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User-Based Vehicle Relocation Techniques for Multiple-Station Shared-Use Vehicle Systems

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ABSTRACT

Multiple-station shared-use vehicle systems allow users to travel between different activity centers and are well suited for resort communities, recreational areas, as well as university and corporate campuses. In this type of shared-use vehicle system, trips are more likely to be one-way each time, differing from other shared-use vehicle system models such as neighborhood carsharing and station cars where round-trips are more prevalent. Although convenient to users, a multiple-station system can suffer from a vehicle distribution problem. As vehicles are used throughout the day, they may become disproportionally distributed among the stations. As a result, it is necessary on occasion to *relocate* vehicles from one station to another. Relocations can be performed by system staff, which can be cumbersome and costly. In order to alleviate the distribution problem and reduce the number or relocations, we introduce two user-based relocation mechanisms called trip joining (or ridesharing) or trip splitting. When the system realizes that it is becoming imbalanced, it urges users that have more than one passenger to take separate vehicles when more vehicles are needed at the destination station (trip splitting). Conversely, if two users are at the origin station at the same time traveling to the same destination, the system can urge them to rideshare (trip joining). We have implemented this concept both on a real-world university campus shared vehicle system and in a high-fidelity computer simulation model. The model results show that there can be as much as a 42% reduction in the number of relocations using these techniques.

Keywords: shared-use vehicle systems, vehicle-station distribution, vehicle relocations

1. INTRODUCTION

Shared-use vehicle systems continue to gain interest as an innovative mobility alternative. Loosely defined, shared-use vehicle systems allow individuals to access a fleet of shared vehicles (e.g., cars, bikes, scooters, etc.) on an as-needed basis, rather than using their personal vehicles for all trips. Various studies have outlined and shown a variety of potential advantages of shared-use vehicle systems, including cost savings to the user, better utilization of vehicles (leading to higher transportation efficiency), energy/emissions benefits, and improved access to established transit operations. For further information on the history and benefits of shared-used vehicle systems, see *(1)*, and *(2)*.

When people think of shared-use vehicle systems, the most common perception is the neighborhood carsharing model (see short description below). However, many different shared-use vehicle system operational models and purposes have developed over the years that go beyond neighborhood carsharing. Recently, the authors have developed a shared-use vehicle system typology that attempts to categorize these different models *(3)*. This typology includes instances such as[*]:

Neighborhood Carsharing: individuals in dense metropolitan areas access shared-use vehicle distributed throughout neighborhood lots. Vehicles are placed in strategic locations and users can reserve the use of the vehicle in advance. The keys are typically obtained through a common lock box, and then the vehicle can be used for a period of time. At the conclusion of the trip, the vehicle is returned to the original location and the mileage and time are recorded. At the end of the month, each user is billed a small user fee plus a mileage-based charge.

Station Cars: vehicles are deployed at passenger rail stations in metropolitan areas and are made available primarily to rail commuters. Many of these systems have been initiated by rail transit operators seeking to relieve parking shortages. As such, they can serve as a demand-responsive transit feeder service on both ends of a commute (see *(4)*). In this scenario, "reverse" commuters can also utilize the same dedicated station car for their station-work/station-home trips. Furthermore, non-commute trips could also be made by other users during the day when the vehicles would otherwise sit idle at a station *(5)*.

Multiple-Station Shared-Use Vehicle Model: A more generalized shared-use vehicle system is one in which shared-use vehicles are used among multiple stations to go from one activity center to another. Such systems may be set up in resort communities, recreational areas, defense facilities, as well as university and corporate campuses *(3)*. In this type of shared-use vehicle system, the trips are more likely to be one-way each time. This is in contrast to the typical roundtrips made in traditional commute-based station car systems or errand-based neighborhood carsharing.

In this paper, we focus on a key issue associated with multiple-station shared-use vehicle systems, referred to as the *distribution problem*. Because there are many more one-way trips in a multiple station scenario, the number of shared-use vehicles at each station can quickly become disproportionally distributed among the stations. As a result, it is often necessary to *relocate* vehicles

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[*] It is important to note that many other existing carsharing models have mixed attributes, often referred to as hybrid models *(3)*.

periodically each day so that the system operates efficiently and user demand satisfaction is maximized. The authors have operated a multiple-station shared-use vehicle system for over four years and have been studying this distribution problem and relocation issue in detail. Predictive tools have been developed in order to anticipate when a system will become imbalanced, so that preemptive measures can take place *(6)*. These measures typically include physically moving vehicles from one station to another, referred to as *vehicle relocation*. In this paper, our multiple-station shared-use vehicle system testbed called UCR IntelliShare is first described, with a focus on on-demand use and reservations. Next, different relocation methodologies are outlined, followed by a description of an innovative user-based relocation methodology. Preliminary results are presented and initial conclusions are drawn.

2. UCR INTELLISHARE OVERVIEW

In previous work, the authors have carried out extensive research and analysis on multiple-station shared-use vehicle systems using a variety of shared-use vehicle system computer simulation tools *(7)*. The simulation analysis has shown that the multi-station shared-use vehicle concept is both viable and potentially economically profitable. However, there are always limitations to what can be simulated; in particular, human behavior and how people will react and use such a system. Further, detailed knowledge is needed on how to actually implement and operate intelligent shared-use vehicle systems. For these reasons, a shared-use electric vehicle system "testbed" has been designed and implemented on and near the University of California-Riverside campus. This shared-use electric vehicle system is called *UCR IntelliShare* and was initiated in April 1999 as a joint research program between the University and Honda Motor Company. The overall goal of the UCR IntelliShare testbed is to improve our understanding of the operating details of a multi-station shared-use vehicle system. Other goals include: 1) evaluating the user segment response; 2) using operational data from the system to improve the fidelity of our simulation modeling tools; and 3) providing the UC Riverside campus with a convenient, environmentally-friendly transportation system. The UCR IntelliShare system testbed is flexible and can be used to evaluate many different variations of shared-use vehicle system operation.

