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Relocation Simulation Model for Multiple-Station Shared-Use Vehicle Systems

Alvina G. H. Kek[#]
Department of Civil Engineering, National University of Singapore
1 Engineering Drive 2, Singapore 117576
Telephone: +65-6874-5035
Fax: +65-6874-2248
Email: alvina@nus.edu.sg

Ruey Long Cheu
Department of Civil Engineering, National University of Singapore &
Institute of Transportation Studies, University of California at Davis
1 Shields Ave, Davis, CA 95616
Telephone: (530)-752-3180
Email: rlcheu@ucdavis.edu

Miaw Ling Chor
Department of Civil Engineering, National University of Singapore
1 Engineering Drive 2, Singapore 117576
Telephone: +65-6874-5035
Email: u0205542@nus.edu.sg

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[#] Corresponding author

Abstract: A shared-use vehicle system has a small number of vehicles reserved exclusively for use by a relatively larger group of members. Challenged by accessible and economical public transportation systems, multiple-station shared-use vehicle companies are driven to gain a competitive edge by using an operator-based relocation system to ensure privacy, simplicity and convenience to their users. To assist operators in identifying measures to maximize resources and enhance service levels, a simulation model is developed, with an emphasis on operator-based relocation techniques. A qualitative analysis conducted on operator-based relocation systems provides insights on the key issues involved and their influences over each other. Based on this analysis, a time-stepping simulation model is developed and three performance indicators are proposed to evaluate the effectiveness of the different relocation techniques. The model has been validated using commercially operational data from a local shared-use vehicle company. Using the existing operational data as the base scenario, two proposed relocation techniques, namely the shortest time and inventory balancing techniques, and various operating parameters are studied. The simulation results have shown that, if inventory balancing relocation technique is used, the system can afford a 10% reduction in car park lots and 25% reduction in staff strength, generating cost savings of approximately 12.8% without lowering the level of service for users.

INTRODUCTION

Over the last decade, the concept of shared-use vehicle systems has slowly emerged as a novel and popular alternative to owning a car. Essentially an alternative means of car ownership and use, the key concept behind shared-use vehicles is for a large number of people to share a small number of cars that are reserved for them and used individually as required (*1*). Users pay only for the time used and distance traveled while the shared-use vehicle company owns the vehicles and handles all the repairs and insurance. This should be distinguished from carpooling and car rental where in the former, vehicles are shared for some time but the main ownership and arrangements remain unchanged, and in the latter, vehicles are rented over an extended period of time.

The earliest origins of shared-use vehicles can be traced back to 1948 where a cooperative known as "Sefage" (Selbstfahrergemeinschaft) initiated services in Zurich (*2*). Other initiatives included "Procotip", which began in Montpellier, France in 1971 and "Witkar" which was deployed in Amsterdam in 1973 (*2*). Unfortunately, due to various reasons these programs did not take off successfully. However, mistakes made were experience gained and with the advancement of communication technology, several successful programs were launched in the 1980s. These included "Mobility CarSharing" in Switzerland with over 1400 cars, "Stattauto" in Berlin with over 300 and many more (*1*). The concept of shared-use vehicles also began gaining popularity in the U.S. during the 1990s. Several pilot projects were carried out to gain a better understanding of how to implement and operate these intelligent shared-use vehicle systems. These included UCR Intellishare at University of California at Riverside (*3*), ZEV.NET at University of California at Irvine, and Carlink I and II at the Bay Area Rapid Transit station in Dublin/Pleasanton (*4-5*). These projects provided insights on users' response to shared-use vehicles and evaluated the potential for it to be operated as a business. A natural progression to the commercialization of this concept in many countries such as the U.S., Japan and Singapore was thus not unexpected. Further details on the history of such systems may be found in (*2*) and (*6*).

Simulation-based research carried out to investigate the viability of this concept suggests that multiple-station shared-use vehicle systems have the potential to become economically profitable (*7*). Another future innovative mobility scenario conducted for the Sacramento region also indicated a modest reduction in vehicle travel and emissions and a significant net economic benefit for home-based work trips (*8*).

A key issue which arises in multiple-station shared-use vehicle systems that allow one-way trips, is the dynamically disproportionate distribution of vehicles across the stations. As a result, periodic relocation becomes necessary to ensure an even distribution of vehicles. The main objective of this research is to aid multiple-station shared-use vehicle operators in implementing an efficient relocation system, capable of maximizing the allocation of resources such as vehicles, staff, car park lots, etc. while maintaining certain levels of service. A unique and versatile simulation model of the relocation system is developed, essentially functioning as a decision support tool in helping to identify enhancements and quantify impacts to the relocation system. The model is tested and validated on real data from a commercially operational shared-use vehicle company, Honda ICVS Singapore Pte Ltd (hereafter referred to as ICVS in short). Barth and Todd (*7*) wrote an excellent paper on the development of a shared-use vehicle system simulation model, dealing with vehicle availability, distribution and energy management using simulated trip data. However, none has dealt extensively with operator-based relocation of vehicles, using commercially operational data.

In this paper, the authors begin by first hightlighting the need for enhanced relocation techniques in multiple-station shared-use vehicle systems. Next, a brief overview is given on the shared-use vehicle system operated by ICVS, to provide the background on the data used for model validation. A qualitative analysis then highlights various key parameters affecting the implementation of an operator-based relocation system and their varying influences on each other. Based on this understanding, the simulation model is developed, validated and tested on a real set of operational data. From the results of simulation experiments, two parameter combinations, incorporating the two proposed relocation techniques with significant cost savings are recommended.

