UTILIZING TAXI EMPTY CRUISE TIME TO SOLVE
THE SHORT DISTANCE TRIP PROBLEM

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ABSTRACT
Short distance trips are crucial for urban mobility and accessibility. They can contribute to integrated transportation (the “last mile” problem), and more generally to urban ad-hoc ride sharing scenarios [1]. Since no transport provider covers short distance trips where demand arises, private car use is flourishing in recent decades, with all the known disadvantages of traffic congestions, resource wastes, air pollution, and insufficient parking space especially in city centers. Taxis are focusing on providing a door-to-door service, but they do not perform well in short distance trip pickup and delivery services. This paper identifies the obstacles, and suggests the empty cruise time of taxis as (a) a feasible solution for the short distance trip problem, and (b) a contribution to develop a short distance trip market for the taxi industry. This empty cruise contribution hypothesis is investigated by testing different models that define ad-hoc matches of passengers and empty cruising taxis. An agent-based simulation is designed to study the match probability by these models. Based on the experimental results it is shown that taxi empty cruise match models have the potential to solve the short distance problem and to develop the taxi short distance trip markets.

INTRODUCTION
The term transport disadvantage is used extensively in the literature, and was for example seen in the report Strategies to overcome transport disadvantage [2]. Transport disadvantage is experienced by those people who have frequent mobility or access problems. Apparently, the ultimate goal of most transportation is access, people’s ability to reach desired goods, services and activities [3]. In recent decades, urban transport infrastructure has been under fast development, but transport disadvantage remains an issue in particular for short trips. Transport disadvantage, as the lack of suited means of transport, hits short trips by disproportional waiting times, disproportional efforts to reach transportation means, or disproportional fares. So the short distance trip problem (SDTP) arises when the trip range is relatively short for a car trip and far enough when walking to think about alternatives. Contributing to the SDTP are the limitations of public transport networks in terms of frequency of services or lack of network density, the costs of using a car especially in finding parking spots, and the fare structure of taxis. This means short distance trips also occur when people have to walk to public transport stops for a longer public transport journey, or from the terminus to the final destination, or between sectors of a public transport journey.
Research indicates that 40% of trips within the metropolitan area of Melbourne are less than two kilometres, and almost two-thirds are less than five kilometres. It is reasonable to suggest that most of these travellers are not starting at a public transport stop, or have a destination at a public transportation stop, so they would suffer SDTP. Therefore it is likely that a large number of people regularly face the SDTP.

Due to the characteristics of the SDTP, there are four candidate transport modes in addition to public transport. These are private cars, taxis, bicycles or walking, and are all currently in use to varying degrees throughout the city. Each alternative has its advantages and disadvantages shown in Table 1.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Private car</td>
<td>Fast</td>
</tr>
<tr>
<td></td>
<td>Low flexibility, congestion</td>
</tr>
<tr>
<td>Taxi</td>
<td>Fast, high flexibility</td>
</tr>
<tr>
<td></td>
<td>High cost</td>
</tr>
<tr>
<td>Bicycle</td>
<td>Moderate speed, no cost</td>
</tr>
<tr>
<td></td>
<td>Low flexibility</td>
</tr>
<tr>
<td>Walk</td>
<td>High flexibility, no cost</td>
</tr>
<tr>
<td></td>
<td>Slow</td>
</tr>
</tbody>
</table>

Table 1: Advantages and disadvantages of alternative short distance trip modes.

Taxis are not well prepared to solve this problem due to flag-falls and booking surcharges, such that short trips cause high fares per kilometre for passengers. Disregarding the high fares of travelling by taxi especially short distances, among the alternatives of Table 1 a taxi is the best candidate for a short distance trip; its fast door-to-door delivery can show a performance as good or even better as a private car since it does not need to search for parking spaces, and its actual costs would be negligible if empty cruise times can be exploited. Moreover taxis, as shared vehicles, cause less traffic congestion than private cars.