In the UCR IntelliShare system, 25 Honda EVPlus and 10 GEM electric vehicles are currently available to UCR faculty, staff, and student employees at five stations set up on and near campus: 1) the College of Engineering-Center for Environmental Research and Technology (CE-CERT), located approximately three miles from campus which serves as an off-campus research laboratory for the College of Engineering; 2) the north campus station servicing engineering, physics and chemistry; 3) the south campus station servicing the graduate school of management and entomology; 4) the east campus station services the university main administrative buildings and fine arts; and 5) University Village, located approximately one mile off the main campus, consisting of retail shops, movie theaters, restaurants, and several university-related offices (see Figure 1).

The shared-use vehicles are available to run errands in the Riverside area or to drive to another location in the system. In order to make this shared-use vehicle system convenient to users and operators, the system makes use of the latest ITS technology such as a smartcard access system, internet-based reservations and check-out procedures using touchscreen displays, and vehicle position-tracking and status monitoring (e.g., battery state-of-charge, odometer, etc.) using telematics.

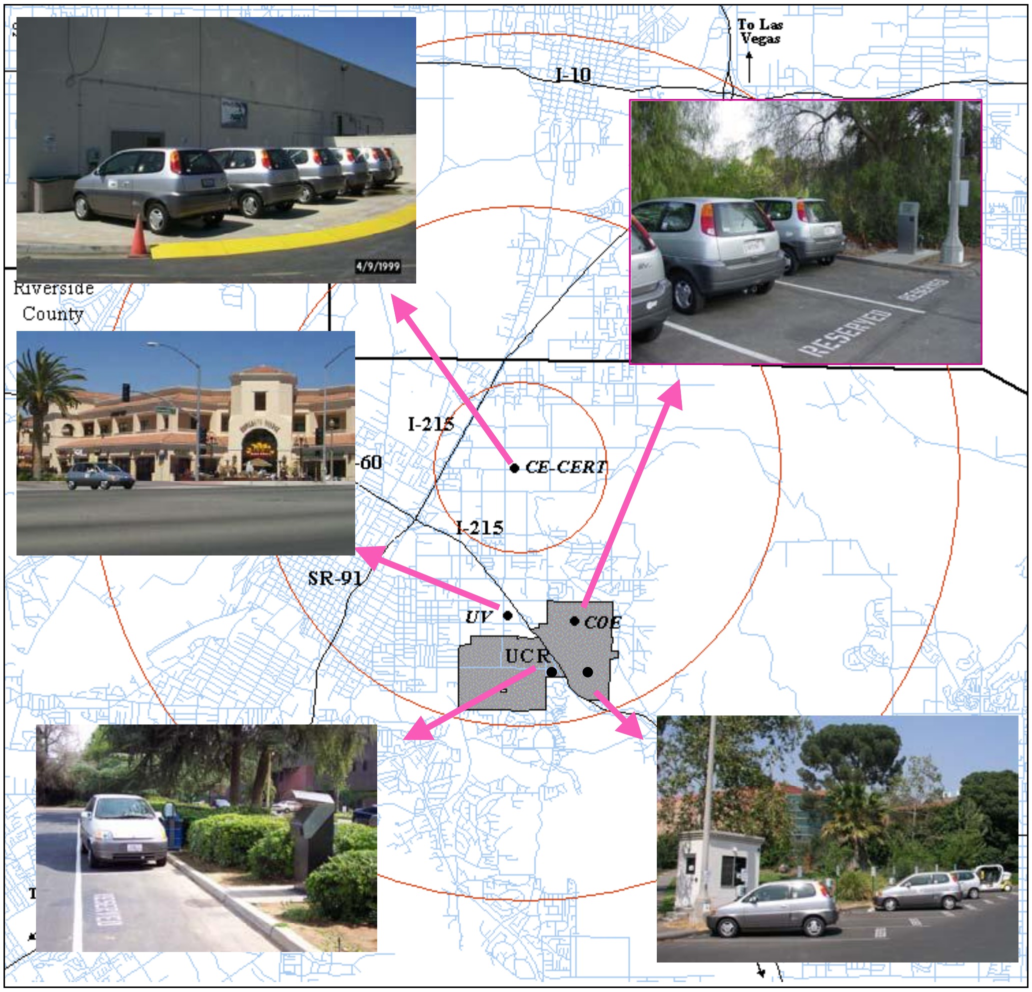

Figure 1. UCR IntelliShare shared electric vehicle system.

Users can either reserve a vehicle in advance (via the Internet) or simply walk up to a station (defined as on-demand access) and checkout an available vehicle (see the next section on how reservations and on-demand access is handled). At the time of check out, a registered user provides information about his or her anticipated trip using the kiosk touchscreen computer and smartcard and is assigned a particular vehicle in the fleet. The system enables that vehicle for the user, and the driver uses the smartcard and PIN code to unlock the driver-side door and to engage the ignition. Once the driver is underway, vehicle status is sent to the system management center every 30 seconds. Drivers can also send and receive messages using a small keypad located in each vehicle. For instance, if a car has a flat tire, the driver can notify the system management center. When a user arrives at a station (not necessarily the originally specified destination station), parks the car, and steps out of the vehicle, the system automatically logs the user off, locks down the vehicle, and makes the vehicle available for other users. If the user is on an errand trip, parks the vehicle, and gets out at a non-station location, the system still locks down the vehicle without removing user access. The user can return and use his smartcard again to gain access to the vehicle. Only when the vehicle is returned to a station will the user be logged off.

A non-linear incremental fee is charged for trips. Short trips (5 – 60 minutes) are very inexpensive, longer trips are more expensive (2 hours +). Keeping the vehicle longer than a few hours is prohibitively expensive. As an initial user base, approximately 500 staff and faculty members at UC Riverside are using the system.

