Improve the Carpooling Applications with Using a Social Community Based Travel Cost Reduction Mechanism

Yu-Tso Chen and Chen-Heng Hsu

***Abstract*—Carpooling on the strength of information and communications technology (ICT) has been a widely accepted concept to implement better transportation system. However in reality, most of current carpooling systems or applications are not functioned well as the expected. The reason varies according to the weakness of different carpooling designs. This paper reviews and analyzes literatures and projects in terms of carpooling applications through a proposed CRS analysis model. Based on the results of CRS analysis, this paper designs a Social Community based Carpooling (SCC) model with the feature of travel cost reduction for both supply and demand sides.The presented SCC scheme can provide a considerable business model for potential carpooling operators, indicate a valuable research direction of promoting carpooling services, and also implicate initiatives for environmental sustainability.**

***Index Terms*—Carpooling, ICT, social community, travel cost reduction, environmental sustainability.**

I. Introduction

With the growth of economic development in urban area, the needs of transportation is exponentially increased, meanwhile brings various threats. These threats, mainly the rise of oil prices, air pollution, and urban traffic congestion, are not only worsening people's quality of life but also overwhelming natural and human-centered ecosystems.

In most cities, traffic facilities including roads, parking lots, and the like provide insufficient capacities to serve good transportation especially on rush hours. In addition, the use of public transportation is relatively inconvenient than the use of private one. More use of private vehicles more the mentioned threats. For solving the problems due to these threats, various theories and methodologies were continuingly proposed in academic, industrial, and political circles. A well-known idea, carpooling, has been a widely accepted concept. In recent years, carpooling in conjunction with the use of information and communications technology (ICT) shows its potential to implement real trails of better transportation style. However in reality, most of current carpooling systems or applications are not functioned well as the expected. The reason varies according to the weakness of different carpooling designs.

In theory, carpooling is still a good candidate to sketch an ideal transportation mode, therefore why carpooling systems work failed in practice are worth discussing. Base on the above, this paper reviews and analyzes literatures and projects in terms of carpooling applications and further designs a Social Community based Carpooling (SCC) model with the feature of travel cost reduction for both supply and demand sides. The remainder of this paper is organized as follows. In the next section, literatures and works related to carpooling are reviewed through a proposed CRS analysis scheme. Section 3 introduces the SCC model including its Travel Cost Reduction scheme and its operation process. The last section concludes this paper and indicates future works.

II. Research Reviews

In order to figure out why not most of current carpooling systems or applications are practically functioned as their theoretically expected, it is considerable to analyze the existed carpooling related mechanisms and trail systems. Nevertheless, carpooling is a sort of multi-factors service; it is complicated to be parsed without a structured analysis. For this reason, a CRS model as detailed in the next paragraph is first presented to help classifying the selected 31 literatures.

A. The CRS Model

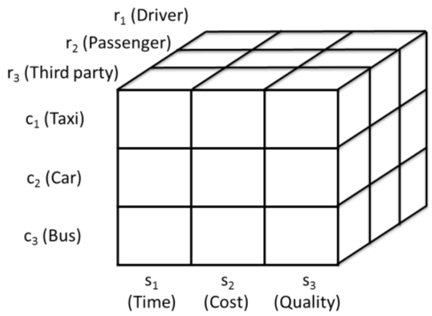

Fig. 1. The CRS model for structuring research reviews.

Carpooling is a kind of transportation service, it relates to various transportation carriers and different roles that operate, or use, or assist such service. In other word, carrier and role are certainly two key factors of carpooling operation. Besides that, the implementation and commercialization of carpooling service is commonly in a project manner, the strategy constraints of project will also affect the promotion of carpooling system. Consequently, the CRS is thus designed as a three-dimension analysis model composed of Carrier, Role, and Strategy constraints. According to Chen [1], she defined that the carrier in carpooling operation could be classified into taxi, car (private vehicle), and bus (mass and public transportation). Tao et al. [2] investigated the stakeholders of carpooling promotion. Government, operator, driver, and passenger are four stakeholders introduced in their study. The CRS leverages their idea and further simplified the stakeholders into three main roles: driver (the

Manuscript received October 15, 2012; revised December 20, 2012. This work was supported in part by Lien-Ho Foundation, Taiwan R.O.C., under the grant 101-NUU-12 (1011008-12).