A NEED FOR ENHANCED RELOCATION TECHNIQUES

The commercialization of shared-use vehicle systems is potentially viable in land scarce cities with high vehicle ownership costs (*9*). In these cities, more efficient utilization of vehicles such as carpooling or shared-use vehicle concepts are a welcome relief from increasingly high taxes which exist to curb congestion. Faced with the high costs of owning a vehicle, commuters can easily be tempted to switch to a shared-use vehicle system, should that work out to be competitively priced, easily accessible and yet provides a relatively high level of privacy.

Singapore is one such city which has seen the development of four shared-use vehicle companies in the last seven years (*9*-*12*). To provide an alternative for high-cost vehicle ownership and through strict government controls, the public transportation system in Singapore is well developed and provides a convenient means of transport at relatively economical rates for commuters. Operators of shared-use vehicle companies in cities such as this would thus not only be challenged by other competitors in their field but also by comparable modes of public transportation. Any shared-use vehicle system implemented in these cities needs to be at its most cost effective for operators to be profitable. Efficient running of the system while providing maximum convenience to commuters thus becomes vital to its success.

Stiff competition from both the public transportation and competing shared-use vehicle companies has prompted ICVS to provide users with the freedom of picking-up and returning vehicles at stations (referred to as 'ports' by ICVS) of their choice. These stations are designated parking areas rented by operators for the placement of their vehicles. As an added flexibility, users may change their destination station at any time during the trip and are also not required to state their return time (*11*). This however burdens the operator with the added cost of relocating vehicles to prevent an under or over supply of vehicles at any station in the system.

The Intellishare research team at the University of California at Riverside proposed and experimented two user-based relocation methods, namely trip splitting and trip joining which successfully reduced the number of relocations required (*13*). When users wanted to travel from a station with a shortage of vehicles to one with an oversupply, they were encouraged to share a ride in a single vehicle (trip joining), minimizing the number of cars moved. Conversely, when users wanted to travel from a station with an oversupply of vehicles to one with a shortage, they were encouraged to drive separate vehicles (trip splitting), balancing the number of vehicles in the stations. These user-based relocation techniques cleverly shifted the burden of relocating vehicles to the users through a price incentive mechanism.

Unfortunately, these techniques may not be a viable option in cities such as Singapore where most commuters value privacy and convenience over minor cost savings in transportation. A case in point is the failure of the 'Share-A-Cab' scheme launched in 1980 to improve the system capacity of taxis in Singapore in the period when passenger demand exceeds vehicle supply (*14*). It is hence unlikely for operators of shared-use vehicle systems in cities such as these to adopt user-based relocation techniques to manage vehicle imbalances. In pursuit of offering to commuters, privacy, simplicity and convenience of their shared-use vehicle system, ICVS makes use of in-house staff to relocate vehicles. A clear need thus arises for the development of intelligent operator-based relocation techniques to support this operation.

A further encumbrance to the problem is the lack of an expected return time and the unpredictability of return stations. This additional flexibility given to users results in vehicles being relocated without any anticipatory information and as a result, creates the possibility of redundant relocations.

OVERVIEW OF HONDA ICVS

Honda ICVS launched a multiple-station shared-use vehicle system in Singapore on March 2002 (re-branded as Honda Diracc in June 2003) (*11*). In competition with them in Singapore are three other shared-use vehicle companies, NTUC Car Co-Op, CitySpeed and WhizzCar. These companies generally offer shared-use vehicle services with differences in their technology and pricing schemes. The key differences between ICVS and its competitors is that ICVS allows their users the flexibility of making one-way trips without having to commit to a return time in advance. The return station specified by a user prior to a trip may also be changed en-route. ICVS is thus constantly challenged to maintain an even distribution of vehicles in all stations with as efficient a relocation system as possible. A delicate balance needs to be struck between having available vehicles for pick-up and having enough empty space for other vehicles to return to.

Currently, ICVS has 12 stations located all over Singapore with a high majority concentrated in the CBD (*11*). Fifty environment-friendly Honda Civic Hybrid vehicles are available for members' use. The system makes use of the latest ITS-related technologies such as GPS and RFID vehicle location systems, contactless smartcard access, internet or phone-based reservations and touchscreen display units. Communicating with the backend computer system periodically, information from these vehicles prompts the system manager to relocate vehicles between the stations when needed.

Having been in operation for over three years, a tremendous amount of trip data has been collected and stored on a database. This information has proven to be particular useful in helping to understand user behavior and forecast future trip data (*15*). For the purpose of this research, this data is further used to both validate the simulation model as well as aid in the identification of effective operating parameters for ICVS.

UNDERSTANDING THE OPERATOR-BASED RELOCATION SYSTEM

Prior to embarking on an operator-based relocation system, it is essential for the operator to have a clear understanding of the dynamics involved. Drawing on the knowledge base of various shared-use vehicle research (Carlink, Intellishare, etc.) and an understanding of shared-use vehicle operations from publicly available information, this section conducts a qualitative analysis of an operator-based relocation system for multiple-station shared-use vehicle systems. It highlights the key issues involved and their varying influences over each other.

