Passenger-Pooling and Trip-Combining Potential of High-Density Demand Responsive Transport

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ABSTRACT

The aim of transport services is to find a good balance between efficiency and quality of service. Passenger-pooling and trip-combining increase efficiency but in most cases require passengers to compromise on the quality. In this paper, we analyze the passenger-pooling potential (PPP) and trip-combining potential (TCP) in Demand Responsive Transport (DRT) in high demand density situations. The studied DRT system operates on a real-time basis without pre-order times. Simulation study is used to analyze the effect of demand density on PPP and TCP, without relying on any particular control and routing algorithms. We also examine the effect of spatial and temporal dimensions of a DRT system to the potential of pooling and combining. The results indicate that both PPP and TCP have a strong positive correlation with demand density. With low demand densities no distinct potential for trip-combining and large-scale passenger-pooling is possible except with large walking distances. Increasing the demand density increases the possibilities of producing more efficient DRT services with better quality of service. The presented results argue for further research of DRT in high demand density situations, even though DRT system has conventionally been seen applicable mainly for low demand density situations.
Keywords*: demand responsive transport, passenger-pooling potential, trip-combining potential, high demand density*

INTRODUCTION

In a transport system, passengers and vehicles have to connect each other so that the passenger perceives a benefit from the ride. In practice, the connection means that the passenger and the vehicle have to be in the same place at the same time to enable passenger boarding. In addition, the vehicle must transport the passenger sufficiently near the destination. The connection is enabled by the temporal and spatial flexibility of a vehicle or a passenger or both. The flexibility of passengers is connected to a group of service quality attributes, such as walk, wait and ride time, that passengers value and accept differently (*1; 2*). Similarly, the flexibility of vehicles is connected to the efficiency of the transport service, as vehicle route kilometreage is typically increased as the flexibility increases.

The aim of a *Demand Responsive Transport* (DRT) system is to operate without fixed routes and timetables, thus enabling flexible service based on the passenger's trip requests. However, in order to achieve the efficiency of the system, passengers also need to be flexible in most cases by walking to and from stops and adjusting departure times based on the vehicle schedule. A central concept here is passenger-pooling. Passengers are pooled so that many passengers can either board to or alight from the vehicle at one stop. Trips are combined using the same vehicle so that the total vehicle kilometreage is decreased from the sum of direct trip lengths, but at the same time each passenger may have to travel more than the shortest distance to his or her destination.

Conventionally, DRT is seen as a transport service for special user groups or situations where the demand is too low for other public transport services (*3-6*). Low demand density, however, means that the trips are dispersed temporally and spatially. This results in low trip-combining ratio and low average occupancy (*3; 7*). Demand density has a significant impact on DRT system efficiency (*8*). The presumption we have made is that with state-of-the-art technology the DRT system can be implemented in high demand density situations so that the average occupancy is high even though the trips are ordered without pre-ordering times. One proposal for this kind of system is presented by Cortés and Jayakrishnan (*9*).

Few studies and implementations of DRT have addressed passenger-pooling. The probable reason for neglecting passenger-pooling is that the majority of current implementations have been focusing on door-to-door systems for special user groups. Imagine a system with an average of 10 passengers picked up per vehicle-hour, average ride times of 0.25 hour excluding stop times, and stop times of 30 seconds including deceleration, service at stop and acceleration. A straightforward calculation shows that if the *average number of passengers boarding or alighting the vehicle per stop* (ρ) is one, the stop times increase the ride time by 15%. With ρ=2 the increase in ride time is 7%: and with ρ=3 it is 4%. These calculations demonstrate the significance of passenger-pooling in a high demand density situation and show that the passenger-pooling is one essential part of the development of dispatching strategies.

The presented paper is a part of ongoing research project developing and studying new concepts and dispatching strategies for DRT in metropolitan areas. Our aim is to analyze the potential for passenger-pooling and trip-combining under reasonable conditions without relying on any particular control and routing algorithms under intensive study in our project. The main goal of this paper is to understand whether passenger-pooling and trip-combining are significant enough factors for more detailed studies in the DRT systems operated in the high demand density situations.

HIGH-DENSITY DEMAND RESPONSIVE TRANSPORT (HD-DRT)

In this paper, we study DRT operated in a high demand density situation. The concept is labeled as a *High-Density Demand Responsive Transport* (HD-DRT). The HD-DRT has at least the following characteristics: the *service region* is pre-defined and fixed, no timetables and predefined routes are used, passengers are picked up from stops and delivered to stops (*stop-to-stop*), service is offered from any stop to any stop within the service region (*many-to-many*) and no pre-ordering is required. We consider an HD-DRT system where the dispatching system selects the stops for customers.

The *demand density* DD is the number of trip requests per hour per square kilometer. This study considers demand density to be high when there is at least ten trip requests per hour per square kilometer. Of note is that demand density can be a misleading measure in cases where the demand density varies greatly within different parts of the service region (*10*). The presumption is that the inhomogeneous demand distribution gives more potential for passenger-pooling and trip-combining as trips take place between high-density "clusters". If the area of the service region is A, an average *trip request time interval* $\lambda = 1 / (DD*A)$.

