A New Framework to Enhance Carpooling Service Profitability

Nada Khalid Mohamed
Business Information Systems Department
Faculty of Commerce and Business Administration
Helwan University

Laila Abdelhamid
Information Systems Department
Faculty of Computers and Artificial Intelligence
Helwan University

Atef Zaki Ghalwash
Computer Science Department
Faculty of Computers and Artificial Intelligence
Helwan University

ABSTRACT

Carpooling or ride-sharing systems are considered to be an economical efficient method to solve many traffic problems. Carpooling allows drivers to share their journeys with other passengers. This reduces passenger fares and travel time, in addition to traffic congestion, while also increasing driver income. So, several carpooling systems have been introduced in recent years. This research proposed a ridesharing analysis framework to find the shortest route between any two carpooling system nodes. Also, to represent how the matching process between passengers and drivers can be performed in an economical and efficient method to study the profitability for passenger/s and driver/s. The framework was applied to real carsharing test data and the recorded results showed a 40% saving for passengers and a high level of added revenue for drivers compared to the existing systems in the market.

Keywords

Carpooling, ride-sharing, network analysis, shortest path algorithms, ride-hailing

1. INTRODUCTION

The continuous increase in cities' populations leads to a rise in the number of cars, which leads to roadblocks, which consequently cause useless fuel consumption, increased vehicle depreciation, and harmful emissions that negatively affect air quality. In addition, roadblocks lead to the unavailability of parking slots and the production of exhaust gases. This issue has increased because of low car utilization, as in most commutes it is used by one person (the driver). Carpooling or ridesharing systems have appeared as a solution to overcome these problems. Ridesharing systems have started as a way for a group of individuals to share the same car directed to the same destination [1].

Different authors define carpooling or ride-hailing differently. However, agreement can be found in the following definition, in which carpooling is "*an arrangement where two or more people share the use of a privately-owned car for a trip (or part of a trip), and the passengers contribute to the driver's expenses*" [2]. In its simplest form, carpooling entails a driver and a passenger who share the same origin and destination for the journey. Carpooling or ride-hailing services require the public to make changes to their commuting behavior. However, it is difficult to change people's behavior and make changes to their travel routine. So, it requires strong support from the business community and planning organizations [3][4].

Carpooling has grown in popularity as an environmentally friendly and cost-effective mode of transportation Since there are fewer cars on the road, pollution is reduced. In addition, it is also economical, since the travel expenses are shared among the riders. Finding people with whom to share a ride is a challenge for carpooling services, as it is difficult to find a person targeting the same destination and time.

Advancement in technology allows many companies to improve the quality of life in the urban environment. Companies rely on the evolution of the internet to enable online platforms to facilitate direct access to services. Many websites and application systems have been implemented to assist people in meeting up to share rides. These applications allow users to create and share their trips as well as find passengers. So, in recent years, we have seen an increase in the popularity of ride-hailing, ride-sharing, or carpooling services that rely on maps and positioning systems around the world. Examples of such systems include "Uber", "Lyft", "Mytaxi", "Gett" and "Addison Lee", especially in Egypt, such as "Uber", "Careem", "Lyft", "Ousta", "pink taxi", "easy taxi", "Raye7", "Foorera", and "Swvl". The downside of those applications is that they are location and time-limited. In addition, most of the existing applications use fixed routes only.

This research focuses on the problem of managing carpooling services. This study proposes a carpooling analysis framework and a shortest path algorithm to solve the drawbacks raised by most of the current service providers. The proposed framework enables users to plan a trip at the preferred time using the shortest route between the preferred source and the preferred destination. This overcomes the problem of having only fixed routes through which users should choose and improves both the driver's profit and the passenger's cost.

The rest of this paper is organized as follows: Section 2 discussed the literature reviews. Methodology and a carpooling framework are introduced in Section 3. After that, in Section 4, the experiment of system implementation and an illustrative example for vehicle sharing are presented. Section 5 evaluates and discusses our system results with real trip data. The conclusions and future work are reported in section 6.Finally, The references in section 7.

2. RELATED WORKS

This section provides an overview of the literature reviews and related works applied to ride hailing services and ride sharing. In addition, this section represents the most recent techniques applied in this area.

