# PTRider: A Price-and-Time-Aware Ridesharing System

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## ABSTRACT

Ridesharing is popular among travellers because it can reduce their travel costs, and it also holds the potential to reduce travel time, congestion, air pollution, and overall fuel consumption. Existing ridesharing systems (e.g., lyft, uberPOOL) often offer each traveler only one choice that aims to minimize system-wide vehicle travel distance or time. In this demonstration, we present a price-and-time-aware ridesharing system, termed as PTRider, which provides more options. It considers both pick-up time and price, so that travellers are able to choose the vehicle matching their preferences best. To answer the ridesharing request in real time, PTRider builds indexes on the road network and vehicles separately, and utilizes corresponding efficient matching methods. A real-life dataset that contains 432,327 trips extracted from 17,000 Shanghai taxis for one day (May 29, 2009) is used to demonstrate that PTRider can return various options for every ridesharing request in real time.

**PVLDB Reference Format:**
Lu Chen, Yunjun Gao, Zixian Liu, Xiaokui Xiao, Christian S. Jensen, and Yifan Zhu. PTRider: A Price-and-Time-Aware Ridesharing System. *PVLDB*, 11(12): 1938-1941, 2018.
DOI: https://doi.org/10.14778/3229863.3236229

## 1. INTRODUCTION

Ridesharing refers to a transportation scenario where travellers with similar itineraries and time schedules share a vehicle for a trip and split the travel costs such as fuel, tolls, and parking fees. Many ridesharing systems (e.g., lyft [1], uberPOOL [2], etc.) already exist, due to the reduced travel costs, travel time, congestion, fuel consumption, and air pollution, for the travellers, for society, and for the environment.

Existing real-time ridesharing systems [6], [7], [8] find only one option per request that tries to minimize system-wide vehicle travel time or distance. Nonetheless, considering the case below. Assume that a couple has finished dinner at the seaside, which is far from the city center. They now want to travel home. Given that there are few nearby vehicles, getting a vehicle quickly is likely to cost extra because some vehicles must make a detour in order to pick them up. However, if they are willing to wait longer, they may pay less since some vehicles will be nearby later on. If we offer more options with different pick-up times and prices, travellers can choose the options they prefer. Motivated by this, we develop a price-and-time-aware ridesharing system based on our previous work [5], termed as *PTRider*, which offers several options per ridesharing request. The options have different pick-up times and prices as well as they do not dominate each other (option $r_i$ dominates option $r_j$ iff the pick-up time and price of $r_i$ are earlier and lower than those of $r_j$ [3]).

Although one study [4] considers both pick-up time and price to return multiple options for each ridesharing request, it cannot be employed to solve our problem, due to the following two reasons. First, the problem definition is different. Cao et al. [4] assume that every vehicle has one pair of a start location and a destination, and serves *only one* group of riders during a trip, which limits the usability and scalability of the ridesharing system. In contrast, we assume that the destination of a vehicle is not limited and that it can accommodate *any number* of rider groups during a trip as long as it satisfies a capacity constraint. Second, Cao et al. [4] use Euclidean distance for pruning, which is inefficient. In order to answer the ridesharing request in real time, we build indexes on the road network and vehicles separately, and propose two efficient matching methods. To sum up, the key contributions of this demonstration are as follows:

- PTRider considers both pick-up time and price, and thus, it can return different options for each rider to choose.
- PTRider utilizes efficient indexing techniques for both the road network and the vehicles, and adopts two efficient matching approaches, which follow the single-side search paradigm and the dual-side search paradigm, respectively.
- We demonstrate PTRider using a real dataset that contains 432,327 trips extracted from Shanghai taxis, with high simulated ridesharing request and update workloads.

The rest of the demonstration is organized as follows. Section 2 defines the price-and-time-aware ridesharing. Section 3 presents a PTRider prototype. Section 4 provides demonstration details.