Thus we put forward a taxi empty cruise contribution hypothesis which may largely reduce the fares of travelling short trips by taxis. The hypothesis identifies the empty cruise times of taxis as the key to address the SDTP. We will show that exploiting empty cruise time provides (a) a feasible solution for the short distance trip problem, and (b) a contribution to develop a short distance trip market for the taxi industry. This will be demonstrated by investigating taxi-traveller matching models. Based on such matching models, match probabilities can be discovered through statistical geo-simulated experiments, and influencing factors can be identified by varying the simulation parameters.

If we can solve the SDTP by exploiting empty cruises of taxis another benefit of this research emerges. This research is done in the context of a larger project developing an integrated ad-hoc ride sharing model for urban mobility (see next section for details). Exploiting taxi empty cruise times will remove the economic barrier from using taxis in a generic and fully integrated ad-hoc ride sharing service. Being able to include taxis in the mix of modes is desirable since taxis form a major group of vehicles in inner-urban traffic—i.e., areas with high demand of short distance trips—, and taxis are per se trusted hosts of rides, which addresses another potential issue with ad-hoc ride sharing.

The next section summarizes previous work on ad-hoc ride sharing, and the state of the art in taxi allocation. Then we describe the taxi empty cruise contribution hypothesis and two possible taxi-traveller matching models. The following section designs experiments and describes how match probabilities are discovered. Then the experiments results are discussed for their support of the hypothesis. Finally we present conclusions and future work.
PREVIOUS WORK

AD-HOC RIDE SHARING

Ad-hoc ride sharing can enhance urban mobility [1, 4, 5] and to a large extent solve the SDTP. For ad-hoc ride sharing, travellers (transportation clients) and nearby vehicles (transportation hosts) negotiate ad-hoc about transport via short range radio (e.g., 802.11p) in a peer-to-peer manner. The traveller applies route planning based on the limited transport knowledge collected from the nearby vehicles, and books a host of matching travel plans and free transportation capacities. This ad-hoc ride sharing can involve any type of vehicle, including private cars, public transport means or taxis, but also shared bicycles or cars. In this mix taxis are currently least attractive due to their fare structures, and this paper will overcome this barrier by enabling taxis to offer short distance trips in an economic model that is beneficial for both, the taxi industry and the short distance traveller. Ad-hoc ride sharing is challenging the current transport systems as it integrates transportation modes, works ad-hoc without prior booking, and hence, has some convenience for low costs. Ad-hoc ride sharing relies on some social conventions as much as on technological progress [6]. Besides it may also trigger oppositions from car manufacturers and public transit operators, fearing that ride sharing may reduce the utility of public transport and put off consumers to buy cars. Car producing companies have already begun to appeal to stop ride sharing [7]. In fact, ad-hoc ride sharing does the opposite: its integrative function can enhance usage of public transport, and, as we will show, open up new markets for the taxi industry.

TAXI ASSIGNMENT MODES

Taxis are transportation means adjunct to buses, trams and trains, which provide fast, individualized transport services for people with mobility and accessibility problems [8].

Taxi-task assignment is the process of allocating vacant taxis to passengers. Based on the availability of location information of passengers and taxis respectively, there are four possible combinations illustrated in Figure 1 and correspondingly four taxi-task assignment modes.

![Figure 1: Location availability in four taxi-task assignment modes [9].](image)

Random searching is the mode where neither the taxis’ nor the clients’ locations are known.
They randomly search each other. Clients can not call a taxi at any time in any location meanwhile drivers struggle to find clients. It increases taxis’ empty cruise time, thereby, causes resource wasting and contributes to air pollution and traffic jams. This mode is gradually vanishing since centralized dispatch systems are deployed more and more.

Fixed-stop mode and broadcasting mode are in the middle level of efficiency as either the clients’ locations or the taxis’ locations are known. In fixed-stop mode, the taxis’ locations are known. This mode can be frequently found at airports, hotels, hospitals and shopping centres, which are locations of high population density and corresponding high mobility demand. It is convenient for clients such as hotel guests and hospital patients, but less suitable for a client walking in the streets and watching out for a taxi.