Y. T. Chen and C. H. Hsu are with the Department of Information Management, National United University, Miaoli, 36003 Taiwan R.O.C (e-mail: yutso.chen@nuu.edu.tw, M0033008@smail.nuu.edu.tw).

supply side), passenger (the demand side), and the third part (covers all the other stakeholders). As for the strategy constraints of project, Cadle and Yeates [3] list three main constraints: time, cost, and quality. As a result, the CRS is defined as depicted in Fig. 1. In brief, the strength of CRS is to simplify the dissection of the carpooling related research results and practices to be reviewed.

B. Research Reviews on the Dimension of Driver (r_1)

There are 13 literatures reviewed on the dimension of Driver (r_1), they are positioned in the appropriate location respectively in the CS matrix as shown in Table I.

TABLE I: RESEARCH REVIEWS TOWARDS TO DRIVER (R_1) ON THE CS MATRIX OF CRS

Taxi (c_1)	-	Wu[4] Chen[5] Chou[6] Wu[7] Wu[8] Chen[9] Chen[10]	Shyr[11]
Car (c_2)	Chen et al.[12] Chen [13] Megalingam et al.[14] Wang[15]	-	-
Bus (c_3)	-	Wu[33]	-
	Time (s_1)	Cost (s_2)	Quality (s_3)

1) {Taxi (c_1), cost (s_2)} on driver (r_1)

Wu [4] presented a taxi-pooling system with a taxi-passenger matching mechanism consisting of several matching models. Chen [5] and Chou [6] developed their matching optimization system with considering multiple origin-destination tuples to help taxi carriers to arrange better riding schedules. In addition, other researchers [7]-[10] proposed real-time and door-to-door taxi-pooling service systems which can significantly increase the performance of the cooperation with public transportation systems in urban areas.

2) {Taxi (c_1), quality (s_3)} on driver (r_1)

Shyr [11] made a questionnaire survey with the data were collected from their 17-day taxi-sharing experiences. They further analyzed the collected data to realize user's degree of satisfaction regarding taxi-sharing and to explore the internal and external factors affecting the planned practices by using multivariate analysis methods.

3) {Car (c_2), time (s_1)} on driver (r_1)

Chen et al.[12] developed a smart ride-share system with an efficient scheduling algorithm for ride sharing, which can potentially achieve better vehicle utilization, energy consumption and user convenience. In addition, Chen [13] proposed an automatic carpooling system which can overcome the difficulties on traditional text-based systems. Besides, Megalingam *et al.*, [14] presented an Automated Wireless Carpooling System, which can curtail the over usage of on road vehicles to a considerable amount. Furthermore, Wang [15] introduced an idea to find the best group for a new passenger with considering the set of ridesharing groups.

4) {Bus (c_3), cost (s_2)} on driver (r_1)

Wu [16] made a study in terms of the service of shuttle bus as one type of paratransits. The study aimed at examining the relationship among demand requests, service arrangements, and fare discounts.

C. Research Reviews on the Dimension of Passenger (r_2)

There are 13 literatures reviewed on the dimension of Passenger (r_2), they are positioned in the appropriate location respectively in the CS matrix as shown in Table II.

TABLE II: RESEARCH REVIEWS TOWARDS TO PASSENGER (R_2) ON THE CS MATRIX OF CRS

Taxi (c_1)	-	-	Tsao[17]
Car (c_2)	Martino et al.[18]	DeLoach &Tiemann[19] Holguı´n-Veras et al.[20] Buliung et al. [21] Yan&Chen [22]	Han&Yan[1] Blumenberg & Smart[24] Chen et al.[25] Lovejoy & Handy[26] Nurul Habib et al.[27] Singhirunnusorna et al.[28] Selker & Saphir [29]
Bus (c_3)	-	-	-
	Time (s_1)	Cost (s_2)	Quality (s_3)

1) {Taxi (c_1), quality (s_3)} on passenger (r_2)

Tsao [17] built a new feeder mode for taxi-pooling. His feeder mode adopts their stated preference method to identify important factors influencing the traveler's choice.

