A Social-Network-Optimized Taxi-Sharing Service

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Social-network-based taxi sharing is a potential smart city service with social and economic benefits. The authors designed a framework for planning social-network-based taxi travel and successfully applied it in a practical scenario.

Through smart cities, the next generation of ICT, including the Internet of Things (IoT), cloud computing, sensors, and transmission systems, will enable intelligent urban management, operation, and maintenance for residents.[1] To achieve these goals, smart cities must fully utilize public resources and increase service quality for citizens while either maintaining or decreasing resource costs. In this innovative new society, scholars and resource administrators will need to pay more attention to human resource management, environmental protections, and infrastructure management.[2] Various new management methods are emerging that not only enhance quality of life for citizens but also promote the creation of new services.

Taxi sharing is a potential smart city service that can solve the problem of limited taxi resources. It can relieve pressure on a city's transportation management system and, based on an effective arrangement of resources, improve users' quality of experience. Taxi-sharing services work via users' smartphones to provide sharing opportunities and the best route options. To promote a successful sharing agreement, such services provide potential consumers and taxi drivers with online notifications. Hence, the taxi-sharing solution has generated interest in both academic and industry circles in recent years.[3]

 Published by the IEEE Computer Society

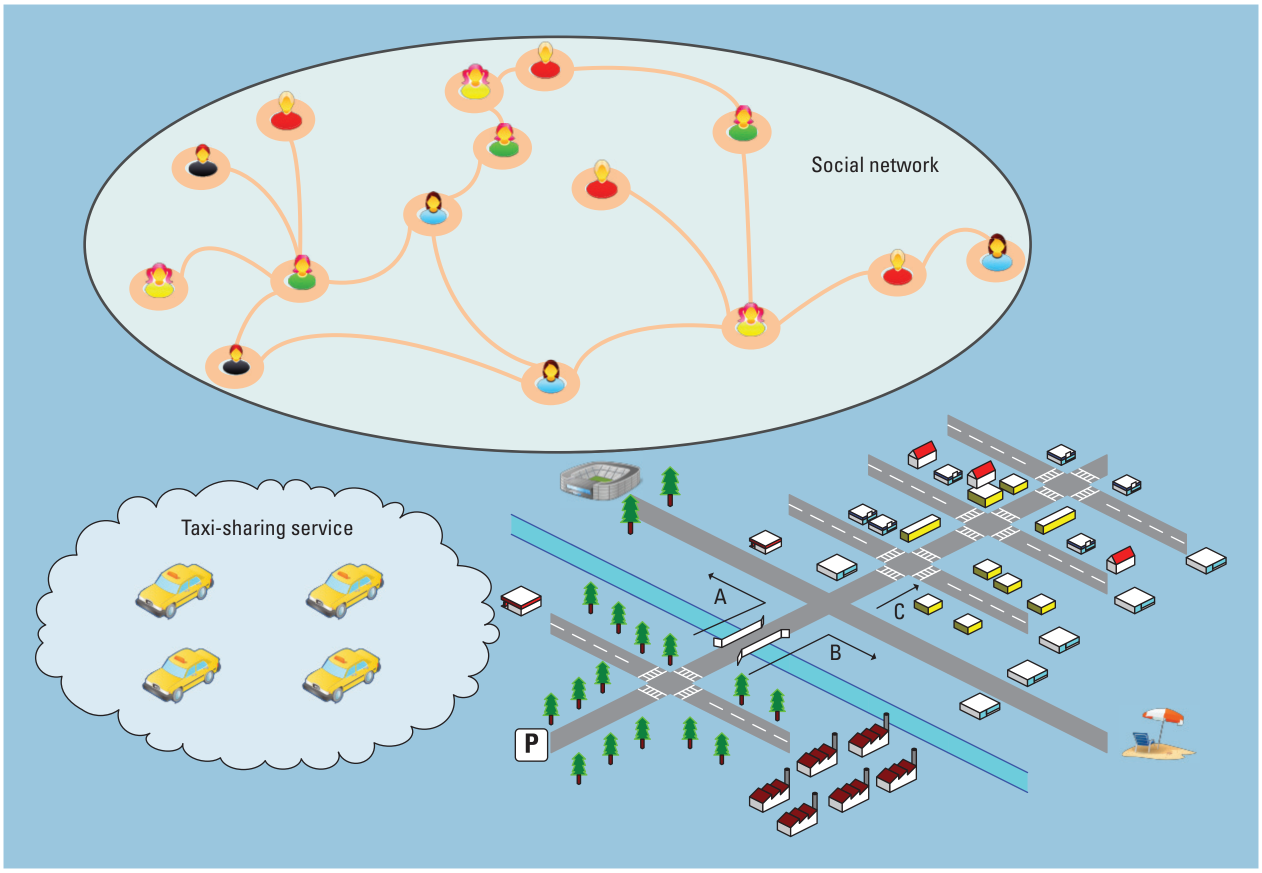

Figure 1. Social network and taxi-sharing cloud service. The system coordinates users' travel plans and social network connections to assign passengers to different taxis.

Traffic congestion and environmental concerns are the main reasons consumers tend to use taxi-sharing services.[4] However, consumers might resist using services that don't consider potential social interactions.[5] For example, a female consumer might feel uncomfortable sitting beside a male stranger who happens to be her taxi-sharing companion. For this reason, some countries (such as Japan) have women-only passenger cars, especially during the summer months. Aiming to solve this issue, our solution focuses on both the cost benefits and social interaction aspects of a shared journey by using a specific taxi-service scenario.