In broadcasting mode, the clients’ locations are known. A client calls the taxi dispatch centre to book a taxi, the dispatch centre will broadcast the request fleet-wide, and taxi drivers will either bid or the first responding driver will get the job. Broadcasting mode ensures that even clients in some distance from a taxi can get a ride. In such cases slower processes of manual dispatch may be applied [10].

The GPS-based mode is in the most efficient mode because of knowing both the taxis’ and the clients’ location. In GPS-based mode, there are two common taxi dispatching rules namely “least utilized vehicle prior rule” and “nearest vehicle prior rule” [11]. Both the least utilized rule or the nearest vehicle rule cannot balance the drivers’ working times and the clients’ waiting times, why one would want to look into a “fuzzy rule” [12]. The fuzzy rule takes both factors into account. A special GPS-based taxi dispatch approach is the sub-regional dispatching approach [13]. According to this approach the whole urban area is divided into sub-regions. There is at least one taxi rank in each sub-region. The dispatch centre will assign the job to a driver with longest waiting time in the rank of the sub-region where the call was made from.

THEORETICAL MODEL

TAXI EMPTY CRUISE CONTRIBUTION HYPOTHESIS

The empty cruise contribution hypothesis originates from the strategy of increasing marginal benefit deployed by airline companies. Vacant seats are the biggest waste for an airplane in flight. The marginal benefit increases for the airline every time a new passenger buys a ticket for a certain flight. So airline companies usually adopt means of discounting the ticket price to encourage more customers to fill up the vacant seats a few hours before the airplane leaves.

Taxi drivers face a similar problem to an airplane flight. No matter what dispatch rules are used in GPS-based mode, there must be an empty cruise from the taxi’s rank to the client’s location. The state of a taxi varies with time during a working day. Generally speaking, a taxi can be in one of three states: busy, free and empty cruising. Table 2 describes these states in more detail. Any optimization of resources must address the states of being free or empty cruising.

The period of taxi empty cruise occurs when the driver is going to pick up a (booked) passenger or going back to a taxi rank. This period of time is already paid by the booked passenger as part of their booking surcharge. If empty cruising is built in the overheads
already, exploiting these empty cruises for further transport does not need cost recovery at rates applied for booked passengers. Significantly lower fares (per kilometre) for short trips are attracting short distance passengers and are still beneficial for the taxi industry. One way to think of the taxi in this context is as a form of ride sharing host during the empty cruise trip.

<table>
<thead>
<tr>
<th>State</th>
<th>Taxi status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Busy</td>
<td>Taxi is occupied by customer.</td>
</tr>
<tr>
<td>Free</td>
<td>Taxi is waiting for jobs in a queue or randomly driving around to search for a street pickup job.</td>
</tr>
<tr>
<td>Empty cruising</td>
<td>The trip involving going to pick up passengers or going back to taxi queue.</td>
</tr>
</tbody>
</table>

Table 2: Taxi states.

Taxis being ad hoc ride sharing host has many advantages. As we know ad-hoc ride sharing enhances urban mobility and to a large extent solves the SDTP. But ride sharing is controlled more by social convention than documented legal policy. The establishment of trust between passengers and vehicle drivers is the most crucial step in the negotiation for ad-hoc ride sharing [14]. Therefore, it is hard to solve disputes arising from ride sharing activity. If the transport host, however, is a taxi and the activity is formalized by the taxi industry, disputes in the ride sharing process would be reduced and the situation is easier to control. Additionally empty cruise is already a wasted resource so taxi organizations will be interested in the chance to increase profit without additional investment. Hence, the idea is to utilize taxi empty cruise trips to provide a cheap delivery service to short distance trip customers. The use of taxi empty cruise time therefore benefits both drivers and passengers as the driver may receive additional income in one trip and passengers will enjoy a fast and safe trip whilst paying relatively low taxi fares. This explains the origin of the *empty cruise contribution hypothesis* and we call the event of going to pick up passengers or going back to taxi queue while carrying someone else as the *empty cruise contribution process*.