## 2. DEFINITIONS FOR PTRIDER

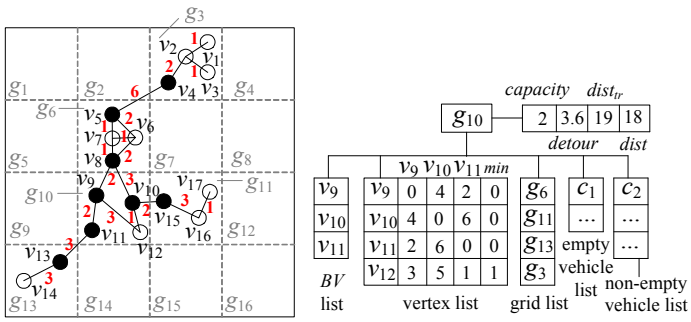
In this section, we give the definitions related to the price-and-time-aware ridesharing.

### 2.1 Road Network

A road network $G = \langle V, E, W \rangle$ consists of a vertex set $V$ and an edge set $E$. Each vertex $v \in V$ denotes the intersection of two roads. Each edge $e = (u, v) \in E$ that connects two vertices $u$ and $v$ is associated with a weight $W(e)$, in which $W(e)$ represents the travel cost between $u$ and $v$. The travel cost could be either time or distance. When the speeds of vehicles are known, they can be


*Proceedings of the VLDB Endowment,* Vol. 11, No. 12

DOI: https://doi.org/10.14778/3229863.3236229




(a) Grid partition (b) Information of a grid cell $g_{10}$

**Fig. 1. Illustration of a road network grid index**

converted from one to another (e.g., distance = time × speed). In our demonstration, a constant speed is assumed.

Given two vertices $u$ and $v$ in a road network, the shortest path distance $dist(u, v)$ between $u$ and $v$ is defined as the minimal cost for paths connecting between $u$ and $v$. Consider the road network in Fig. 1(a) where $V = \{v_1, v_2, \ldots, v_{17}\}$ and the digit assigned for every edge denotes its weight. Based on the road network, we define the ridesharing request below.

## 2.2 Ridesharing Request

Every ridesharing request can receive multiple options, in which each option contains pick-up time and price. Thus, a rider is able to choose the option that is preferred.

**Definition 1 (Ridesharing Request).** A ridesharing request $R = \langle s, d, n, w, \varepsilon \rangle$ on a road network $G$ is defined as a start location $s$, a destination location $d$, the number $n$ of riders, the maximal waiting time $w$ (i.e., the maximal time allowed between the planned pick-up time and the actual pick-up time), and a service constraint $\varepsilon$ (the detour acceptable in a trip, i.e., the travel distance from $s$ to $d$ is bounded by $(1 + \varepsilon) \times dist(s, d)$).

The planned pick-up time is the pick-up time in a returned result, while the actual pick-up time is the time when the riders in $R$ get on the vehicle. As an example, a request is submitted at 8:00 PM, a result shows the pickup time is 8:05 PM, but the vehicle actually arrives at 8:12 PM, then the planned pickup time is 8:05 PM and the waiting time is 7 min. In Fig. 1(a), a ridesharing request $R_1 = \langle v_2, v_{16}, 2, 5, 0.2 \rangle$ means that two riders travel from $v_2$ to $v_{16}$ with the maximal waiting time 5 and a service constraint 0.2.

## 2.3 Vehicle Trip Schedule

Each vehicle can be assigned an empty or a non-empty set of unfinished ridesharing requests. A non-empty vehicle (i.e., having a non-empty set of unfinished ridesharing requests) has a set of valid vehicle trip schedules.

**Definition 2 (Vehicle Trip Schedule).** Each trip schedule $tr = \langle o_1, o_2, \ldots, o_k \rangle$ contains a sequence of locations (i.e., vertices in $G$), where $o_1$ is the current location $c.l$ of vehicle $c$, and $o_i$ $(2 \le i \le k)$ represents the start location or destination of an unfinished ridesharing request. The whole trip distance $dist_{tr}$ equals to $\sum_{i=1}^{k-1} dist(o_i, o_{i+1})$. A valid trip schedule satisfies four conditions:

(1) **Capacity constraint:** At any time, the number of riders in a vehicle cannot exceed vehicle's capacity.