2.1 Carpooling System Initiative

Many researchers discussed the development of carpooling systems. The first appearance of ride hailing systems were through a simple and easy GUI that allowed passengers to collaborate with other like-minded people and plan out their journey after signing into it. such as the system used in [16].

They developed an android system using PHP and MySQL databases. To create a carpool, the person who owns a vehicle is the only one who can create a trip, and passengers can only choose between their trips; they didn't create their own trips (choices). But after using this system, the results were as follows: the GUI was very easy to use with no need for any experience, but the routes are decided by the driver only according to how he thinks best. Therefore, the path obtained from this may not always be the shortest path. Also, there is no evaluation process to evaluate the system.

[5] They designed a model and called it "a *commute carpooling system*" to go to work every day at a fixed time and fixed route, such as in Egypt (Uber bus, Swvl, Careem bus), but in the form of buses, not cars. This platform works according to four stages: Information retrieval, information matching, Mutual Selection and Mutual Evaluation. After applying this system, the process of selecting passengers for drivers and vice versa reduces the possibility of mistakes and increases user satisfaction. Also, both the driver and the passengers will try to improve their characteristics and themselves for the evaluation process and to be selected again. However, this platform also has some disadvantages. Users must be fully aware of the system in order to avoid mistakes in the selection process. The process of selection takes a long time. If the evaluation process is inaccurate, it will cause a big gap between drivers or passengers and the fixed time and routes. It cannot satisfy all cases.

2.2 Carpooling Development 1

[9] reviewed a variety of reasons to encourage carpoolers. This work suggests reducing parking costs, free parking, or rewards from those applications, such as discounts. In addition, they provided an overview of the factors that affect the use of carpooling applications. This study identified two internal factors (demographic factors and judgmental factors) and two external factors (situational factors and third-party interventions). They discussed that demographic factors such as age, gender, and income do not typically influence mode choice or share trip behavior. But their analysis showed that in some cases, women were slightly more likely to carpool than men were. On the other hand, they found that judgmental factors, such as saving money, reliability, and the desire to reduce congestion, all had small effects, but the biggest effect was the desire to reduce congestion.

[15] studied the demographic factors and the findings suggested that early users of ride hailing services tend to be younger, highly educated, have higher incomes, and are more likely to reside in urban areas.

[11][12] showed that judgmental factors are more important than demographic factors in decision-making. Attitudes and norms tend to have the most influence when choosing a trip. such as convenience, commuter attitudes, socializing, and privacy. Other motivators include cost savings, convenience, commuter attitudes, socialization, and privacy. reducing traffic and living at a high level of quality.

[14] studied the challenges facing carpooling services as the external factors (third-party interventions and situational factors), such as transportation policy, scheduling issues, problems with being unable to travel during the work day, problems with being unable to transport items, lack of flexibility, inconvenience, additional time needed to pick up or meet each rider, and incompatibility with short-distance commuting.

[1] They measured the benefits of ridesharing services to travelers in the San Francisco Bay Area. They included Uber as a representative ridesharing service and quantified the welfare gain that it provides to travelers by estimating the difference in total benefits with and without its service. The results showed that consumers gain roughly $1 billion annually from Uber's non-fare attributes, which they value but taxis have not provided. Annual benefits to travelers in major U.S. cities are likely to amount to several billions of dollars.

2.3 Techniques Applied in Carpooling Systems

[26] proposed a framework called "highest aggregated score vehicular recommendation (HASVR)." The framework recommends a driver's vehicle with the highest aggregated score to a passenger who requests a trip. This aggregated score is mainly based on some parameters such as: vehicle's capacity, average time delay, driving distance, fare reduction, and profit increment. They used an NN-scheduling algorithm to evaluate their framework with a real-world dataset that contains GPS traces data of 61,136 taxicabs. An evaluation confirmed the efficacy of their "HASVR" framework in limiting passenger fares, increasing driver profit, as well as increasing the percentage of fulfilled passengers.