**STRICT MATCHING**

The empty cruise contribution process can be illustrated in match models. In the GPS-based dispatch mode, the taxi’s route is calculated by the GPS device. This route is usually a shortest path in terms of network distance. The strict match model matches short distance trip passengers waiting along the taxi’s empty cruise route, and having destinations that are also on the further route of the taxi (Figure 2).

Figure 2 shows a simple street network graph. A taxi rank is at node A. A booking passenger at node E calls the taxi dispatch centre asking for a taxi to go somewhere. The operator
assigns this task to a taxi waiting at node $A$. The GPS device calculates the shortest path between these nodes, which is via nodes $C$ and $D$. Meanwhile, a short distance trip (SDT) passenger is at node $C$ and their destination is node $D$. In this case the SDT passenger and taxi are matched because this passenger’s route is a portion of taxi’s route to the booking passenger. In this way the taxi can provide a ride as part of its empty cruising.

However, the restrictions of the strict match model may rarely be satisfied. More frequently, a passenger’s route will not exactly match the taxi’s empty cruise route (in origin, destination or both). Therefore we consider next a matching model that will be more frequently applicable.

**SHIFT MATCHING**

The shift matching model allows passengers or taxis to compromise on routes. Ad-hoc negotiations between the mobile transportation resources of, for example, an empty cruising taxi and the transportation demand expressed by a mobile passenger can lead to the taxi making a (small) detour, or the passenger advancing the taxi route ahead. A short trip passenger could also assist in avoiding an area of traffic congestion by moving to another location, therefore enabling the taxi to avoid the congestion. With increased flexibility the match probability will be enhanced by the shift match model. The shift match model can be divided into a taxi shift match model and a SDT passenger shift match model (Figure 3).

**EXPERIMENTS AND RESULTS**

**MATCH ALGORITHMS**

The constraints of the strict match model are harder to satisfy. Three parameters will be taken into account. They are the passenger origin, destination and direction. Correspondingly, the conditions are the (1) the short trip departure location on the taxi empty cruise route, (2) the destination is also on the route, and (3) the passenger’s route is in the same direction as the taxi’s route. The third condition can be translated as meaning that the distance between the passenger’s origin and taxi’s origin is shorter than the distance between passenger’s destination and taxi’s origin.

Algorithm 1 describes a *strict match* model. Several parameters in this algorithm may affect the final match probabilities:

- The number of empty cruising taxis ($N$);
- The shift buffer radius ($R$);
- The distance of empty cruising taxi trip ($DT$);
- The distance of SDT passenger trip ($DP$).
**Algorithm 1: Strict Match Algorithm**

**Input:** origins and destinations of passengers and taxis  
**Output:** match results  

for i=0 to taxi number  
    route (i) = shortest path between originTaxi (i) and destination (i)  

for j=0 to passenger number  
    if originSDTpassenger(j) is on route(i) and destinationSDTpassenger(j) is on route(i) and distance (originSDTpassenger(j), originTaxi(i)) shorter than distance (destinationSDTpassenger(j), originTaxi(i)) then  
        match is successful  
    next j  
next i

For the *shift match* model, the algorithm is similar to Algorithm 1, only that route (i) becomes a buffer of route (i). Implemented algorithms will be available from http://www.geom.unimelb.edu.au/winter/proj-isort/.

**IMPLEMENTATION**

The strategy of implementation is utilizing a large number of runs to discover a statistical match result. Imagine a certain number of taxis are pre-booked by passengers and leave their taxi ranks to pick up the booking passengers. One SDT passenger is looking for a ride in the street. The question is what the probability is for this SDT passenger finding a ride by one of the empty cruising taxis. This problem is implemented as follows.