(2) **Point order:** For any unfinished ridesharing request $R = \langle s, d, n, w, \varepsilon \rangle$ in the vehicle trip schedule $tr_i$, the location of the vehicle that receives the request $R$ must happen before the start location $s$, and $s$ must happen before the destination $d$.

(3) **Waiting time constraint:** For any unfinished request $R = \langle s, d, n, w, \varepsilon \rangle$ of vehicle $c$, the waiting time between the planed and actual pick-up times should not exceed the constraint $w$. Let $tr_i$ be the actual trip schedule for vehicle $c$ to pick up the rider of $R$, and $tr_j$ be the planned trip schedule when assigning $R$ to $c$, $dist_{tr_j}(c.l, s) - dist_{tr_i}(c.l, s) \le w$.

(4) **Service constraint:** For any vehicle trip schedule $tr$, the actual travel distance $dist_{tr}(s, d)$ from a start location $s$ to a destination $d$ should not exceed $(1 + \varepsilon) \times dist(s, d)$.

## 2.4 Price Model

As with an existing price model [4], the price of a request is the sum of prices for the detour and the original trip distances.

**Definition 3 (Price Model).** For a ridesharing request $R = \langle s, d, n, w, \varepsilon \rangle$, assume that $tr_i$ is the current trip schedule of a vehicle $c$ and $tr_j$ is the new vehicle trip schedule after inserting $R$ into $tr_i$, the price can be computed as $f_n \times (dist_{tr_j} - dist_{tr_i} + dist(s, d))$, in which $f_n$ is the price ratio that depends on the number $n$ of riders.

For simplification, we set $f_n = 0.3 + (n - 1) \times 0.1$. For instance, in Fig. 1(a), for a non-empty vehicle $c_1$ with the trip schedule $tr_1 = \langle v_1, v_2, v_{16} \rangle$, inserting the request $R_2 = \langle v_{12}, v_{17}, 2, 5, 0.2 \rangle$ into $tr_1$ results in a new trip schedule $tr_2 = \langle v_1, v_2, v_{12}, v_{16}, v_{17} \rangle$. Then, the price equals to $f_2 \times (dist_{tr_2} - dist_{tr_1} + dist(v_{12}, v_{17})) = 4$.

## 2.5 Price-and-Time-Aware Ridesharing

We proceed to present the definition of dynamic ridesharing.

**Definition 4 (Price-and-Time-Aware Ridesharing).** Given a set $C$ of vehicles in the road network $G$ at a specific time and a real-time trip request set $S_R$, a price-and-time-aware ridesharing finds, for each request $R \in S_R$, all qualified and non-dominated results $\langle c, time, price \rangle$. Here, result $r_i$ dominates another result $r_j$ iff $(r_i.time \le r_j.time \wedge r_i.price < r_j.price)$ or $(r_i.time < r_j.time \wedge r_i.price \le r_j.price)$.

In PTRider, a greedy strategy is used when multiple requests are issued simultaneously. Each vehicle $c$ can offer one or more pairs of a pick-up time (i.e., *time*) and its corresponding *price* for $R$. Since time can be transformed to distance, we use the trip distance from $c$'s current location $l$ to $R$'s start location $s$ (termed as $dist_{pt}$) to denote *time*. Thus, the result can also be denoted as $r_i = \langle c, dist_{pt}, price \rangle$. In Fig. 1(a), assume that two vehicles $c_1$ (with only one trip schedule $tr_1 = \langle v_1, v_2, v_{16} \rangle$) and $c_2$ (with only one trip schedule $tr_2 = \langle v_{13} \rangle$) exist. Given a ridesharing request $R_2 = \langle v_{12}, v_{17}, 2, 5, 0.2 \rangle$, a dynamic ridesharing returns results $r_1 = \langle c_1, 14, 4 \rangle$ and $r_2 = \langle c_2, 8, 8.8 \rangle$, where $r_1$ has a lower price, but $r_2$ has an earlier pick-up time.

# 3. PTRIDER PROTOTYPE

In this section, we first introduce the framework of PTrider, and then, we present indexing and matching algorithms, respectively.