[6] presented a "*hybrid GA-A**" In the field of multi objective optimization, an algorithm is used to find optimal routes for the ridesharing problem. The goal of this algorithm is to maximize the service provider's profit by minimizing travel and detour distances, and also picking up and dropping charges, while optimizing the car's utilization. The proposed algorithm was already put into action in the Salt Lake area of Kolkata. When compared to the similar data collected using the existing approach [7], the route distance and detour distance for the optimal routes created using the proposed algorithm are consistently reduced for the same number of passengers. Various statistical tests, such as boxplots, have shown that the suggested algorithm consistently outperformed the existing algorithm based only on genetic algorithms.

[27] used the most widely classified techniques in machine learning to create a model for the selection of travel partners. They applied K-NN, K-Means, ID3, NV, NN, and Friedman's test to a carpooling dataset. After experimenting with each of the datasets for each of the techniques, the results showed that the K-NN technique was the most effective one compared to K-Means, ID3, NV, and NN, with 95.23% accuracy on the first dataset and 93.75% on the second dataset, but the most precise results were obtained through using Friedman's.

[8] The purpose of this study is to solve the dynamic ridesharing problem and to conduct a detailed quantitative analysis of ridesharing efficiency for different demand levels and carrying capacities using a series of mathematical experiments. They calculated the success rate of serviced requests, trip travel time, taxi fare discount rate, and total energy consumption for various carrying capacities and demand levels in Shenzhen's road network. According to the simulation results, the ride-matching success rate within 3 minutes allows them to increase by more than 13% in the ridesharing mode, and more than 80% of the passengers can be served within 6 minutes if the carrying capacity is set to four.

[9] They searched for an on-demand ridesharing system that included a ridesharing platform, multiple drivers, and multiple passengers. They begin by studying a choice problem for a passenger who chooses between a rideshare and a taxi service,

as well as a choice problem for a driver who decides whether or not to serve. Then they calculated the optimal service price charged to passengers and the optimal rate of pay paid to

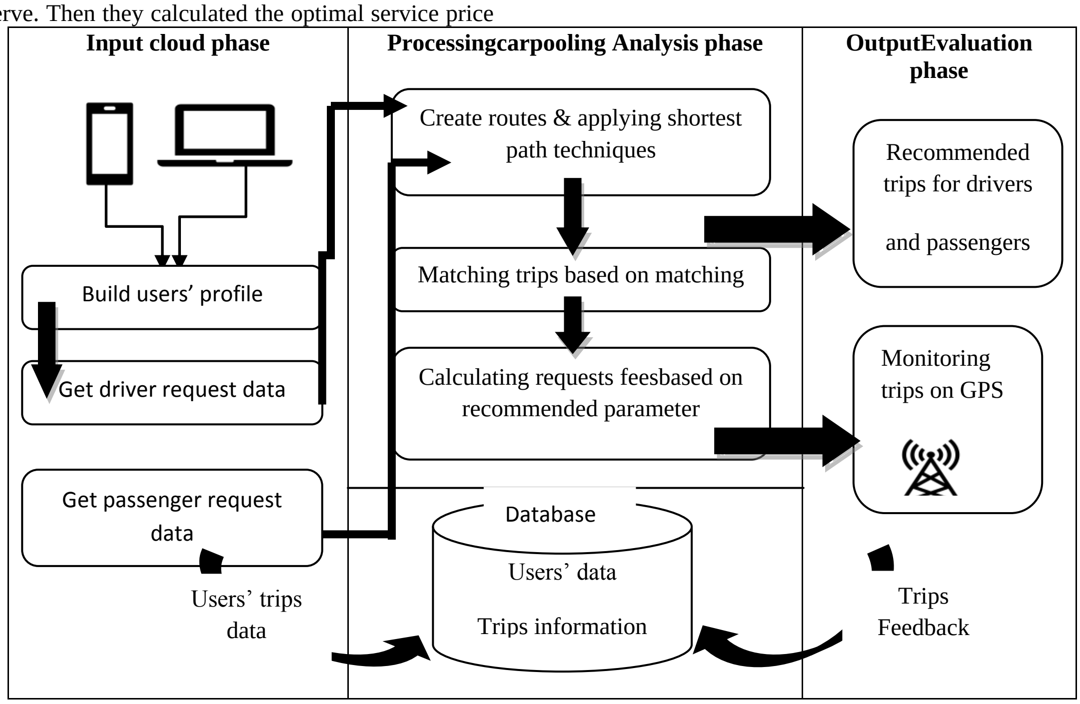

Figure 1 The Proposed Framework

Finally, they found that the platform benefits from an increase in both the number of passengers and drivers, and that an increase in the passengers' personal costs for taxi service can help increase the platform's profit. Moreover, the dynamic pricing strategy has the potential to not only increase the platform's profit but also generate larger earnings for passengers and drivers.