2) {Car (c_2), time (s_1)} on passenger (r_2)

Martino et al. [18] demonstrated a Sustainable Mobility system on a basis of a Cloud computing-based platform.

3) {Car (c_2), cost (s_2)} on passenger (r_2)

DeLoach and Tiemann [19] made an investigation through surveying commuting trends of American workers. They found that the changes in the price of gasoline will influence the incidence of driving alone. In addition, Holguı´n-Veras *et al.*, [20] summarized some key findings from a research project that assessed the impacts of the Port Authority of New York and New Jersey's Time of Day Pricing Initiative on the mutual behaviors between passengers and car drivers. Moreover, a study by Buliung *et al.*, [21] aimed to figure out how service worker engagement with an Internet-based carpool formation software, known as Carpool Zone, meanwhile to analyze how workplace transport policies can affect the formation and use of carpooling. Furthermore, Yan and Chen [22] employed a time–space network flow technique to develop a model for solving carpooling problem with pre-matching information.

4) {Car (c_2), quality (s_3)} on passenger (r_2)

Han and Yan [23] conducted a carpooling survey in Hsinchu City in Taiwan. They studied the influence factors of carpool behavior via an effective sampling mechanism. Blumenberg and Smart [24] examined the determinants of carpooling by using the 2001 National Household Travel Survey in conjunction with multinomial logic mode choice models. They found that the immigrants are far more likely to form household carpools as well as external carpools (outside the household) than the native-born adults. And what is more, Chen et al. [25] made efforts on understanding the relevant requirements of domestic drivers and accordingly established a model for portraying driver's adopting behavior. Lovejoy and Handy [26] shared their insights on the nature of vehicle use by those with potentially limited vehicle access; they presented qualitative findings from focus groups with recent Mexican immigrants living in California, half of whom owned no cars.

In addition, NurulHabib *et al*., [27] investigated the carpool mode choice option in the context of overall commuting mode choice preferences. Singhirunnusorna et al. [28] co-worked with Mahasarakham University to complete a scenario-based case study by setting up three hypothetical conditions—Ridesharing or Carpool, Car-free day, and Ribbon-Bicycle projects. Selker and Saphir [29] described a system that extends the concepts of social networking application to create a physical social network. Such system design could also contribute an extra advantage of energy saving.

D. Research Reviews on the Dimension of Third Party (r_3)

There are 5 literatures reviewed on the dimension of Third party (r_3), they are positioned in the appropriate location respectively in the CS matrix as shown in Table III.

TABLE III: RESEARCH REVIEW TOWARDS TO THIRD PARTY (R_3) ON THE CS MATRIX OF CRS

Taxi (c_1)	-	-	-
Car (c_2)	-	-	Chung[30] Chung[31] Wang[32] Qian&Zhang[33]
Bus (c_3)	Wei et al.[34]	-	-
	Time (s_1)	Cost (s_2)	Quality (s_3)

1) {Car (c_2), Quality (s_3)} on Third party (r_3)

Chung [30] examined the rideshare program in southern California and suggested that the GREEN Rideshare and SAFER Rideshare are two key success factors considerable to be adopted in Taiwan. These two suggested factors indicated the following functions including security enhancement for rideshare participants, affordable commute cost, fast high-occupancy vehicle (HOV) lanes, easy rideshare match and park-N-ride, and reliable ride home service in an emergency. Also, Chung [31] brought four local topics of freeway HOV lanes into discussion: first, Policy position of HOV lanes; second, Market position of HOV lanes; third, Limitation of bus dedicated lanes; and fourth, Timing of HOV lane implementation.

Wang [32] discussed the carpooling in China by exploring a series of questions and acknowledged the social benefits of voluntary carpooling. Wang's study provided the following argues: (1) bus lanes may be a better choice than HOV lanes when converting general motor vehicle lanes; (2) policies subsidizing carpoolers cannot be justified on either efficiency or equity grounds because a marginal carpooler is more likely transitioning from a transit user or non-motorized traveler than from a driver. Besides, Qian and Zhang [33] studied the morning commute problem with three modes: transit, driving alone, and carpool. The transit mode uses its own separate guide way, but the auto modes can access two parallel routes to reach the destination – a freeway and an arterial road (AR).