## 3.1 Framework of PTRider

Fig. 2 shows the framework of PTRider. The main components include two index modules (i.e., Road Network Index Module and Vehicles Index Module) and a matching method module. PTRider

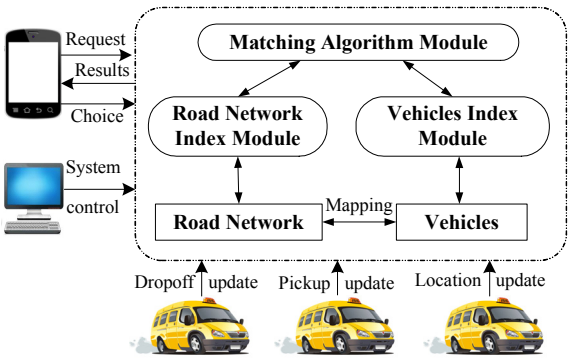



**Fig. 2. Framework of PTRider**

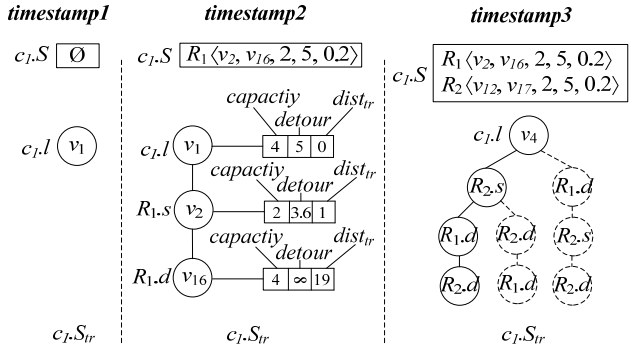



**Fig. 3. Kinetic tree examples on vehicle trip schedules**

answers a ridesharing request follows three steps. (i) A rider requests a trip using his/her smart phone. He/She specifies the number of riders, and the start location and destination of the request. PTRider sets a global maximum waiting time and a global service constraint. (ii) Once the request is submitted, the matching method module finds all the qualified options, and sends them to the rider. Here, an option contains the pick-up time and price provided by a specific taxi. (iii) The rider chooses one that matches his/her preference best, and sends it back to the system. Then, the index modules are updated according to the rider's choice. Note that, the taxis update their locations periodically, and update their trip schedules when they pick up or drop off riders. Therefore, the index modules need to be updated.

## 3.2 Indexing of PTRider

### *3.2.1 Indexing the Road Network*

We partition the road network using a grid, as illustrated in Fig. 1(a). If an edge $e = (u, v)$ belongs to more than one grid cell, we call $u$ and $v$ **border vertices**. In order to estimate the shortest path distance more accurately, we maintain a matrix that stores the lower bound distance for every grid cell pair. Also, the lower bound distance is associated with a vertex pair $(x_i, y_j)$, where $x_i$ and $y_j$ are border vertices in the grid cells $g_i$ and $g_j$ respectively, i.e., $(x_j, v_1, \ldots, v_k, y_j)$ is the shortest path connecting $g_i$ and $g_j$.

As depicted in Fig. 1(b), each grid cell maintains five lists: (i) a **border vertex list** of border vertices belonging to the grid cell; (ii) a **vertex list** of vertices belonging to the grid cell, as each vertex $v$ is associated with its shortest path distances to the border vertices ($BV$) of the grid cell ($\{\langle u, dist(v, u)\rangle \mid u \in BV\}$) and is also associated with $min\{dist(v, u) \mid u \in BV\}$ (denoted as $v.min$); (iii) a **grid cell list** of other grid cells sorted in ascending order of the travel time from those grid cells to the grid cell (i.e., sorted in ascending order of the lower bound distances when speed is constant); (iv) an **empty vehicle list** of the vehicles with empty ridesharing requests in $g_i$; and (v) a **non-empty vehicle list** of vehicles $c_j$ having a non-empty set of ridesharing requests, i.e., vehicles $c_j$ are currently located in $g_j$ or are scheduled to enter $g_i$.

Base on the grid index, several pruning lemmas are developed by estimating price and pick-up time. For more technical details, please refer to our full research paper [5].