Figure 1 presents a schematic showing the interactive dynamics between the various components in an operator-based relocation system. Depending on the usage patterns of commuters in the system, operators may choose the appropriate amount of resource to invest into the system and the type of relocation model to implement. These chosen parameters in turn interact with the current operational set-up to reflect the expected service level and the resulting rate of relocations (i.e., number of moves). The implementation of this system naturally results in some shifts in usage pattern as existing users accustom themselves to the new flexibility and new users are attracted to make use of it. These changes should feedback to the model, allowing for adjustments of parameters to maintain efficiency.

The first component on the left highlights the key usage patterns which should be noted for their influence in an operator-based relocation system. Knowing the peaks and troughs in usage levels, length of usage and net flow of vehicles in individual stations is essential in deciding on the appropriate level of resource and choosing a suitable relocation model. Net flow of vehicles in a station is the difference between the number of vehicles being picked-up and returned during a time period (*15*).

The second component is the additional resource required for implementation of the system. These include extra car park lots in the stations and manpower to relocate the cars. Assuming full utilization of all resources in the company with no excess, additional staff needs to be hired for the purpose of relocating vehicles between stations. Extra car park lots are also needed at each station to accommodate the temporary over supply of vehicles. Ideally, the ratio of lots to cars should be kept as close to one as possible for maximum cost effectiveness (and space utilization). However, the trade-off would be a compromise on service levels when there are not enough empty lots in certain stations for users to return their vehicles. The choice of resource level thus depends on the peaks and troughs in usage levels and the net flow of vehicles to and from stations.

The next component is the relocation model. In deciding whether to relocate vehicles between stations, certain threshold values need to be set. These are the upper and lower limits on the number of vehicles in a station which when reached, indicate a need to remove or add vehicles at the station. Choosing more extreme threshold values (which gives a larger range between the upper and lower limits) would cause the relocation alarms to be triggered less frequently, reduce the number of relocations but may compromise on service levels (vehicle and lot availability). Conversely, more conservative threshold levels would allow more relocations to be carried out and thus maintain a higher level of service, but at the expense of more frequent relocations, causing cost to go up. Two techniques of relocating vehicles are proposed in this paper, namely '*shortest time*' and '*inventory balancing*'. Relocating vehicles by *shortest time* means moving vehicles to or from a neighboring station in the shortest possible time. Time here comprises of both the travel time of staff (if any) from his existing location to the port where the vehicle to be moved is parked, and the time to drive the vehicle to the destination port. In short, to perform a relocation from stations B to C, a staff may be at station A and he needs to travel to station B to drive the vehicle from station B to C. The sum of travel times from A to B and then to C needs to be considered. Relocating by *inventory balancing*, means filling a station with vehicle shortage, with a vehicle from another station with over supply, or vice versa. While the shortest time relocating technique places a larger emphasis on service levels (i.e., to restore the service levels at the shortest possible time), the inventory balancing relocation technique focuses on cost efficiency (i.e., moving only one vehicle to simultaneously solve a pair of vehicle shortage-overflow problems). Depending on the usage volume at that point in time, an appropriate choice of relocation technique should be made. During periods of low usage, when relocation of vehicles may not be time critical, it would be more cost effective to relocate by *inventory balancing*. In times of high usage, relocating by *shortest time* may be more appropriate in view of maintaining good service levels.

Depending on the current operational set-up, application of the above choices would result in varying outcomes. For instance, given a fixed number of vehicles and car park lots, a greater number of stations imply a sparser distribution of lots. This in turn means a lower upper threshold value and may result in a larger number of relocations being triggered. In situations where the number of required relocations exceeds staff strength and relocations are not carried out, service levels will be affected. Distance between stations also impact on the speed of relocation. Shorter distances generally imply faster relocations and as a result, better service levels. The distinction between shortest time and inventory balancing relation techniques may not be significant when the stations are near each other. The distribution of car park lots in each station is also an important factor. A small number of car park lots in a particular station generally means a narrow range of upper and lower threshold values, thus creating the need to constantly relocate vehicles to and from that station whenever its threshold values are hit. The components, resource levels, choice of relocation model and current operational set-up thus interact to give an indication of the expected service level and the number of relocations carried out to achieve it.

Finally, there may be a shift in usage pattern resulting from the implementation of such a system. Adapting to the new system, users may begin to change their trip patterns. The flexibility of the system allows for the making of one-way trips from origin to destination of activity, or breaking a return trip into a series of one-way trips with stops at different ports. Thus trips may become shorter and more frequent. Usage levels may also rise as more users are attracted to use the system. These changes should feedback to the beginning of the system where appropriate adjustments can be made to the resource levels and choice in relocation model. At this point, it is important to note that besides the impact from the implementation of this system, usage patterns are also likely to be influenced by changes in price. More information on how some shared-use vehicle operators in Singapore make use of their pricing model to influence usage patterns can be found in (*16*).

RELOCATION SIMULATION MODEL

Model Development

In order to provide insights on performance issues in an operator-based relocation model, a unique and versatile computer simulation model is developed and applied on a real set of commercially operational shared-use vehicle data. The developed model is a time-stepping simulation, whose input parameters are the operational set-up and real-time events such as vehicle usage, refueling, cleaning and inspections of vehicles. Based on available resource and relocation techniques adopted, the model will then trigger off and effect required relocations in the system at each time step. Finally, key output parameters defining system performance are tabulated and analyzed for the time period simulated. The impact of employing different relocation techniques under various operating conditions can thus be studied using this simulation model. The simulation algorithm is presented in the flowchart in Figure 2.