UCR IntelliShare vehicle fleet currently consists of 25 Honda EVPlus four-seat sedans and 10 GEM neighborhood electric vehicles (NEVs) distributed at the five stations. Re-charging docks are located at all of the UCR IntelliShare stations. All of the vehicles are equipped with on-board electronics to facilitate the vehicle access process, provide a means of data exchange between the vehicles and the system, and allow the user to communicate with the overall system (see *(8, 9, 10)* for further details). Although UCR IntelliShare consists of an entirely electric vehicle fleet, other vehicle types would work just as well, e.g., gasoline-powered vehicles or hybrids. The methodology and results of this paper are independent of vehicle type.

One of the unique aspects of the system is that a tremendous amount of trip and user behavior data are automatically collected and stored in a database for each day of operation. The system has been operational since April 1999, so this database has grown to be quite large. By analyzing these data, it is possible to gain considerable knowledge on user trip behavior, vehicle operation, and the effect of system management techniques. Further, these data can be compared to the results of the simulation models implemented for the same system. In this way, the accuracy and fidelity of the shared-use vehicle system simulation models is constantly being improved.

3. RESERVATIONS AND ON-DEMAND OPERATIONS

In recent years, there has been significant development and proliferation of automated reservation systems throughout society in general. For example, lodging, traditional car rental, and the airline industries now employ automated reservation systems that can be accessed both from the phone (entering data via a touch-tone pad) and from the Internet. For shared-use vehicle systems, it is a natural fit to have both phone- and/or internet-based automated reservation systems. Generic automated reservation systems are easily modified for shared-use vehicle systems, little specialization is required for this implementation. Most on-line automated reservations systems show a calendar with dates and times for which there are available vehicles and have a simple intuitive interface. These systems are quickly replacing “manual” reservation systems where a user first calls a reservation center (system management center), requests a vehicle for a trip, and subsequently an operator checks previous reservations for the vehicle(s) of interest and if a time slot is available, the reservation is recorded.

Reservations provide users with the comfort and security of knowing that a vehicle is available for them at a specific time and place. Reservations are also useful for system management, allowing the system to maximize vehicle usage throughout the day. For multi-station shared-use vehicle systems where one-way trips are common (see *(3)*), reservations can play an important role in maintaining a proper distribution of vehicles at all stations throughout the day. By knowing the travel demand ahead of time via reservations, it is possible to estimate when a lack of vehicles may occur at any one station and corrective action can take place *(6)*.

Although reservations can provide user trip security and can enhance system operations, many vehicle trips in our lives are not planned well in advance. Often there is a need for a vehicle on a walk-up, “on-demand” basis. On-demand access to the shared-use vehicles provides high convenience to users, however it places additional burden on the system management to satisfy user demand. Pure on-demand shared-use vehicle systems exist today (i.e., systems operating without any reservation capability) that rely on past historical trip information to anticipate vehicle demand. In a pure on-demand system, the reservation process is often replaced by a "check-out" process where the users use a kiosk terminal located near the shared-use vehicle(s). In some shared-use vehicle systems, a kiosk terminal may not be necessary; in this case, the user simply approaches an available vehicle and performs the checkout and vehicle access process in one step.

To maximize vehicle use in a shared-use vehicle system, a combination of reservations and on-demand use can be implemented. The objective is to minimize total unused time for the vehicles and achieve a balance between reservations and on-demand use. Pricing strategies can be used to maximize vehicle use by controlling this balance. This is the current practice with train and airline seats: walk-up customers are usually charged a higher price to limit the number of on-demand users. Even when a plane is overbooked, passengers are sometimes offered financial incentives to take a later flight. Many algorithms can be developed and used to manage this supply and demand problem and maximize vehicle use and financial revenue. The balance between reservations and on-demand use should be considered both on a short-term and long-term basis: short-term controls can be dynamic to adjust to different daily travel demand; however, it is important to maintain customer satisfaction over the long-term to maintain significant usage levels.

For much of its operating history, UCR IntelliShare only provided on-demand service, operating without reservations. Operating in this on-demand-only mode has been very successful, generating approximately 6 to 7 trips per day per vehicle with an average vehicle in-use time of approximately 30% *(6)*. As a set of measures to alleviate the vehicle distribution burden, we have recently integrated a reservation system with the on-demand check-out system. It is now possible to reserve a vehicle in advance, or still used the on-demand method of walking up to a station and acquiring an available vehicle when desired. The general flowchart for handling both reserved and on-demand trips is shown in Figure 2. In this flowchart, a user first enters the UCR IntelliShare web pages either at a station kiosk or from any web-enabled computer. The main menu allows four choices: 1) carry out an on-demand checkout; 2) make a reservation; 3) checkout a vehicle for a previously reserved vehicle; and 4) cancel a reservation.

For the on-demand checkout, the origin/destination information is first obtained, followed by an inquiry on whether the trip will be a direct trip (i.e., directly from one station to another) or it will be an indirect trip (i.e., the user will stop along the way, or the trip is simply an errand trip, returning to the same station). If it is an indirect trip, then the user has the ability to request addition time and/or miles for his rental[*]. Prior to confirming the checkout, another input request is made regarding the number of passengers.

The process of making a reservation is much like an on-demand checkout, as shown in Figure 2. As before, the origin/destination is obtained along with direct/indirect trip information. The user can then see a schedule and select a reservation date and time. This is followed by a vehicle preference request and the passenger count query. The reservation is then confirmed and logged. When the user shows up within a 10-minute window of the reservation, it is a simple process to check out the reserved vehicle: the reservation record is confirmed and the checkout is immediately processed.

[*] time and distance for all combinations of direct trips are already known from historical use.

Canceling a previously made reservation is also a simple task: a list of reservations is shown, each of which are deletable.