### *3.2.2 Indexing Vehicles*

Each vehicle $c$ is represented by using (i) the unique identifier $c.ID$ of the vehicle; (ii) the current location $c.l$ of the vehicle; (iii) the set $c.S$ of unfinished ridesharing requests assigned to it, sorted in ascending order of their timestamps; and (iv) the set $c.S_{tr}$ of all valid vehicle trip schedules.

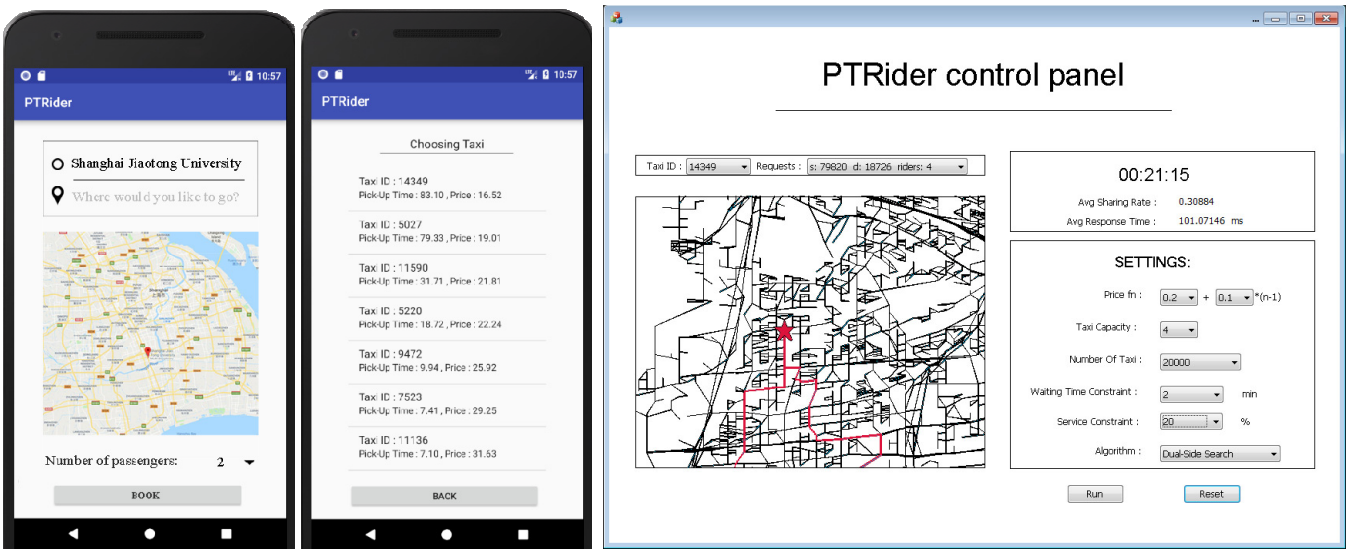
The set $c.S_{tr}$ of all valid vehicle trip schedules can be managed by a kinetic tree [7], as illustrated in Fig. 3, where every branch denotes a valid trip schedule. In addition, we add three variables to each node $o_x$ in the kinetic tree: (i) a current vehicle's *capacity*, (ii) the minimal *detour* distance allowed, and (iii) the trip distance $dist_{tr}$ from $c$'s current location to $o_x$. The *detour* can be computed easily from the waiting time and service constraints. If an edge $\langle o_x, o_y\rangle$ of vehicle $c$'s kinetic tree intersects with, or is contained in a grid cell $g_i$ (i.e., the shortest path between $o_x$ and $o_y$ intersects with or is included in $g_i$), then $\langle o_x, o_y\rangle$ belongs to the non-empty vehicle list of $g_i$. The kinetic tree is updated per time unit.

## 3.3 Matching Algorithms

A naive method can be extended directly from the kinetic tree algorithm. We evaluate every vehicle to find all possible pairs of pick-up time and price that cannot dominate each other when inserting the request $R$ into its kinetic tree. However, it can be improved in two ways: (i) we can filter unqualified vehicles in advance instead of verifying all vehicles; and (ii) the number of the shortest path distance computations ([7] calculates all the distances before verification) can be reduced when inserting the request into the kinetic tree. To boost efficiency, PTRider utilizes two algorithms proposed in [5], as described below.