The program initializes by first reading in the input parameters. There are two sets of input data, the *operational set-up* which is consistent throughout the simulation and *dynamic events* which vary with each time step. Under *operational set-up*, there are four parameters. Firstly, *station parameters* refer to the number of stations in the system, the actual number of vehicles in each station at the start of the simulation, the travel time matrices specifying staff traveling time and relocation time between stations, number of car park lots and each station's threshold values. Next, *basic job parameters* refer to type and average time taken for duties such as refueling, cleaning and inspection of vehicles. *Staff parameters* refer to the staff strength and shift hours. Finally, *relocation technique* will dictate how relocation is carried out. This involves setting decision rules on how to select the most critical station for relocation, and subsequently the corresponding station to relocate vehicles to or from. There are three parameters under *dynamic events*. Firstly, *trip data* refers to the pick-up and return of vehicles by users at different stations during each time step. *Staff status* refers to the availability and location of each staff at the beginning of each shift. Finally, *basic job status* refers to the frequency and occurrence of basic jobs at different time steps.

Next, relocation simulation is carried out on a time-stepping loop. At each time step, the algorithm begins by first checking if a *staff* is *available*. If no staff is available, the algorithm *waits till the next time-step*. Otherwise, the algorithm checks for a *basic job* request and only if there is none, proceeds to check for a *relocation* request. Priority is given to basic jobs over relocation in this algorithm because until basic jobs are completed, vehicles will not be available for use. In the algorithm, basic job requests are *assigned* on a first-come-first-served basis to available staff, and *staff status* for these staff is updated as unavailable for the number of time steps required for the job. Upon completion, the final location of the staff and availability and location of vehicle are then reflected under *staff status* and *station status* respectively. Once a basic job request is assigned, the algorithm *waits until the next time-step*.

In deciding whether relocation needs to be carried out, an adaptation of the 'static relocation' *(7)* approach is used. Barth and Todd *(7)* defined this as relocating vehicles based on immediate needs at a particular station. A minimum threshold is used before a relocation event is generated for a particular station, and the station with an excess of vehicles maintains a minimum threshold before it can give-up vehicles in a relocation event. At each time step, the number of vehicles in each station is checked against the station's threshold values (input earlier under station parameters). This method has however been shown by Barth and Todd *(7)* to be simple to implement, but not very efficient when compared to other predictive methods. Thus, looking only at the physical number of vehicles in the station may not be such a reliable guide. Vehicles awaiting basic jobs or reserved by users may physically be in the station but are in effect not available for use. Vehicles scheduled for return to a particular station (return time unknown) are also not accounted for. A *virtual station status* is thus created for a more realistic representation. This refers to a virtual number of vehicles at each station, which is checked against the station's threshold values to determine if relocation is necessary. The virtual number, $V_s(t)$ for station s at time step t is defined as follows:

$$V_s(t) = P_s(t) + nR_s(t) - NA_s(t) \tag{1}$$

where $P_s(t)$ is the real number of vehicles in station s at time t, n is a factor multiplied by $R_s(t)$, the total number of vehicles scheduled for return to station s as of time t (return time unknown) and $NA_s(t)$ is the number of vehicles which are not available for use because they have either been reserved or are awaiting for basic jobs. When $V_s(t)$ violates the threshold values of station s, a *relocation request* is issued, otherwise the algorithm *waits until the next time-step*. The algorithm then checks for *availability* of space or vehicles for relocation depending on whether an overflow or shortfall is identified. Subject to availability, the decision on which origin and/or destination station to relocate vehicles to and from is then dependent on the relocation technique set. These are the shortest time and inventory balancing techniques, as detailed earlier. If an available origin-destination station pair can be found, the relocation is assigned to a staff and as with basic jobs above, the *staff status* and *station status* are similarly updated. The algorithm then *waits until the next time-step*. If no available station can be found, the algorithm also *waits until the next time-step*.

At the end of each wait, the algorithm checks if it is the *final time-step* in the entire simulation. If so, the algorithm ends, otherwise, it loops back and begins checking for *staff availability* again.

Performance Indicators

Data from the simulation model is collected at each time step, analyzed and used to assess system performance. Three performance indicators are proposed as measures of effectiveness. Using these indicators, the simulation model is iteratively evaluated and used as a decision support tool in helping operators to identify enhanced operating parameter values. The impact of applying different relocation techniques under a variety of operating conditions is hence studied using a real set of commercially operational data.

The three key performance indicators proposed are *zero-vehicle time* (ZVT), *full-port time* (FPT) and *number of relocations*. When ZVT occurs, the station is without vehicles and users requesting for vehicles at that station will be rejected. Conversely, when FPT occurs, the station has no empty car park lots and users requesting to return to that station will also be rejected. Both ZVT and FPT reduce the attractiveness of shared-use vehicle systems to users. From operator's point of view, ZVT implies a possible lost in revenue. From user's point of view, ZVT forces users to use other ports, or other modes of transport, while FPT forces users to return the vehicles to other ports or later, incurring additional usage cost. As for the number of relocations, the greater the number that needs to be carried out, the higher the cost of operations. Thus, for optimal performance of the system, all three indicators need to be kept to a minimum.

