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Evaluation of carsharing network's growth strategies through discrete event simulation

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ABSTRACT

Carsharing organizations are nowadays faced with the emergence of new markets due to the growing popularity of their services. To keep up with the growing demand, they have to constantly adapt their network and balance their stations' capacities by implementing new strategies. These strategies involve creation of new carsharing stations, increasing the capacity of stations, merging or demerging carsharing stations etc. Currently, the decision makers rely on an intuitive strategy selection process which often results in inadequate decisions being made representing an immediate loss in resources, time and market penetration. This paper presents a discrete event simulation based decision support tool that assists the decision makers in selecting best network growth strategies to implement for meeting adequately the demand growth while maximizing the members' satisfaction level and minimizing the number of vehicles used. Our discrete event simulation model allows modeling the activities at any given set of carsharing stations, regardless of their number and capacities. A benchmarking comparison of different potential strategies is done. An application of the proposed model on a region of Communauto's Montréal (Québec, Canada) carsharing network is provided.

1. Introduction

Carsharing is an alternative form of private transportation whose primary objectives are to reduce the load of public transportation as well as decrease the number of vehicles on the roads and therefore reduce traffic congestion. These services rely on a fleet composed of small to large vehicles at numerous stations located throughout a given region, composing the carsharing organization's (CSO) network. Its members get access to vehicles by making a reservation in advance or by taking the vehicle on-the-go, depending on the operational model used by the CSO (Awasthi, Parent, Reverllere, & Breuil, 2005; Axhausen, Balmer, & Ciari, 2008; Shaheen, 2000; The World CarShare Consortium, 2009).

According to Moses report on *mobility services for urban sustainability* (2005), this new transportation mode is particularly prevalent in regions where there is a significant amount of pressure for parking spaces. Moreover, the high density population, which is relatively intertwined with the previous factor, influences greatly the success magnitude of such a system. This factor has been measured to be ideally above or equal to 100,000 people per km^2. Moreover, a reliable public transportation service is fundamental to the long-term success of the carsharing stations since people need to easily access them throughout the year, be it in summer or winter; hence, the greater the number and frequency of public transportation access links are, the higher the probability of local carsharing success (Awasthi, Chauhan, & Breuil, 2009; Barth, Shaheen, & Todd, 2004; Cohen, Darius, & Shaheen, 2006; Drews, Welch, Juedes, & Fleeman, 2004; Fukuzawa, Shimazaki, & Shimohara, 2005). Furthermore, it has been proven by several authors that stations should be located on average at less than 10 min walking distance from the members' households or locations (such as train stations, etc.). Celsor and Millar-Ball (2007) evaluated this distance, referred as the *station's radius of action*, to 800 m. Nevertheless, when analyzing a given CSO's network, it is worth mentioning that this value should only serve as a competitive benchmark since each carsharing network has its own specificities and dynamics and, therefore, can eventually efficiently perform even with a higher distance factor (Mokhtarian, Shaheen, & Stillwater, 2008).

In this paper, we present a decision support tool based on discrete event simulation that will allow any CSO to model a given set of stations, where a growth potential has been preliminarily identified, and test different growth strategies to effectively satisfy the demand. It is worth mentioning that this approach,

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primarily based on a discrete event simulation (DES) model (Kelton, Sadowski, & Sturrock, 2004), has the capability of modeling any stations set's size, from two stations to the overall CSO's network, regardless of the number of vehicles used. In literature, very few quantitative studies have been carried out for simulation based performance evaluation of carsharing network growth strategies. Barth and Todd (1999) present simulation model performance analysis of a multiple station shared vehicle system. Nakayama and Kitamura (2007) present simulation analysis for the management of an electric vehicle–sharing system in Kyoto. Fan, Machemehl, and Lownes (2008) present a dynamic decision-making model for vehicle allocation in carsharing service. Kek, Cheu, and Chor (2007) present a relocation simulation model for multiple-station shared-use vehicle systems.

The rest of the paper is organized as follows. In the next section, we define the four prerequisite activities necessary for the implementation of the DES model. Section 3 presents the proposed discrete event based simulation model for evaluating carsharing network growth strategies. In Section 4, we present an application of the proposed model through case study on Communauto Inc. in Montreal. Finally, the conclusions and future work are provided in Section 5.

