Evaluating car sharing fleet management strategies using Discrete Event Simulation

Alfred John Chellanthara

A Thesis

in

the Department

of

Concordia Institute of Information Systems Engineering

Presented in Partial Fulfillment of the Requirements for the Degree of

Master of Applied Science (Quality Systems Engineering) at

Concordia University

Montreal, Quebec, Canada

October 2013

CONCORDIA UNIVERSITY

School of Graduate Studies

This is to certify that the thesis prepared

By: Alfred John Chellanthara

Entitled: **Evaluating car sharing fleet management strategies using Discrete Event Simulation**

and submitted in partial fulfillment of the requirements for the degree of

Master of Applied Science (Quality Systems Engineering)

complies with the regulations of the University and meets the accepted standards with respect to originality and quality.
Signed by the final examining committee:

________________________Chair

Dr. Chun Wang

________________________Internal Examiner

Dr. Amin Hammad

________________________Examiner External

Dr. Govind Gopakumar

________________________Supervisor

Dr. Anjali Awasthi

Approved by ________________________________

Chair of Department or Graduate Program Director

_________2013 ________________________________

Dean of Faculty

Abstract

Evaluating car sharing fleet management strategies using Discrete Event Simulation

Alfred John Chellanthara

Concordia University

Dynamic fleet management is often faced with the problem of managing real time customer requirements and unforeseen events that affect the performance of transport operations. In a car sharing organization, vehicle availability is considered as a measure of quality of service, which is defined by the availability of a car at the time when the user arrives at the station. This thesis presents a decision support tool in order to test the efficiency of a round trip (return to same station) model as compared to a one way (return to any station) model for fleet management in a car sharing organization. The proposed tool employs a discrete event simulation (DES) model which evaluates rejection rate for each of the individual strategies and recommends the one with least number of rejections. A case study is conducted on the CommunAuto car sharing network of Montreal. The results show that the one way model has a greater request rejection rate with an average rejection rate of 13%, while the round trip model has an average rejection rate of 8%. The utilization rate of the round trip model is much higher with 92% utilization as compared to the one way model which has a utilization rate of 87%. Therefore, the round trip model is recommended to CommunAuto for managing its current fleet operations.

Acknowledgements

I wish to acknowledge my supervisor Dr. Anjali Awasthi, who has not just been a guide and a supervisor, but also a mentor. I would like to appreciate her constant motivation and patience, which has helped me to strive for more throughout the course of my thesis work.

I wish to acknowledge my family and friends for their love and support. I'd like to thank my fellow research lab mates for their constant support. I would like to thank my friend Anubhuti for all his help. Also I would like to thank CommunAuto in particular Mr. Marco Viviani for providing me with this opportunity to work on the project.

Finally I'd like to thank God for all the blessings he has showered upon me.

I dedicate this work

to my dear parents, Elsy & John.