Model Validation

To validate and ensure fidelity of the model, real commercial trip data from ICVS over a typical one month period was applied on the model to compare the simulated system performance against the real system performance. The validation data set has a total of 1287 customer trips and 282 relocation trips. The ICVS's system parameters for their stations, basic jobs, staff and in-house relocation techniques were first coded into the model. Next, trip data, basic jobs and staff status for inspection, refueling, etc. over a one month period were also read in. The model was then run to produce simulated values of the three key performance indicators during the one month period. All FPT and ZVT presented in this paper have been scaled by a factor m to dimensionless values in accordance to Honda ICVS's privacy policies. Comparisons of simulated against real FPT and ZVT values are presented in Figure 3. It can be observed that across all stations, regardless of simulated or real values, ZVT occurs more frequently than FPT. This is consistent with the higher priority placed on preventing FPT by the existing ICVS's relocation rules. The peak observed at station 8 is due the unique relocation priority placed by ICVS on this smaller station, with only half the usual number of car park lots. As for the number of relocations, the actual number of relocations exceeded the simulated counts by 19%, due to the unplanned and unscheduled relocations non-promoted by the system.

In general, it is observed that the simulated indicators appear capable of replicating the trends in the real indicators. They are however consistently lower in value (i.e., showing a higher level of service), which may be attributed to the near ‘perfect’ environment in the simulation. In reality, the time taken for different relocation trips for a particular origin-destination station pair fluctuates according to stochastic nature of travel time, and is dependent on the traffic condition. In addition to that, unexpected or unscheduled relocations also occur. The availability of real ZVT data at 15-minute intervals, not in a higher resolution, may also have contributed to the disparity. This difference observed between the simulation and reality is systematic in nature and in general, not an issue when comparing between different relocation techniques. While results from the simulation are likely to present a more ideal reflection of the level of service, they nevertheless show a high fidelity to the trends observed. Unless faced with chronic congestions or a high frequency of unscheduled relocations, the model should be capable of distinguishing between the impacts of different relocation techniques under various operating conditions.

Model Results

One of the key uses of this simulation model is to explore how variations in operating parameters impact system effectiveness. In this section, the simulation model has been run iteratively to evaluate and hence identify enhanced operating parameters for the ICVS. Performance indicators, ZVT, FPT and the number of relocations are used to gauge the resulting service levels.

Two relocation techniques, namely inventory balancing and shortest time were studied under a variety of operating parameters. The parameters are staff strength and shift hours, factor n in (1), threshold values and number of car park lots in each station. Each factor was varied over a range of values. These different parameter values and relocation techniques were rigorously permuted against each other. The simulation model is then applied iteratively to study the impact of each permutation using three months of real vehicle trip data. Subject to data availability, these three months of data are selected for its maximum range of vehicle to trip-station ratio, thus enabling the study of potential benefits from different relocation techniques across a wider range of data.

Results reveal that individually changing any of the above parameters does not significantly improve system performance. This is because of the interrelation between the operating parameters and their reliance on one another in the system. For example, changing the number of car park lots in a station without changing the threshold levels may result in many unnecessary relocations being triggered, causing an unnecessary rise in staff utilization. And although applying the shortest time relocation technique may improve service levels, this technique may not work so well if the virtual number of vehicles in each station is incorrectly reflected by too large or too small a factor n. Two cost effective parameter combinations are thus identified from the simulation results and highlighted below.

In the first combination denoted by C1, the use of inventory balancing relocation technique is implemented together with a relaxation in threshold values (allowing more vehicles to be taken out from corresponding stations for relocation), a 10% reduction in the number of car park lots and a 25% reduction in staff strength. Implementing inventory balancing relocation alone is found to have no significant impact on system performance because without relaxing the threshold levels, many potential relocations cannot be carried out. Conversely, relaxing the threshold levels alone without inventory balancing (a more selective relocation process) results in too many unnecessary relocations being triggered, and a staff strength bottleneck situation arises. Thus, both changes need to be effected together for enhanced performance. With this increased efficiency, resources such as car park lots and staff strength can thus be reduced for cost effectiveness.

In the second combination denoted by C2, the use of shortest time relocation technique is implemented together with a 50% reduction in the value of factor n (currently used by ICVS) in (1). As with C1, a similar relaxation in threshold values and reduction in the number of car park lots and staff strength are also applied. When threshold values are relaxed in tandem with the application of the shortest time relocation technique, unnecessary relocation are triggered. This is compounded by the artificial inflation of vehicles in station by the factor n. It is found that reducing the value of this factor enhances system performance when the above changes are effected. With this increased efficiency, resources can once again be reduced.

Besides being influenced by the relocation technique adopted and the operating parameters, the performance indicators are also primarily influenced by the vehicle to trip-station ratio. When there are x vehicles, y trips a day and z stations, this ratio is calculated as $x/(yz)$. A lower ratio means vehicles are utilized more heavily, and spread across more stations. Results generated from the simulation are thus plotted against this ratio. A comparison of simulated performance indicators for the base model adopted by ICVS against C1 and C2 are shown in Figures 4(a) and 4(b) respectively. The number of relocations have been scaled by a factor p to dimensionless values in accordance to ICVS's privacy policies.

A reduction of resources in the number of car park lots and staff strength is naturally expected to worsen the service levels, ZVT and FPT. It is however observed from both Figures 4(a) and 4(b) that when this reduction is balanced with the right combination of relocation techniques and operating parameters, performance indicators can not only be maintained but even improved for some. Excesses in the system are thus identified and eradicated. From Figure 4(a), we see that the use of inventory balancing technique in combination C1 successfully brings down the number of relocations while maintaining the ZVT and FPT levels. With shortest time relocation technique in combination C2 (where more emphasis is placed on ZVT and FPT), we can observe from Figure 4(b) an increase in the number of relocations, coupled with visible improvements in ZVT, while FPT levels are maintained. A tradeoff relationship is thus observed to exist between the service levels.

