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Ridesharing: The state-of-the-art and future directions

Masabumi Furuhata [a], Maged Dessouky [b,*], Fernando Ordóñez [c], Marc-Etienne Brunet [d], Xiaoqing Wang [b], Sven Koenig [a]

[a] Department of Computer Science, University of Southern California, 941 Bloom Walk, SAL300, Los Angeles, CA 90089-0781, United States
[b] Department of Industrial and Systems Engineering, University of Southern California, 3715 McClintock Avenue, GER240, Los Angeles, CA 90089-0193, United States
[c] Industrial Engineering Department, Universidad de Chile, Republica 701, Santiago, Chile
[d] Department of Electrical and Computer Engineering, McGill University, 3630 University Street, Montreal, Quebec H3A 0C6, Canada

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ABSTRACT

Although ridesharing can provide a wealth of benefits, such as reduced travel costs, congestion, and consequently less pollution, there are a number of challenges that have restricted its widespread adoption. In fact, even at a time when improving communication systems provide real-time detailed information that could be used to facilitate ridesharing, the share of work trips that use ridesharing has decreased by almost 10% in the past 30 years.

In this paper we present a classification to understand the key aspects of existing ridesharing systems. The objective is to present a framework that can help identify key challenges in the widespread use of ridesharing and thus foster the development of effective formal ridesharing mechanisms that would overcome these challenges and promote massification.

1. Introduction

Travelers today typically have a number of transportation modes available to go from their origins to their destinations. In selecting between these different transportation modes, travelers consider a number of criteria, such as cost, travel time, flexibility (ability to adapt to changes in schedule), convenience (such as the location of the pick-up and drop-off points, the ability to listen to music, or privacy), reliability, and perception of security. To illustrate, first consider systems such as buses or subways that provide a travel option with a fixed geographic route and a fixed schedule, hereafter referred to as fixed-line systems. These fixed-line systems charge a small fee to the traveler, but come with little convenience. In contrast, private cars or taxi services come at a higher cost, but provide a more flexible, more convenient, and often faster option.

Ridesharing refers to a mode of transportation in which individual travelers share a vehicle for a trip and split travel costs such as gas, toll, and parking fees with others that have similar itineraries and time schedules. Conceptually, ridesharing is a system that can combine the flexibility and speed of private cars with the reduced cost of fixed-line systems, at the expense of convenience. Advantages of ridesharing for participants (both drivers and passengers), to society, and to the environment include saving travel cost, reducing travel time, mitigating traffic congestions, conserving fuel, and reducing air pollution (Ferguson, 1997; Kelley, 2007; Morency, 2007; Chan and Shaheen, 2012). For the most part, however ridesharing coordination is an informal and disorganized activity and only in certain cases can travelers make use of ridesharing as a regular transportation alternative. The requirement that itineraries and schedules be coordinated between participants and the lack of effective methods to encourage participation are some of the factors that have inhibited a wide adoption of ridesharing.

* Corresponding author. Tel.: +1 213 740 4891.
E-mail address: maged@usc.edu (M. Dessouky).

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By effectively using new communication capabilities, including mobile technology and global positioning system (GPS), there are several attempts to enable *dynamic* or *real-time* ridesharing systems (see Chan and Shaheen (2012), Ghoseiri et al. (2011), Amey (2010c), Heinrich (2010) for some case studies). Dynamic ridesharing refers to a system which supports an automatic ride-matching process between participants on very short notice or even en-route (Agatz et al., 2012). While to date there is no de facto standard in the industry to coordinate travelers effectively, a better understanding of past attempts is essential to generate the methodological background that could enable the development of successful ridesharing.

The objective of this survey paper is to describe and characterize the state of the art of current ridesharing systems and from this background describe some of the existing challenges to a wide adoption of ridesharing. Toward this goal we survey the history and new emerging industry trends in ridesharing as well as recent research in this field. We provide both basic definitions in ridesharing and a classification (or taxonomy) of current matching agencies in terms of matching search method and target demand segment. In particular, we focus on the emerging ridesharing industry that has been enabled by the use of new communication technologies and computing capabilities. A few of the challenges identified from this review include pricing, high-dimensional matching, trust and reputation, and institutional design. Since some barriers of current ridesharing systems span multiple disciplines, we review both recent work on ridesharing and some relevant work in other domains such as auction mechanisms. A recent review of dynamic ridesharing systems, Agatz et al. (2012), focused on the optimization problem of finding efficient matches between passengers and drivers. This ride-matching optimization problem determines vehicle routes and the assignment of passengers to vehicles considering the conflicting objectives of maximizing the number of serviced passengers, minimizing the operating cost, and minimizing passenger inconvenience. However, to the best of our knowledge, there is no prior work that surveys and compares the existing ridesharing systems in a broad sense, taking into account some of the other relevant issues mentioned here such as demand types or matching search criteria.

The first *organized* ridesharing, Car-Sharing Club, was led by the U.S. government as a regulation policy in order to conserve fuel during WWII. Similar to how financial institutions operated at that time, ridesharing was arranged on bulletin boards at local matching institutions. Then in the 1970s several ridesharing methods emerged as a result of the oil crisis. The first *employer vanpool programs* were established by 3 M and Chrysler, which provided vans for employees commuting to working at the same location. Employers also started supporting the formation of *carpools*, in which employees take turns driving each other to work. Carpooling is a regular, advanced, and cost effective means of transportation (Ferguson, 1997; Morency, 2007), but it does not accommodate unexpected changes of schedule. By contrast, *dial-a-ride* provides shared rides in response to advanced requests of trips between any origin and destination within a specific area. This practice has received significant attention from many researchers (see Berbeglia et al. (2010) for a review) because it involves a complex vehicle assignment problem, which is a root of the ride-matching optimization problem reviewed by Agatz et al. (2012).

Flexible carpooling, which is a semi-organized ridesharing practice, is gaining popularity as a result of individual travelers wishing to gain access to faster High-Occupancy Vehicle (HOV) lanes or reduced tolls. These practices are characterized by no prearrangements or fixed schedules for matching drivers and passengers. Rather, ridesharing is formed spontaneously at predetermined locations on a first-come-first-service basis. These practices were not initiated by, nor are they run by, a public or private entity (Levofsky and Greenberg, 2001). Examples of this practice are *slugging* in the Washington D.C. area, which is free of charge to the participants (LeBlanc, 1999; Spielberg and Shapiro, 2000), and *casual carpooling* in the San Francisco Bay Area and Houston, with a fixed-price for each rideshare route (Burris and Winn, 2006; Kelley, 2007). A major advantage of these flexible carpooling examples is the convenience it provides participants without requiring any commitment. Something that is difficult to achieve in regular carpooling or vanpooling. A disadvantage is that these practices require a large volume of participants. Thus, they are limited to specific locations or circumstances and are difficult to replicate elsewhere.

With the advent of the Internet, a number of private matching agencies emerged to provide diverse ridesharing services for travelers (Dailey et al., 1999). These internet-based matching agencies have focused on two types of demands: *commute* trips and *long-distance* trips. While the target population for commute trips has been carpoolers, the demand for long-distance ridesharing tends to be one-shot travelers with schedules defined well in advance and that allow some itinerary flexibility. Typical matching agencies do not charge any commission fees and the sources of revenue are advertising fees and government subsidies. The New York Times (January 29, 2011) however recently reported that ridesharing has continued to decline, reaching only 10% of work trips in 2009, down from 19.7% of work trips in 1980 (Ferguson, 1997). This indicates that Internet-based matching agencies have not caused travellers to fundamentally shift their choice of transportation mode, and innovative systems and services are necessary to overcome inhibitors of ridesharing.

An anticipated breakthrough in ridesharing is the ability to satisfy *on-demand* requests that do not require participants to schedule their trips in advance. Such a system could provide a participant the reassurance that they would still be serviced if their travel-needs change unexpectedly (Levofsky and Greenberg, 2001). To satisfy these on-demand requests, a few matching agencies have implemented dynamic ridesharing systems based on mobile technologies enhanced by smart phones with GPS. These technologies enable matching agencies to communicate with participants and detect their current locations. In such a system, a ride request can be matched with a driver having a similar itinerary currently in proximity to the requested pick-up location. Systems like these are currently used in specific transportation corridors or by taxi services and shared ride vans.

In addition using communication technologies, dynamic ridesharing systems must establish a procedure that enables travelers to form ridesharing instantaneously (Agatz et al., 2012). This procedure must help match participants, as well as assist in establishing itineraries, prices and payment methods. Different matching agencies take different approaches, and what constitutes the best procedure is still a matter of debate. With regard to pricing and payments, matching agencies typically suggest a price per mile or a ridesharing fare which can be subsequently adjusted by the participants until an agreement is reached. Payments are made directly in vehicles or via electronic payment systems such as credit cards and PayPal. In order to build trust between unacquainted ridesharing partners, some matching agencies provide systems that help establish a participants reputation. They may, for example, integrate the ride-matching system with social networking sites that enable users to obtain more background information of potential drivers and passengers.

The rest of this paper is organized as follows: In the next section we outline the main characteristics to describe different aspects of ridesharing systems. Based on these definitions, Section 3 presents a review of current practice in ridesharing, classifying the existing systems into six classes depending on their matching search criteria and demand target segments. Section 4 describes additional concerns regarding how to motivate participation and concerns on convenience. In particular we discuss how challenges of fair distribution of benefits, security, and government participation have been addressed so far and possible research directions in this area. Finally, we provide conclusions in Section 5.

2. Background

As was mentioned in the introduction, ridesharing has a long history with various coordination methods. This section provides notation and definitions to help classify the different existing ridesharing systems.