Social-Network-Based Sharing

In general, when we consider the coordination between consumers during a taxi-sharing arrangement, differences between when they must depart and arrive are the primary reasons why users' requirements are rarely met. Furthermore, long wait times and determining how to divide trip costs make sharing arrangements difficult to establish. This dynamic ride-sharing problem gives system developers the crucial challenge of satisfying as many consumer requirements as possible. Although various constraints discourage consumers from sharing their trips with strangers, people still frequently share rides with others they already know, such as those in their social network.[6] Unlike relationships that are established purely online, such as through online fan forums or gaming sites, social networks at least partly mirror real-world relationships—that is, family and colleagues—so consumers are more likely to trust ride-sharing companions if the relationship stems from their social network.[7] Because such real-world relationships are more reliable than those between complete strangers, if those in the former share a trip, they can not only save on costs but can also feel safer due both to the high quality of the taxi service and to having psychological support from their companions.[8]

Designing the Sharing Service

Figure 1 provides an overview of a social-network-based taxi service that uses groups of potential

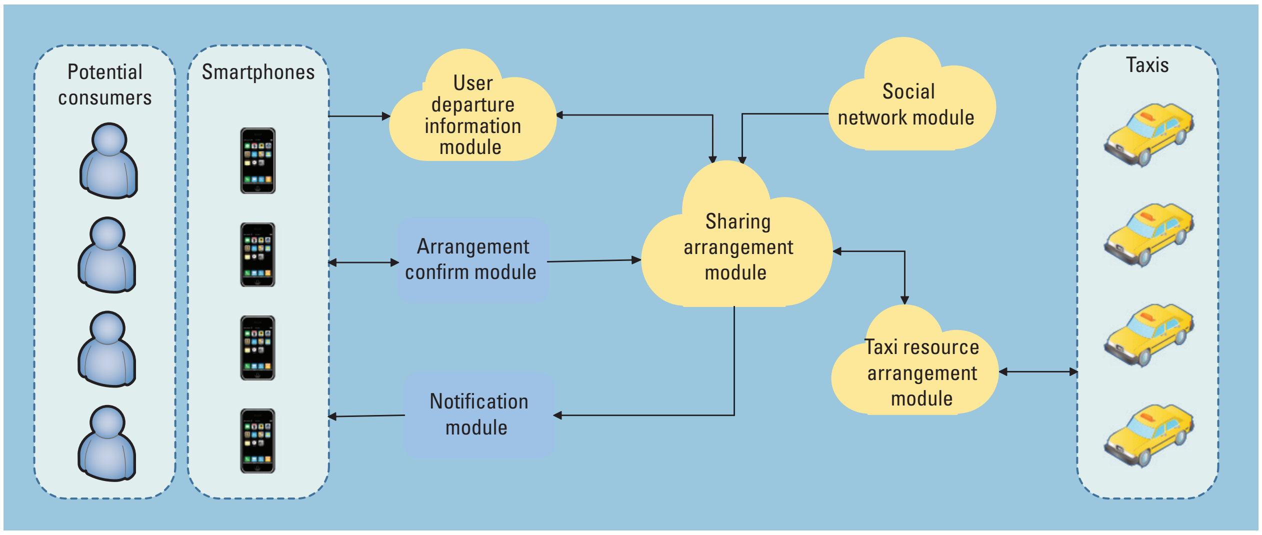

Figure 2. **Structure of the social-network-based taxi-sharing service. The cloud service uses social network data to arrange resources for potential consumers wishing to share a taxi.**

consumers who have strong or weak social network connections with each other. These users must have smart devices with access to the Internet and must be willing to reach their destinations by sharing a taxi. The sharing system provides the taxis and the passenger allocation service by coordinating users' different travel plans and social network connections.