Jitneys are one form of DRT that operate along fixed routes. Jitneys are the mainstay of the transit network in many parts of the developing world with high numbers of served customers (*3; 11*). The systems could have millions of daily users and the demand density is well over fifty. Truly flexible DRT systems with many-to-many service have not been implemented with high demand densities (*4; 7; 12-14*). The largest systems are typically offering services for special user groups such as individuals with disabilities in the metropolitan areas. The highest number of passengers is a few million per year so that the demand density remains below or just over one.

A HD-DRT could be achieved by offering an open-for-all service mainly to current private car users. For instance, the land area of the Helsinki metropolitan area is 769 square kilometers. The number of daily private car trips in the area is 1.3 million, and the trip count during a peak-hour is approximately 10% of the daily trip count. The peak-hour demand density of the private car trips in the Helsinki metropolitan area is thus 169 trips per hour per square kilometer. The trip count and demand densities of the daytime traffic are about one-half of the peak-hour values. The demand density of ten trips per hour per square kilometer would be obtained, if 6% of the peak-hour private car trips or 12% of the daytime private car trips shift to HD-DRT.

TEMPORAL AND SPATIAL PARAMETERS

The following temporal and spatial parameters might be specific for each trip. However, in this paper it is not necessary to indicate the trip specificity. Thus, the indexes representing that parameters are referring to the *ith* trip are not shown.

Every trip has an *origin a* and a *destination b*. The *Direct trip length s* is the shortest path from *a* to *b*. The HD-DRT system serves customers from a *pickup point u* to a *delivery point v*. The *Actual trip length s'* is the length of the vehicle route between *u* and *v*. It is possible, but not usual, that the pickup and delivery points of a customer are the same as his or her origin and destination.

The *order time* t_O is the time a trip request is made known. If a customer is picked up from the origin, the *earliest pickup time* t_{EP} of the trip is the same as its order time. Otherwise, the earliest pickup time is set by the walking time between the origin and the pickup point. For purposes of this study, walking times are ignored thus defining that the earliest pickup time is the same as order time for all trips.

The HD-DRT system responds immediately to a trip request by setting a *pickup time* t_P. If the pickup time is delayed from the earliest pickup time, the customer has to adjust his or her departure time from the origin. Thus, we define an *adjustment time AT* to be the time difference between pickup time and earliest pickup time. The nature and weight of adjustment time is not discussed in this paper. The customer arrives at the delivery point at the *delivery time* t_D. *Ride time RT* is the time difference between pickup time and delivery time. In reality, the HD-DRT application will have additional system flexibility for the pickup so that the customer is not always picked up exactly at the declared pickup time. *Waiting time WT* is the time difference between actual pickup time and declared pickup time. This study considers all customers to be picked up at the pickup time and therefore ignores waiting times.

Passenger-pooling and trip-combining mean scheduling and routing new trips so that the decisions made for existing trips and routes are exploited as much as possible. Pooling is possible at both the pickup points and the delivery points. If a pickup of a customer cannot be pooled to any of existing stops, a new vehicle stop must be scheduled. The same applies to the delivery of a customer. If a trip cannot be combined to the existing routes, a new route must be created for the trip. We use separate studies for analyzing passenger-pooling and trip-combining. For the studies, we define the following system parameters:

WK_{max}, *the maximum walking distance* defines maximum distance between the origin and the pickup point as well as between the destination and the delivery point.

AT_{max}, *the maximum adjustment time* defines the time difference between earliest pickup time and *latest pickup time* t_{LP}

RTI_{max}, *the maximum ride time index* defines the maximum ratio of *maximum ride time* RT_{max} and *direct ride time* RT_{dir}, where maximum ride time is the time difference between pickup time and *latest delivery time* t_{LD}, and direct ride time is the ride time along the shortest path from *a* to *b*.

In a study of passenger-pooling, we define *pooling base trips* to be trips that cannot be pooled at the moment they are ordered. The pooling base trips will be picked up from the origin so that $u=a$ and delivered to the destination so that $v=b$. The pickup time of the pooling base trips is delayed from the earliest pickup time for improving passenger-pooling. Thus we define that:

DF, *the delay factor* describes how much the pickup times are delayed from the *ATmax*.

For example, values $DF=0.5$ and $AT_{max} =30\ min$ would mean that for all pooling base trips the pickup time is set 15 minutes after the earliest pickup time.

Possibility for passenger-pooling of a trip is examined so that the trip is picked up at the same time from the same pickup point as the existing pooling base trips. A trip that can be pooled is called a *pooled trip*. In this study, we define that each pooled trip is pooled only to one pooling base trip. If a pooled trip can be pooled to more than one pooling base trips, the one where the walking distance for the pooled trip is the shortest is chosen. *Passenger-pooling potential (PPP)* is defined as the average number of pooled trips that are pooled to the same pickup point with pooling base trips under reasonable assumptions. The value of *PPP* states what the achievable maximum is for passenger-pooling for dispatching strategies. The efficiency of dispatching strategies determines how well the potential is utilized.