From a cost perspective, a 10% reduction in the number of car park lots together with a 25% reduction in staff strength generates cost savings of about 12.8% from the manpower cost and car park rental. Other intangible benefits such as increased operational efficiency and potential increase in profit margins are also present. It is important to note that these benefits are contingent on the stability of usage patterns. As described earlier and illustrated in Figure 1, shifts in usage patterns influence interactions in the simulation and are likely to affect performance of the system. Significant shifts in usage patterns should thus be accompanied with additional simulation runs to identify suitable adjustments to the system in order to maintain a high level of efficiency.

Model Versatility

It is interesting to note that despite the high information specificity required, the modeling framework proposed and the simulation model developed in this paper remain versatile in its application to other multiple-station shared-use vehicle systems allowing one-way trips. Differences in system configurations and travel demand impact only on the initialization process, where input data such as *operational set-up* and *dynamic events* are read in. The framework on which these data interact throughout the rest of the simulation however, remains unchanged. This model is thus easily adaptable to a wide variety of systems for the purposes of identifying efficient resource combinations and system set-up.

SUMMARY

A unique and robust simulation model with an emphasis on operator-based relocation techniques has been developed in this research, catering to multiple-station shared-use vehicle systems allowing one-way trips. A qualitative analysis conducted on operator-based relocation systems provided insights on the key issues involved and their influences over each other. Based on this analysis, a versatile time-stepping simulation model was developed. Essentially functioning as a decision support tool, this simulation model aids multiple-station shared-use vehicle operators in identifying the efficient resource combination and system set up. Validated against a set of commercially operational data from a local shared-use vehicle company, the model showed a high fidelity in replicating performance indicator trends observed in the real data. Through an intensive iterative process, simulations on two proposed relocation techniques, permuted against a variety of operating parameters were carried out using a set of commercially operational data over a three month period. Three performance indicators were proposed to evaluate the effectiveness of the system. The results have identified two cost effective parameter combinations, generating cost savings of approximately 12.8%.

Although a cost reduction approach is taken in this research using ICVS as a case study, it should be noted that the versatility of the simulation model also allows for easy adaptation to other shared-use vehicle systems with different operating conditions.