Taxi Supply and Demand

On some occasions, many consumers will need taxis simultaneously during a specified time period; we refer to this as "taxi-needed peak time." For example, during lunch or business closing time, many potential consumers are waiting for taxis at the front of an office building. Traditionally in this scenario of limited taxi resources, sharing taxis by street hailing is considered a suitable solution.[9] Obviously, potential consumers might share social network connections if they have similar activities in common or share a workplace. With these types of trusted relationships, and if they happen to be traveling a similar route, consumers are willing to share the same taxi. Some passengers, such as students, are willing to share taxis because they are sensitive to the cost and might also desire more social interaction. Another indispensable component is experienced (especially high-profit) taxi drivers, who will wait for potential consumers in areas where taxis are considered a limited resource. The drivers choose to wait not only because they can attract many potential customers in those specific areas but also as a means of cutting down their operational costs. During taxi-needed peak time, several taxis are ready for potential consumers, who have no need to waste time by calling. From the consumers' viewpoint, their only concern is who they'll sit next to.

Social-Network-Based Travel Plan

Except for potential companions in their physical area (for instance, the same office or classroom), it can be difficult for users to rapidly search for companions they can trust. Consumers need an online service that can arrange both suitable taxi resources and human resources immediately and during peak times. Our taxi cloud service based on social networking is proposed for such scenarios. It solves the problem of companion choice by using social network connections.

A social network is an online service through which users can establish social relationships with people who have similar interests and engage in similar activities.[10] Similar social features are why social network users connect to each other. Such networks can also help us find people who can provide recommendations to other consumers.[11] Such networks are useful when recommending statuses and choosing the correct companions for doing the same activities. For example, having several mutual friends is a reference factor that our system uses to put consumers together so they can be satisfied with a trip.

Taxi-Sharing Framework

Figure 2 shows the architecture of the proposed taxi service, which consists of three parts: potential consumers, the cloud service, and taxi resource arrangement. Potential consumers are a set of people who wish to share a taxi with those in close physical proximity to them. The cloud service performs the computation and companion arrangement with help from users' social network data. It comprises several modules.

The user departure information module includes all of the basic sharing plan information sent by potential consumers from different areas. When the taxi-needed peak time comes, users submit their sharing plans to this module via their smart devices. Before the taxi-needed peak time ends, any untimely information submitted by potential consumers will be stored in this module and updated dynamically. When the peak time is close, this information will be sent to the *sharing arrangement module*, which coordinates the schedule of the entire arrangement for every taxi, taking into account that an effective schedule is the solution for allocating limited taxi resources to potential consumers. To calculate the consumer arrangement, we propose an algorithm based on users' social networks. The calculation is based on the shared data from the user departure information module and social network data from the *social network module*. The sharing arrangement module sends the arrangement results to the *arrangement confirm module* for final confirmation.

The social network module manages users' social interactions, which are based on social networks (such as Facebook, Twist, and YouTube). Data mining with these social networks is done dynamically by the cloud, and the useful, featured user data are classified into a dataset. These features will be used as the standard by which the system measures the strength of the relationship between two potential consumers. For a pair of users, the number of mutual friends is one indication of the strength of the social network relationship. We believe that the stronger this relationship is, the greater the possibility that two consumers will want to sit together in a taxi.

The arrangement confirm module pushes the acquired arrangement results from the sharing arrangement module to the specific consumer. The pushed information includes the distance of the entire trip, the adjusted departure time (one taxi, one departure time), the number of passengers that will be in the taxi, and the cost. After all the informed consumers in a specific taxi have confirmed the arrangement, we consider this taxi's arrangement to be complete. If it isn't confirmed by one consumer, we assume this consumer has given up his or her opportunity to share the taxi with others; reasons for this might include dissatisfaction with the departure time. The unconfirmed arrangements are sent back to the sharing arrangement module for a new solution.