In a study of trip-combining, we define *combining base trips* to be trips that cannot be combined at the moment they are ordered. Similarly than with the pooling base trips, the combining base trips will be picked up from the origin, delivered to the destination and picked up at the time defined by the earliest pickup time, AT_{max} and *DF*.

Possibility for trip-combining of a new trip is examined so that such route is created that would serve both the new trip and the combining base trip. A trip that can be combined is called a *combined trip*. In this study, we define that each combined trip is combined to only one combining base trip. If combined trip can be combined to more than one combining base trip, the one with the largest *kilometreage reduction* from the sum of direct trip lengths is chosen. *Trip-combining Potential (TCP)* is defined as the average number of combined trips that are combined with combining base trips under reasonable assumptions.

The temporal and spatial parameters in the before described studies are presented in Figure 1. Even though, the temporal and spatial parameters are used with the above mentioned simplifications, it is reasonable to argue that the *PPP* and *TCP* values represent the potential for passenger-pooling and trip-combining with sufficient detail. The values have to be noted only as indicative, so that detailed studies in the future could concentrate on the right issues based on the results of this paper.

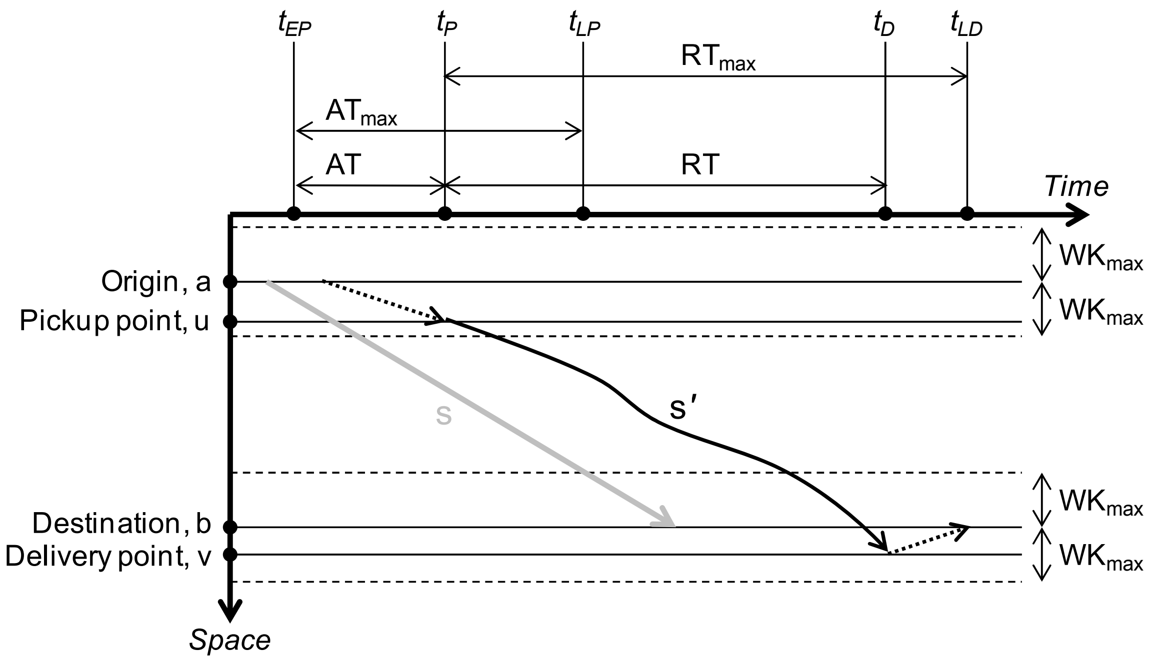

FIGURE 1 Spatial and temporal parameters in the examined HD-DRT system.

METHODOLOGY

The effect of demand density and system parameters was studied using a MATLAB simulation study. The simulations assumed a square service region with sides of 20 km and area of 400 km^2. The area was divided into 2*2 km *grids* numbered consecutively from left to right and down to top. Simulations were run with three demand distributions:

1. *Homogenous demand.*
2. *Peak-hour demand.*
3. *Daytime demand.*

The peak-hour demand and daytime demand were generated based on the unpublished traffic survey data of the Helsinki Metropolitan Area Council (YTV). The 20*20 km square study area was located in the Helsinki metropolitan area (Figure 2). Only those trips that were inside the study area using a private car, van, motorcycle or bus as their main travel mode were included. Peak-hour demand included trips with departure hour 7 (the trips between 7:00 and 8:00). Daytime demand included trips with departure hour between 8 and 16. The sample included 467 morning peak trips and 2,301 daytime trips that fulfilled the criteria. After the sample expansion, they represent a total of 89,133 and 429,598 trips. Origin-Destination (OD) matrix between grids was formed by means of the origin and destination coordinates. Origin grid and destination grid were drawn based on the OD matrix so that the probability for trip from grid *i* to grid *j* was $P_{i,j}=s_{i,j}/\Sigma s_{i,j}$, where $s_{i,j}$ is the trip count in the expanded traffic survey data from grid *i* to *j*. The origin of a generated trip is a random point inside the origin grid and destination a random point inside the destination grid.