2.1. Basic definitions

Seattle Smart Traveler, which is a Federal Highway Administration field operational test, defines a *trip* as a single instance of travel from one geographic location to another (Dailey et al., 1999). Each traveler has a demand for his or her trip consisting of the *origin* and the *destination*. Ridesharing is a joint-trip of at least two ridesharing participants that share a vehicle. Successful ridesharing requires coordination with respect to itineraries that include the specification of a pick-up and drop-off of a passenger. This coordination can, in addition, take into account other issues, such as travel cost, compensation for alternative ride provision, gender, and reputation of drivers and passengers.

Unorganized ridesharing that involves family, colleagues, neighbors, and friends has a long history. Even without such a personal relationship, ad hoc ridesharing has occurred, e.g., hitchhiking. These types of ridesharing activities, however, do not scale well due to limited and inefficient communication methods.

Organized ridesharing is operated by agencies that provide ride-matching opportunities for participants without regard to any previous historical involvements (Dailey et al., 1999). Due to this, organized ridesharing has great potential as a scalable service. *Prearrangement* by service providers is a key characteristic of organized ridesharing unlike hailing a taxi or hitchhiking which are typically sought on the street.

Prearrangement can start when ride requests or offers are submitted through the Internet or telephone to the service providers, which then aim to match the supply and demand for rides. These service providers can be classified into two types:

- *Service operators*: operate ridesharing services using their own vehicles and drivers.
- *Matching agencies*: facilitate ridesharing services by matching between individual car drivers and passengers.

Representative examples of service operators are vanpooling and airport shuttle transportation services. Typically, they accept requests from passengers and assign these ride requests to vehicles that they operate. This matching process is called *one-sided matching* in economics and *centralized transportation management* in management science and operations research. A notable characteristic is that most of the decisions are made by service operators while participants simply decide whether or not to partake. In general, pick-up and drop-off locations are tailored for participants but pick-up and drop-off times can sometimes require some amount of slack time. Moreover, service areas are often restricted and requests are required in advance by the service operators.

In contrast, matching agencies focus on ride-matching services between individual car drivers and passengers. Unlike service operators, matching agencies do not provide vehicles and drivers. Instead, individual drivers have their own trip plans and provide their unoccupied seats for passengers to share their travel expenses. Matching agencies use ridesharing offers and requests received from drivers and passengers, respectively, to find suitable ridesharing matches. This is called *two-sided matching*. The value of a matching agency for participants of one side, either drivers or passengers, depends on how efficiently and effectively suitable matches can be found. As a result, the nature of matching agencies gives rise to the chicken-and-egg problem (Caillaud and Jullien, 2003): in order to attract car providers, a matching agency should have a large number of requests, but requests will arrive at a matching agency if passengers expect that there are a large number of drivers. Thus, a central challenge faced by researchers and matching agencies is the design of market mechanisms that are attractive enough for both car providers and passengers to participate in the market.

2.2. Positional elements of ridesharing

Ridesharing takes on different characteristics when it is run by service operators and when is it coordinated by matching agencies. This is primarily because the drivers coordinated by matching agencies have their own travel plans, which is not the case when drivers are employed by service operators. That is, drivers are not considered as ridesharing participants in the latter case. Some service operators specify either a fixed pick-up or drop-off location, such as an airport, while others allow passengers to choose both. Typically, the routing problem for service operators is to construct a ridesharing route for a fleet of vehicles that minimizes the cost of servicing all the passengers. By contrast, in the case of matching agencies, drivers also have their original trip plans and preferences. Thus, all of the participants must agree on the costs and schedules, which depend on the routes used, including the pick-up and drop-off locations of passengers. These differences bring about the notion of single-sided versus double-side matching. Since the single-sided matching amounts to the well studied pick-up and delivery routing problem, here we focus on how matching agencies help the coordination for specific types passenger and driver requirements. Thus, we now focus on positional elements of ridesharing to classify ridesharing services. In the literature, Morency (2007) classified carpooling according to positional elements. Here, we extend her classification to extract how these differences influence rideshare matching in general.

We now present some symbols and notations of positional elements. When we say a driver's *original route* we mean the route he or she would have taken if driving alone; when participating in a rideshare, we call it a *ridesharing route*. Note that a passenger's origin can differ from their pick-up location; the same is true for the destination and drop-off location. We use the following notation to clarify this difference. Let us denote a as a driver, and b as a passenger. Each driver and passenger have their origin o and destination d. We denote u as a pick-up location and v as a drop-off location. We assume that each driver a has his or her original route $R(a)$. The ridesharing route formed by driver a and a set of passengers B is denoted as $R(a,B)$.

We classify ridesharing patterns into four as illustrated in Fig. 1. In the following, we describe the pattern for the single passenger case. There are similar patterns in the multiple passenger case.

- **Pattern 1 (identical ridesharing)**: Both the origin and destination of driver a and passenger b are identical, i.e., $o_a = o_b = u_b$ and $d_a = d_b = v_b$. All the identical trips are accomplished by ridesharing.
- **Pattern 2 (inclusive ridesharing)**: Both the origin o_b and destination d_b of passenger b is on the way of an original route $R(a)$ of driver a, i.e., $o_b, d_b \in R(a)$. All the trips are accomplished by a single driver, but a passenger does not have an identical trip with the driver.
- **Pattern 3 (partial ridesharing)**: Both the pick-up location u_b and drop-off location v_b of passenger b are on the way of an original route $R(a)$ of driver a, but either the origin or the destination of the passenger is not on the way, i.e., $u_b,\ v_b \in R(a)$ and $\neg(o_b = u_b$ and $d_b = v_b)$. Ridesharing is only a part of passenger b's trip.
- **Pattern 4 (detour ridesharing)**: Either the pick-up location u_b or drop-off location v_b or both of passenger b are not on the way of an original route $R(a)$ of driver a. Thus, taking a detour, ridesharing route $R(a,b)$ covers both the pick-up and drop-off locations. We further distinguish between two subcases: (1) Both the pick-up and drop-off locations match the passenger's origin and destination, i.e., $o_b = u_b$ and $d_b = v_b$. (2) Otherwise.

Traditional matching agencies do not take these patterns into account. Instead, matching is done via proximity rather than the exact locations. That is, a driver and passenger are matched as if identical ridesharing would form (pattern 1). State-of-the-art matching agencies should consider these different ridesharing patterns for routing, scheduling, and pricing. Partial ridesharing (pattern 3) is not currently facilitated by matching agencies. When partial ridesharing occurs, the pick-up and drop-off locations are either input as if their origins and destinations are located on major streets or determined by negotiations. In addition, passengers need to find an alternative transportation method to complete their trips. Among these four ridesharing patterns, detour ridesharing (pattern 4) causes difficulties on instantaneous decision making for drivers, since the additional travel costs and detour-time incurred by the driver is not usually paid by passengers. Furthermore, passengers need to find alternative transportation methods to complete their trips in subcase 2 of pattern 4, similar to pattern 3.

When considering multiple passengers (such as two passengers in Fig. 1) in the same vehicle, we have similar patterns to those of 1, 2, and 3 from the single passenger case. However, detour ridesharing (pattern 4) is more complicated when there are multiple passengers. To exemplify this, we describe two scenarios: (1) a detour is beneficial for all passengers and (2) a detour is beneficial only for one (or a subset) of the passengers. In the latter case, permutations of how passengers join the rideshare have a significant impact on the cost and thus possibly participation. Consider an example with driver a and passenger b and b'. Suppose passenger b has an identical trip with driver a; passenger b' requires detour for driver a. If passenger b' agrees on ridesharing with driver a first, these parties form detour ridesharing. Then, the decision of passenger b to join in the rideshare is based on the detour ridesharing. In contrast, if passenger b agrees on ridesharing with driver a first, these parties form identical ridesharing. Whether to form ridesharing with passenger b' now requires the joint agreement of driver a and passenger b, since both parties incur additional costs of travel for the detour. Moreover, this example demonstrates a pricing problem. We will discuss this problem in Section 4.

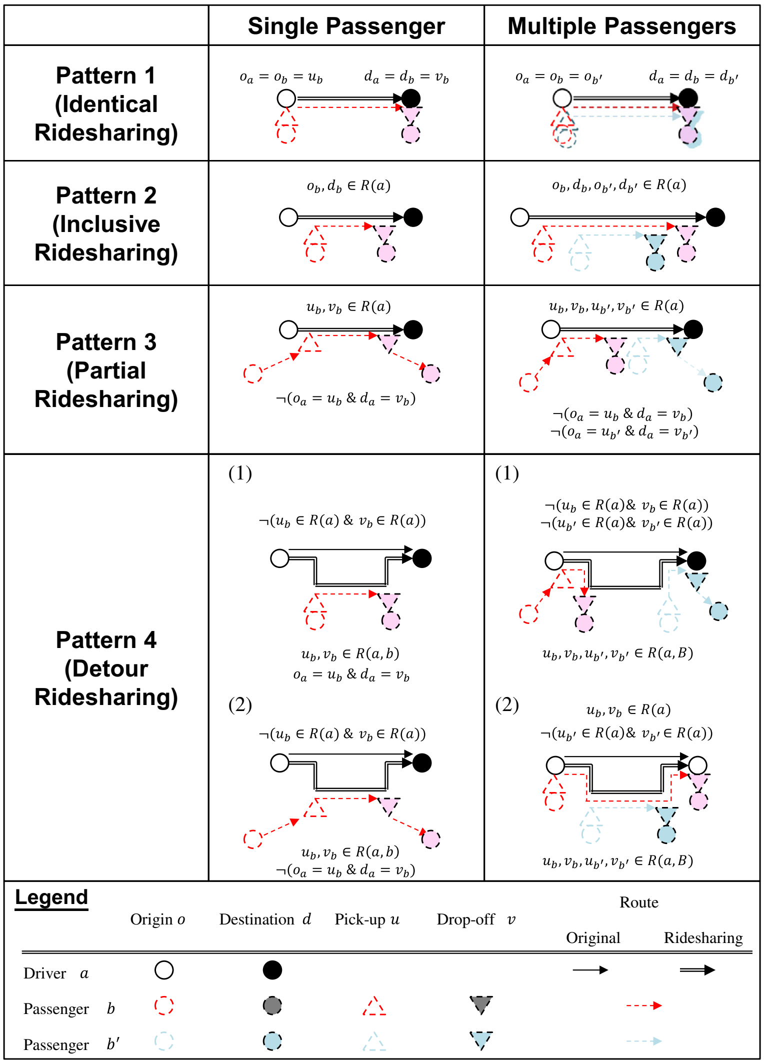

Fig. 1. Positional elements of ridesharing.