The *notification module* pushes confirmed results from the sharing arrangement module to the specific consumer. A reminder function is embedded in the user's smartphone application to guarantee consumer attendance.

Finally, the *taxi resource arrangement module* has two main functions and provides an interface for taxi drivers. First, this module monitors all the taxi resources in a specific area and informs the sharing arrangement module about which taxis are available for a sharing arrangement. Additionally, the module pushes detailed information about the acquired arrangement to the taxi driver, including the destination, drop-off location for each passenger, identity information, and departure time. This module connects to the taxi company and the taxi service data, which can be further reused for data mining in better taxi-deployment services in the future.

Practical Taxi Sharing

Because we view social networks as improving the user experience in taxi sharing, we define a utility value to measure the benefit of social connections. Passengers with closer social connections have more utility during a shared taxi ride. This utility comes from a principle of diminishing marginal returns based on distance, which describe the benefit of the trip.[12]

Cost and social network utility are the main trade-offs in taxi sharing. The main objective is to decrease the cost of taking a taxi by placing as many passengers into the car as possible. Meanwhile, another objective of the passenger is to gain something from the journey, making it more reasonable to convene a group of passengers who have good relationships. Considering these two conditions, we use an *integrated cost* to describe the recommended system's trade-off, where a low integrated cost means lower travel costs and higher social network profit.

The sharing arrangement problem is solved by searching for the best integrated cost solu-

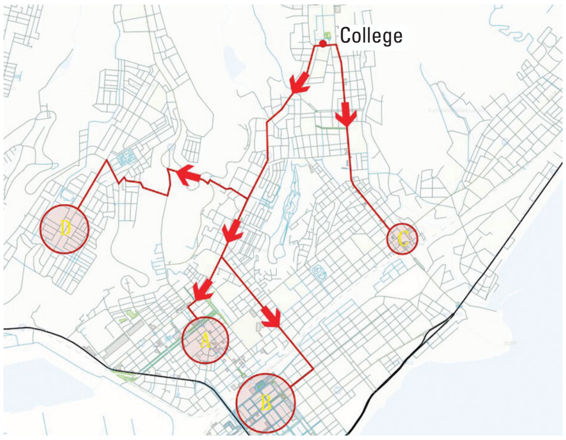

Figure 3. Routes beginning from the college to specific areas. We divided destinations into specific areas to make the system less complex. Areas A and B are entertainment districts in an urban area; area C includes the supermarket and restaurants closest to the college; and area D is a residential area.

tion using a proposed heuristic algorithm. We considered this to be an optimization problem with several constraint conditions, including time coordination, shared price, and social network relationships. Before finding the minimum integrated cost of the whole arrangement, our algorithm considers the scheduling of only one taxi. By mathematical analysis, we proved that the cost of taking a taxi is based mainly on the longest distance of all passengers in one taxi. By that comparison, shorter distances have little influence. The proposed algorithm is organized as a two-step process. In brief, the main idea of the heuristic algorithm is to find the consumer with the largest probability of decreasing his or her integrated cost. Then, the algorithm searches for other passengers, step by step, until one taxi is filled to create an optimized option. Furthermore, to select the best option, the algorithm compares all the taxi's options for the optimization arrangement solution. Finally, this heuristic algorithm is applied to the other taxis in the queue, finding the optimized solution for all taxis.

Next, we evaluate our algorithm using a practical taxi-sharing experiment with the social dataset collected from our university, Muroran Institute of Technology. Other settings were used in the same local city, including a map with destinations and taxi fares.

Users

Our user dataset is based on real students with active Facebook accounts. First, we wanted to collect users who had social network connections with each other and those who might be classmates or members of an in-person student group. We started with the school's Department of International Communication Center. The department has a public Facebook account. Most of the associated friends are foreign students and zealous local students who share motivations and reasons for traveling. Some of these students belong to several student clubs with strong reputations, such as music or sports. Thus, we gathered the members of these clubs, some of whom play a role as the core of this growing network. The highest number of mutual friends for one user was 86, and senior students tended to have more mutual friends. Finally, we collected a dataset of 300 students, which we considered to be our number of potential passengers.