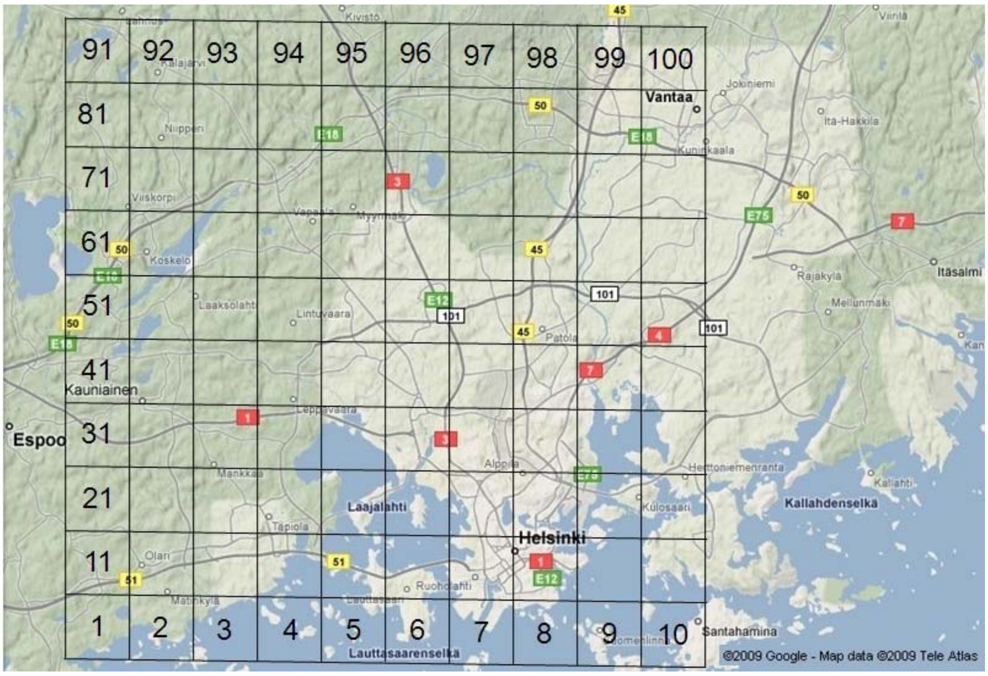

FIGURE 2 Study area in the Helsinki metropolitan area.

In the case of homogeneous demand, the origin was a random point inside the service region. The destination was determined based on the direct trip length distribution of the peak-hour demand simulation using Euclidean distances. Destination point generation was based on the origin and direct trip length. The generation was repeated until the destination was inside the service region.

Trip requests were generated so that $\lambda \sim \mathrm{Exp}(DD*A)$. The trip request generation time became the order time for each trip.

Each simulation included a set of system parameters, which were constant for all trip requests (Table 1). Simulations studying passenger-pooling varied parameters AT_{max}, DF and WK_{max}. Simulations studying trip-combining varied parameters AT_{max}, DF and RTI_{max}. System parameters were varied one at a time so that default parameter values for the others were used. Each set of system parameters were simulated with four levels of demand density, from which three were regarded as high demand density.

TABLE 1 Used System Parameters*

Parameter				
Demand density (DD), no. of trips/(hour*km^2)	5	10	50	100
Maximum adjustment time (AT_{max}), min	10	**15**	20	30
Delay factor (DF)	0.25	**0.50**	0.75	1.00
Maximum walking distance (WK_{max}), km	0.1	**0.3**	0.5	0.8
Maximum ride time index (RTI_{max})	1.25	**1.50**	1.75	2.00

** Default parameter values have been bolded*

The first generated trip request in the passenger-pooling simulations became the first pooling base trip. We define that new trip can be pooled with pooling base trip if three criteria are fulfilled. Firstly, the distance from the origin of new trip to the pickup point of the pooling base trip cannot be more than WK_{max}. Secondly, the earliest pickup time of new trip has to be before the pickup time of the pooling base trip. Thirdly, the time difference between the earliest pickup time of new trip and the pickup time of the pooling base trip cannot be more than AT_{max}. If the new trip cannot be pooled with any of the pooling base trips, it becomes a new pooling base trip.

The first generated trip request in the trip-combining simulations became the first combining base trip. We define that new trip can be combined with combining base trip if a route can be created so that four criteria are fulfilled. Firstly, the pickup time for both trips must be before the delivery time. Secondly, the length of the route has to be less than the sum of direct trip lengths. In other words, the kilometreage reduction has to be larger than zero. Thirdly, the time difference between the earliest pickup time and pickup time of new trip cannot be more than AT_{max}. Fourthly, the ratio of ride time and direct ride time of the trips cannot be more than RTI_{max}. If the new trip cannot be combined with any of the combining base trips, it becomes a new combining base trip.