As it resulted from the previous reviews, whatever the technique applied to ride-hailing or carpooling systems, they depend on the use of graphs to express the problem or system with its components and the relationships between them (nodes and graphs). Many works have concentrated on the optimization problem, but only a few have worked on modelling the driver's mobility in order to find the shortest path or route and better matches at an appropriate cost in order to achieve the highest financial return for both the driver and the passenger. Therefore, in this research, graph theory was used as a basis with its algorithms for the analysis and development of ride-sharing services.

3. THE PROPOSED CARPOOLING FRAMEWORK

The proposed carpooling framework divided into 4 main modules. As shown in figure (1), with their components: (a) the input module, (b) the processing module "carpool analysis", (c) the output module, and (d), which is the database used to store trip data.

3.1 INPUT MODULE (Cloud Phase)

The input module has 3 major components, which are named: building users' profiles, getting driver request data, and getting passenger request data.

3.1.1 Build users' profiles:

As shown in Figure 1 (top left), this step occurs when any user sends a login request via their mobile phone or website for the first time, which contains personal information, whether this request is for a passenger or a driver, such as name, address, national number, phone number, email, social networking email ("Facebook"), and a personal photo.

3.1.2 Get driver request data:

As shown in Figure 1 (middle left), in this step the driver puts the information about his trip, such as: source, destination, and time of this trip. Also, his personal license, driving license, and vehicle details: car model, color, and maximum capacity per trip.

3.1.3 Get passenger request data:

As shown in Figure 1 (bottom left), at this step, the passenger puts the information about his trip, such as: source, destination, time of this trip, and how many people will ride from the starting point.

3.2 Processing Module (Carpooling Analysis Phase)

As shown in Figure 1 (middle), ride requests from drivers and passengers are imported to the processing module (carpooling analysis phase), which includes three stages that must be completed in the following order: Create routes and apply shortest path techniques. Matching trips based on matching parameters and calculating request fees based on recommended parameters.

3.2.1 Create routes and apply shortest-path techniques:

As shown in Figure 1 (top middle), in this step, the Dijkstra algorithm is applied to the source and destination that were entered by the driver to get the shortest distance and path between them to be processed for the next stage.

3.2.2 Matching trips based on matching

parameters:

As shown in Figure 1 (middle), in this step, matching processing is done between the source and destination entered by the driver and passengers who can share the driver's trip.

3.2.3 Calculating requested fare based on recommended parameters:

As shown in Figure 1 (bottom middle), in this step the cost of the trip is calculated for each passenger based on a specific discount percentage that depends on the shared distance.

Trip fares were calculated using the following equation:

$$Distance\ =\ D\ \epsilon\ (D_0\ ,D_1\ ,D_2\ ,D_3)$$

$$Fare\ =\ F$$

$$Pricing\ Factor\ =\ PF$$

$$F\ =\ D\ *\ P$$

3.3 OUTPUT MODULE (EVALUATION PHASE)

The last module of system architecture, as shown in Figure 1 (right), is the recommendation or evaluation module, which includes 3 stages: recommended trips for both drivers and passengers; monitoring trips on GPS; and taking users' feedback because every vehicle needs to be evaluated with respect to vehicle capacity, fare reduction, and recommended route.

4. EXPERIMENT

After taking a look at the framework and having some more in-depth understanding of how ride-sharing systems are designed in terms of communications, models, and databases, this paper presents the carpooling analysis phase, which is described as follows:

Step 1: Initially, all sources and destinations for a given area are extracted.

Step 2: A network graph is built to represent the connectivity between different nodes (locations) in this area.

Step 3: All distances among the network nodes are calculated (in kilometers) and shown as weights on the edges between nodes.

Step 4: The Dijkstra algorithm is used to identify the shortest route and distance between any two nodes in the graph.