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LIST OF FIGURES

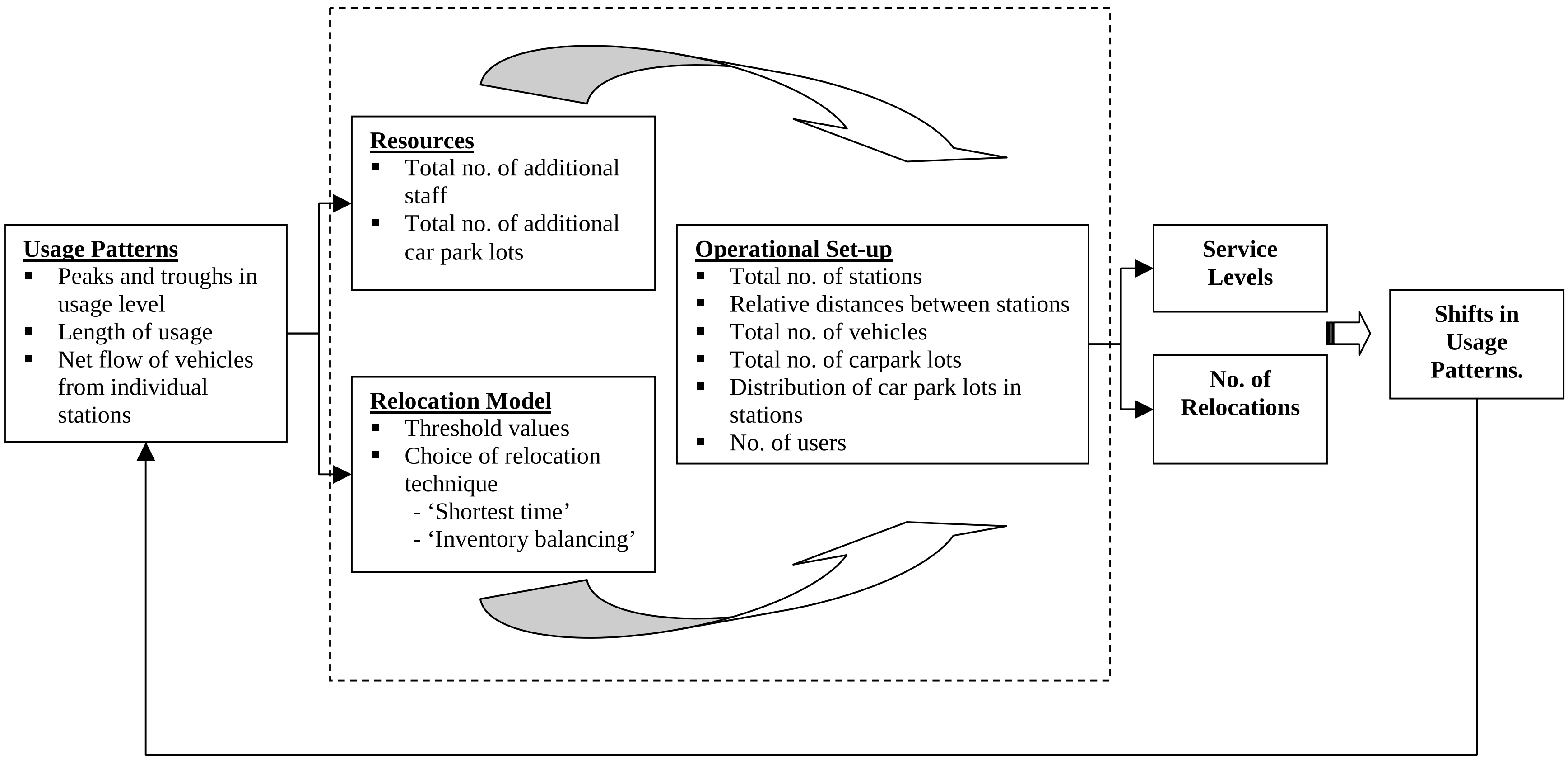


FIGURE 1 Interactive dynamics between components in an operator-based relocation system

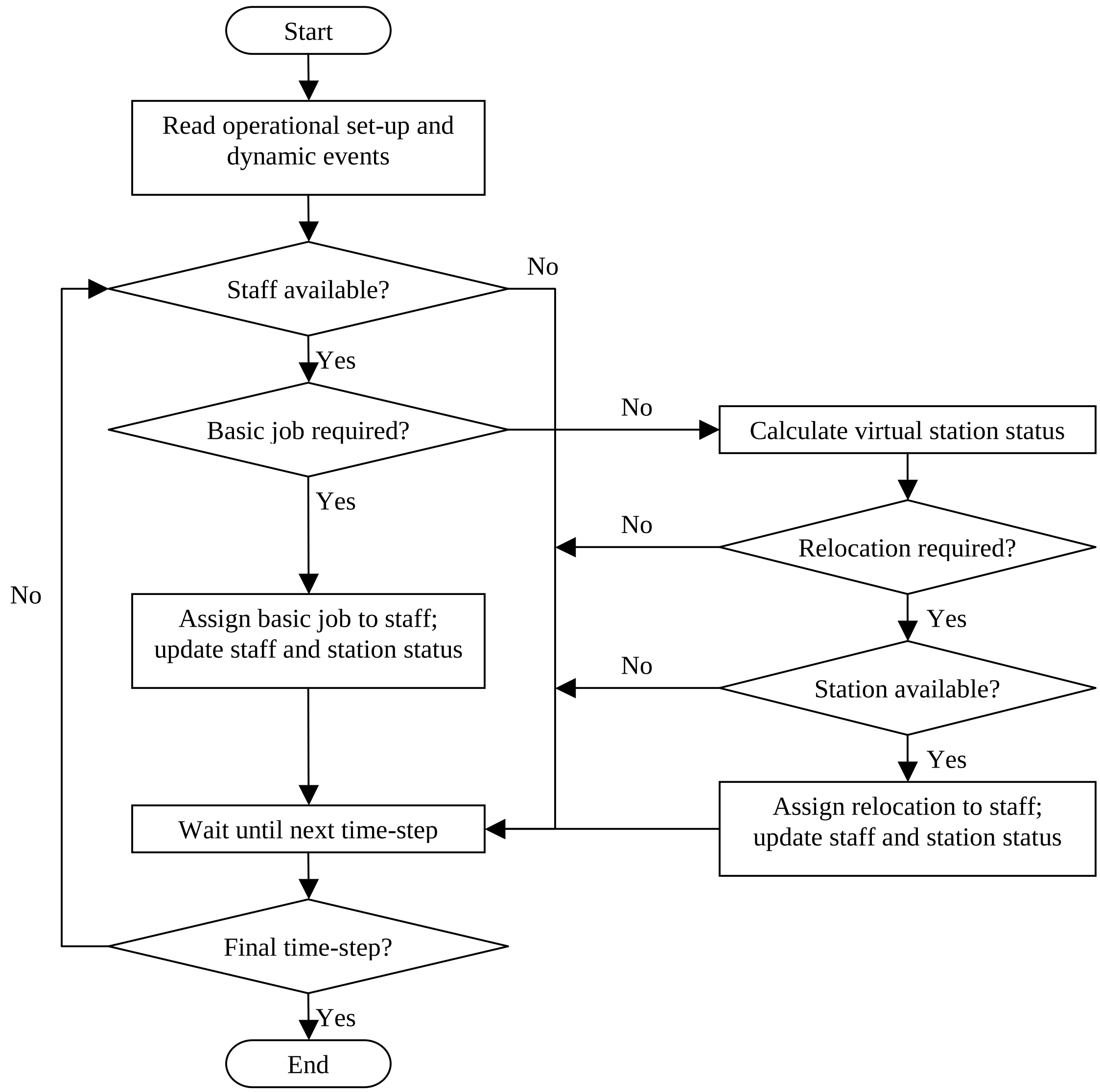
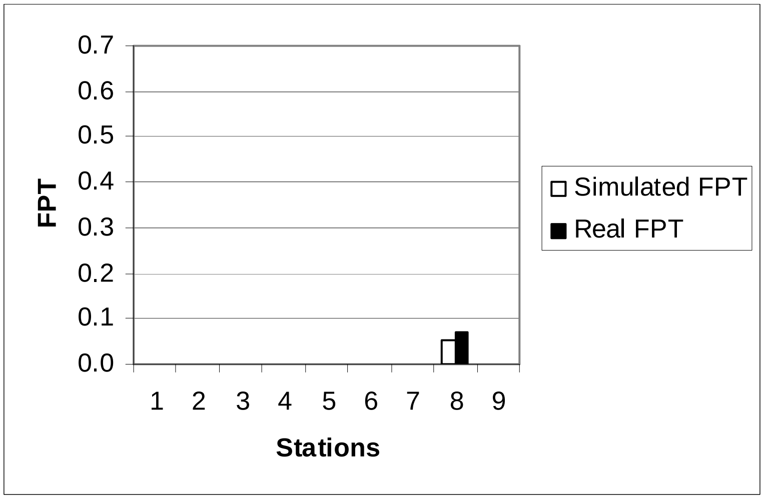
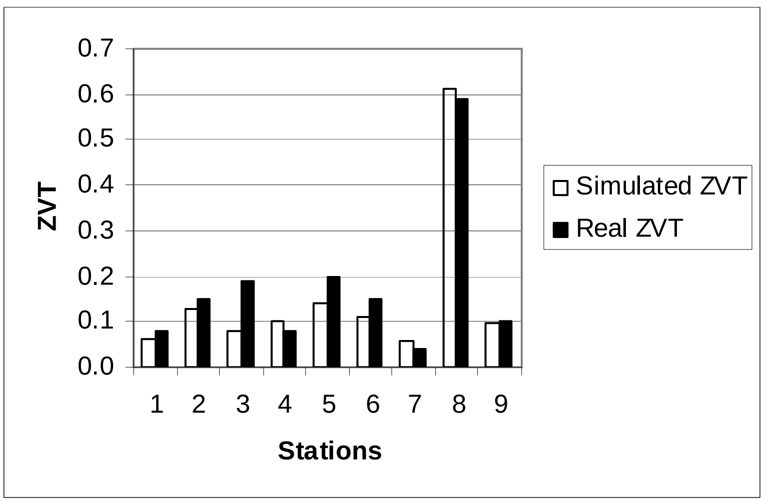