In addition to passenger-pooling potential and trip-combining potential, some average values were reported. Average walking distance between the origin and the pickup point and average adjustment time were reported from pooled trips. Average adjustment time, average ride time index and average kilometreage reduction of routes were reported from combined trips. These are not directly applicable for estimating the quality of service or efficiency of HD-DRT as the simulations didn't model the actual HD-DRT transport but the passenger-pooling potential and trip-combining potential within it.

The simulation system was tested to determine needed warm-up period and reporting interval. Tests indicated that the model needs at least $DF * AT_{max}$ for warming up and AT_{max} to empty. Therefore, a half-hour warm-up period was set at the beginning of the simulation time and a half-hour period at the end of simulation when no results were reported.

Trip generation includes randomness that has an effect on the results. The longer the simulation time, the less randomness had an effect on the results. The effect of randomness was studied with test simulations varying simulation times. Test simulations used default parameter values, DD=10, and the above-mentioned warm-up and reporting periods. The results of test simulations indicated that the averages and standard deviations of *PPP* and *TCP* were converged as the simulation time was increased. Simulations with a 6-hour and longer simulation times had results where no significant variation based on the simulation time was observed. A 7-hour simulation time was used on the basis of the test simulations.

RESULTS

We presumed that the inhomogeneous demand distribution would lead to larger values of *PPP* and *TCP* than the homogeneous distribution. However, simulations do not support this presumption. Demand distributions appeared to have an insignificant effect on *PPP* and *TCP* as shown in Figure 3, even though the significance was not tested with statistical methods.

(a) (b)

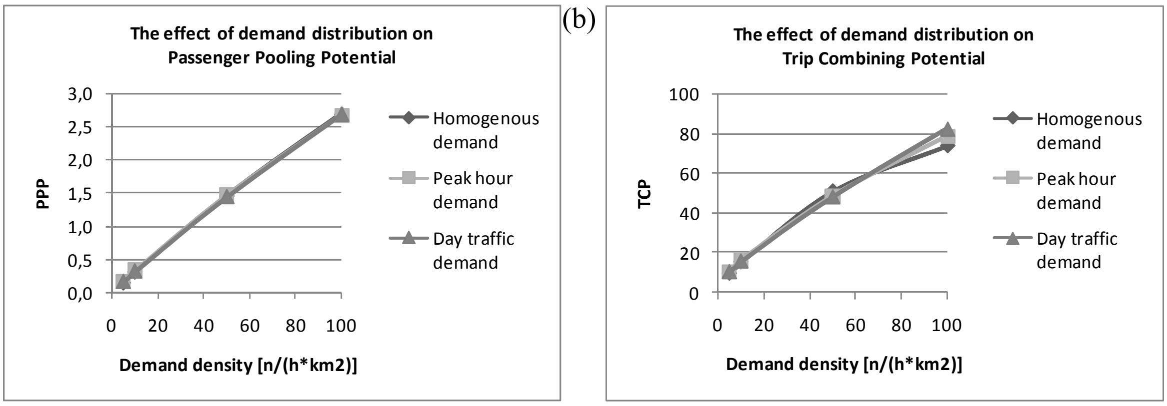

FIGURE 3 The effect of demand distribution to (a) Passenger-pooling Potential and (b) Trip-combining Potential with default parameter values.

One explanation for the insignificant difference between the demand distributions is that origins and destinations in inhomogeneous demand distributions were drawn so that origins and destinations within one grid were homogeneously distributed. This did not bring out the “trip clusters”. For example, a large shopping market inside a grid would gather a large portion of origins and destinations to a small area inside the grid. The traffic survey data we used was not detailed enough to enable simulations in address detail. Based on this, only results with homogenous demands are presented in this paper.

Simulation results indicate a positive linear correlation existing between demand density and *PPP*. With default parameter values, the dependence is $PPP = 0.0274 * DD$ ($R^2 = 0.9964$). This means that *PPP* value over 1 must have DD=36.5 and *PPP* value over 5 results in a *DD=182* (Figure 4). The results also indicate a correlation existing between *PPP* and AT_{max}, between *PPP* and *DF* as well as between *PPP* and square of WK_{max}.

(a) (b) (c)