2.3. Temporal elements of ridesharing

This section examines temporal elements of ridesharing. In all instances, ridesharing requires an agreement between all participants with respect to the schedule of the pick-up and the drop-off times. The simplest case is identical ridesharing (pattern 1) in which it is easy to determine the pick-up and drop-off time while satisfying demands for the driver and passenger. However, in the rest of the three ridesharing patterns, the determination of the pick-up and drop-off times is more difficult to obtain, since it requires routes and estimates of travel times. Thus, assisting ride-matches via scheduling is of significant value for participants. However, this becomes increasingly complex as we attempt to coordinate rideshares with multiple passengers. We will discuss this problem in Section 4.

For every ridesharing trip, all the decisions have to be made before the latest notification time. Typically, the latest notification time is determined by the departure time of a driver, whereas the latest notification time for a passenger may be the latest pick-up time that would satisfy his or her trip requirement. Following Agatz et al. (2012), we call the time period between the time a ridesharing request or offer was listed and the latest notification time the matching time window. Since the quality of the matching service depends heavily on its ability to allow participants to come to agreement with ease, it is important for matching agencies to offer services that enable participants to optimize the use of their matching time windows. Some matching agencies allow participants to use the latest pick-up time as the latest notification time. This is enabled by advanced technologies. We detail this in Section 3.

2.4. Strategic consolidations

Ridesharing matching agencies undertake certain strategies to consolidate diverse offers and requests for the assistance of ridesharing coordination. The most common consolidation method of a matching agency is to organize information flow, in particular the process of listing and searching.

Some providers propose methods to consolidate demands physically. They set ridesharing routes and major stops as landmarks of pick-up and drop-off locations, typically major streets, park-and-ride lots, and transit centers. Using physical consolidations, detour ridesharing (pattern 4) can be transformed into partial ridesharing (patterns 3) with consolidated pick-up and drop-off locations.

Another approach to alleviate the difficulties of rideshare matching is to extend the matching time windows by tracking the location information of the car drivers using GPS and mobile technologies. Ridesharing systems implementing such technologies are able to notify drivers of rideshare matches even after a departure from their origin. This type of ridesharing is sometimes referred to as *dynamic* or *real-time* ridesharing. A primary advantage of these services, enjoyed by ridesharing participants that do not share the origins of drivers and passengers (patterns 2, 3, and 4) is the extension of the matching time window.

3. Ridesharing matching agencies

The main objective of this section is to present how a representative set of ridesharing matching agencies operate their businesses and how target markets are separated. The intent is not to provide a complete survey of the current companies doing ridesharing matching, but to develop a taxonomy of how ridesharing matching is performed. This taxonomy can serve as a useful guide for researchers when considering the design and development issues for each type of system. First, we classify matching agencies into six classes. Then, we describe characteristics of some important business functions and how matching agencies implement them as ride-matching systems. We also compare current matching agencies to other transportation systems.

3.1. Overview of classification

We investigated characteristics of 39 representative matching agencies (listed in Table A.6) that are accessible online. This is not an exhaustive list. The classification proposed aims to group in the same class matching agencies that have similarities in their implemented business functions. We identified two main taxonomic criteria for ridesharing systems: *primary search criteria* and *target market*. The primary search criteria refers to what is the information used by the system to form driver-passenger matches, while target markets are segmented by demand types of ridesharing participants. In the following, we show how primary search criteria reflects important characteristics of ridesharing systems to fulfill certain types of demands. First, we list the primary search criteria:

- **Routing and time**: The system suggests a routing and scheduling of ridesharing that satisfy the request of the pick-up and/or drop-off locations and times and the requirements of the departure and arrival time of the driver considering the route. The necessary inputs are origin, destination, and time windows of the participants.
- **OD pair and time**: A request and an offer are matched by their OD-pairs and time. The system provides potential ridesharing partners according to the similarities of requests and offers. The level of geographic similarities can be cities, regions, districts, and areas within a user-specified radius from specific addresses. A detailed routing and scheduling are determined by the participants.
- **Keyword/list**: A request and an offer are searched by keywords (such as city names) of predefined lists (including bulletin boards).
- **OD pair and first-come first-serve**: Drivers and passengers are matched at predetermined meeting spots on a first-come first-serve basis. Thus, there is no prearrangement supported by ride-matching systems.

In the above, the degree of assistance in forming ridesharing by matching systems declines from top to bottom. Routing and time is the only criterion which is capable of ride-matching in an automated way even if a driver and a passenger do not share origin or destination (patterns 2, 3, and 4 in Fig. 1).

The target markets are classified as follows:

- **On-demand**: a casual, one-time, and irregular trip for relatively short distances requiring almost a real-time response.
- **Commute**: ridesharing for commuters with regular work schedule and long-term relationships. Participants often take turns in using their vehicles.
- **Long-distance**: ridesharing for a long-distance trip with advanced scheduling and less restrictive requirements of meeting time and place.

The types of demands listed above are common for ridesharing participants. There are, however, a few other types of trips: *Event* trips are formed among travelers that share some specific reason for travel, such as going to concerts, beach, or going home during school breaks. We classify event trips as long-distance trips. Amey (2010c) defined *occasional* trips as trips where drivers and passengers are reminded daily, at a fixed time (e.g., 11 am), to post offers and requests for trips in the afternoon. Occasional trips are casual, flexible, and have a moderate time window in which to match rides. We consider them as either on-demand or commute trips depending on their frequency.

According to the taxonomic criteria, we classify the 39 matching agencies analyzed into six classes (see Fig. 2). We also give the details of the classification for each of the matching agencies in Table A.6. In the description below we name each class and describe the taxonomic criteria in parenthesis (primary search criteria; target market):

1. **Dynamic real-time ridesharing (Route and Time; On-Demand and Commute)** (Gruebele, 2008; Agatz et al., 2012; Deakin et al., 2010; Amey et al., 2011): providing an automated process of ride-matching (routing, scheduling, and pricing) between drivers and passengers on very short notice or even en-route. This is the most recent class. Since the matching time-window can be very short, the system makes an automated rideshare match including a routing specifying pick-up and drop-off locations and times based on the simple input of participants' itineraries and schedules. Notice that a passenger's pick-up and drop-off locations need not be the same as the OD-pair of the car driver as long as they are on the route of the driver's original trip. Matching agencies in this class propose a suggested cost for each participant based on their own pricing rules.
2. **Carpooling (OD-Pair and Time; Commute)** (Teal, 1987; Ferguson, 1997; Morency, 2007): servicing for commuters that share transportation to work in a private vehicle with another worker. Typically, matched participants have a similar OD-pair and prefer on-going and regular carpooling. Commuters place importance on their work locations as well as the start and end times of their work.
3. **Long-distance ride-match (OD-Pair and Time; Long-Distance)**: servicing for travelers taking long-distance trips (inter-city, inter-state, and inter-country). Typical long-distance travelers have more flexible travel schedules than on-demand travelers and commuters. Some matching agencies in this class provide an alternative search choice which is a list-based search. At first, users specify the departure region, and then they search for the candidates in the list. This allows users to select their departure time based on ride availability instead of specifying their preferred departure time.

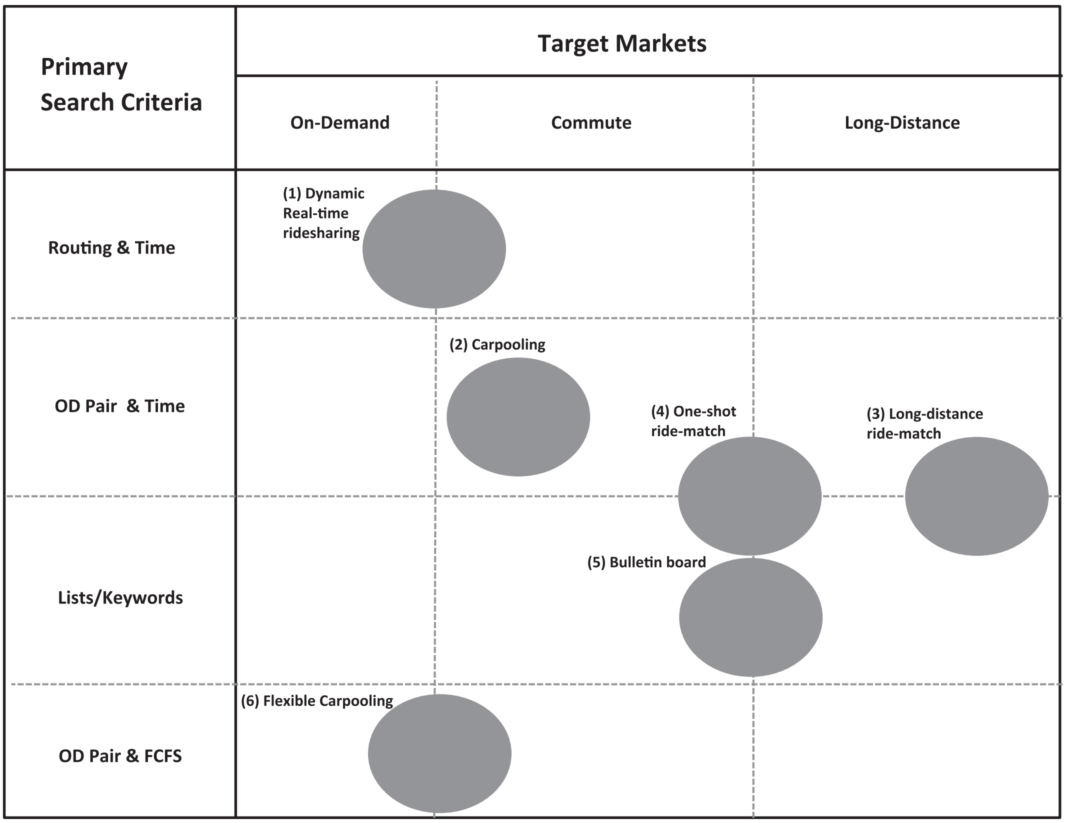

Fig. 2. Six classes of ridesharing matching agencies.