Step 5: A Python code is written to calculate the fare for a passenger request based on the travelled distance, considering a fare deduction depending on the travelled distance.

Step 6: A matching process to allow the driver to carry more passengers on his trip, resulting in an extra profit for the driver.

Step 6: Finally, all customer data, whether passengers or drivers, vehicle data, occurred trip data, cancelled trip data, and user feedback about each journey are collected and analyzed here in order to evaluate both drivers and passengers.

4.1 Illustrative example

This is an illustrative example of some trips (scenarios) whose trip costs were calculated randomly in order to work on them to extract results.

4.1.1 The areas that have been worked on and extracted from a specific area are shown in the following figure 2.

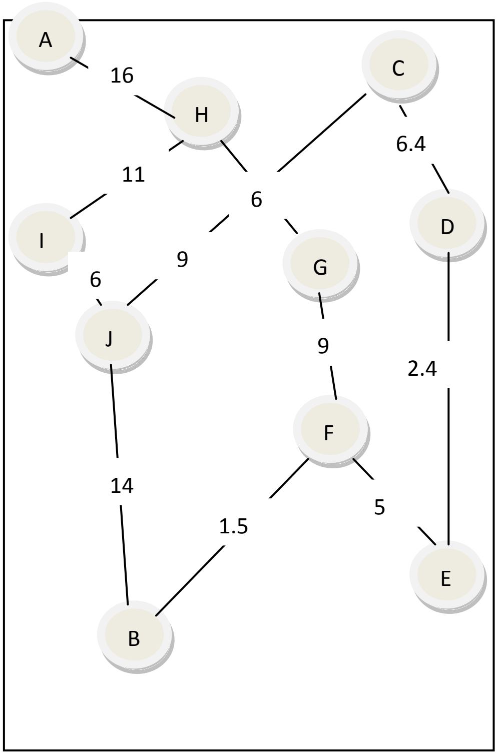

Figure 2 selected areas

4.1.2 A connectivity and cost matrix were created to be used in the Dijkstra algorithm, and it is clarified in the following table 1, table 2.

Table 1 The connectivity matrix

	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**
A	0	0	0	0	0	0	0	1	0	0
B	0	0	0	0	0	1	0	0	0	1
C	0	0	0	1	0	0	0	0	0	1
D	0	0	1	0	1	0	0	0	0	0
E	0	0	0	1	0	1	0	0	0	0
F	0	1	0	0	1	0	1	0	0	0
G	0	0	0	0	0	1	0	1	0	0
H	1	0	0	0	0	0	1	0	1	0
I	0	0	0	0	0	0	0	1	0	1
J	0	1	1	0	0	0	0	0	1	0

Table 2 the cost matrix

	A	B	C	D	E	F	G	H	I	J
A	0	0	0	0	0	0	0	16	0	0
B	0	0	0	0	0	1.5	0	0	0	14
C	0	0	0	6.4	0	0	0	0	0	9
D	0	0	6.4	0	2.4	0	0	0	0	0
E	0	0	0	2.4	0	5	0	0	0	0
F	0	1.5	0	0	5	0	9	0	0	0
G	0	0	0	0	0	9	0	6	0	0
H	16	0	0	0	0	0	6	0	11	0
I	0	0	0	0	0	0	0	11	0	6
J	0	14	9	0	0	0	0	0	6	0

*4.1.3*The following table 2shows the trips for which the costs were calculated randomly.

Table (2) random trips

Source	Destination	Distance	fare	capacity	AVG Fare
Example 1					
A	C	42	105	1	105
A	J	33	82.5	1	82.5
A	H	16	48	1	48
J	C	9	31.5	1	31.5
H	C	26	78	1	78
			345	PROFIT	345
Example 2					
A	C	42	105	4	26.25
			105	PROFIT	26.25
Example 3					
A	H	16	48	4	12
H	J	17	51	4	12.75
J	C	9	31.5	4	7.875
			130.5	PROFIT	32.625
Example 4					
A	C	42	105	3	35
J	C	9	31.5	1	31.5
			136.5	PROFIT	66.5
Example 5					
A	J	33	82.5	2	41.25
J	C	9	31.5	4	7.875
			114	PROFIT	49.125
Example 6					
A	H	16	48	4	12
H	C	26	78	4	19.5
			126	PROFIT	31.5
Example 7					
H	C	26	78	4	19.5
			78	PROFIT	19.5

5. RESULTS AND DISCUSSION

This work proposed an algorithm for the shortest path problem in free-floating car-sharing systems. This algorithm has been tested under different trip scenarios using real-world carsharing data. Test results showed that the algorithm was able to efficiently solve the problem by providing benefits for both the driver and the passenger. The graphs below show the various scenarios that were tested throughout the algorithm's testing.

