the zone would ultimately be defined by the proximity of the stations located along the route before or after the first rider's selected station.

It may be even be possible for passengers to indicate their destinations to the system prior to arriving at the station (e.g. by smart phone applications) so that travel groups could be formed with almost no waiting by anybody involved. However, given the short waiting times involved of, say, five minutes or less, this is likely to be problematic. Even a short delay on the way to the station could disrupt the process. Also, the likelihood of four passengers arriving simultaneously for the same dynamic zone is low and so some waiting is unavoidable.

Regardless of whether the dynamic zones are formed after passengers arrive at the station or while they are en route to the station, it will be desirable to congregate passengers riding together in designated areas. This will be especially true in larger stations with long platforms and numerous bays. Unless the groups are pre-assembled in proximity to their assigned vehicles, confusion will ensue and boarding times as well as vehicle dwell times will increase.

The station configuration shown in Figures 2 and 3 will also work well for a dynamic zone system. In this case, the entrance lanes would be numbered sequentially. A passenger selecting a destination for which a new dynamic zone is to be formed would be directed to a particular lane by its number. Following passengers bound for the same dynamic zone would then be directed to the same entrance lane. Once the group is gathered (or the maximum time has elapsed since the first passenger arrived) a vehicle in a bay proximate to the lane will be assigned to the group and they will depart.

DYNAMIC ADDITION OF SUPPLEMENTAL PASSENGERS

Any vehicle that is not full could have the ability to pick up a passenger en-route to its next stop. This functionality could increase average vehicle occupancies at the expense of most passengers experiencing more intermediate stops. It would also complicate system and station operations. While it is believed this capability merits investigation, a detailed exploration of the advantages and disadvantages of this option is not included in this paper.

PRELIMINARY OPERATIONAL ANALYSIS

The following analysis is based on simplifying assumptions and is intended to demonstrate the preliminary viability of this ridesharing methodology. The following system parameters are assumed in this analysis:

- The PRT system serves an area of 400 square units (miles or kilometers) with a regular (north-south, east-west grid) ½ mile (0.8 kilometer) guideway and station spacing.
- The area is divided into four hundred, one unit square, subzones each containing at least one station.
- At each station the subzones are combined into twenty to forty zones in such a way that the trip demand (for the time period being considered) to each zone is roughly uniform (Figure 1 depicts such a system).

Consider a station in subzone G15 of zone KK. Simple observation reveals the following results:

- There are 15 zones
- A vehicle trip from G15 to zone GG is depicted by the grey line. The thickness of the grey line is proportional to the vehicle occupancy. The occupancy will be at maximum achievable (assumed to be 4) for the portions of the trip through zones KK, LL and MM. In zone GG the occupancy will decline until, at the end of the trip it equals to the average occupancy without ridesharing (assumed to be close to 1).
- Ridesharing to stations within zone KK is probably not practical
- Ridesharing to the 4 zones abutting zone KK will result in vehicle occupancies averaging about 75% of maximum achievable occupancy. This results from about 35% of each trip being within zone KK at maximum achievable occupancy (4.0) and the remainder being in abutting zones at an average occupancy of 2.5 (a value between maximum achievable and the natural occupancy without ridesharing).
- By the same methodology, ridesharing to the 5 zones one zone removed from zone KK (DD, EE, FF, JJ and NN) will result in vehicle occupancies averaging about 85% of maximum achievable occupancy.
- Ridesharing to the 5 remaining zones will result in vehicle occupancies averaging about 90% of maximum achievable occupancy because most of the trip will be at the maximum achievable occupancy since passengers are only dropped off in the final portion of the journey.

Thus, if the average vehicle occupancy without ridesharing is α and the maximum achievable vehicle occupancy with ridesharing is β, the following vehicle occupancy will result in the above circumstance:

- One zone has average occupancies = α
- Four zones have average occupancies = 0.75β
- Five zones have average occupancies = 0.85β
- Five zones have average occupancies = 0.90β

Thus the system-wide average occupancy for trips leaving a station in Zone KK is 1/15α + 4/15x0.75β + 5/15 x 0.85β + 5/15 x 0.90β

= 0.07α + 0.78β

= average occupancy for trips leaving any station (simplifying assumption)

The average vehicle occupancy without ridesharing (α) will likely be lower than present average automobile occupancies because there will be no need for drivers to drive others to their destinations. Therefore, α has been assumed to be 1.20 for this analysis.