4. **One-shot ride-match (OD-Pair and Time; Commute and Long-Distance)**: a hybrid of carpooling and long-distance ride-match. They offer choices for a ridematching method according to trip types. Each matching method is similar to ones used in carpooling and long-distance ridesharing. Matching agencies in this class provide OD-Pair and Time as primary search criteria, but they provide other search criteria lists/keywords and route and time. They do not provide an automated pricing function.
5. **Bulletin-board (Keyword/List; Commute and Long-Distance)** (Beroldo, 1991): providing ridesharing opportunities (information) based on notice boards. Some matching agencies in this class aim to keep the ridesharing offers and requests as flexible as possible. They delegate to the users what kind of information they should include in their offers and requests. Thus, users search methods are based on the keywords/lists. Most ridesharing conditions are determined by negotiation among the participants.
6. **Flexible carpooling (OD-Pair and FCFS; Commute and Long-Distance)** (LeBlanc, 1999; Spielberg and Shapiro, 2000; Burris and Winn, 2006; Kelley, 2007): providing ridesharing opportunities without prearrangement in advance but coordinated on the spot. Typically, flexible carpooling is a semi-organized service, i.e., usually using no matching agency. The destination, the meeting place and time are all predetermined and publicly known among the potential participants. Ridesharing is formed spontaneously based on a first-come first-service basis at the meeting points. A typical meeting point is a parking lot (so passengers may drive to the site and leave their cars) in proximity to major transportation corridors with HOV lanes (Kelley, 2007).

A rising trend in the ridesharing industry is to provide general services that cover multiple target segments like the class of dynamic real-time ridesharing, and carpooling and one-shot ride-match rather than specific services.

3.2. Business functions

In the early nineties, Beroldo (1991) identified five fundamental components of successful ride-matching systems: a storage system for trip information, a matching system, an information dissemination method, a database update and validation system, and an evaluation system. By contrast, from the user-side, we point out the fundamental business functions are the following three: planning, pricing, and payment.

3.2.1. Planning

Planning trips is one of the main functions of matching agencies to support matching between drivers and passengers. Drivers and passengers list their offers and requests for ridesharing on the matching system. At the time of listing, *active* matching enables finding potential partners. This is in contrast to *passive* matching, which does not perform any matching during listing. In this case, filtering and keyword searches are necessary to find potential partners. We distinguish these two as activity level. Drivers and passengers seek opportunities according to the primary search criteria mentioned above. Primary search criteria and matching activity level in Table A.6 show the classification of current matching agencies with respect to planning. Matching agencies in the class of dynamic real-time ridesharing suggest itineraries of ridesharing actively with a vehicle routing function. Some of the matching agencies in the class of one-shot ride-match have a similar function.

3.2.2. Pricing

Pricing specifies the amount of money transferred between the involved parties, including how to share the costs of gas, toll, and parking, and how to charge transaction fees by the matching agencies. In industry, the following three types of pricing rules are used:

- **Catalog price**: drivers or passengers specify their limit prices while listing. Therefore, the owners of the listing determine their price.
- **Rule-based pricing**: a price is determined by a cost calculation formula specified by a matching agency. Typically, a formula is a predetermined standard rate per distance multiplied by a computed distance between the pick-up and drop-off locations.
- **Negotiation-based pricing**: a matching agency is not involved in pricing. It is negotiated between the potential partners while they determine the pick-up and drop-off locations.

In Table A.6, we show the classification of current matching agencies with respect to pricing. Matching agencies that implement rule-based pricing and catalog price have abilities to provide ridesharing prices at the time of matching, while others delegate the negotiation of the ridesharing prices to the participants. Rule-based pricing is an important function to support real-time ridesharing formation. However, current pricing methods have some limitations such as multiple passengers in the same vehicle and detour ridesharing (pattern 4). Since carpooling participants frequently take turns driving each other to work, they do not always involve money transfers. Thus, they use price negotiation. Typically, long-distance ridesharing matching agencies use catalog pricing to support identical ridesharing (pattern 1). Some matching agencies allow a choice between catalog price and rule-based pricing in order to deal with both pricing automation and user specific situations. We will point out some issues with the current pricing mechanisms in Section 3.5.

3.2.3. Payment

The following two payment methods are used by ridesharing matching agencies in practice:

- **Direct payment**: a passenger makes direct payment to a driver.
- **Payment via third party**: payment from a passenger to a driver is made via a third party such as PayPal (an online clearing service provider).

While payment via third party avoids the problem with direct payment such as no-show, lack of cash in hand, and lack of change, it is necessary to pay commission fees to online clearing service providers. Ridesharing matching agencies that charge a transaction fee use a third party to collect payment, because drivers do not directly work for the matching agency and direct payment is not sufficient for matching agencies to collect transaction fees from them. In Table A.6, we show the classification of current matching agencies with respect to payment. Payment via third-party is implemented by matching agencies in the class of dynamic real-time matching agencies. Thus, it is beneficial for passengers to pay transaction fee to enjoy the services provided by these companies.

3.3. Service types

Each matching agency runs their ridesharing services differently. We classify matching agencies according to service types that are determined by their implemented business functions. We observed four service types as listed below and that are shown in Table 1:

- **Integrated services**: involve all the three business functions to assist instantaneous ridesharing.
- **Coordination services**: involve planning and pricing functions to promote the coordinated behavior among the participants.
- **Classified advertising services**: only supports planning functions. Instead of including the pricing function, matching agencies leave pricing for the participants to negotiate.
- **Casual services**: do not deal with prearrangement, but matching is based on a first-come first-service basis at the predetermined meeting place and time. Routes and pricing rules are fixed.

In Table A.6, we show the classification of current matching agencies with respect to service types. Integrated services that support instantaneous ridesharing formation are important properties for matching agencies in the class of dynamic real-time ridesharing. All the matching agencies in the class of carpooling and bulletin board provide classified advertising services. In addition, all the matching agencies in the class of flexible carpooling provide casual services. Matching agencies in the class of long-distance provide either coordination services or browsing services. Finally, matching agencies in the class of one-shot ride matching do not have a specific trend regarding service types.

3.4. Comparison with other transportation systems

We further illustrate the characteristics of the different ridesharing systems by comparing them against other service operators. We compare them according to the degree of trip flexibility and the cost/benefit motivation. First, we classify ridesharing systems according to the cost/benefit motivation of drivers that are either cost-sharing or revenue maximization. In general, a unique characteristic of ridesharing is that it is motivated by cost-sharing unlike some other shared vehicle transportation services that are driven by revenue maximization (e.g., taxi companies). Next, we consider the flexibility of the rides offered by the service operators. Some service operators can offer a tailored trip for a passenger, while others require passengers to align to predetermined routes and schedules. Typical ridesharing falls in between these two extremes. Fig. 3 presents a diagram illustrating where the six classes of matching agencies would fall with respect to the cost/benefit motivation in the vertical axis and route flexibility in the horizontal axis. This plot also places where five popular shared vehicle transportation services (taxi, vanpooling, airport shuttle services, dial-a-ride, and fixed-route transit services) would fall along these two dimensions.

Table 1
Service types of matching agencies.

Service	Business function		
Type	Planning	Pricing	Payment
Integrated Services	✓	✓	✓
Coordination Services	✓	✓	
Classified Advertising Services	✓		
Casual Services		✓	