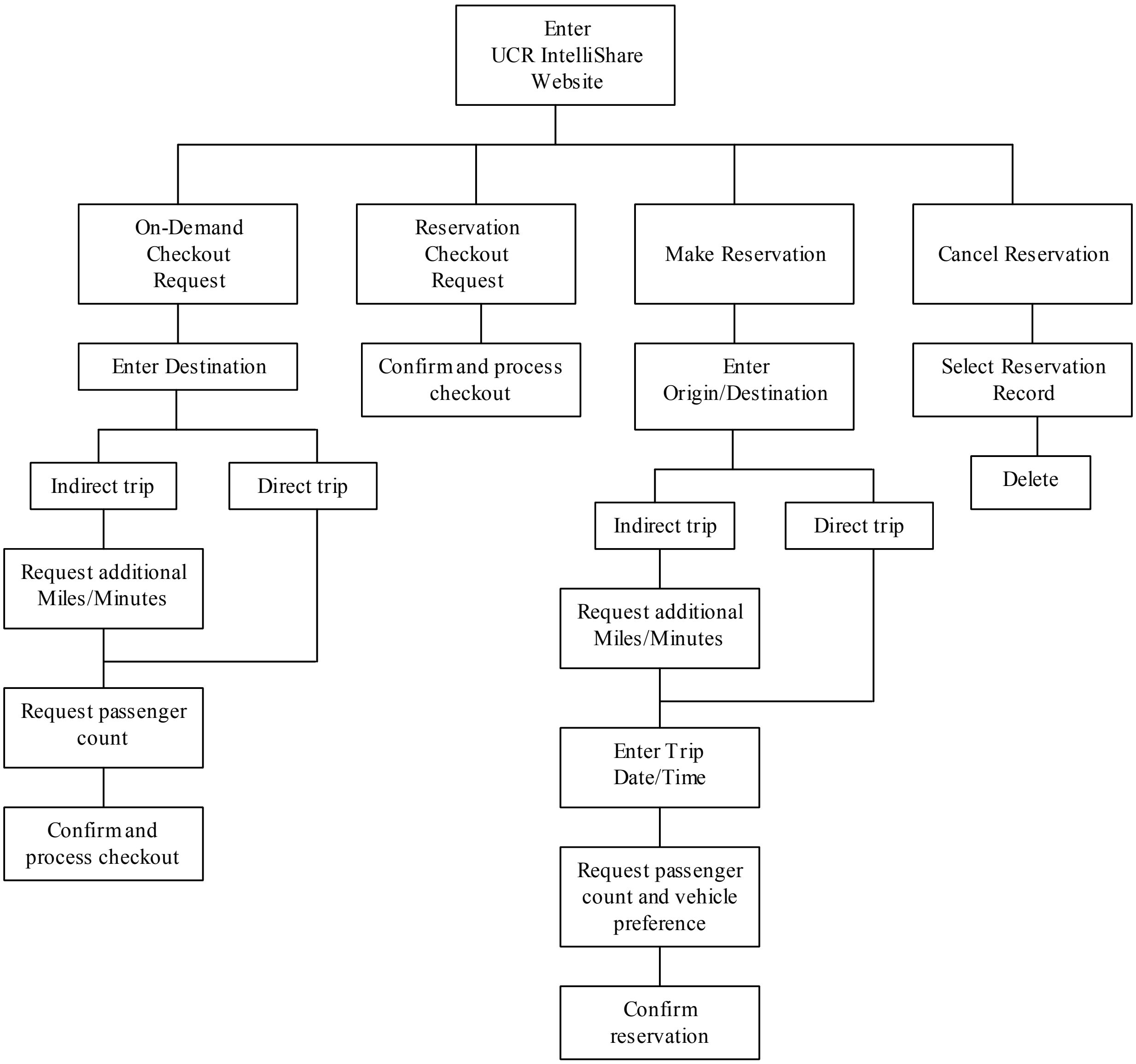

Figure 2. UCR IntelliShare operation flowchart for on-demand checkout and reservations.

In the current mixed reservations/on-demand implementation, the vehicle management algorithms have been designed to always hold a certain number of vehicles at each station for on-demand use. This number is set based on historical reservation/on-demand activity for each station during certain periods of the day.

4. VEHICLE RELOCATION METHODOLOGIES

As describe previously, in a multi-station shared-use vehicle system configuration, many one-way trips are possible leading to a potential imbalance of vehicles at the different stations. Throughout the day, some stations may end up with an excess of vehicles while other stations may have too few. If multi-station systems are to succeed, vehicles must be available at all stations throughout the day in order to satisfy user demand. In these systems, it is crucial to have vehicle-monitoring capability so that vehicle distribution can be closely observed and potentially predicted. Several measures of system performance have been developed that focus on the vehicle distribution issues in the multi-station environment *(6)*. Short-term prediction of these measures based on historical data is a current research thrust *(11)*.

When a multi-station system does become imbalanced, there has to be some type of *relocation* mechanism that moves vehicles from one station to another. Relocating vehicles from station-to-station can occur in a number of ways:

Towing: vehicles can be towed from one location to another using a dedicated towing vehicle or simply using another vehicle that is part of the system. Techniques were developed in the Praxitele car sharing system to perform electronic towbar towing (see *(12)*) where no mechanical linkages were necessary to connect a lead and following vehicle. Instead, a range sensor and control system were used to allow the following vehicle to move under its own power, maintaining a pre-determined following distance from the lead vehicle. Electronic towbar techniques were also developed for the vehicles in the Motegi demonstration car sharing system (see *(13)*). In the UCR IntelliShare system, each vehicle has a towing hitch in front and back, allowing any vehicle to (mechanically) tow another vehicle in the system, as shown in Figure 3.

Ridesharing: vehicles can also be moved within a system by having multiple drivers take separate vehicles, then return by sharing a ride in a single vehicle. In this method, one or more system operators can drive the vehicles and obtain return travel from another operator or even via a regular user trip.