Table of Contents

List of Figures ... viii

List of tables ... ix

Chapter 1 Introduction ... 1

1.1 What is car sharing? ... 1

1.2 How does car sharing work? ... 2

1.3 What are the types of car sharing organizations? ... 3

1.4 When does it work and who are the target group of people? ... 3

1.5 When does it not work? ... 4

1.6 Car sharing around the world ... 5

1.6.1 History ... 5

1.6.2 Actual list of CSO in the world ... 7

1.6.3 Government support ... 8

1.7 About CommunAuto ... 9

1.8 Future of car sharing ... 10

1.8.1 Electric vehicle ... 10

1.8.2 Multimodality ... 10

1.9 Thesis contribution ... 11

1.10 Organization of the thesis ... 12

Chapter 2 Literature Review ... 13

2.1 Fleet management ... 13

2.2 Problems in dynamic fleet management ... 14

2.2.1 Weather ... 15

2.2.2 Traffic ... 15

2.2.3 Accidents ... 16

2.2.4 Uncertain demands ... 16

2.2.5 Immediate demands ... 17

2.3 Possible solutions to the problems in dynamic fleet management ... 18

2.3.1 Optimization ... 19

2.3.2 Simulation ... 22

Chapter 3 Problem Statement ... 27

Chapter 4 Solution Approach ... 29

4.1 Setting of objectives and overall project plan ... 32

4.2 Input modeling 32

4.2.1 Data collection 33

4.2.2 Identifying probability distribution 36

4.2.3 Data generation 40

4.3 Model conceptualization 42

4.4 Model translation 45

4.4.1 DES algorithm 45

4.4.2 Elements of the DES model 48

4.5 Verification 51

4.6 Validation 53

4.6.1 Parameter-variability sensitivity analysis 54

4.6.2 Face validity 54

Chapter 5 Model development in Arena 56

5.1 Assumptions 56

5.2 Model explanation 57

Chapter 6 Case Study for CommunAuto 76

6.1 Input parameters 76

6.2 List of elements 77

6.3 List of input files 78

6.4 Output Analysis 78

6.4.1 Alternative Configurations 83

6.4.2 Recommendations for Communauto 87

Chapter 7 Conclusions and future work 90

7.1 Conclusions 90

7.2 Future work 91

References 93

Appendix A 107

Appendix B 112

List of Figures

Figure 1: Canadian carsharing growth from 1998-2012 (Shaheen and Cohen, 2012) 7
Figure 2: Network map of CommunAuto stations across Montreal city....................................... 9
Figure 3: Problems in dynamic fleet management.. 14
Figure 4: Solutions to dynamic fleet management problems 18
Figure 5: Steps in simulation study (Banks et al 2010)... 31
Figure 6: Average number of hours per reservation for the year 2011 for CommunAuto 34
Figure 7:Number of reservations per month for year 2011 for CommunAuto 35
Figure 8: Random number generation in Excel 40
Figure 9: Process map 44
Figure 10: Flowchart for the DES algorithm... 47
Figure 11: Request generation module blocks... 58
Figure 12: Create block attributes.. 58
Figure 13: ReadWrite attributes for request create module.. 59
Figure 14: Record attributes for the request create module.. 60
Figure 15: Car Creation module 60
Figure 16: Create attribute for car creation module 61
Figure 17: ReadWrite attributes for for car creation module.. 62
Figure 18: Route attributes for car creation module 63
Figure 19: Request rejection module 64
Figure 20: Create attribute for request rejection module.. 64
Figure 21: Decide dialog box attributes for request rejection module 65
Figure 22: Remove dialog box attributes for request rejection module 66
Figure 23: Record dialog box attributes for request rejection module.. 66
Figure 24: Main module... 67
Figure 25: Match dialog box attributes for Main module 68
Figure 26: Station dialog box attributes for main module.. 69
Figure 27: Batch dialog box attributes for main module.. 70
Figure 28: Record dialog box attribute for the main module 71
Figure 29: Delay dialog box attrtibutes for main module 71
Figure 30: Separate dialog box attribute for main module 72
Figure 31: Decide 1 dialog box attribute for main module 72
Figure 32: Assign 3 dialog box attributes for main module 73
Figure 33: Delay 2 dialog box attributes for main module.. 73
Figure 34: Assign 2 dialog box attributes for main module 74
Figure 35: Record new car value dialog box attribute for main module..................................... 75
Figure 36: Route 2 dialog box attributes for main module.. 75
Figure 37: List of selected stations mapped on Google Earth 81
Figure 38: List of stations with the output display parameters.. 82

List of tables

Table 1: Summarization of studies on car sharing 25
Table 2: Sample input table for the round trip model 41
Table 3: Sample input table for one way model 41
Table 4: Sample input table for the number of cars at each station 42
Table 5: Sample data verification 52
Table 6: Sample data verification cars 53
Table 7: Number of tests and the corresponding results 54
Table 8: High rejection stations 55
Table 9: Stations with good acceptance rate 55
Table 10: List of elements in DES model 77
Table 11: List of files in the DES model 78
Table 12: Sample output report table for one way model 79
Table 13: Dialog box format 83
Table 14: Sample output for one way model 84
Table 15: Sample output for one way model with alternative configuration 84
Table 16: List of stations with high rejections 85
Table 17: List of stations with zero rejections 85
Table 18: New value of stations after alternative configuration 86
Table 19: The actual list of CSO in the world (http://www.carsharing.net/where.html) 107
Table 20: Detailed results of the One way model for Test_1 112
Table 21: Detailed results of the Round_trip model for test 1 119

List of acronyms

DES	Discrete Event Simulation
CSO	Car Sharing Organization

Chapter 1

Introduction

This chapter focuses on the concept of car sharing, the working of car sharing, about its history, the problem statement, the thesis contribution, and finally about the structure of the thesis.

1.1 What is car sharing?

A Car Sharing Organization (CSO) operates a small to a medium size fleet of vehicles for its members at designated stations spread over a city (Shaheen *et al.,* 1999). Over the past decade Car Sharing Organizations have been on the rise and use of carsharing vehicles is considered as an alternative to owning a vehicle (Kek *et al*., 2009). A car sharing organization is mostly defined by its environmental and social purpose such as decreasing personal car ownership, reducing the vehicle distance travelled, positively impacting urban mobility, and reducing the emission of greenhouse gases (What is Car Sharing org, 2013). There is often confusion between car rental, ride share and car sharing. The most common difference between a car sharing organization and a car rental is that car sharing is convenient for people who want to rent a car for a shorter period of time and want to be billed based on the usage which is basically the distance travelled. Ride sharing is a totally different concept than car sharing and car rental. The ride sharing system is similar to a car pooling system wherein the owner of a car decides to share the journey of the car with one or more person travelling to a common destination.

1.2 How does car sharing work?

A CSO provides its members with shared-use vehicles for a short period of time such as few hours, to almost up to a day or a week. The CSO has its fleet of vehicles stationed at various parking stations geographically distributed throughout the city and more concentrated towards the members residence or close to the nearest public transportation station. Each member selects the nearest station to the member's household location for beginning his/her trip (El Fassi *et al*., 2012). The members need to sign up with the CSO for an annual fee, after which they could choose from any of the offered service plans as per their needs or requirements. In order to commence a trip the vehicle has to be reserved either online or through telephone beforehand for a specific trip, and the vehicle is made available to the member at the nearest station. Once the member finishes the trip, the car is returned back to its original station. Due to the rise in competition among car sharing organizations, some CSO's provide the flexibility of returning the car to any station (Kek *et al*., 2009). The member is billed at the end of each month for a specific fixed fee plus a mileage based charge according to their individual usage or distance travelled.