The maximum achievable vehicle occupancy (β) is computed as follows:- β will always be less than or equal to the maximum vehicle capacity – assumed to equal 4. Assuming that a station has two PRT berths that each have a throughput of 120 vehicles per hour, the station capacity would be (120 x 2 x 4) x 14/15 + (120 x 2 x 1.2) x 1/15 = 915 passengers per hour. Since the zones are formed to each have approximately the same number of trips from each station, there will be approximately 61 (915/15) passenger trips per hour to each zone. On average, it will take approximately three minutes for the additional three riders to show up once an initial rider has arrived for a specific zone. Thus, if groups are held a maximum of five minutes prior to being assigned a vehicle, β will approximately equal the maximum vehicle capacity (4 in this case). The system-wide average occupancy would then approximate 0.07 x 1.2 + 0.78 x 4 = 3.20. This is a 167% improvement over average vehicle occupancy without ridesharing (α).

A similar analysis for a vehicle with a maximum capacity of six indicates a station throughput of 1,363 passengers and a system-wide average occupancy of around 4.7 (a 292% improvement over α). However, for the same station throughput of 915 passengers per hour, the average wait time for the five additional passengers to arrive increases to five minutes. Thus about one half of the six passenger vehicles will depart with fewer than six passengers if the maximum wait time remains five minutes. Reducing the number of zones will increase the occupancy of departing vehicles destined for ridesharing zones without increasing the maximum wait time. However, as illustrated below, this will also reduce the system-wide average occupancy.

A similar analysis for lower demand situations where there are only a total of four approximately equal zones results in:

- One zone having average occupancies = α
- Three zones having average occupancies = (α + β) / 2

- Thus the system-wide average occupancy for trips leaving a station in any zone is 1/4α + ¾ (α + β) / 2

= 0.25α + 0.37α + 0.37β

= 0.62α + 0.37β

= average occupancy for trips leaving any station (simplifying assumption)

If α = 1.2 and β = 4 as before, the system-wide average occupancy would then approximate 0.62 x 1.2 + 0.37 x 4 = 2.22. This is an 85% improvement over α.

Since approximately 60 passenger trips per hour are required to each zone in order to keep the maximum wait time below about five minutes, this lower demand situation would need about 240 passengers per hour to achieve high occupancies without longer wait times.

Note that higher volume stations will require more vehicle berths but will still have the same number of destination zones. Concurrently, the average and maximum waiting times for groups to form will be less. Also note that, as the demand decreases (or for stations with less demand), the waiting times will increase or the number of zones must be reduced (thereby decreasing the efficiency of ridesharing).

In practice there will likely be numerous impediments to achieving ridesharing at the idealistic rates simplistically derived above. Not the least of these could be that a significant portion of any population could choose not to ride share.

ADVANTAGES

The ridesharing system described here has the obvious advantage of increasing the average ridership per vehicle – possibly by two or more times. This in turn means that fewer vehicles will be required to serve the same demand, or a higher demand could be served with the same number of vehicles. Either option will reduce the operating cost per passenger carried. In addition, stations will need fewer vehicle bays per passenger.

The increased vehicle occupancy will permit lower fares to be charged for those sharing rides while revenue per vehicle could actually increase. For example, if the average occupancy more than doubled and the ridesharing fare was half the regular fare, there would be a net increase in revenue per vehicle.

The two-tiered fare system will allow PRT systems to provide first class service to those willing to pay for it, while also providing mass transportation at a reasonable cost for the ridesharing passengers. Even those sharing rides will receive service at a much higher level than provided by conventional transit, due to reduced wait times and the by-passing of stations not included in the passengers' travel route.