Figure 3. Manual towing to relocate vehicles in the UCR IntelliShare system.

In past operation, UCR IntelliShare utilized a variety of methods for relocating vehicles between stations. A single system operator monitors the system and performs relocations by towing one electric vehicle with another. If the system operator needs to get to another station without moving a vehicle, a small scooter is available to travel between stations. This scooter can be mounted on the towing hitch of any system vehicle. If more than one system operator is available, then it is possible to share rides as necessary and split up to move vehicles where appropriate.

To further ease the burden of vehicle relocation, we now introduce the concept of *user-based ridesharing* to the multiple-station carsharing model. This method takes the operator-based ridesharing method described above and extends it to *users* in the system. For example, if multiple users wanted to travel from one low-vehicle-quantity station to a high-vehicle-quantity station, the users could share a ride in a single vehicle, minimizing the number of cars that are moved (referred to as *trip joining* or *ridesharing*). Conversely, if multiple users wanted to travel from a high-vehicle-quantity station to a low-vehicle-quantity station, they could drive several separate vehicles to essentially balance vehicles in the system (referred to as *trip splitting*). To facilitate this, we have introduced new system operating techniques that allow users to participate in this fashion, influenced by trip pricing techniques.

These new system operating techniques are illustrated in Figure 4, which is an extension of Figure 2 with differences outlined in yellow. For the on-demand checkout, things are processed as usual with a potential added trip split request if three conditions are met: 1) the requested trip has more than one passenger; 2) it is scheduled to be a direct trip between stations; and 3) a vehicle relocation is necessary based on a computed system balance measure[*]. To influence the users to split up and take separate vehicles to their destination station, their trip cost is cut in half. If the trip split request is agreed upon by the users, then the second user quickly checks out another vehicle and the two vehicles are then used to get the users to their destination station. If a trip split is not necessary, the case of a *trip join* action is evaluated. If 1) there are no available on-demand vehicles; 2) a reserved trip exists in the next 5 minutes going directly to the same station; and 3) the reserved trip user is willing to rideshare, then the on-demand user is matched with the reserved trip so that the on-demand trip is satisfied. This is a somewhat seldom case and for the most part, the main mechanism in the on-demand check-out process will be the action of trip splitting.

The process for making a reservation remains largely the same, except near the end of the process when a request is made on whether the user is willing to share a ride with another potential user traveling at the same time to the same location. At the time of making the reservation, it is often unknown whether another user will make a similar reservation. However, if two potential reservations are made independently and both users are willing to rideshare, then the rideshare match can be made and the trip join process takes place. Trip pricing is used again to influence users to rideshare, offering the users half the normal rental cost.

When a reservation checkout occurs with a user, the potential for a trip split process is examined if deemed necessary by the system using its calculated system balance measure. The same conditions as with an on-demand checkout are applied: 1) the requested trip has more than one passenger; 2) it is scheduled to be a direct trip between stations; and 3) a vehicle relocation is deemed necessary. On the flip side, the system can request a trip join action if three other conditions apply: 1) both users with similar reservations are willing to rideshare and have similar matching times; 2) both are direct trips to the same station; and 3) the system determines through the system balance measure that the

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[*] see *(7)* for a description of the system balance performance measure; in the current implementation, this measure is simply compared to a set threshold. When the threshold is exceeded, either a trip split or trip join is deemed necessary based on the vehicle quantities at the stations in question.

number of vehicles moving from the origin station to the destination station should be minimized. If the rideshare match is confirmed, then both users receive a discount to their trips.