A certain number (N) of taxis are empty cruising, the origins and destinations are randomly generated by system. The distances between origin and destination are controlled in a certain range (DT). The A* shortest path algorithm is used to calculate the route for each taxi. Then a SDT passenger’s origin and destination is generated randomly such that the trip distance is controlled in a certain range (DP). A match algorithm is applied to judge whether this SDT passenger’s route can be matched by one empty cruising taxi. This is one run. The result from one run is 1 or 0: 1 means match succeeds and 0 means match does not succeed. Totally we have 100,000 runs for a trial, where the number of 1s (N1) is recorded. The match probability can be simply calculated from N1 divided by 100,000. The experiment investigated the match probability of the Melbourne CBD and its adjacent areas. The graph network contains 2791 arcs and 2034 nodes. The simulator can be applied in any other cases through adjusting the parameters.

**RESULTS**

The first experiment is going to discover the match probabilities by different parameters N and R. When the R is 0, it can be regarded as the strict match. Here, we apply 10, 20, 30 and 40 taxis for N and 0, 50, 100, 150, 200, 250, 300 meters for R. The match results are shown in Table 3 and Figure 4.
Table 3: Match probabilities by different taxis numbers with increasing shift range.

<table>
<thead>
<tr>
<th>Shift range</th>
<th>Taxi count</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 m</td>
<td>10</td>
</tr>
<tr>
<td>50 m</td>
<td>0.21%</td>
</tr>
<tr>
<td>100 m</td>
<td>2.16%</td>
</tr>
<tr>
<td>150 m</td>
<td>3.90%</td>
</tr>
<tr>
<td>200 m</td>
<td>6.57%</td>
</tr>
<tr>
<td>250 m</td>
<td>10.51%</td>
</tr>
<tr>
<td>300 m</td>
<td>14.37%</td>
</tr>
</tbody>
</table>

Figure 4: Match probabilities increased both with longer shift distances and higher taxi counts.

The second experiment is going to investigate the impacts of related factors $DT$ and $DP$ on the match probabilities. Here the parameters are set as two groups, in the first group parameters $N$ is 40, $R$ is 0, $DT$ is between 2000 and 4000 meters and $DP$ is divided into four ranges 0...500, 500...1000, 1000...1500 and 1500...2000 meters. For each $DP$ range we test 10 trials and get the average value. The results are shown in Table 4 and Figure 5. In the second group $N$ and $R$ are same with the first group, different $DP$ are randomly set between 0...2000 and DT is divided into four ranges namely 2000...2500, 2500...3000, 3000...3500 and 3500...4000 meters. The results also get from the average value of 10 trials, which are shown in Table 5 and Figure 6. The results are the successful match counts out of 100,000 runs.

Table 4: Impacts of $DP$ on match probabilities.

| 0 to 500 | 1st 2nd 3rd 4th 5th 6th 7th 8th 9th 10th average |
|----------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| 1037     | 1023            | 1008            | 1013            | 989             | 951             | 1071            | 1016            | 982             | 1044            | 1013.4          |
| 500 to 1000 | 995 1046 952 966 1023 1039 1042 960 1020 959 | 1000.2          |
| 1000 to 1500 | 992 1018 1032 977 976 1001 970 1071 952 954 | 994.3           |
| 1500 to 2000 | 954 933 950 1022 1006 1027 963 987 998 970 | 981             |

Table 5: Impacts of $DT$ on the match probabilities.

| 2000 to 2500 | 1st 2nd 3rd 4th 5th 6th 7th 8th 9th 10th average |
|--------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| 913          | 939             | 894             | 897             | 866             | 963             | 900             | 941             | 855             | 880             | 904.8           |
| 2500 to 3000 | 1291 1219 1172 1223 1178 1214 1245 1199 1232 1201 | 1217.4          |
| 3000 to 3500 | 1222 1343 1242 1357 1271 1302 1337 1229 1215 1259 | 1277.7          |
| 3500 to 4000 | 1220 1337 1294 1241 1321 1318 1326 1318 1225 1402 | 1302.2          |
DISCUSSION