2) {Bus (c_3), Time (s_1)} on Third party (r_3)

Wei *et al*., [34] examined the main features of the specific routing concerns associated with Fu-kang Bus and developed an efficient solution procedure.

E. Review Summary

According to the reviews, three key findings are summarized as follows: (1) The taxi is the main carrier considered in these existed studies; (2) In these proposed researches, the passenger is the main role when discussing carpooling matching, especially on short-distance cases; (3) Most of these carpooling investigations emphasize the minimization of travel cost. Nevertheless, it is believed that more carpooling cases completed more real carpooling performance. It implies that the carpooling on taxis is significantly limited than the one on mass general-purpose cars. It also addresses that the carpooling applications should take care both short-distance and long-distance cases. Furthermore, the travel cost won't be the only factor which affects the success of carpooling, in particular on long-distance cases; security considerations and the trust relationships between driver and passenger are also key elements of carpooling designs.

III. THE SOCIAL COMMUNITY BASED CARPOOLING (SCC) MODEL

According to the review summary above, a practical as well as worth of commercialization design of carpooling application may include the listed features below: (1) The supply side is including taxi and general-purpose cars; (2) The demand side should cover short-distance and long-distance requests; (3) The matching factors are not only travel cost but human-based considerations. The first and second features mean to extend the involvement scope on supply and demand sides; the third one means to take account of possible human-oriented characteristics like community advantages. Selker and Saphir [29] said that ridesharing on a community level increases the opportunity for socializing and can lead to new relationships based on mutual interests. With the system developed, participants will have an opportunity to carpool with a purpose, with people they already have something in common with, as the same way people chapter meet on Face-book, eHarmony, Occupied, or LinkedIn. On such pattern, the impression of carpooling with a stranger will be decreased, thus possibly increase the rate of carpooling applications. In order to fulfill the summarized features into a carpooling design, a mechanism of travel cost reduction and a carpooling operation process relying on social community are introduced next.

A. The Travel Cost Reduction Model

There are plenty of methods presented for achieving travel cost optimization for carpooling, although most of them are focus on taxi-pooling. These existed methods are still valuable to create a new travel cost reduction scheme.

Yan and Chen [22] employed a time-space network flow technique to develop a model for carpooling with pre-matching information. The objective function of their model is to minimize the overall system cost containing pre-matching carpool member group's traveling cost. Besides, Wu [4], Wu [7], and Chen [25] developed their mission-oriented taxi-pooling mode with the same mission of collecting random feeder demand. The object function of their model are basically to minimize the total travel cost by calculating the related cost according to the taxi operation, the user, the hail station, the vehicle numbers, total passenger's waiting time, and total in-vehicle time.

The Travel Cost Reduction Model presented in this paper is nearly on the basis of the taxi-pooling functions introduced above, but further considers the particular characteristics of general-purpose car. The model is composed of an object function, as the formula (1) and three constraints as the formula (2) to (4) the notations are defined in the next paragraph.

$$\text{Min. } TC_{\mathrm{pd}} = \mathrm{VC} \times VM_{pd} + \mathrm{WV} \times WT_{pd} + \mathrm{TV} \times TT_{pd} \qquad (1)$$

st.

$$\mathrm{V}M_{pd} <= \mathrm{R}M_d + \mathrm{V}M_d \qquad (2)$$

$$TT_{pd} <= RT_p + TT_d \qquad (3)$$

$$WT_{pd} <= WT_p + WT_d \qquad (4)$$

Notations:

- TC_{pd}: The total cost, where p means passenger ID, d means driver ID.
- VC: The vehicle's travel cost.
- VM_{pd}: The carpooling travel distance, where p means passenger ID, d means driver ID.
- VM_d: The original travel distance if not attending carpooling, where d means driver ID.
- RM_d: The extra travel distance if attending the carpooling, where d means driver ID.
- TV: The fixed value of travel time.
- TT_{pd}: The travel time, where p means passenger ID, d means driver ID.
- TT_p: The original travel time if not attending carpooling, where p means passenger ID.
- RT_p: The extra travel time if attending the carpooling, where p means passenger ID.
- WV: The fixed value of waiting time.
- WT_{pd}: The waiting time, where p means passenger ID, d means driver ID.
- WT_p: The original waiting time if not attending carpooling, where p means passenger ID.
- WTd: The extra waiting time if attending the carpooling, where p means passenger ID.