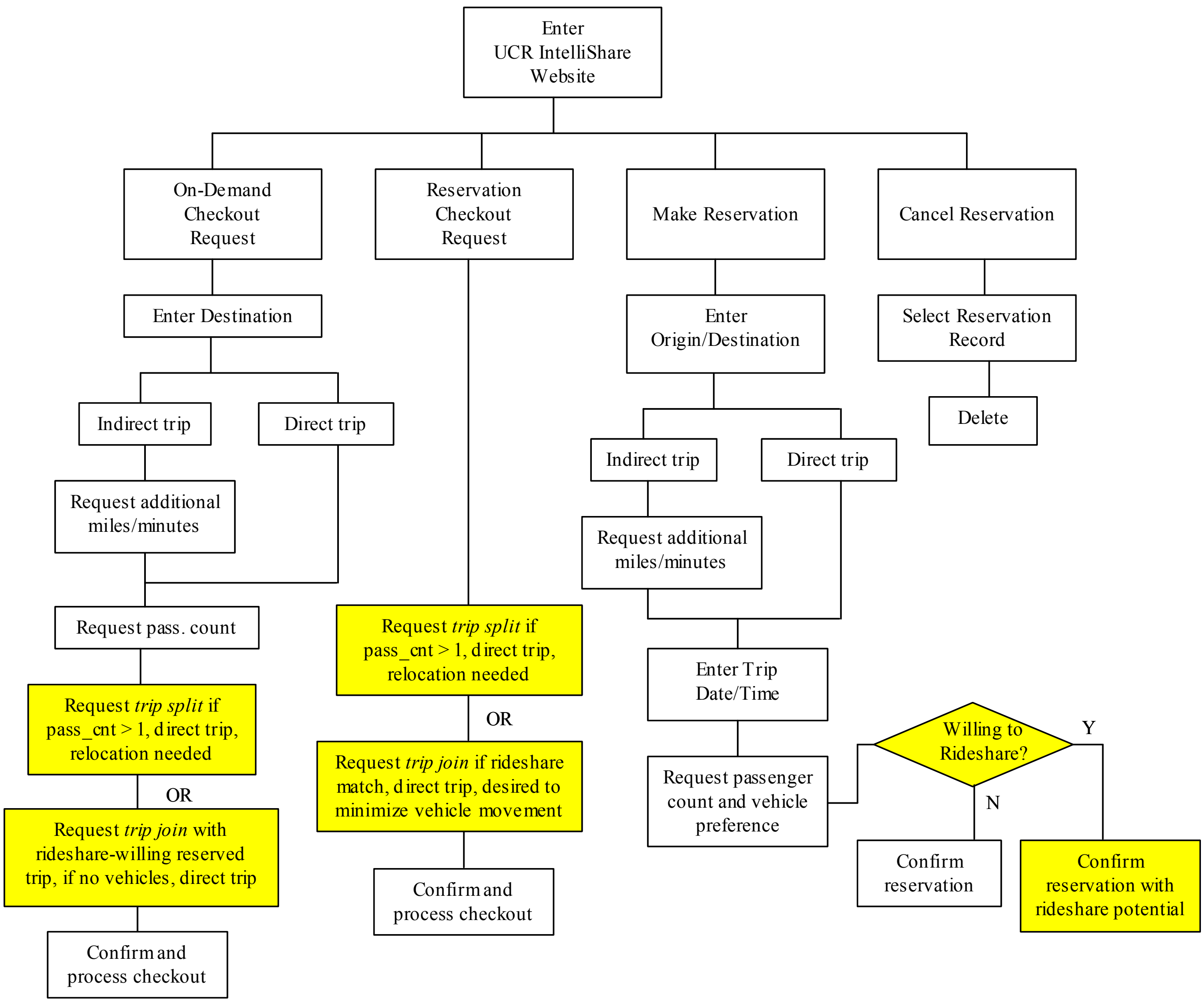

Figure 4. UCR IntelliShare operation flowchart with user-based relocation mechanisms of trip splits and joins.

It is interesting to note that the trip join process is very similar to many organized ridesharing systems setup by transportation agencies to promote carpooling for commute travel (e.g., see *(14)*). For these systems, typically a database is maintained of commuters who are willing to rideshare, to which potential new commuters with similar origins and destinations can be matched. The key to any ridesharing program is strong commuter awareness of such programs *(14)*. Another important aspect of ridesharing is providing incentives. It has been shown that providing incentives for ridesharing (carpooling) increases the frequency of rideshare events *(15, 16)*. In the UCR IntelliShare system, user-based ridesharing is unique in the sense that it is coordinated in real-time and on a trip-by-trip basis. Users do not have to pre-coordinate their trips or modify their schedules. The potential for ridesharing is monitored by the system and combines trips when desired for system balance as well as user convenience. Users also receive pricing incentives for willingness to rideshare and not just when a rideshare trip has occurred.

Based on past historical use data of the UCR IntelliShare system, the potential for user participation in the trip joining and trip splitting process was thought to be quite high. In the past, UCR IntelliShare users were already forming informal carpools when more than one users were obtaining vehicles at stations and discussing their destinations. The overall average vehicle ridership for UCR IntelliShare was consistently around 1.45, much higher than the average values associated with regular commuters.

4. SIMULATION SETUP AND RESULTS

4.1. Simulation Model Background

Prior to the extensive real-world data analysis of the impact of the user-based trip-splitting and trip-joining actions described in the previous section, the method was evaluated using a sophisticated computer simulation model. The authors have carried out multiple-station shared-use vehicle simulation model development for a number of years in order to carefully analyze a variety of carsharing scenarios and relevant parameters (e.g., how many vehicles, station location, etc.) prior to an actual implementation. As part of the on-going research, the operating UCR IntelliShare system is modeled in parallel, using real-world operational data to calibrate the simulation model. Details of the simulation model are described in *(7)*. In summary, the model is a queuing-based, discrete event simulation which models each individual vehicle in the shared vehicle network over a specified period of time (typically 24 hours). Vehicle "trips" are generated based on estimated travel demand data. The model implements the current operational procedures, providing output on the overall system effectiveness in terms of vehicle balance, vehicle availability, efficiency, and number of relocations required (see *(7)* for measures of effectiveness). Different input variables such as travel volume, number of vehicles, etc. are varied to examine the overall effect on the output. The overall modeling structure is shown in Figure 5.

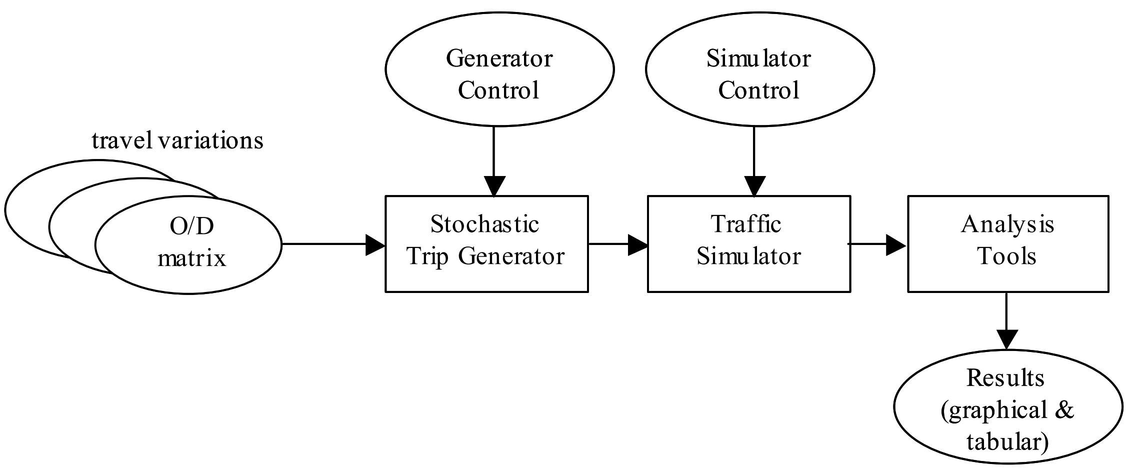

Figure 5. Shared-use vehicle system simulation block diagram.