The system has the flexibility to allow for those passengers not wishing to share rides and make intermediate stops, or those travelling with large objects such as bicycles or wheelchairs, to choose to pay per vehicle and receive the type of nonstop, little, or no, waiting service typically associated with PRT. Additionally, system owners could choose to further discount the fare to selected members of this group, such as passengers with disabilities.

The system has the flexibility to change the zones served by each lane dynamically through changeable message signs to meet changing demand at different times of the day. The lanes can also easily be changed to serve as exits or to be closed.

By collecting passengers into pre-assembled groups destined to ride together to the same zone, the system reduces confusion in the station and promotes the orderly and efficient boarding of vehicles. Since any vehicle in a PRT station can be dynamically assigned any destination, it will be an easy matter to assign a vehicle to a group in a nearby lane that is ready to depart.

DISADVANTAGES

While the system promotes order, it adds a level of complexity to PRT station operations. However, it could be argued that assigning passengers to boarding areas related to their destinations could facilitate orderly and prompt passenger boarding even if ridesharing was not actively promoted and all passengers paid per vehicle.

The system adds a level of complexity to the PRT control system since vehicles must accept multiple destinations. In addition, optimal routing must be found to these multiple destinations. This additional complexity is not considered onerous since optimal routing algorithms are common. Multiple destination coding simply requires the vehicle to remember which station to proceed to next (if any) after it has stopped at an intermediate station.

Entrance lanes with changeable message boards also add a level of complexity. A demand management application could be used to automatically handle the conversion of the station platform configuration during various times of the day, based on utilization of the station. The application could be adjusted to reflect the observed operation of the station over time. Alternatively, it could be possible to use manually-changed chalkboards in “low-tech” stations. Further, ensuring that passengers easily find their assigned entrance lanes could be accomplished by simply assigning particular zones to an area of the station (e.g. northwestern zones on the left).

The system requires increased platform area to serve the same demand because people spend more time waiting in the station. However, the increased area may be marginal compared to the platform area desirable at a busy station subject to backups during peak periods. In any event, the increased platform area is expected to be offset by the reduced need for station bays and vehicles to serve the same demand.

While passengers wanting to share rides will have a reduced fare, they will also have to wait longer for a ride. This extra waiting time is expected not to exceed five minutes. It is anticipated that most of those wanting to pay a lower fare will consider the short extra wait and the intermediate stops an acceptable tradeoff.

CONCLUSIONS

This ridesharing system has the potential to be of significant benefit in applications where the demand is high and a large proportion of the passengers have limited disposable income. It is flexible and deemed to be easily implemented. It reduces the number of vehicles and station bays required (and thus the operating costs) for meeting the same passenger demand. The additional capital costs associated with the larger station platform size needed will likely be more than offset by the capital cost savings resulting from the reduction in vehicles and station bays. Alternatively, the ridesharing system allows increased demand to be met with a fixed number of vehicles and station bays.

It appears that individual station departures need to approach one thousand per hour in order to support ridesharing in four-passenger vehicles to fifteen different zones and to keep maximum wait times less than about five minutes. The equivalent station demand rises to about 1,350 if six-passenger vehicles are used. This result seems to indicate that larger vehicles may be more appropriate in denser communities. However, the numerous detriments of larger vehicles have not been addressed here. The need for significant station demand in order to support ridesharing points to a potential tradeoff between close station spacing (short walking distances) and efficiency.

As station demand increases, additional berths will need to be added. However, additional platform space requirements are anticipated to be minimal.

Optimizing this ride-sharing methodology for a specific application will be a fairly complex process that will require consideration of maximum vehicle occupancy, station spacing (and therefore, demand), station operations, service area demographics, zone and subzone boundaries, fare/ridesharing elasticity, etc. While the preliminary results reported here appear favorable, further detailed analyses are required to provide a foundation upon which a specific application can be designed. It is suggested that further research could include such topics as focus groups, human factors testing, large system simulations with and without ridesharing, and station passenger and vehicle operations simulations.

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