FIGURE 2 Simulation algorithm flowchart

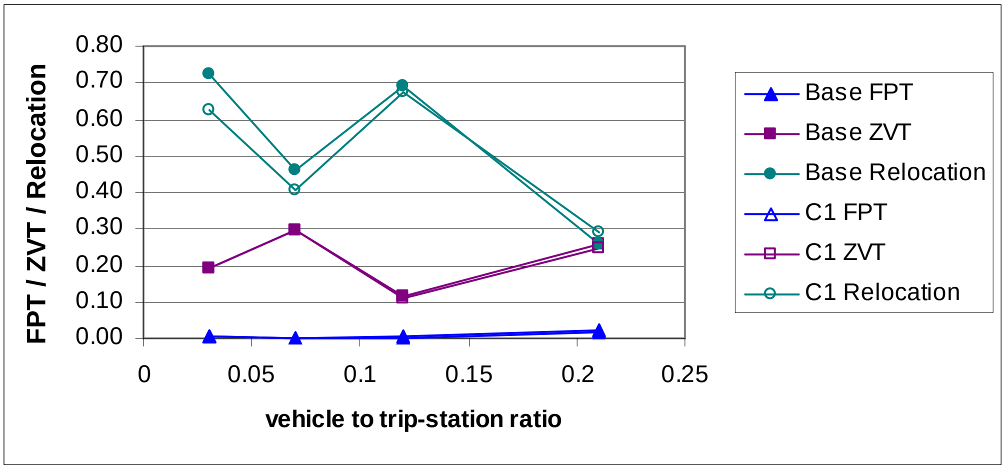


(a) Comparison of real against simulated FPT

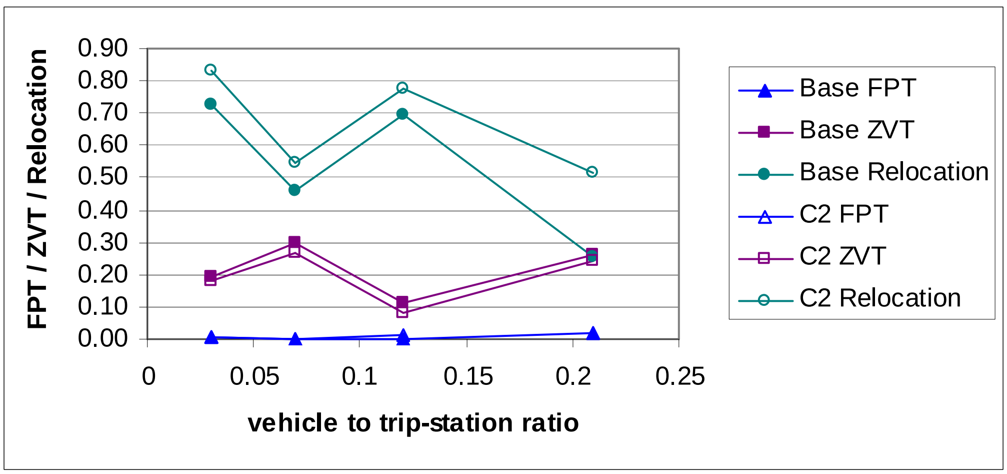


(b) Comparison of real against simulated ZVT

Figure 3 Comparison of FPT and ZPT during model validation
(values of plotted FPT and ZVT have been scaled to dimensionless values)



(a) Comparison of C1 and the base model



(b) Comparison of C2 and the base model

FIGURE 4 Comparison of simulated performance indicators