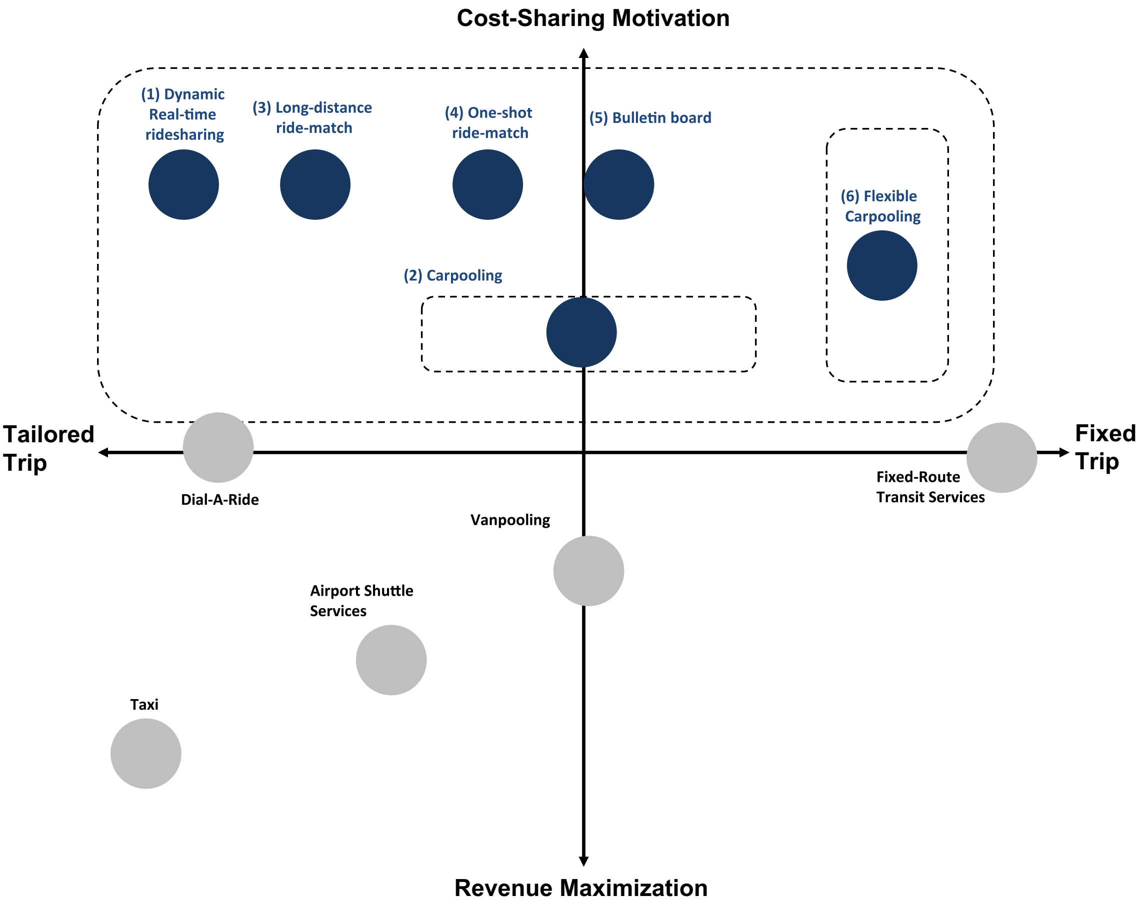

Fig. 3. Comparison between matching agencies and other shared vehicle transportation services.

In the following, we describe these five popular shared vehicle transportation services according to these two dimensions. First, a taxi provides a tailored trip for a passenger or a group of passengers at the highest cost. Second, dial-a-ride is an advanced reservation transportation service tailored to the elderly and persons with disabilities that allows passengers to request any pick-up and drop-off locations as long as they are in the service coverage area. This service is subsidized in many cases and the total payment of passengers can be less than the incurred cost of travel. Third, in airport shuttle services, each passenger can specify a single location for either the pick-up or drop-off, but the opposite end of the trip (i.e., an airport) is fixed. Typically, a fee for a ride is fixed and each passenger needs to be flexible with respect to his or her pick-up and drop-off times. Fourth, vanpools can provide a trip from the specified pick-up and drop-off locations by a passenger, but the travel time depends on servicing other passengers. Finally, operations of fixed-route transportation services have a fixed route and schedule. Passengers are forced to align to the offered services.

The different types of matching agencies give different degree of trip flexibility. This does, of course, depend on the specific match being made, in particular, the number of passengers in the same vehicle is highly related. However, generally speaking, we can sort the different classes with respect to trip flexibility as indicated in Fig. 3. Carpooling's service level can be contrasted with service operators (vanpooling and airport shuttle services). In carpooling, a work place would correspond to an airport of the airport shuttle service. Finally, in flexible carpooling, passengers are required to go to the meeting spot and there is a fixed drop-off location which is typically not the final destination of the passenger.

3.5. Discussions of current ridesharing matching agencies

We next point out some opportunities to improve current ridesharing systems. Dynamic real-time ridesharing matching agencies have distinctive characteristics such as the ability to provide pricing, routing, and scheduling in a detailed and automated way. However, only simple ridesharing can be arranged according to the current pricing rules. For example, a matching agency specifies the standard mileage cost (cost-per-distance) and a passenger pays the amount of the cost for the distance between the pick-up and drop-off locations. This has two major limitations: (1) matching is limited to a pair of a single car provider and passenger and (2) detour ridesharing is not matched. A recent survey on dynamic ridesharing found that participants were not inclined to commit for rides in advance but they do not trust that rides can be arranged in the last-minute (Deakin et al., 2010). These findings show that users expect only limited usage for dynamic ridesharing. To deal with this issue, matching agencies need to implement pricing mechanisms that satisfy the following conflicting requirements: advantages for posting request/offers early, flexibility to schedule changes, and adaptability to traffic or environmental changes.

Matching agencies targeting commuters implement a function that is able to filter geographical differences between their origins and destinations. This function is aligned with the results of a survey on carpoolling: partners are found mostly within one km radius of their residential locations (Buliung et al., 2010). In reality, filtering by estimated time to pick-up increases the usability of the ride-matching process, since congestion in certain directions cannot be neglected in peak-time. In order to compute such a time, carpooling matching agencies need to have functions of routing and scheduling for ridesharing arrangement.

Another important opportunity for improvement is a periodic reallocation for carpoolers. In current matching agencies, once a match is made it is final, even though as more requests/offers are posted there may be a better match. Periodic reallocation would enable carpoolers to swap their partners to everyone's benefit. This swap function brings flexibility in carpool formation and mitigates barriers for carpoolers.

All matching agencies in the class of carpooling, long-distance, and bulletin board supports prearrangement, but the meeting spot and time, and prices are determined by negotiations between participants. System users cannot expect service levels until the agreement is made. Thus, the service levels are said to be highly dependent on a case-by-case basis.

A key difference of ridesharing services between matching agencies and the five service operators are the drivers as described in Section 2.1. Since drivers are not hired by matching agencies as professional service drivers, establishing trust is an important requirement for passengers to participate in ridesharing. Another difference is related to the motivation of drivers to participate in ridesharing. Drivers that submit ridesharing offers to matching agencies are motivated to share the travel expenses, and thus passengers have prospects of enjoying the benefit of cost sharing with drivers and possibly other passengers. Since drivers in these five providers do not share the incurred travel cost strictly with participants, one of the unique challenges is to design attractive cost-sharing mechanisms for matching agencies.

For matching agencies, a fundamental challenge is to attract enough participants consistently and persistently to exceed the critical mass. For this, we detail some open questions of establishing attractive matching agencies in the following section.

4. Desirable services of matching agencies

In the previous section, we described how current matching agencies offer diversified ridesharing services with some limitations. However, none of these services is used as a standard means of transportation by public. Recently, Agatz et al. (2012) reviewed challenges of dynamic ridesharing focused on the ride-matching optimization problem, which deals with how to determine the routes and schedules of the vehicles (including how to assign passengers to drivers) in the presence of conflicting objectives, such as maximizing the number of serviced passengers, minimizing the operating cost or minimizing the passenger inconvenience. In this section, we aim to identify remaining challenges including pricing, high-dimensional matching, trust and reputation and institutional design. Our intention is to give clues to design novel mechanisms for the future ridesharing services. Since some barriers of current ridesharing systems span multiple disciplines, we review both recent work on ridesharing and some relevant work in other domains.

4.1. Recent dynamic real-time ridesharing studies

There are still only a limited number of papers that deal with issues of dynamic real-time ridesharing services (see Agatz et al. (2012) for a recent review) and we list some representative papers that propose novel mechanisms to form ridesharing in Table 2. The rideshare matching problem is modeled as an optimization problem (Agatz et al., 2011; Amey, 2011; Herbawi and Weber, 2012). A commonly used objective is to minimize the overall travel distances in the optimization problem, while Herbawi and Weber (2012) considering multiple objectives including to minimize the overall travel times, and to maximize the number of ride-matches. Kamar and Horvitz (2009) propose a heuristic to determine ridesharing formation and the

Table 2
Recent dynamic ridesharing studies.

Reference	Method	Objective	Cycle	Passengers/trip	Pricing
Agatz et al. (2011)	Optimization	D	Rolling Horizon	One	NA
Amey (2011)	Optimization	D	One-shot	One	NA
Herbawi and Weber (2012)	Optimization	D, T, N	One-shot	Multiple	NA
Kamar and Horvitz (2009)	Heuristic	V	Rolling Horizon	Multiple	Vickrey
Kleiner et al. (2011)	Auction	V	Rolling Horizon	One	Second price

D: Travel Distance, T: Travel Time, N: The Number of Matching, V: Value.

payments of participants. The system supports to form ridesharing from the participants that gain the highest value due to a ridesharing plan first, where the value for each participant is calculated by the combination of the gain due to a cost saving and the loss due to an additional travel time that are determined by the formed ridesharing plan. They use the Vickrey payment scheme (Vickrey, 1961) to determine the payment of each participant, which is roughly the difference between the overall value of the rideshare without the participant and the overall value of the ridesharing when the participant is excluded from the system. Thus, the participant is asked to pay the value of their contribution to the whole system. In an auction-based approach, passengers place bids to each driver to form a ridesharing; and the passenger who placed the highest bid is assigned to the driver (Kleiner et al., 2011). This is limited to the single passenger assignment and the payment is determined by the second price payment (Vickrey, 1961; Clarke, 1971; Groves, 1973) which is the second highest bid price. Under this pricing mechanism, it is known that the best bidding strategy is to be truthful. These five studies postpone the time of matching as much as possible to wait for new drivers and passengers for the efficient matching in either case of matching cycles: one-shot matching or a rolling horizon. Even though studies based on the optimization-based approach do not focus on the pricing of ridesharing, this postponement could be an issue regarding an instantaneous notification of ridesharing costs.