1.3 What are the types of car sharing organizations?

The different types of CSO's are peer to peer, business to consumer and not-for-profit. In a peer to peer CSO, the owner of a car lets other drivers rent his/her car for a certain fee on an hourly basis or daily basis. Few examples of such type of car sharing are RelayRides, Wheelz and Getaround. In a business to consumer type of CSO, the company owns a fleet of cars which is shared among its members for a fee and a charge based on the usage. Some examples of such type of CSO are Communauto, Zipcar, Statauto and Goget. The not-for-profit or co-op CSO is more concerned about changing the driving habits within a community or a local organization than making a profit; examples of such type of CSO are City Car Share, Philly Car Share and I-GO Chicago (Future of Car Sharing, 2013).

1.4 When does it work and who are the target group of people?

Andrew & Douma (2006) state the various reasons for a CSO to be successful in any neighborhood based on the following points:

1. High density of individuals within the age group of 21-39.
2. Large proportion of residents commuting by walking or by transit.
3. Parking space is not easily available or expensive.
4. High residential density.

The target groups are as follows (Koch, 2001):

1. **Residents**: The resident user group can be classified based on various types such as social which are from the low to average income types, who do not travel frequently and who prefer sharing a car than owning one, and the ones who travel more frequently but also make use of public transit.
2. **Employers**: Employers are a target group of CSO as more and more companies are providing their employees with the facility of using a car to travel for work.
3. **Independent** (**self-employed**): The independent and self-employed groups of people make use of CSO as a means to reduce the overhead costs.
4. **Tourists**: There have been an increasing number of tourists opting for car sharing services over car rental services. However, it has been observed that car sharing is a better choice 99% of the time when the tourist destination is a city and only 26% when the destination is a region (Danielis *et al.*, 2012).

1.5 When does it not work?

The most common reasons a CSO would not work in a community or a city are as follows:

- The public transport system of the community/city is under-developed which makes it necessary for the people to own a car.
- The public transport system is so well developed, reliable and affordable that owning a car seems expensive and cumbersome.

- Driving conditions are difficult because of various reasons such as bad driving conditions, high levels of congestion, severe parking problem and so on (The Moses guide, Chapter 1).

1.6 Car sharing around the world

This section explains how car sharing came into existence and about the various CSO across the world and the government and community support provided to the CSO's.

1.6.1 History

Car sharing can trace its existence back to as early as 1948 by a company named Sefage (Selbstfahrergemeinschaft) in Zurich, Switzerland. The reason for the car sharing organization was economically motivated and primarily founded for people who could not afford a car (Harms and Truffer, 1998). This gave rise to a series of other CSO in the 1970/80 era around Europe. For e.g. PROCOTIP in Montpelier and Witkar in Amsterdam, both of the CSO were not successful and had to shut down operations due to organization or technical problems (Muheim, 1996; Doherty *et al*.,1987). By the late 1980's more and more successful car sharing experiences started all over Europe from Switzerland, Germany, Austria, the Netherlands, Denmark, Sweden, Norway, Italy and Great Britain. The late 1990's saw the birth of two of the oldest and largest CSO's as of then, Mobility CarSharing Switzerland (a May 1997 merger of Auto Teilet ATG AutoTeilet Genossenschaft (ATG) and ShareCom Genossenschaft) and Stadtuto Drive in Germany (Shaheen *et al.,* 1999). By 1997 the French Praxitele started its operations from

11 Praxiparcs across transit stations and office blocks. However, after two years of operation the program ended because of less demand and high costs (Massot and Lapierre, 1999).

Car sharing across North America in the 1980's was demonstrated by two formal carsharing programs. The first one was Mobility, operated as a Purdue University research program from 1983 to 1986 in West Lafayete Indiana and the second one was Short Term Auto Rental (STAR) which was operated as a private enterprise from 1983 to 1985 (Doherty *et al*.,1987). However, both the CSO stopped as Mobility Enterprise was deployed as a research experiment and STAR failed half way through the planned three year program. The first and oldest CSO of North America located in Quebec City named Auto-Com was initially started as a nonprofit cooperative, later changed to for-profit business in 1997. CommunAuto was launched by the same group in Montreal in September 1995 as a for-profit business (Shaheen *et al.,* 1999). There has been immense growth of car sharing in Canada over the past years as highlighted in the figure below (Shaheen and Cohen, 2012).