Street Map

We set users' route data based on open street map data and students' personalities. The departure location was in front of the college, which has a large parking area where experienced taxi drivers normally stand by for passengers. Figure 3 shows an example of normal passenger routes that begin from the college. During lunch time, we interviewed students about their destinations. The city in question is bordered by the sea and mountains, which makes bypassing some main roads impossible. We divided destinations into several areas. Destinations for meals and entertainment were in areas A and B, which included an urban area; the distance from the college was more than 3.8 km. Area C included the nearest supermarket and restaurants, but was still a distance of more than 2.5 km. Area D was a mature residential area and had a distance farther than 5.8 km. We set the user route data as described. When some passengers submitted their schedules, the system divided them into specific areas. We ranked users with similar routes and destinations as more likely to share a taxi. This division of areas makes the system less complex.

Taxi Fares

The fares are determined by the taxi service in Hokkaido, Japan. There are two main types of cost distribution in taxi-sharing agreements: one is based on the mileage taken and the other is the average. In this case, because the destination was

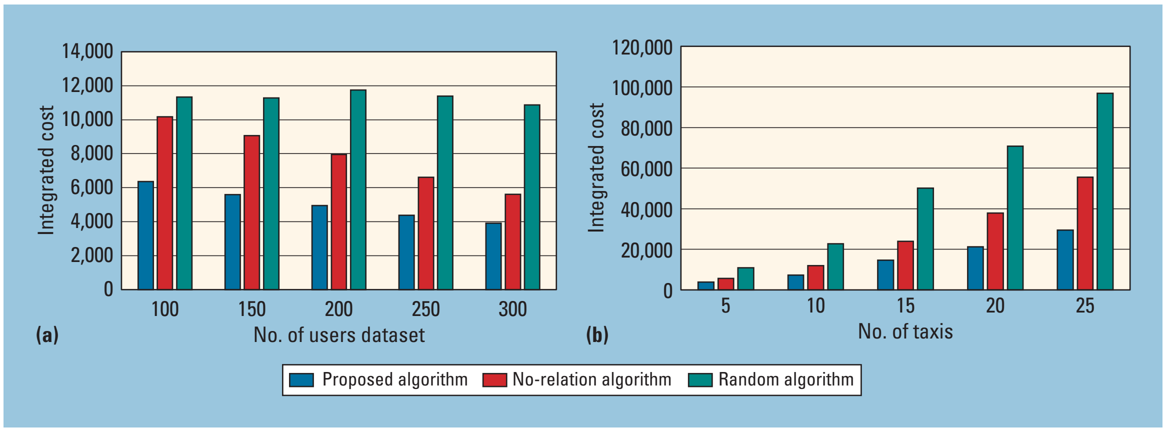

Figure 4. **Integrated cost of the taxi-sharing algorithm based on (a) the user dataset and (b) the number of taxis. Compared with others, the integrated cost of the taxi-sharing algorithm is relatively lower when applied with the proposed algorithm.**

mostly restricted to specific areas and the divided price difference was extremely low, we selected average for greater accuracy.

Simulation Results

We simulated the taxi-sharing system under this heuristic algorithm. Additionally, we applied two other algorithms within the same user environment of the Muroran Institute of Technology. The first was a no-relation algorithm that did not consider users' social interactions, searching for the optimal solution based only on cost and user constraints such as departure time. The other was a random algorithm that continues randomly searching until it finds the solution for the assignment problem. The main status unit of integrated cost was based on the taxi cost in Japanese yen, and we used a balance parameter to transform the benefit into an influencing factor of cost. We repeated experiments to adjust the parameter until it could balance perfectly with taxi cost. The parameter is adjustable and aims to cater to the local transportation environment and the objectives of the system designer.

Figure 4 shows the integrated cost comparison of the whole social-network-based taxi resource allocation, based on these three algorithms. In Figure 4a, we observe that the absolute value of the proposed algorithm and the no-relation algorithm gradually becomes smaller when there are sufficient user data. We consider that both algorithms have more options for calculating the minimum, thus making their absolute values with the best solution smaller. In Figure 4b, we can see that by increasing the number of taxis, the cost of random selection is almost three times the cost compared to our proposed algorithm and the absolute value of the no-relation algorithm. Furthermore, the proposed algorithm becomes larger as the number of taxis increases, which means that the benefit of the social network becomes more obvious. We truly believe consumers would be pleased to use this taxi service based both on how they benefit from the social interactions and how many end up satisfied with the encounter.

Social-network-based taxi services still face several challenges, ranging from taxi tracing to social network data mining. The public resource and human resource allocation within a smart city environment require further improvement and application. In fact, the range of usable resources for a smart city system is rather wide, thus making the creation of new services broader and the creation process itself more unpredictable. IT

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