The ridesharing problem is similar to the dynamic pickup and delivery problem (DPDP) in which each transportation request has a pickup and delivery point and all these points must be serviced within a given time window (Lu and Dessouky, 2006). A representative application of this problem is dial-a-ride which is done by an organized service operator. Studies of the DPDP are extensive (see Berbeglia et al. (2010) for a recent literature review), while we point out two differences. First, the ridesharing problem includes pricing issues, whereas drivers in the DPDP are part of the same service industry, which is not concerned with splitting the incurred cost among the participants. Second, drivers in the ridesharing problem have their own origins and destinations with time-windows similarly to passengers, whereas drivers in the DPDP aim to provide transportation services typically all day without having their own travel destinations. Since the number of drivers can be different at each decision time point in the ridesharing problem, we raise a pricing issue of the rolling horizon approach frequently used in the DPDP in the following section.

4.2. Pricing for dynamic real-time ridesharing

As mentioned above, the pricing problem has received less attention in the literature as compared to the ride-matching optimization problem. Stock exchange (Harris, 2002) and ad exchange (Muthukrishnan, 2009) are two successful examples that facilitate real-time matching between sellers and buyers by providing opportunities for sellers (or buyers) to sell (or buy) trading items at the highest (or lowest) prices. However, it is not straightforward to apply these systems to ridesharing. Typically, ridesharing participants are motivated by sharing travel costs, traveling fast by the use of high occupancy vehicle lanes, and mitigating environmental concerns rather than making profits. In addition, since the final form of ridesharing is determined only when the last passenger in a vehicle is determined, participants cannot evaluate the value of ridesharing at the time of order submission unlike stock and ad exchanges.

We now describe some remaining challenges and opportunities related to the pricing problems that have been studied in the mechanism design literature. There are two streams of research in mechanism design based on non-cooperative game theory and cooperative game theory, and ridesharing is related to both streams. Non-cooperative game theory deals with how individual travelers form ridesharing, while cooperative game theory considers how to share costs among participants so that they agree to form ridesharing.

- **Truth-inducing mechanism**: A fundamental question in non-cooperative game theory is to design truth-inducing mechanisms. A few studies design mechanisms for dynamic ridesharing to specify how to charge ridesharing fees from passengers in such a way to induce truthful ridesharing requests from passengers and offers from drivers based on the Vickrey payment scheme (Kamar and Horvitz, 2009; Kleiner et al., 2011). However, proposed mechanisms have some limitations and we point out two challenges. The first challenge is to identify how participants can manipulate the system when the mechanism determines their payments according to the participants in the same vehicle instead of considering the entire alternatives (Kamar and Horvitz, 2009). The second challenge is to extend the work of Kleiner et al. (2011) which determines the payments according to an auction mechanism, but is limited to a single passenger assignment per vehicle.
- **Fair cost-sharing mechanism**: A fundamental question in cooperative game theory is to design fair cost-sharing mechanisms to allocate costs to participants rather than the specification of the agreement procedures of payments. Several different cost-sharing mechanisms have been designed and they are applicable to share the transportation cost in a static setting (Frisk et al., 2010; Winter and Nittel, 2006). One of the remaining challenges is to design cost-sharing mechanisms when the participants form ridesharing in an online setting in which drivers and passenger send their offers and requests sequentially. This involves the consideration of fairness for intra-vehicle and inter-vehicle participants, because ridesharing is not formed simultaneously.
- **Online mechanism**: The ride-matching cycle is an important factor to design market mechanisms for dynamic ridesharing. A small difference in the submission time of a ridesharing request or offer can lead to a different outcome. A related example can be found in e-Bay, where multiple sellers offer the same commodity with different deadlines and the clearing prices are not identical. It is known that sellers and buyers play a game to set their deadlines in order to choose the best one so that the supply and demand balance works best for them. Even though ridesharing participants have

incomplete information about the future behaviors of the other participants, they can play a game with their submission times and their time-windows similarly to the e-Bay example. This is related to the fact that drivers of ridesharing do not provide service all day. This type of problem is known as the online mechanism design problem (Parkes, 2007; Juda and Parkes, 2009; Gerding et al., 2011). The main difference of dynamic ridesharing from the typical online mechanism literature is the effect of multiple passengers on ridesharing formation. To add a passenger in ridesharing can lead to a cost saving in the case of identical, inclusive, and partial ridesharing, but it can also incur an additional cost in the case of detour ridesharing. Thus, a remaining challenge is to design a mechanism that specifies the way of clearing the market with a payment update rule reflecting some changes of ride-matching allowing the assignment of multiple passengers in a vehicle. This involves the following two extensions of truthfulness. The first extension is to give incentives for participants to submit their ridesharing requests or offers as soon as possible. The second extension is to induce the truthful time-windows from the participants. For these criteria, the mechanism designers should consider how to notify and guarantee the prices to the participants in the dynamic sense with a consideration of the two fundamental criteria: *budget-balance* which is satisfied when the collected payments are fully paid to the drivers except for the transaction fees; and *individual rationality* which is satisfied when all the participants enjoy the benefits of ridesharing.
- **Robust mechanism**: There are many complex requirements in practice including urgent requests, cancellations, changes of schedules, and no-shows. Changes of schedules occur due to personal reasons and unexpected events such as breakdowns of vehicles and stuck in congestion. A few studies consider these ridesharing situations (Xiang et al., 2008; Beaudry et al., 2010), but they do not consider the pricing problem.

4.3. High-dimensional matching

The screening of ridesharing partners grows in importance if there are many potential partners. For instance, in carpool formation, gender may play a role (Charles and Kline, 2006). In practice, most matching agencies have functions to store profiles of participants including photos, gender, short descriptions, car make, model, and year, while the screening process is based on manual selection. In addition, ratings from other participants are stored in reputation systems (which will be discussed in the following section). In this section, we focus on the issues regarding ride-matching. A key technical challenge of screening is to integrate with ride-matching. While some screening items treated as hard constraints are easy to set, tuning parameters for soft constraints requires some skill. Elicitation of precise priorities among screening items can be complex even for experienced users.

Another challenge for high-dimension ride-matching is a complex recommendation system. Gruebele (2008) lists and specifies some desired functions to be implemented in the future: multiple routes option for ride-matching, recommendation of route settings that have higher chances to be accepted, and multiple rides to accomplish a single request from the origin to the destination (conditional commitments for ride-matching). Potential transfer points should be transportation hubs having large parking spaces such as public transport terminals, park-and-ride spots, and large shopping centers. Recently, some fast algorithms to generate the shortest path satisfying the requirements of multi-hop ridesharing are proposed by Herbawi and Weber (2011) and Drews and Luxen (2013), while they do not consider pricing issues.

A great number of choices for participants increases the importance of assistance by software agents that enable personalized travel planning and execution. For instance, it would be helpful for a car driver be informed of which route, and at which time, she or he should drive in order to maximize the opportunity of ride-matching.

4.4. Trust and reputation

Since most matching agencies leave the physical part for ridesharing services to individual car providers, a main concern of matching agencies is to provide consistent ridesharing services with a variety of individuals. Of greater concern, is to convince individuals to participate in ridesharing services. This is not a specific issue just for matching agencies, but it is common in informational intermediation service providers that delegate individuals to provide actual services.

While a direct experience is the most reliable foundation of trust, some intermediation service providers mitigate the limitation of users' direct experiences according to an implementation of a large-scale word-of-mouth network, which is known as reputation systems (Dellarocas, 2006; Jøsang et al., 2007). For instance, e-Bay's feedback mechanism supports buyers to build trust to unknown sellers and elicits honest behavior (Resnick and Zeckhauser, 2002). Typical reputation systems use a feedback report that is filled out by users who have experienced services or providers who have offered services; the collected feedback is shared among the community members in order to provide an opportunity to evaluate whether these individuals are trustworthy to exchange services in the future. This well-established e-Bay like reputation system is implemented in some ridesharing matching agencies (see for example, Avego, Carpool World, and Golco).

In academia, e-Bay like reputation systems are well-studied and the most critical issue is how to ensure that it is in the best interest of a rational agent to actually report reputation information truthfully (Jurca and Faltings, 2003):

- Reporting positive feedback can lead to increased competition with others in the future (Jurca and Faltings, 2003; Dellarocas, 2006).
- Fake negative feedback can cause scarce resources to exit the competition (Jurca and Faltings, 2003; Dellarocas, 2006).

- There is a bias towards a positive report in order to protect against a retaliation of a negative report by a counter partner (Resnick and Zeckhauser, 2002).
- It is easy to create a new ID to wipe out past records (Dellarocas, 2006; Jøsang et al., 2007; Witkowski et al., 2011).
- All service providers are not around long enough to be incentivized by future returns that are dependent on today's feedback (Dellarocas, 2006; Jøsang et al., 2007; Witkowski et al., 2011).

Recently, Witkowski et al. (2011) proposed *escrow mechanisms* to deal with these issues instead of using reputation systems. The main idea is to install a trusted intermediary that forwards the payment from the buyer to the seller only if the buyer reports that she or he has received the good in the promised condition. In a ridesharing example, escrow mechanisms work as follows. At the time of ridesharing arrangement, the passenger sends her payment to the center (the trusted third party) which holds it in escrow. The center then acknowledges receipt of payment to the car provider. Once the car provider has taken a passenger to the drop-off location, the passenger is asked by the center what signal (feedback score) she or he received. Only if the passenger reports a high signal does the center forward the passenger's payment to the car provider. Currently, this function has been implemented by several ridesharing service providers as mentioned in Section 3.2.3. However, currently used escrow procedures in practice do not satisfy some desirable properties such as incentive compatibility (sending the truthful signal is the best behavior for participants), efficient (the winning price is the highest bidding price of the rational passenger), individual rational (no negative utility), and budget-balance (no subsidy required) simultaneously. Their proposed escrow mechanism does not simply reimburse every passenger who reports a low signal. The main idea is whether or not a passenger receives a rebate (equal to his/her escrow payment) depends on the report of another passenger which may not necessarily be on the same ride. Essentially, by a passenger reporting a signal, she or he enters into a lottery for receiving a rebate back from the escrow mechanism. It remains the case that the center forwards the payment to the car provider if and only if the respective passenger reports a high signal.