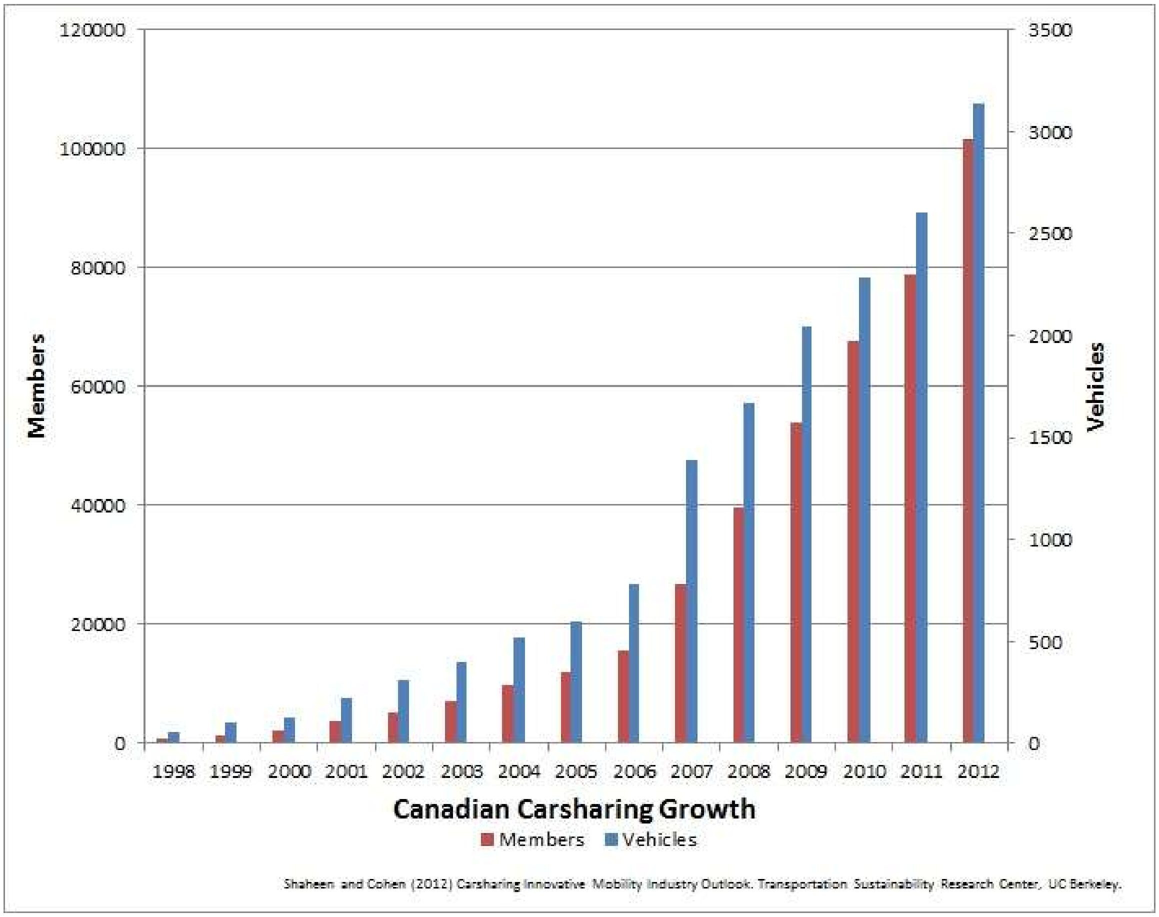

Figure 1: Canadian carsharing growth from 1998-2012 (Shaheen and Cohen, 2012)

1.6.2 Actual list of CSO in the world

The actual list of CSO in the world is provided in the appendix A. The list contains the city/region, organization name, charges per 4 hour trip, the size of the CSO, and whether the CSO is a non-profit or for-profit organization. The most common and renowned ones are ZipCar, Car2go, CommunAuto and so on.

1.6.3 Government support

Car sharing organizations help in reducing congestion and ease the space requirement for cars in the city which could in turn be used for parks, facilities for pedestrians and cyclists and make the city more attractive. The government can therefore support and influence car sharing among citizens. The Moses guide: Keys to car-sharing discusses about the various ways the government can contribute to the success of car sharing which is as follows:

- **National and regional level**: The government can help by allocating on street road-space for car sharing vehicles. The national government can help CSO not just in terms of policy but also with regards to funding, for example in the year 2000 the Italian government provided 9.3 million Euros for car sharing schemes in 8 Italian cities.
- **Local municipalities**: The city planning department can provide a framework that could include the car sharing at the strategic planning level by identifying land that should be safeguarded for car sharing infrastructure, also setting out expectation that new developments contain car-free elements.
- **Land and property administration**: The government can also help by administering that developers have generated enough funds to support car sharing infrastructure and setup costs, assembling and making land is available for car sharing vehicles, and limiting the number of CSO in the city through the use of tender.

1.7 About CommunAuto

Communauto is a privately owned car sharing organization founded in the city of Québec in 1994 and was then merged with its competitor, Auto-com, in 2000. Since then, Communauto has expanded its activities in a large portion of the Quebec province by servicing four different agglomerations: Québec, Montréal, Gatineau and Sherbrooke. By May 2012, Communauto had a total of 36000 members, 883 vehicles, and 330 stations. The network map of the 330 CommunAuto stations across the city of Montreal is shown in figure 2 below:

Figure 2: Network map of CommunAuto stations across Montreal city

1.8 Future of car sharing

In this section we discuss about the future direction of car sharing organizations, the use of electric vehicles to further reduce the level of Co2 emissions, use of one way versus the round trip mode of transport, and finally integration of car sharing in multimodality.

1.8.1 Electric vehicle

There has been an increasing number of CSO's who have introduced electric vehicles (EV) to their existing fleet of vehicles. CommunAuto which is one of the oldest and the largest car sharing organization in Montreal, has introduced 50 EV which include the Nissan Leaf. This is also the largest EV fleet available to the people of Canada. According to *Self Service Electric Vehicle in Canada* survey, 81% of the EV users found the service as very good, for 16% it wasn't so good, and for remaining 3% it was good. 61.84% of people said they would book an EV if it was available, 13.16% said they would only book the EV and 25% said they would try both type of vehicles from time to time (Viviani, 2012).