B. The Carpooling Operation Process Relying on Social Community

This paper proposes a SCC model with the feature of travel cost reduction for both supply and demand sides. Since the SCC is a kind of carpooling service, it certainly provides some common functions as the other similar approaches have. For example, Selker and Saphir [29] summarized their carpooling method as the listed functions including:

1) By describing the time and the place of the ride, a user is likely to find a ride that matches his source and destination addresses.
2) The rides resulting from that request provides users with a list of possible rides based on time, source and destination address.
3) The system identifies departure time, starting place, and destination place based on a user's ride information.
4) Users can extend their ride request by providing their interests and preferences.
5) Based on the extent of matching, the possible rides are on an interesting activity for the user so as to help the user to select the best possible ride.
6) The system considers a user's interests and preferences for a more specific match.
7) A user can label a person for his/her future engagements and can also provide rating for the ride to help other riders make a good choice.
8) The participant can choose his partner and send a request for confirmation. The driver must "Accept" before calling the ride committed.
9) Before choosing a ride, users can learn more information about the driver who offers the ride such as the extent of matching, common interests and preferences.
10) When a user has decided with whom to ride with; the user (also called the rider) can make a request for a ride. The driver who offers the ride is then notified of the request.
11) The driver can accept a request or reject it. If the driver accepts the request, the rider will send a message that asks for confirmation.
12) After the rider confirms the ride by clicking on confirm, it is considered as 'Committed' and the driver will receive a notification.

The operation of the SCC contains the following functions different from the other existed carpooling methods, so that may provide more capabilities of improving the carpooling applications in practice.

1) The SCC considers driver's original travel time if not attending carpooling according to the extra travel distance, the extra travel time, and the extra waiting time.
2) The SCC can recommend the minimized travel cost for users' reference, thus can reduce the overall travel cost.
3) The SCC can provide a list of possible carpooling tuples with showing the associated information such as travel time, waiting time, and projected cost for users to make a reasonable choice.
4) The SCC uses personal information for better carpooling matching but hides the sensitive information carefully due to the privacy considerations.

The SCC particularly records every complete carpooling application for each member, so that can benefit to service customization.

IV. Conclusion and Future Works

This paper reviews and analyzes literatures and projects in terms of carpooling applications through a proposed CRS analysis model. Based on the results of CRS analysis, this paper designs a Social Community based Carpooling (SCC) model with the feature of travel cost reduction for both supply and demand sides. The presented SCC scheme can provide a considerable business model for potential carpooling operators, indicate a valuable research direction of promoting carpooling services, and also implicate initiatives for environmental sustainability.

Finally, three potential research issues that may merit further investigations are provided as follows:

1) To develop a simulation system to practically evaluate

the proposed SCC to be compared with the other methods.

2) To build a novel cooperation mechanism by combining the functions of the SCC and the mass transportation systems, so that achieves better seamless transportation.
3) To design a business model through analyzing the stakeholder needs.

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Yu-Tso Chen is an Assistant Professor of Department of Information Management, National United University, Taiwan. He received his Ph.D. degree from Institute of Information Management, National Chiao-Tung University, Taiwan, in 2004 and his M.S. degree from Department of Information Management, National Yunlin University of Science and Technology, Taiwan in 1998. He was a researcher of Industrial Technology Research Institute, Taiwan from 2004 to 2009. His research interests include Service Science & Management Engineering, Information Security, Communications Networks, and Technology Foresight.

C. H. Hsu now is a postgraduate student of Department of Information Management, National United University, Taiwan. His research interests are in the areas of ICT-enabled service innovation and management.