In practice, there are some challenges in applying an escrow mechanism to ridesharing. The main issue is an identification of causality of failure. Indeed, difficulties increase in the multiple passengers' case, since realized ridesharing is determined by the interactions of the ridesharing participants. For instance, consider a driver and two passengers that form ridesharing. In a ridesharing plan, the driver is feasible to form ridesharing with both passengers. However, the first passenger delayed to appear at the pick-up location which caused a dishonest activity for the second passenger regarding a pickup. However, it is unknown to the second passenger who caused the delay. How should passengers evaluate their experiences? A question is whether the second passenger has to identify the causality of the delay due to the driver, the first passenger, or something else. Another issue is transfer of perceptions. Different people have different perceptions of received services. For instance, different people have different tastes for driving skills of others, cleanness, and conversations. Moreover, required service levels between carpoolers and long-distance riders are significantly different and a question is whether signals from these two should be mixed or not. Thus, there remains some obstacles to use this mechanism in practice.

A ridesharing survey for students in a university (Chaube et al., 2010) indicates that a close relationship is a key factor of successful ride-matching: 7% would accept rides from strangers, whereas 98% and 69% would accept rides from a friend and the friend of a friend, respectively. Thus, another way to build trust is to associate acquaintances in efficient ways. Recently, social network sites (SNSs) play important roles in this point. Regarding advantages of using SNSs for ridesharing, Wessels (2009) explains that participants can get information about other participants by simply checking the profile on their social network; they can evaluate the profile and decide if the other traveler seems trustworthy and friendly. In industry, some matching agencies, such as ZimRide, Avego, and Carticipate, offer services in conjunction with SNSs in order to find acquaintances in efficient ways, to increase the transparency of profiles of travelers, and to share common interests in a community. Indeed, ZimRide also provides an option to search from a limited community such as a university. While SNSs allow users to closely communicate with each other online, in reality there is a barrier to meet offline if they have not met each other before. Thus, it is interesting to identify the relationship between preferences as ridesharing partners, closeness of acquaintances, and ridesharing trip types. A better understanding of this point should help in the development of successful ride-matching systems.

4.5. Institutional design

A fundamental question is how many matching agencies should coexist in a certain region. A greater number of matching agencies leads to a fragmentation effect that can cause a failure for matching for a particular agency, even though an offer or request can be matched by a different agency. In contrast, a monopoly frequently sets back investment on developing technologies and increases costs. In financial markets, this controversial issue has been discussed for many years (Chowhdry and Nanda, 1991). Increasing liquidity in fragmented markets can be achieved using a smart order routing system that aims at maximizing the opportunities of matching. This system would use technology that consolidates offers in different markets and routes orders accordingly (Foucault and Menkveld, 2008). It is a challenging task to extend such a system to the ridesharing industry.

Travelers of dynamic real-time ridesharing may not complete their trips by ridesharing. Therefore a ridesharing system with information of alternate and complementary transportation methods increases usability of ridesharing for participants (Deakin et al., 2010). One of the largest obstacles to greater multi-modal integration has been a lack of availability of travel information in a consistent format (Amey, 2010b). Recently, Google's Transit Feed Specification has become the unofficial industry standard for coding transit data (Amey, 2010a). However, current specification focuses mainly on simple data exchange. A key challenge is to define specifications for a business processes in order to deal with dynamically changing data, which is necessary to be a dynamic real-time matching agency.

High-Occupancy and Toll (HOT) lanes have been adopted by several metropolitan areas in order to apply effective pricing rules for congestion mitigation and off-peak usability, and to allow single occupancy vehicle drivers who are willing to pay. As pointed out by Konishi and Mun (2010), there are a limited number of papers that analyze the effect of congestion pricing on ridesharing formation from a social welfare point of view. Yang and Huang (1999), Small and Yan (2001), and Verhoef and Small (2004) analyzed the effect of a few congestion pricing mechanisms for carpoolers. A more complex problem is to deal with congestion pricing for dynamic real-time ridesharing involving routing, scheduling, and pricing. In addition, this is relevant to the traffic assignment problem that deals with a prediction of travelers' behaviors to choose routes over a road network (Bar-Gera, 2010).

4.6. Examples of design issues

We finish this section with some ridesharing examples. An important aspect of the literature relevant to the design of future ridesharing markets is that the above topics have been considered separately. In the following, we show some ridesharing examples to clarify complex issues to design mechanisms.

Example 1. Consider a situation where two drivers (D_1 and D_2) and a passenger (P_1) have the demands of travel as shown in Fig. 4. Suppose all drivers travel at an identical speed of *40* miles per hour. They want to form ridesharing if their requirements (the start and end locations, the earliest departure time, the latest arrival time, and the willingness to pay) are satisfied. Each participant submits its request or offer at its own submission time. Information on the participants is listed in Table 3. Driver D_1 wants to travel from location L_1 to location L_3, which is 16 miles, with the earliest departure time 8:00 and the latest arrival time 9:00; the truthful cost per mile of driver D_1 is \$0.3; and driver D_1 submits its offer at 0:00. Then, Driver D_2 submits its offer at 0:01 with the truthful cost per mile \$0.4. Finally, passenger P_1 submits a request at 7:00 from location L_4 to location L_3 with the earliest departure time 8:30, the latest arrival time 9:00, and the maximum willingness to pay \$1.6. This request is on the way of both drivers D_1 and D_2.

In this example, the request of passenger P_1 is feasible to match either with driver D_1 or D_2 with respect to their schedules and their requirements on the payments. If passenger P_1 is assigned to driver D_1, it is possible for driver D_1 to pick up P_1 at location L_4 between 8:30 and 8:48 which corresponds to the departure time of driver D_1 between 8:18 and 8:36 at location L_1 and its arrival time between 8:42 and 9:00 at location L_3. If the payment of passenger P_1 is between \$0 and \$2.4, it is beneficial for both D_1 and P_1, and \$1.6 is proportionally fair. Otherwise, it is possible for driver D_2 to pick up P_1 at location L_4 similarly to the case of driver D_1; and \$2.4 is proportionally fair. One solution is to assign passenger P_1 to driver D_1 with \$1.6 as the payment from passenger P_1 to driver D_1. In addition, a mechanism that generates this outcome satisfies budget-balance and individual rationality. However, this assignment makes driver D_1 less flexible to be matched with other passengers in the future. In the following example, we consider such a case.

Example 2. Consider a situation similar to Example 1 and assume that passenger P_1 is assigned to driver D_1 and the payment of P_1 is \$1.6. There are two additional passengers P_2 and P_3 that submit their requests after passenger P_1 having the identical OD-pairs as shown in Table 4.

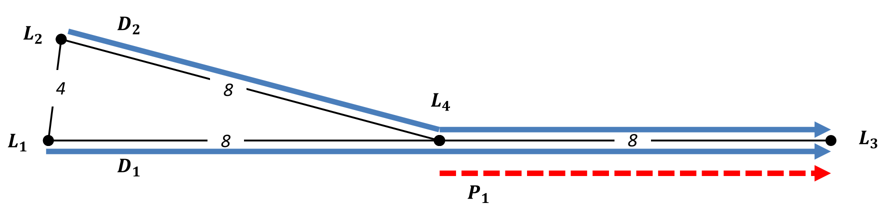

Fig. 4. Ridesharing demands in Example 1.

Table 3
Ridesharing requirements in Example 1.

Participant	OD-Pair	Submission time	Earliest departure time	Latest arrival time	Cost
D_1	$L_1 \rightarrow L_3$	0:00	8:00	9:00	\$0.3 per mile
D_2	$L_2 \rightarrow L_3$	0:01	8:30	9:00	\$0.4 per mile
P_1	$L_4 \rightarrow L_3$	7:00	8:30	9:00	\$2.4

Table 4
Ridesharing requirements of additional passengers in Example 2.

Participant	OD-Pair	Submission time	Earliest departure time	Latest arrival time	Cost
P_2	$L_1 \rightarrow L_4$	7:02	7:15	8:15	2.4
P_3	$L_1 \rightarrow L_4$	7:05	7:15	8:15	2.4

It is feasible to assign both passengers P_2 and P_3 to driver D_1 but not to driver D_2. However, driver D_1 needs to wait at least *15* minutes at location L_4 between the drop-off of passengers P_2 and P_3 at 8:15 and the pick-up of passenger P_1 at 8:30. In this example, two questions may arise. First, when passenger P_2 submits a request at 7:02, how should driver D_1 be compensated for the additional wait time? If this cost is shared by D_1, P_1, and P_2, the payment of P_1 will be increased; and such a cost increase may not be accepted in general. If it is shared by D_1 and P_2 or owned by either D_1 or P_2, should a reassignment be considered to save such a compensation? If passenger P_1 is reassigned to driver D_2, the compensation to driver D_1 can be reduced but the truthful cost of driver D_2 is higher than D_1. Alternatively, at the time of the initial payment notification of passenger P_1 in Example 1, should the decrease of the flexibility of driver D_1 be considered for the determination of the payment? Second, when passenger P_3 submits a request at 7:05 which does not incur any additional cost, how should the payments be determined? If passenger P_2 does not enjoy the benefit of the cost-saving due to the participation of passenger P_3, passenger P_2 is better-off submitting its request after the request of P_3. Thus a question is whether a mechanism can prevent such a gaming.

Example 3. Consider a situation where two drivers D_1 and D_2 and two passengers P_1 and P_2 have their travel demands as shown in Fig. 5 with their requirements as shown in Table 5. Two drivers have different origins but the same destination, while passengers have the same origin but different destinations. Each driver is feasible to be matched with both passengers or with either one of the passengers. It is necessary to deviate from the original route to satisfy the request of passenger P_1, whereas it is not necessary to do so for passenger P_2. If both passengers are in the same vehicle, passenger P_2 needs the additional travel compared to the case of the different vehicle.