1.8.2 Multimodality

In order to make car sharing go hand in hand with the public transport certain factors have to be addressed. The presence of a car sharing station near a public transport hub could lead to a smooth integration of both modes of transport. Making the customers aware of the cost difference between owning a car and having combination of public transport along with car sharing system can enhance its usage. Providing schemes to the customer for the combination package of car sharing along with public transport would encourage the customers to try the services. CommunAuto provides its customers a scheme for a 12 consecutive month transit pass along with the car sharing membership leading to savings up to 36$/year.

1.9 Thesis contribution

The contribution of the proposed thesis is a DES model that could help car sharing organizations in selecting between a round trip model versus a one way model. The simulation model can present detailed results such as the number of cars present at each station at the start of the simulation, the number of cars present at each station at any given time, the number of rejections at each station, the utilization rate, and finally the total request rejection rate that facilitates decision making. The proposed model is designed in such a way that it works for both one way trips as well as the round trip for return of vehicles, just the inputs for the models are changed. The output also helps analyze the utilization rate of each individual station, which could be used in order to move the cars from the less utilized stations to the one with more utilization. The model can also be used by other dynamic systems such as bikesharing . The results of the model can help the operator in making a decision about the less utilized stations, stations with more cars, and decisions of rerouting cars to stations with higher rejection rate. Hence, by making use of the proposed simulation model as a decision support tool to decide the type of fleet management model that better fits the CSO's needs, customer dissatisfaction and poor levels of quality which would eventually lead to end of service can be prevented (Mitchell *et al.*, 2010 ; Tan, C. 2008).

1.10 Organization of the thesis

Chapter 2 presents the literature review.

Chapter 3 states the problem definition.

Chapter 4 explains the DES based solution approach.

Chapter 5 presents the proposed DES based simulation model development in Arena.

Chapter 6 presents a case study on CommunAuto using the proposed simulation model.

Chapter 7 provides the conclusions and the future works.

Chapter 2

Literature Review

In this chapter, we present the literature review on fleet management, the various common types of problems that occur in dynamic fleet management and the possible solutions, why the simulation method and in particular the DES method is suitable for addressing fleet management problems.

2.1 Fleet management

Fleet management models can be traced back to as early as 1950's which made use of state time network in order to formulate the problem in fields of aircraft, tankers and freight cars (Dantzig and Fulkerson, 1954; White, 1972; White and Bomberault, 1969; Ferguson and Dantzig, 1955). But these models were mostly deterministic assuming the load time in the planning horizon was known in advance. Several fleet management models that took into consideration stochastic demands were also developed in the late 1980's-90's (Crainic *et al*., 1993; Jordan and Turnquist, 1983; Frantzeskakis and Powell, 1990). There has been extensive research done in the field of fleet management. Some methodologies include optimal solution for fleet management problems in underground mines using enumeration algorithm based on dynamic programming (Beaulieu and Gamache, 2006). Pasquier *et al.* (2001) highlights heuristic approach that includes the Black-Board based approach for dynamic transportation-planning problem.

Technological tools such as software algorithms and simulation software have been used in order to solve fleet sizing and allocation problem (Kochel *et al.*, 2003). Fleet management is a very diverse field since it deals with managing fleets of rail, aircrafts, buses, taxis, cars and so on. Hence, our literature review is limited only to dynamic fleet management problems of cars and the solution approaches using various methodologies but mostly concentrating on simulation.

2.2 Problems in dynamic fleet management

The travel times in dynamic fleet management models are assumed to be deterministic. However, various hindrances in the form of weather conditions, traffic blocks, and accidents can cause changes in the travel time schedule. Also customer demands especially immediate demands and uncertain/stochastic demands can cause discrepancy in the system as well. In the following section we will look at each of these problems individually. The figure below lists the problems in dynamic fleet management.