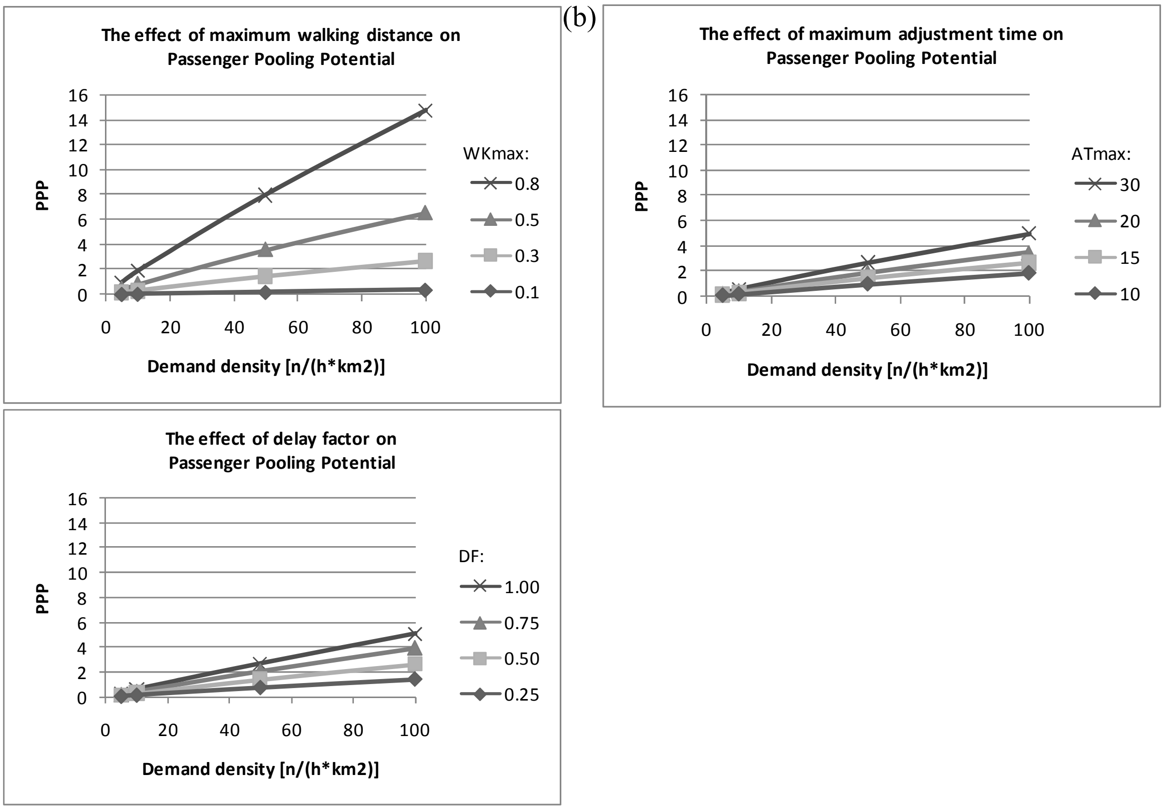

FIGURE 4 Passenger-pooling Potential with various values of (a) maximum walking distance, (b) maximum adjustment time and (c) delay factor on homogenous demand distribution.

The increase of WK_{max} had evident effect on average walking distances (Table 2). Average walking distances were 55% to 66% of the maximum walking distances. The *DF* and AT_{max} had no effect on average walking distances on the results. The effect of demand density on average walking distance was low.

Demand density and WK_{max} had no effect on average adjustment time. However, the effects of *DF* and AT_{max} were evident. The adjustment times with *DF=1.00* were over three times as large as with *DF=0.25*. Similarly, the adjustment times with AT_{max} *=30 min* were about two times as large as with AT_{max} *=10 min*. Average adjustment times with *DF=0.5* were 24% to 26% of the maximum AT_{max} values.

TABLE 2 The Effect of Maximum Walking Distance, Delay Factor, Maximum Adjustment Time and Demand Density on Average Walking Distance and Average Adjustment Time

Average walking distance (km)	Max. walking distance (km)				Delay factor				Max. adjustment time (min)			
Demand density (n/km^2/h)	0.1	0.3	0.5	0.8	0.25	0.50	0.75	1.00	10	15	20	30
5	0.07	0.19	0.32	0.50	0.19	0.19	0.20	0.20	0.19	0.19	0.20	0.20
10	0.07	0.20	0.32	0.49	0.20	0.20	0.19	0.19	0.20	0.20	0.19	0.19
50	0.07	0.19	0.30	0.45	0.19	0.19	0.19	0.18	0.19	0.19	0.19	0.18
100	0.07	0.18	0.29	0.44	0.19	0.18	0.18	0.18	0.19	0.18	0.18	0.18
Average adjustment time (min)	Max. walking distance (km)				Delay factor				Max. adjustment time (min)			
Demand density (n/km^2/h)	0.1	0.3	0.5	0.8	0.25	0.50	0.75	1.00	10	15	20	30
5	3.8	3.7	3.7	3.8	1.8	3.7	5.8	7.7	2.4	3.7	4.9	7.6
10	3.9	3.8	3.8	3.8	1.9	3.8	5.7	7.6	2.5	3.8	5.0	7.6
50	3.8	3.8	3.8	3.8	1.9	3.8	5.7	7.6	2.5	3.8	5.0	7.6
100	3.8	3.8	3.8	3.8	1.9	3.8	5.7	7.6	2.5	3.8	5.0	7.6

Simulation results indicate that the demand density has evident impact on *TCP*. With default parameter values, the *TCP* is just below ten with *DD=5* but more than fifty with *DD=50* (Figure 5). Each simulation parameter had an effect on *TCP*, even though the effect of *DF* was not as significant as the effect of RTI_{max} and AT_{max}. The smaller the value of RTI_{max} was the bigger effect its increase had on *TCP*. Enlargement of AT_{max} increased the value of *TCP* evenly. The values of *TCP* with AT_{max} *=30 min* were 50% to 88% larger than the values with AT_{max} *=10 min*. Simulations with *DF=1.00* gave 11% to 35% larger *TCP* values than simulations with *DF=0.25*.