There are three major processing stages, i.e., 1) stochastically generating vehicle trips; 2) simulating the traffic on the network; and 3) evaluating the results with analysis/visualization tools. In order to generate trips, a trip generator program is used. The trip generator program uses the various O/D matrices as the primary data input. The stochastic trip generator reads in the origin destination pairs contained in the input O/D matrix. The O/D matrix specifies the number of trips made from station to station on an hourly basis (note that round-trips, e.g., running an errand, are possible, originating and returning to the same station). From these hourly trip volume estimates, a *mean time between generation (mtbg)* value is calculated for each station pair, each hour. The *mtbg* value is calculated simply by dividing the number of trips into 60 minutes of an hour. Thus, *mtbg* represents the average time between trip generations (in minutes). Using the hourly *mtbg* data, vehicles are then spawned based on a modified Markov Process. In a normal Markov process, times between generations have an exponential distribution with infinite support. In order to avoid extreme behavior in the simulation, inter-generation times which are extremely high (above five standard deviations) are eliminated and the remaining sample is shifted accordingly. There is also a set of control parameters that adjust the behavior of the trip-generating program. The output of the trip generator is a time-sequenced list of trips which is used as input to the next processing component, the traffic simulator. The algorithmic flow of the traffic simulator is described in *(7)*. It has various input control parameters which affect the overall operation of the simulation. Trip information provided by the trip generator is used as input into the traffic simulator, which then simulates each vehicle trip on the given network for a specified period of time (typically for 24 hours). The traffic simulator is a hybrid discrete-event and time-stepped simulation model, allowing for large network/vehicle size without loss of validity. It is based on the application of queuing theory to networks and features single vehicle level-of-detail.

The traffic simulator models the operation of a shared vehicle system as a collection of independent *processes* which interact with each other using coordination and communication structures. Functional components of a shared vehicle system, such as customers, station managers, and relocation controller are simulated as individual *processes*. Shared resources, such as vehicles, registration kiosks, and parking slots are treated as *facilities* within the simulation environment. The global system behavior is simulated as a collective effect of these numerous relatively simple, locally interacting components. Major *events* that have a significant effect on the overall system status and behavior are simulated in the model. Some examples of events include user arrival at a station, vehicle departure from a station, vehicle arrival at a station, etc.

As the traffic simulator executes, a number of critical parameters are recorded which are subsequently evaluated using a set of analysis tools. In addition, a visualization tool has been developed to illustrate the movements of the vehicles between the different stations.

4.2. Simulation Model Results

To analyze the effectiveness of the user-based trip splitting and trip joining techniques on the number of relocations, the operating procedures illustrated in Figure 2 were first implemented (i.e., those without the trip-joining and trip-splitting mechanisms), using travel demand information that was calibrated from the real-world operation of UCR IntelliShare. The overall travel demand volume is adjustable, and was set to approximately 200 trips per day. The same travel demand data was then applied to a version of the simulation model that has the trip-joining and trip-splitting mechanisms as described in Section 3 and illustrated in Figure 4.

As part of the simulation analysis, we also evaluated the number of vehicles required to meet the travel demand. Keeping the travel demand constant, the number of available vehicles was varied as an independent parameter ranging from 22 to 30. In this evaluation, we are interested in the number of relocations that are necessary throughout the day to keep the system balanced. Based on experience with the real-world system and earlier simulation results, the number of relocations increases when the ratio of demand/vehicles is high (i.e., there aren't enough vehicles to meet demand so more vehicles are relocated). Conversely, the number of relocations decreases when the ratio of demand/vehicles is low (i.e., there are many vehicles to meet demand, therefore the number of relocations is less). This is depicted in Figure 6 (see *(7)*). The results shown in subsequent graphs are looking at only a small part of this overall curve.

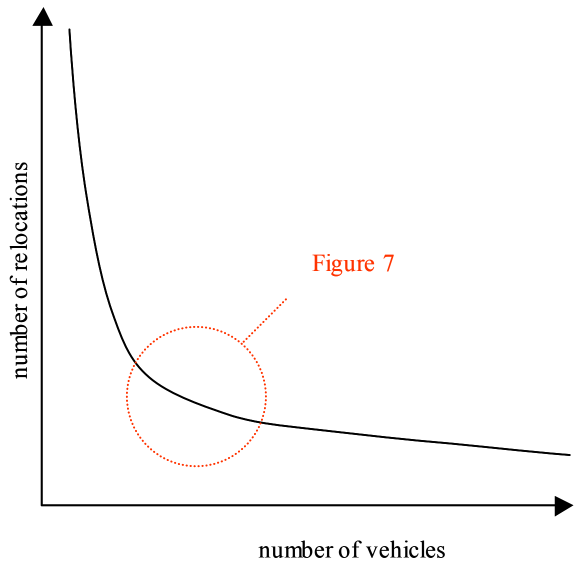

Figure 6. Relationship of relocations to number of vehicles in a multi-station shared vehicle system.

Four scenarios were evaluated: 1) the normal scenario where only manual relocations took place; 2) the same scenario with the trip joining functionality; 3) the normal scenario with trip splitting functionality; and 4) the normal scenario with combined user-based trip splitting and trip joining. For this set of simulations, we used passenger count distributions that have been observed in the real-world system (average vehicle ridership is approximately 1.45). Further, we are assuming the best possible scenario where the willingness of users to rideshare and to trip split is 100%. This may not be realistic, but it serves as an upper bound as to what can be achieved with the user-based relocation techniques. This "willingness" parameter can always be detuned for less effect.