Two questions may arise in this example. First, while both drivers have the same conditions including the additional cost and the decrease of flexibility when matched with passenger P_1 except for their origins and submission times, what criteria are reasonable to determine the matching? If passenger P_1 is matched with driver D_1, the remaining flexibility of the future matching in total is decreased more than the case of the matching with driver D_2. Otherwise, driver D_1 may depart the start location without any matching and it may leave the market. This also decreases the flexibility of the future matching. Second, ridesharing with passengers P_1 and P_2 are not identical for the drivers and what kind of fairness should be satisfied? Fair cost-sharing within a vehicle is a simple idea, while fair cost-sharing between drivers is more complex.

In the above examples, we have not specified how drivers and passengers are asked to declare their costs and willingness to pay. Fundamentally, a design question includes what type of costs should be shared or owned by whom. For this question, we point out that costs incurred by ridesharing are classified into two types: a physical cost including fuel cost, toll fee, and parking fee; and a cognitive cost including additional or reduced travel time needed to form ridesharing compared to traveling alone, and annoyance caused by behaviors of other passengers.

Another important consideration is the case where drivers and passengers are not completely reliable with respect to showing up at the meeting place at the agreed time. This involves two types of questions. First, how can we use the information of the reputation system to reduce such risks? In Example 1, driver D_2 costs more than driver D_1. But if driver D_2 is more reliable according to the reputation system, how should the assignment and payment of passenger P_1 be determined. Second, what is a reasonable compensation rule for a delay or cancellation? Let us consider Example 2 again. Passenger P_1 is assigned to Driver D_1 at a cost of \$1.6. If this passenger cancels ridesharing, this passenger would be asked to a pay cancellation fee of \$1.6. This cancellation can be propagated to different passengers. If this cancellation occurs between the participation of passenger P_2 and the departure of driver D_1, driver D_1 does not need to wait at location L_4 to pick up passenger P_1. Thus, the cancellation involves changes of the schedules and prices of other participants.

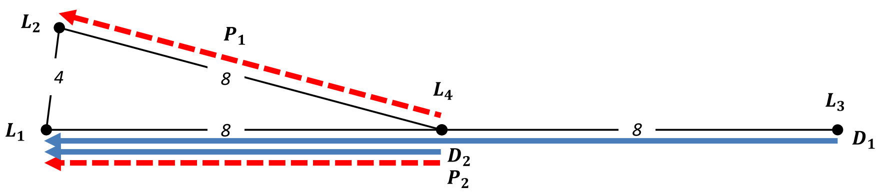

Fig. 5. Ridesharing demands in Example 3.

Table 5
Ridesharing requirements in Example 3.

Participant	OD-Pair	Submission time	Earliest departure time	Latest arrival time	Cost
D_1	$L_3 \rightarrow L_1$	7:00	8:00	9:00	\$0.3 per mile
D_2	$L_4 \rightarrow L_1$	7:01	8:12	9:00	\$0.3 per mile
P_1	$L_4 \rightarrow L_2$	7:02	8:00	9:00	\$2.4
P_2	$L_4 \rightarrow L_1$	7:03	8:00	9:00	\$2.4

Table A.6
Business functions of matching agencies.

Matching agency	Target market	Service type	Primary search criterion	Matching activity	Pricing	Payment
Dynamic real-time ridesharing						
Avego	On-Demand, Commute	Integrated	Route&Time	Active	Rule	Third
flinc	On-Demand, Commute	Coordination	Route&Time	Active	Rule, Catalog	Direct
Zebigo	On-Demand, Commute	Integrated	Route&Time	Active	Rule	Third
Carpooling						
511 SF Bay Area	Commute	Classified Ad	OD-Pair&Time	Active	Negotiation	Direct
Carpool Crew	Commute	Classified Ad	OD-Pair&Time	Passive	Negotiation	Direct
Carpool World	Commute	Classified Ad	OD-Pair&Time	Active	Negotiation	Direct
Carpool Zone	Commute	Classified Ad	OD-Pair&Time	Active	Negotiation, Rule	Direct
RideSearch	Commute	Classified Ad	OD-Pair&Time	Active	Negotiation	Direct
Long-distance ride-match						
amovens	Long-Dist.	Coordination	OD-Pair&Time	Active	Catalog	Direct
Carpooling	Long-Dist.	Coordination	OD-Pair&Time	Passive	Catalog	Direct
Comuto	Long-Dist.	Coordination	OD-Pair&Time	Passive	Catalog	Direct
Covoiturage	Long-Dist.	Coordination	OD-Pair&Time	Passive	Catalog	Direct
Ganji	Long-Dist.	Classified Ad	OD-Pair&Time	Passive	Catalog	Direct
GishiGo	Long-Dist.	Coordination	OD-Pair&Time	Active	Catalog	Direct
Mitfahrgelegenheit	Long-Dist.	Coordination	OD-Pair&Time	Passive	Catalog	Direct
Moovel	Long-Dist.	Coordination	OD-Pair&Time	Active	Catalog	Direct
Notteco	Long-Dist.	Classified Ad	OD-Pair&Time	Passive	Negotiation	Direct
PickupPal	Long-Dist.	Classified Ad	OD-Pair&Time	Active	Negotiation	Direct
Pinchela	Long-Dist.	Classified Ad	OD-Pair&Time	Passive	Negotiation	Direct
RideshareList	Long-Dist.	Classified Ad	OD-Pair&Time	Passive	Negotiation	Direct
Viajamos Juntos	Long-Dist.	Coordination	OD-Pair&Time	Passive	Rule	Direct
ZimRide	Long-Dist.	Coordination	OD-Pair&Time	Active	Catalog	Direct
56	Long-Dist.	Classified Ad	OD-Pair&Time	Passive	Catalog	Direct
One-shot ride-match						
Carticipate	Commute & Long-Dist.	Classified Ad	OD-Pair&Time	Active	Negotiation	Direct
Carriva	Commute & Long-Dist.	Classified Ad	Route, OD-Pair&Time	Active	Negotiation	Direct
GoLoco	Commute & Long-Dist.	Integrated	OD-Pair&Time	Active	Catalog	Third
iCarpool	Commute & Long-Dist.	Classified Ad	Route, OD-Pair&Time	Active	Negotiation	Direct
JayRide	Commute & Long-Dist.	Coordination	OD-Pair&Time, Keyword/List	Passive	Catalog	Direct
NuRide	Commute & Long-Dist.	Classified Ad	OD-Pair&Time	Passive	Negotiation	Direct
ride 4 cents	Commute & Long-Dist.	Classified Ad	OD-Pair&Time	Active	Negotiation	Direct
Bulletin board						
AlternetRide	Commute & Long-Dist.	Classified Ad	Keyword/List	Passive	Negotiation	Direct
Commuter Connections	Commute & Long-Dist.	Classified Ad	Keyword/List	Passive	Negotiation	Direct
Craigslist	Commute & Long-Dist.	Classified Ad	Keyword/List	Passive	Negotiation	Direct
eRideshare	Commute & Long-Dist.	Classified Ad	Keyword/List	Passive	Negotiation	Direct
is anyone going to	Commute & Long-Dist.	Classified Ad	OD-Pair&Time, Keyword/List	Passive	Negotiation	Direct
RideBuzz	Commute & Long-Dist.	Classified Ad	OD-Pair&Time, Keyword/List	Passive	Negotiation	Direct
Flexible carpooling						
Casual Carpooling	Commute	Casual	FCFS	NA	Fixed	Direct
Raspberry Express	Commute	Casual	FCFS	NA	Fixed	Third
Slugging	Commute	Casual	FCFS	NA	Free	Direct

5. Conclusion

This paper presents both a classification of existing ridesharing systems and some specific challenges toward a massification of ridesharing that pose opportunities for new research. The taxonomy for ridesharing introduced can help identify ridesharing matching patterns that current industry practices can satisfy and those that still are difficult. Our description of existing ridesharing systems illustrate how different business functions are implemented as rideshare matching systems. This includes both the degree of automation in matching formations and target demand segment. Dynamic real-time ridesharing matching agencies exploit advanced technologies including GPS, web, and mobile technologies for real-time communication and implement rideshare matching systems according to routing and scheduling functions for the automated ride-matching. However, there are only a few agencies today and their service areas are strictly limited.

Some of the difficulties identified in dynamic ridesharing systems stem from the requirement of instantaneous successful coordination with respect to itineraries, schedules, and cost-sharing among participants. This is difficult because the proper information might not be known or even available to participants and decisions are dynamic and instantaneous. We review existing research that could help address these difficulties. Three major challenges for agencies are: design of attractive mechanisms (instantaneous price quote, incentives for participants, and truthfulness), a concierge like ride-arrangement (preferences of profiles in detail, multi-hop rides, and consolidation with other transportation modes), and building of trust among unknown travelers in online systems.

There are many other challenges to overcome inhibitors of ridesharing. For example, privacy is one major concern for individuals. These concerns include the risk of exchanging private information such as travel information and times with strangers (Chaube et al., 2010) but also the loss of privacy due to the systematic data collection of this private information by agencies (Amey et al., 2011). Another concern is the uncertainty around the legal liability of ridesharing services. Leibson et al. (1994) identified potential legal risks in traditional ridesharing programs. In an environment where ridesharing is able to capture a significant segment of travelers, there is great potential for ridesharing exchange markets traded by automated traders similar to recent stock exchanges and Ad exchanges for Internet advertisement. In such a ridesharing exchange, crucial research questions are developments of real-time bidding agents. Specifically, buyer agents that place bids for ridesharing offers and seller agents that propose ridesharing offers or place advertisements to candidate passengers.

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Appendix A. Classification of ridesharing matching agencies

Table A.6.

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