The following charts represent the relationship between travelled distances and driver profit figure 3 and travelled distances compared to fare deduction or fare discount for the passenger figure 4. The first chart represents that whenever the travelled distance by the passenger increased, i.e., the shared distance in the trip, the driver's profit increased also in the opposite direction, whenever the travelling distance by the passenger increases, the cost per kilo decreases. This means more advantages for the passenger.

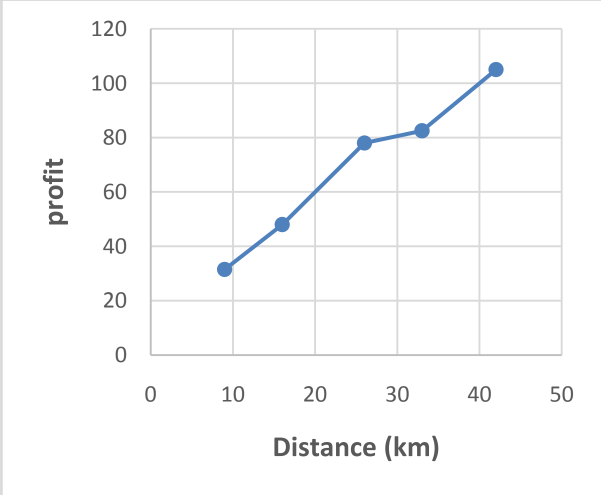

Figure 3 Trip fare compared to distance

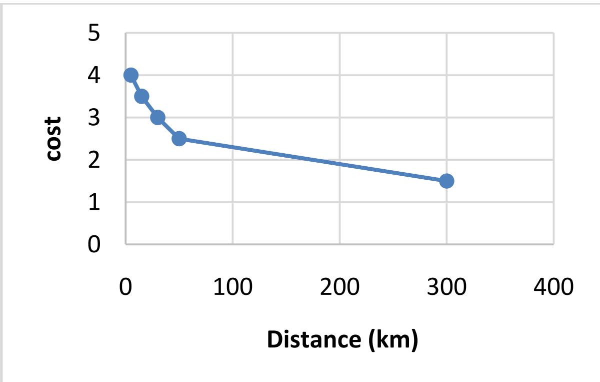

Figure 4 Fare deduction compared to distance

These results were compared to the trip fare of the most famous company for ride-hailing services in Egypt (comp1), and the following charts were reached. The following chart shows that other companies use a fixed rate per kilo regardless of the distance. which means that there is no benefit for the passenger, on the contrary, the proposed model figure 5.

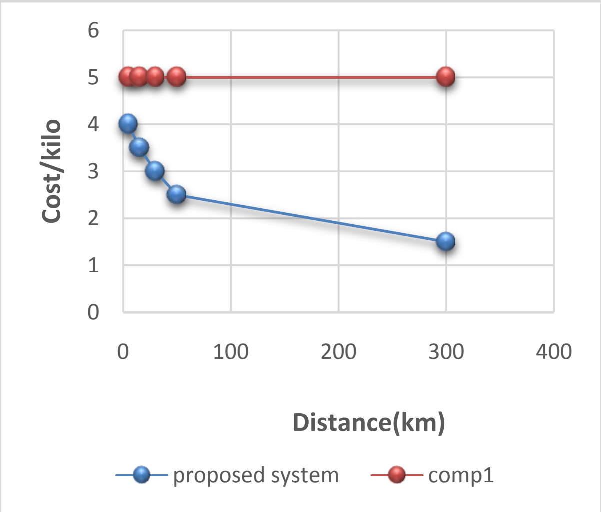

Figure 5 Cost of kilo for proposed system vs comp1

Some sources and destinations were chosen randomly from theproposed system, and the fares were calculated and compared to comp1, generating the chart below figure 6, 7. The figure clearly shows that the cost of trips in this system, which represents ride-sharing systems, is significantly lower than trips taken using ride-hailing services.