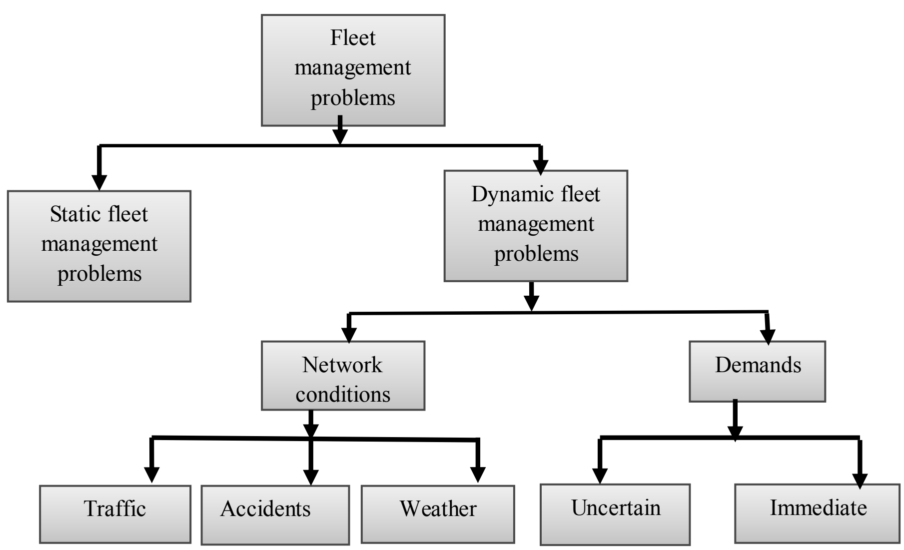

Figure 3: Problems in dynamic fleet management

2.2.1 Weather

Weather can disrupt the transport services across all modes. Sometimes it could be disrupting the road usage by reducing the highway capacity (in case of adverse weather),or increasing vulnerability in the system (due to floods), also disrupting the transport public transport services etc (Nagurney *et al*., 2010). Sumalee *et al*., (2010) shows how weather can also play a pivotal role in influencing the traveler's behavior, for e.g. adverse weather can cause a route diversion, or rescheduling the trip. There have been various studies by Chen *et al*., (1999); Kurauchi *and* Sumalee, (2008), and Taylor, (1999) about effects of adverse weather on transport in the context of network reliability and vulnerability. Adverse weather can also result in degradation of transport system there by restricting access to the stations (Al-Deek and Emam, 2006).

2.2.2 Traffic

In the past 20 years there has been a tremendous increase of traffic on the roads in US and elsewhere (Schrank and Lomax, 2007). Traffic congestion can cause a lot of disruption in the transport services from increasing the response time of emergency service vehicles to increasing wear and tear on vehicles (Cassias, 2005). Studies show that the increase in traffic volume leads to a probable increase in delay (i.e., ≥ 8 min) of the ambulance to travel to the scene (Trowbridge *et al*., 2009). World Health Organization (2005) and Health effects institute (2010) show that traffic congestion contributes to pollutant emissions which degrade the air quality and contribute to risks of morbidity and mortality for drivers and commuters living near roadways. Traffic has a tremendous effect on average speed of the vehicle; it lowers the average speed thereby increasing the travel time and exposure per vehicle. The driving pattern (e.g. speed up, slowdowns, start and stop) is also influenced by congestion, which eventually leads to increase in emission levels (Kai Zhang and Batterman, 2013). The Texas A&M Transportation Institute with the insight from National Center for Freight and Infrastructure Research and Education has concluded additional 56 billion pounds of carbon emission and 2.9 billion gallons of gas wasted due to traffic congestion (Traffic Congestion growing factor 2013).

2.2.3 Accidents

Every occurrence of a road accident affects not just the road on which the accident occurs but also the surrounding area. It causes a lot of disruption to traffic as well as causes delay. The delays due to serious accidents are difficult to quantify by costs. Accidents also lead to lengthy road closures which again lead to congestion and blockage of neighboring roads (Yass, 2010). Almost 2% of the national income is considered as the typical magnitude of the cost of road accidents as stated by the World Bank. Road accidents cost every country 1% of its gross national income irrespective of the level of development, or rate of motorization (Mitchell *et al* 2010).

2.2.4 Uncertain demands

In this problem type, the forecasted demand is based on a probabilistic approach since the order of the demands are stochastic in nature and the occurrence is unknown. The VRPSD (Vehicle Routing Problem Stochastic Demand) belongs to this class of problem.

There has been extensive research done on the VRPSD problem, some of the work dating back to 1988(Bertsimas, 1988). The VRPSD problem is a NP-hard problem, and some solution approaches for the problem include works by Dror *et al* (1989), and Gendreau *et al* (1996). While some of the recent works of trying to solve the VRPSD problem, include transforming an instance of the VRPSD by solving an instance of smaller set of Capacitated Vehicle Routing Problem (CVRP) (Juan *et al*., 2011).

2.2.5 Immediate demands

In the immediate demand problem type the nature of the demand is not just stochastic but also immediate. New customer requests unfold continuously and this information must be send to the vehicles at real time. Some works on this problem type can be found in Powell (1988), Powell and Topaloglu (2003), Godfrey and Powell (2002) and Larsen *et al* (2002). The proposed approach for solving the immediate demand problem is by making new decisions in response to new information/demand (Ichoua *et al*., 2013). Powell and Topaloglu (2003) and Godfrey and Powell (2002) propose an approach using multistage stochastic programming and dynamic programming. A mathematical approach to the problem was proposed by Adelman (2003) and Spivey and Powell (2004) using dynamic programming model for vehicle assignment and inventory routing.

2.3 Possible solutions to the problems in dynamic fleet management

Dynamic fleet management problem has been comprehensively discussed in works by Dejax and Crainic (1987), Powell and Topaloglu (2005), Crainic and Laporte (1998), and so on. Dynamic fleet management problems have been solved using various methodologies. These methods include mathematical models by Cheung *et al*., (2008), simulation models by Regan *et al*., (1998), and various information technology based tools. Fleet management within a car sharing environment has been done using simulation techniques by Barth and Todd (1999), and Kek *et al,* (2006). The various advances in fleet dispatching and dynamic vehicle routing with case studies related to air transport mode, city logistics and courier fleet has been discussed in the book by Zeimpekis *et al*, (2007). Figure 5 presents the various possible ways reported in literature to solve the dynamic fleet management problems:

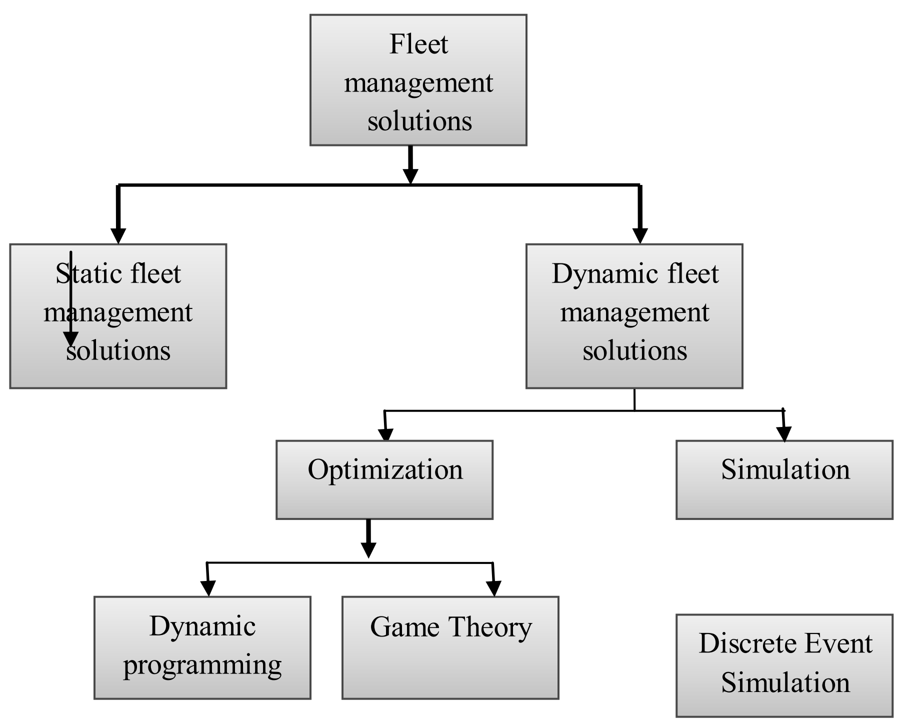

Figure 4: Solutions to dynamic fleet management problems

2.3.1 Optimization

Optimization can be defined as "the study of a problem of maximizing or minimizing a real function by systematically choosing input values within an allowed set and computing the value of the function"(Wiki optimization defintion 2013). The various optimization methods used for fleet management can be broadly categorized as Guided random search techniques, Numerical methods, and Enumerative methods which can be further subdivided into Dynamic Programming, Genetic Algorithms, Game Theory, Tabu Search, Ant colony optimization and so on (Bandyopadhyay and Saha, 2013). The two methods discussed here are dynamic programming and game theory.

2.3.1.1 Dynamic programming

Dynamic programming can be defined as "the process of solving complex problems by breaking it down into simpler sub problems"(Wiki dynamic programming definition, 2013). It is used as a method of optimization in order to address the dynamic fleet management problem. Adaptive dynamic programming algorithm using nonlinear functional approximations has been used in order to address stochastic dynamic fleet allocation problem for single as well as for multi-period travel times in Godfrey and Powell (2002a,2002b). Other works of adaptive dynamic programming include work by Simao *et al,* (2009) in which truck load operations are modeled that includes random travel time. Sensitivity analysis is done in order to show the change in the objective function when a new vehicle or a new load has been added to the system (Topaloglu and Powell, 2007). Dynamic fleet management with random travel times has been addressed using dynamic programming and approximation in Topaloglu (2006). Some other research works include adaptive dynamic programming along with the help of a simulation model to reposition idle ambulances for Emergency Medical Services (EMS) for better management, thereby reducing the response time (Maxwell *et al*., 2009). Since in a dynamic environment, demand throughout the course of the day is variable and sometimes even uncertain making it difficult to model the system which incorporates this stochastic and dynamic behavior. Fleet management using stochastic programming can be seen in works of Dantzig and Wolfe (1960), Wallace (1986), and Morton (2002). In order to maximize profit by determining vehicle allocation among shared vehicle systems, Fan *et al,* (2008) propose a multistage stochastic program. Uncertainty has been handled using scenario trees in stochastic programming in Glockner and Nemhauser (2000). More recent works of solving the Dynamic Vehicle Allocation problem for the Car sharing (DVAPC) by stochastic programming has been explained in Fan *et al*, (2013). Other methods of fleet management within a car sharing environment involve Mixed Integer programming. Making use of mixed integer programming in order to allocate operating staff to redistribute the cars, also generating the redistribution plans and maintenance activities has been discussed in Kek *et al*, (2009). More contributions in the Vehicle Sharing Program using a stochastic mixed integer programming has been elaborated in Nair and Miller-Hooks (2011) which helps to generate least-cost redistribution of cars so as to meet stochastic demands. Mixed linear integer programming has been used in bike sharing systems as well in order to solve the static repositioning problem (Raviv *et al*, 2013).