2. Model prerequisites for the network qualification

The four prerequisites for developing the DES model are network segmentation, network region selection, member's segmentation, and growth factor selection. These are explained in detail as follows:

2.1. Network segmentation

In any CSO network, there exist several market trends due to its heterogeneous nature. These trends are often dictated by the demographic, socio-economic and operational indicators. Grasset (2009) identified seven indicators for segmentation, six being demographic factors (age, employment rate, average household income, population density, average number of persons per household, education level and native language), and the remaining corresponding to a public transportation access index. Using hierarchical agglomerative clustering (HAC), he identified several distinctive networks for which two major parameters were evaluated: the *average distance of households to stations* (in meters) and the aggregated *market growth rate* (% per year or season). As far as our study is concerned, the first parameter is essential for identifying the average station's radius of action in order to cluster the targeted network users, whereas the second one serves as an input to the DES model to simulate the future network activity.

2.2. Network regions' selection

The network region selection involves determining priority regions where carsharing would be of interest to users. Our region selection technique is based on Grasset (2009) and consists of measuring the offer dispersion of the regions based on two main factors: the *station's average center* (SAC, based on the geographical coordinates of all the stations), and the *fleet's center of* gravity (FCG, based on the capacity and location of each station). For both SAC and FCG, we compute the dispersion ellipse, which categorizes both the vertical and horizontal spatial distribution of, respectively, the set of stations and its corresponding fleet. The length of each spatial axis corresponds to two times the standard deviation of the data, which then encloses 68% of the data points. We then obtain a graphical representation of the growth potential of all the network's regions along with the stations' locations and capacities, represented by their radius. The magnitude of the ellipse expansion through time is a valuable indicator of whether there is a higher growth level within the ellipse or in its surrounding area. Then, in order to identify the development niches throughout the network, we use a graphical technique, which consists in comparing the network's map for successive periods of time. This can be done by graphically superposing two maps and circling the regions where new stations were created or existing stations expanded. This overall method enables one to determine the priority regions where such a study should be conducted along with their respective set of stations. An illustration of this technique is presented in Section 4.

2.3. Members segmentation

This step involves segmenting the potential carsharing members/users of a region based on their willingness to join a carsharing service offered in the region. The members' segmentation is based on the principle: "*each member selects the nearest station to his/her household location for his/her trip*". We use the geographical distances between the members' households and the region's stations to perform segmentation. The segmentation process is divided into six steps. In the first step, we select the *active members*, that is, members having performed at least one transaction during the preceding year. The second step computes the *active members' distances in kilometers to all the region's stations*. We use the Great-Circle Distance (2009) defined as the shortest distance between any two points on the surface of a sphere measured along a path on the surface of the sphere. Assuming that the Earth is a perfect sphere, the great-circle distance ($D(S_j, m_i)$), is defined by the following formula,

$$D_{S_j}^{m_i} = 1.05 * d * 2\arcsin\left(\sqrt{\sin^2((La_{m_i} - La_{s_j})/2) + \cos(La_{m_i}) * \cos(La_{s_j}) * \sin^2((Lg_{m_i} - Lg_{s_j})/2)}\right) \quad (1)$$

where: La stands for the latitude of the subscript (radians), Lg for the subscript's longitude (radians), m_i for the active member # i, S_j for the carsharing station # j and d for the radius of the Earth (6371.01 km).

The third step involves the *region's members' selection*. To select the relevant members to the region's study, we use the radius of action as the selection criterion. Two types of regions are considered: a homogeneous versus a heterogeneous region. A homogeneous region is composed of only one specific network segment whereas the heterogeneous region can be, theoretically, composed of several ones. However, for modeling purposes, the studied region should be delimited in the way that it does not include more than two categories; otherwise, the simulation model may result in unrealistic and/or disjointed outputs. In order not to overlook the inclusion of members living at the limit of the zone defined by a circular area whose center is the station location and radius the network's segment distance, we have used a 20% margin. By compensating the selection criterion with this factor, we finally obtain the final following formula,

$$\text{Homogeneous } SC_{ho,r} = 1.2 * C_k \quad (2)$$

$$\text{Heterogeneous } SC_{ht,r} = 1.2 * \left(\sum_{k=1}^{2} N_k * C_k\right) \Big/ n \quad (3)$$

where: N_k stands for the number of stations belonging to network segment # k, C_k for the average distance to stations of network segment # k, n for the total number of stations in studied region, $SC_{ho,r}$ *and* $SC_{ht,r}$ for the selection criterion of respectively homogeneous and heterogeneous region r.

In the fourth step, we perform *region's members high-level grouping*. For each member i, we determine the number of