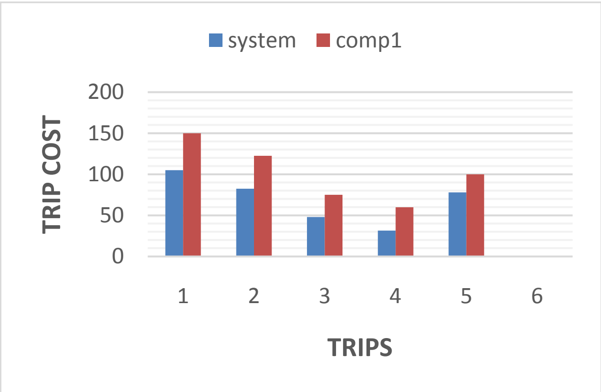

Figure 6Trips fare of proposed system vs comp1

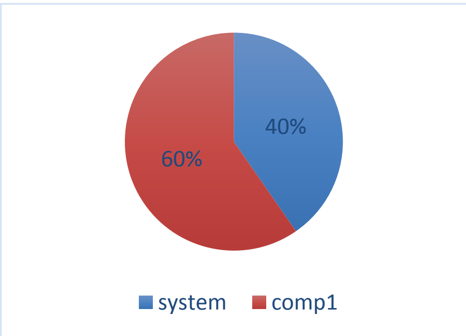

Figure 7 Trips fare compared to comp1

The following chart figure 8, shows the drawbacks found in this system, which is the difference in fare and profit for the driver if he makes trip matches between the 4 car seats along the trip or when the 4 seats are allocated for relatives from the starting point to the destination.

Which means seats are reserved for one person only from a selected source to a specific destination and another person can come in and replace him, which is the best scenario for the driver. If the 4 seats are reserved by one person for relatives from the same source on the route to the same destination, which means the worst scenario for the driver and the best saving for the passenger.

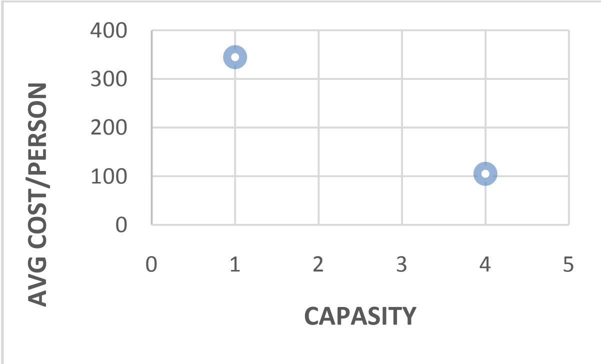

Figure 8 Relatives' problem

Finally, when compared to traditional ride-hailing services, all of these charts demonstrate the validity of these systems in providing a profit for both the driver and the passenger.

6. CONCLUSION AND FUTURE WORK

This paper aimed to present the challenges facing the provision of travel companion assignment services for shared trips. Previous studies showed that carpooling or ride-sharing services are an important part of the transportation infrastructure for large cities. As a result, various studies in the literature try to promote such behaviors by leveraging user preferences to improve the real-world experience of sharing a vehicle. This paper presented a framework for measuring the most commonly used shortest path algorithm to determine which is best suited for use in the carpooling routing and matching process. The proposed algorithm was tested using real carsharing data, and the results showed that ridesharing systems provide a great return for drivers, with a 40% saving for passengers and a high level of added revenue for drivers when compared to traditional ride-hailing services. In the future, more features can be added to find a solution for relatives' drawbacks and include the creation of a comprehensive platform where users can register with their personal preferences in order to make shared trips such as smoking, preferred gender to share with, pets allowed, and so on. Also, try to answer the following questions: How can ridesharing services assist in reducing traffic congestion, fuel consumption, and parking availability? Also, how can the ride-sharing process be made more secure? so that more people will use it.

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