The results of the original scenario (scenario #1) is shown in all graphs of Figure 7. Figure 7a shows the comparison with scenario 2) (trip joining), Figure 7b shows the comparison with scenario 3) (trip splitting), and Figure 7c shows the comparison with scenario 3) (both trip splitting and joining). The average number of relocations has been calculated for the different vehicle quantities. On average, trip joining reduced the number of relocations by 11%, trip splitting reduced the number of relocations by 26%, and when both mechanisms are implemented, the overall number of relocations is reduced by 42%. Keep in mind that the simulation runs are dynamic and the two mechanisms are not linearly additive. Again, this gives an example of the best possible results; actual results will be less since the willingness of all users will be less than 100%, even with cost incentives.

a:

b:

c:

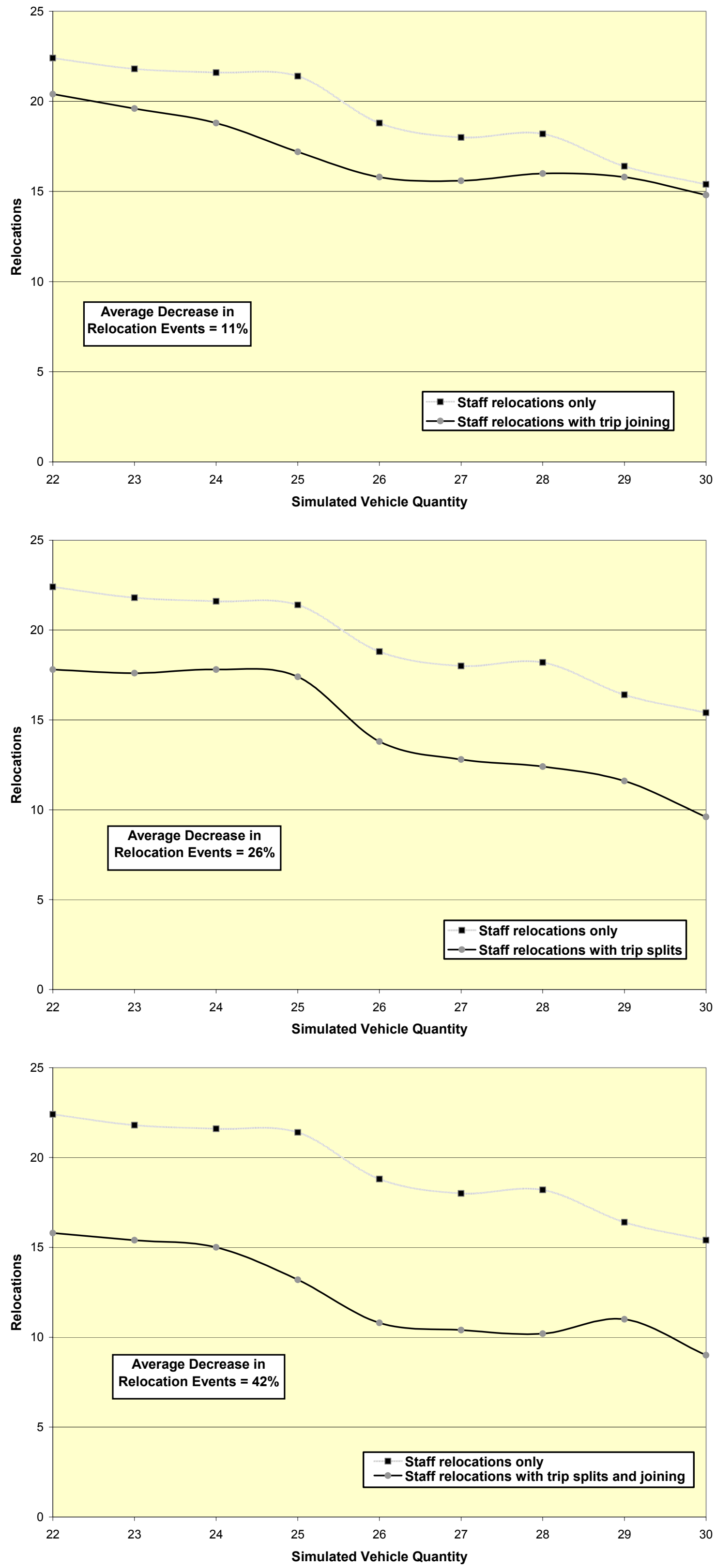

Figure 7. Simulation results of trip joining and trip splitting scenarios: a: trip-joining only scenario; b: trip-splitting only scenario; c: both trip joining and trip splitting.

5. CONCLUSIONS AND FUTURE WORK

Multi-station shared-use vehicles systems are very convenient for university and corporate campuses, however when one-way trips are allowed, the distribution of vehicles at the stations can become a problem. To keep the system balanced, various types of relocation mechanisms are necessary. Manually relocating vehicles from one location to another is effective, but can be time consuming and involves a high degree of staff labor. To help reduce the number of manual relocations, we have devised methods where users in the system are asked to either split or join with other users when the necessary conditions are met. The detailed mechanisms for doing this have been designed and implemented in a real-world system. At this point in time, there is not enough direct data to analyze to evaluate the overall impact. However, we have also simulated the effect with a high-fidelity shared-use vehicle system model and have gotten promising results. For example, with a 100% user participation rate, we have seen that the overall number of relocations can be reduced by approximately 42%. The results of the simulation show that in almost all cases trip splitting is more effective (approximately twice) than trip joining (i.e., ridesharing). The user-based relocation mechanisms highly depend on user participation. For our simulation results, we have assumed a 100% participation rate. Actual participation rates will be known when enough real-world data has been accumulated.

As part of the future work, other simulation parameters will be adjusted to see the overall effect on relocations, such as the “willingness” percentage of users to perform trip splits and joins and adjusting the passenger ridership distribution. As the real-world system continues to operate, we will evaluate the overall effectiveness when enough data have accumulated. It is also planned to eventually use these mechanisms in public shared-used vehicle systems. We feel that with appropriate financial incentives, users can be motivated to implement these mechanisms to help relieve the relocation issues.

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