The strategy of all the experiments is utilizing large amounts of data which is randomly generated to produce a statistical result. In statistical experiments, the most crucial issue is the stability of the simulator. If the results are significantly different to each other with the same parameters in each run, there must be a reason or parameter not yet considered that is affecting the results and therefore the simulator has failed. Based on this idea, a test was done to prove the stability of the simulator. The test used ten sets of taxi data, for each set 10 trials were run, producing 100 values in total. The results are shown in Table 6, and plotted in Figure 7.

All the values are distributed between 850 and 1200 customer-taxi empty cruising matches (i.e. the results vary over 350 matches). But looking at the values for each T collection (taxi booking dataset), they are distributed over a smaller range around the mean value. For instance, values of T10 are generally the smallest, only the 8th and 10th are not the smallest in 10 groups of results (on both occasions T7 is the smallest). Generally the results tend to be stable with 100,000 runs in each trial.

Regarding the related parameters two groups of experiments revealed the impacts of parameters DT (distance of taxi empty cruise trip) and DP (distance of SDT passenger trip) on the match probabilities. The results essentially accord with our assumption, namely DT has a positive impact on match probabilities and DP has a negative impact on match probabilities (see Figure 6 and Figure 7 above). This is illustrated by real world scenario where the shorter the passenger’s trip, the higher the match probability, whilst the longer the taxi’s empty cruise trip, the higher the match probability.
CONCLUSIONS AND FUTURE WORK

Short distance trip problems are common in urban areas. Private cars and public transport do not perform well as a solution: private cars are bound by scarce (and frequently expensive) parking space, and public transport is limited to fix routes and schedules in this respect. Other modes are less restricted, for example bicycles or taxis. Taxis are a good candidate to address the SDTP; they do not only provide a door-to-door service like a private car but also reduce traffic pressure compared to extensive use of private cars. Furthermore, the disadvantage of taxis—their high per-kilometer fares especially for short distance trips—could successfully be addressed by the taxi empty cruise contribution hypothesis.

We calculated the match probabilities of (arbitrary) numbers of empty cruising taxis for 1 SDT passengers through using match models. In general, we have observed match probabilities of up to 42% (observed here, e.g., for 40 taxis in this network, and a shift range of 300 meters corresponding to an approximately 4 minutes walk). The proposed taxi empty cruise contribution hypothesis, therefore, is feasible to contribute to the solution of the SDTP and has the potential to develop a short distance trip market for the taxi industry.

The paper was only interested in the specific contribution of exploiting empty cruising taxis, and hence, it limited the simulation of urban traffic to taxis. But short distance travelling taxis are only one component of an ad-hoc ride sharing service. For a total assessment of the (economic) benefits of this contribution one would add the other modes of travelling and their capacity to share rides, especially over short distances and in an ad-hoc manner. What we have shown here is that taxis offering short distance trips have the potential for a substantial contribution for urban mobility in the context of an ad-hoc ride sharing service, and we have shown elsewhere how other modes contribute.

The following three issues suggest the directions of future work on the taxi empty cruise contribution hypothesis:

The match probability provided in this research only considers the spatial aspect. The probability would decrease when also considering the temporal aspect. This is because in the passenger shift match model, the short trip passenger must arrive on a taxi’s route in advance; otherwise the match fails since the taxi will not wait for the passenger to arrive. This is in order to guarantee to the arrival time at the booking passenger’s location.

The ad hoc ride sharing applying a GPS-based allocation in a decentralized manner needs to be integrated into centralized taxi dispatch system. The negotiation models in ad hoc ride sharing need to be adopted for match models and consider a reasonable fare structure for that short trip.

The taxi empty cruising contribution hypothesis is based on ad-hoc ride sharing. In addition to the technical issues, shared ride schemes raise other problems in the social, economic, privacy and security areas which also require investigation.

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