**Single-Side Search Algorithm.** For each ridesharing request $R = \langle s, d, n, w, \varepsilon\rangle$, single-side search algorithm starts from the grid cell $g_i$ where $s$ locates, and then, it searches the grids in order of their distances to $s$. During the search, empty and non-empty vehicles are processed separately. For empty vehicles that cannot be pruned, $R$ can be easily inserted into its trip schedule set. For every non-empty vehicle that cannot be pruned, the inserting is similar as that in [7], by estimating the lower and upper bounds of the shortest path distance to avoid unnecessary computations.

**Dual-Side Search Algorithm.** Single-side search algorithm filters unqualified vehicles using pruning lemmas when searching from the start location. Similarly, we can also filter unqualified vehicles using pruning heuristics when searching from the destination. Take the following case as an example. One existing trip schedule is near the start location of a ridesharing request, but it is far from the destination of the ridesharing request. In this case, the dual-side search paradigm can avoid more unnecessary verifications of vehicles. Thereafter, similar as single-side search algorithm, dual-side search algorithm verifies each vehicle that cannot be pruned in order to find qualified results.




(a) Request input interface (b) Result display interface (c) The website interface

**Fig. 4. Demonstration of PTRider**

## 4. DEMONSTRATION

PTRider is demonstrated by using a real data set that contains 432,327 trips extracted from 17,000 Shanghai taxis for one day. The ridesharing requests are generated by using trips in the real dataset, or submitted by the users. The vehicles are initialized uniformly in the road network. They follow a specified route when customers are on board or, otherwise, follow the current road segment, choosing a random segment to follow at intersections. A constant speed $D$ (48km/hr) is assumed. The underlying system of PTRider runs on an Intel Core i7 3.6GHz PC of a 16GB memory. PTRider can be visited through a smartphone interface to book a taxi in real time, or via a website interface to set the parameters and view the statistics.

### 4.1 Smartphone Interface

The smartphone interface allows the users to book a taxi that matches their requests best, i.e., sending a ridesharing request and finding their preferred taxis. First, as depicted in Fig. 4(a), the rider inputs a start location (suggested as the current location), a destination, and the number of riders in the textbox, and clicks the book button to send the ridesharing request to the system. Second, the system returns all the possible options back to the rider, including pick-up time and price, as illustrated in Fig. 4(b). Third, the rider selects his/her preferred option, and clicks the chosen option to send his/her choice to the system.

### 4.2 Website Interface

The website interface (i) shows the trip schedules on a map, (ii) provides the statistics of the trip information, and (iii) allows the system administrator to set the constraints.

The left-side of Fig. 4(c) shows the trip secludes for any taxi. The system administrator first selects a taxi ID, and then, the unfinished ridesharing requests assigned to the selected taxi are depicted in a drop-down box next to the taxi ID. In addition, all possible trip schedules of the selected taxi are shown as the red lines on the map, where the red star denotes the current position of taxi. Each red line denotes a possible trip schedule for the selected taxi, i.e., each branch in the corresponding kinetic tree.

The top-right of Fig. 4(c) illustrates the statistics of PTRider, including the current time, the average response time, and the average sharing rate. As observed, the system is efficient (low average response time) and effective (high average sharing rate).

In the bottom-right of Fig. 4(c), the system administrator is able to input the parameters including the taxi capacity, the number of taxis, the maximal waiting time, the service constraint, and the price calculator function. Although some parameters can be set by the rider himself/herself (e.g., the maximal waiting time and the service constraint) or by the taxi driver (e.g., the taxi capacity), PTRider adopts a global setting for simplification. In addition, the particular matching algorithm (i.e., single-side search algorithm or dual-side search algorithm) used in PTRider can be specified.

## 5. ACKNOWLEDGEMENTS

This work was supported in part by the 973 Program Grant No. 2015CB352502, NSFC Grants No. 61522208, and U1609217, MOE2015-T2-2-069, SUG from NUS, DiCyPS project, and Obel Family Foundation. Yunjun Gao is a corresponding author.

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