(a) (b) (c)

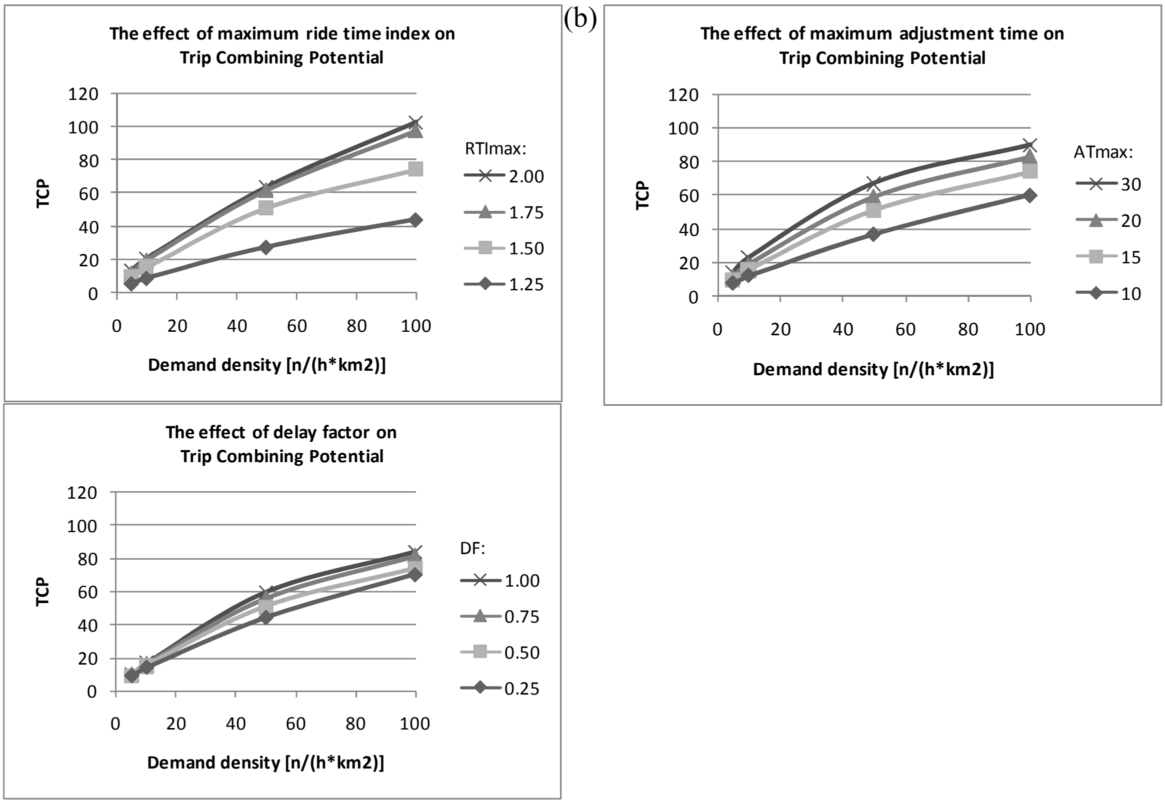

FIGURE 5 Trip-combining Potential with various values of (a) maximum ride time index, (b) maximum adjustment time and (c) delay factor on homogenous demand distribution.

Demand density, *DF* and AT_{max} had no effect on average ride time index (Table 3). However, the effect of the RTI_{max} was evident.

The increase of demand density decreased the average adjustment times. Average adjustment times with *DD=100* were 11% to 23% smaller than with *DD=5*. All system parameters had some effect on average adjustment times. The AT_{max} had the most evident effect. Average adjustment times were 22% to 43% of the AT_{max}.

The average kilometreage reduction was decreased as the demand density was increased. This is explained by the aspect that when the demand density was increased, the probability of finding a suitable combining base trip for the longer trip requests was increased more than the probability for shorter trip requests. Thus, the share of short trips among combining base trips was increased and the average length of the combining base trips was decreased as the demand density increased. RTI_{max} had the largest effect of the simulation parameters on average kilometreage reduction. The reduction with $RTI_{max} = 2.00$ was 29% to 32% smaller than with $RTI_{max} = 1.25$. AT_{max} and *DF* had no significant effect on average kilometreage reduction until the demand density was high and the parameters had loose values. With loose parameter values, the criteria enabled trips to be combined with a combining base trip even though the kilometreage reduction was small. With tighter parameter values, the combining was not possible and the trip became a new combining base trip. Therefore, with tight parameter values, the combined trips more appropriately generate larger average kilometreage reductions, on average.

TABLE 3 The Effect of Maximum Ride time index, Delay Factor, Maximum Adjustment Time and Demand Density on Average Ride time index, Average Adjustment Time and Average Kilometreage Reduction

Average ride time index	Max. ride time index				Delay factor				Max. adjustment time (min)			
Demand density (n/km^2/h)	1.25	1.50	1.75	2.00	0.25	0.50	0.75	1.00	10	15	20	30
5	1.16	1.31	1.43	1.54	1.31	1.31	1.31	1.32	1.31	1.31	1.31	1.31
10	1.16	1.31	1.43	1.55	1.31	1.31	1.31	1.32	1.31	1.31	1.31	1.31
50	1.16	1.31	1.43	1.55	1.31	1.31	1.31	1.32	1.31	1.31	1.31	1.31
100	1.16	1.31	1.43	1.55	1.31	1.31	1.31	1.32	1.31	1.31	1.31	1.32
Average adjustment time (min)	Max. ride time index				Delay factor				Max. adjustment time (min)			
Demand density (n/km^2/h)	1.25	1.50	1.75	2.00	0.25	0.50	0.75	1.00	10	15	20	30
5	5.3	5.5	5.6	5.7	4.8	5.5	6.1	6.4	4.1	5.5	6.7	8.5
10	5.0	5.3	5.5	5.5	4.6	5.3	5.9	6.3	3.9	5.3	6.4	8.2
50	4.5	4.8	5.1	5.2	4.2	4.8	5.4	6.0	3.6	4.8	5.8	7.4
100	4.3	4.6	4.9	4.9	4.1	4.6	5.3	5.7	3.5	4.6	5.5	6.6
Average kilometreage reduction (km)	Max. ride time index				Delay factor				Max. adjustment time (min)			
Demand density (n/km^2/h)	1.25	1.50	1.75	2.00	0.25	0.50	0.75	1.00	10	15	20	30
5	5.28	4.37	3.92	3.57	4.34	4.37	4.39	4.32	4.43	4.37	4.37	4.26
10	5.06	4.45	3.98	3.49	4.31	4.45	4.44	4.17	4.50	4.45	4.39	4.34
50	4.80	4.20	3.73	3.39	3.97	4.20	4.04	3.79	4.12	4.20	4.28	4.05
100	4.64	3.88	3.62	3.19	3.87	3.88	3.95	2.98	4.06	3.88	3.82	3.16

DISCUSSION AND CONCLUSIONS

Although, the used model for determining *PPP* and *TCP* contains some simplifications, it is nevertheless sufficient to say that *PPP* and *TCP* represent the potential for passenger-pooling and trip-combining. Previous DRT related studies have generally concentrated on some particular control or routing algorithms. The model used in this study is more general but anyhow connects the main temporal and spatial parameters to the functionality of HD-DRT systems.

The results indicate that both *PPP* and *TCP* have a strong positive correlation with demand density. The question is, how well the potentials for passenger-pooling and trip-combining can benefit HD-DRT systems? Due to their highly approximative nature, the significance of *PPP* and *TCP* is only indicative. Nonetheless, the results yield new information on the significance of passenger-pooling and trip-combining in HD-DRT. The results argue for further research of HD-DRT, even though DRT systems have conventionally been seen applicable mainly for low demand density situations.

PPP does not pay attention to the direction of trip requests. Counting only trip requests going in the same direction might have potentially resulted in at least four times smaller PPP values. The *PPP* treats only passengers boarding the vehicle at the pickup point. The other side of passenger-pooling at delivery points has left outside the study. The pooling at delivery points might have potentially doubled the *PPP* values. High *PPP* values give hope to large-scale passenger-pooling. Simulation results indicate that no distinct potential for passenger-pooling emerges until high demand density. With low demand densities the large-scale passenger-pooling is possible only with large walking distances.

The criteria for viable routes in *TCP* do not take into consideration route decisions made for other combined trips. Thus, the actual possibilities for route modifications are more limited than when calculating the *TCP* values. Small *TCP* values would most likely mean that trip-combining happens rarely and that the empty kilometreage is high. High *TCP* values enable trip-combining in "tighter packages" so that the average occupancy increases while the quality of service remains high. The simulation results indicate that with demand densities between five and ten the distinct potential for trip-combining is emerging. With low demand densities, no distinct potential exists. When the demand density is fifty, the potential for trip-combining is very high, even with high quality of service.

In this paper, we do not discuss what system parameters values are acceptable to user. The valuations of parameters such as walking distance and waiting time vary largely according to user and trip type. It is a task of the operator of the HD-DRT system to address the trade-off between the offered quality of service and system efficiency.

The presumption was that the inhomogeneous demand distribution would give higher *PPP* and *TCP* values than the homogeneous demand distribution as the origins and the destinations are more concentrated. The used methodology proved to be unsuitable for bringing out the difference between homogeneous and inhomogeneous demand distributions. Thus, only results with homogenous demands are presented in this paper.

The delay factor was introduced to increase *PPP* and *TCP* in dynamic DRT operation with short adjustment times. The effect of the delay factor was more evident on *PPP* than on *TCP*. This can be explained by the possibility of combining trips with the combining base trip even though the combining base trip has already been picked up. If and when the aim of the HD-DRT is to obtain high average occupancy levels, the share of pooling base trips and combining base trips approximates zero. Thus, the importance of delay factor decreases as the demand density increases.

The results of this paper argue for further research of HD-DRT systems. New concepts and dispatching strategies combined with state-of-the-art technology could utilize a large portion of the potential presented in this study.

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