2.3.1.2 Game theory

Game theory can be defined as "the study of mathematical models of conflict and cooperation between intelligent rational decision makers" (Myerson, 1991). There are various optimization algorithms used in game theory, some of which include nonlinear optimization, dynamic programming, nearest neighbor search, and simulated annealing (Adetiloye, 2012). Game theory has been widely used in the industry from analyzing and solving water conflicts using a two level game simulation (Shouke *et al.*, 2010) to exit choice evacuation model selection from a fire zone (Lo *et al.*, 2006). Early works in the field of game theory can be traced back to 1982 in which an equilibrium model for the analysis of duopoly was developed (Viton, 1982). Further extension of that work is proposed by Harker (1998). An iterative scheme to solve the simple corridor model was proposed by Marcotte et al (1990) and it was successfully applied to the city of Santiago de Chile transit network. Game theory in the field of transportation has been discussed in work by Fisk (1984) in which the optimization problem is illustrated as a special case of the von Stackelberg game. In this study the operators competing for the intercity passenger travel are modeled as a Nash non-cooperative game. A passenger choice of route and mode has been modeled using game theory by Sun and Gao (2007). It has also been used in the field of transport to measure performance reliability by envisaging a two player non-cooperative zero sum game (Bell, 2000), using Shapley value from cooperative game theory in order to solve the transshipment problem (Reyes, 2004). Fleet management problem has also been addressed by dynamic rerouting using cooperative theory in Dulai et al., (2008). An extensive literature review of game theory in the field of transport has been presented by Hollander and Prashker (2006). Recent research using game theory includes a two stage game theoretic model designed to help evaluate the implication of greening of transportation fleets (Bae, 2011).

2.3.2 Simulation

Simulation can be defined as "a broad collection of methods and applications to mimic the behavior of real systems, usually on a computer with appropriate software". Simulation helps in recreating the actual system and in evaluating or testing various alternatives without affecting the current process. Simulation models can be classified as Static vs Dynamic, Continuous vs Discrete, and Deterministic vs Stochastic. In static type of simulation model, time does not play a role, while in a dynamic model, time is an important factor. In a discrete simulation model, the state of the system changes based on the occurrence of a discrete event while in a continuous type of simulation model the state of the system keeps changing continuously over time. In a deterministic simulation model, there are no random factors or inputs, while in a stochastic simulation model there is always some randomness mostly in the form of an input (Kelton *et al*, 2010). Simulation can been used as a substitute/complementary tool for optimization in various fields. Here, we restrict ourselves only to simulation model in the CSO. The two most common return strategies which is used within a car sharing organizations are the round trip model and the one way model. First we look at works done in the car sharing organization with regards to a round trip model, then we discuss about the various works in the one way model. Early works of simulation modeling in a round trip model can be dated as old as 1979 (Bonsall, 1979). Other works included making use of microsimulation techniques to model organized car sharing scheme (Bonsall, 1982).

Before actual realization of the Praxitele project in France a virtual urban environment was created for simulation purpose. Various models such as the driver models, along with the sensor models, motion control models, the mechanical simulation, and so on were implemented using a unique simulation model and the results of which was then presented (Arnald *et al*, 1996). Modeling in CSO including discrete event simulation has been applied to the resort community of Southern California to measure the overall system performance for both the one way model as well as the round trip model (Barth and Todd, 1999). Extended work by Barth and Todd includes an operational analysis and survey technique to better understand customer behavior and system use on the UCR Intellishare, the results of which indicated 15 percent more trip being produced (Barth and Todd, 2001). In a one way car sharing system there has to be type of relocation so as to balance the number of vehicles, either by an operator based or a user based relocation technique. Using simulation as a tool for evaluation of user based relocation techniques (trip joining and trip splitting) on a real world system and in a high fidelity simulation model shows that the amount of relocations can be reduced by 42% (Barth *et al*, 2004). Uesugi *et al*, (2007) discusses about solving distribution balance of parked vehicles in a one way car sharing technique using simulation, by assigning optimum level of vehicles to users. There has been extensive research done on operator based relocation technique for the one way model within a car sharing organization. Some of the works include Barth and Todd , 1999, Kek *et al,* (2006), Kek *et al,* (2009), Wang *et al* (2010), and so on. Simulation model has been generated using genetic algorithm technique for optimal management of the system (Nakayama et al., 2001). Recent works using simulation model in a car sharing organization can be seen in Barrios (2012), Cepolina and Farina

(2012), Ciari et al. (2012) and so on. More recent use of simulation for evaluation of a one way trip versus round trip model in a car sharing organization for determining utilization rate and rejection rate using artificial data (Yoon and Lee (2013). The simulation model that is designed for the problem type in this research is a dynamic discrete stochastic model.

2.3.2.1 Why DES?

In the recent years with the advancement of technology, computers are much faster, and are capable of solving complex problems in a short amount of time. Computer simulation softwares make it is easy to design and model complex systems which cannot be solved mathematically. There are various DES softwares available in the market, open source DES softwares (such as CPN_Tools, Facsimile), and enterprise DES softwares (such as SIMPROCESS, Arena™) and so on (Wikipedia "List of Discrete Event simulation software"). DES makes use of mathematical/logical model of an actual system in order to portray state changes at precise points in simulated time (Nance, 1993). The table below shows a summarization of existing studies on car sharing (Adapted from Jorge and Correia (2013).

Table 1: Summarization of studies on car sharing

Authors	Year	Topic addressed	Modelling Approach	Type of carsharing
Bonsall and Kirby	1979	Testing different scenarios, strategies, locations, scales and prices	Microsimulation	Round-trip
Bonsall	1982	Modelling organised carsharing systems and comparing model predictions with actual performance	Microsimulation	Round-trip
Arnaldi, Cozot, Donikian and Parent	1996	Simulation of carsharing systems	Simulation	Round-trip
Barth and Todd	1999	Operator-based relocation operations	Queuing-based discrete-event simulation	One-way
Barth and Todd	2001	User-based relocation operations	Trip joining	One-way
Barth, Todd and Xue	2004	User-based relocation operations	Simulation	One-way
Kek, Cheu and Chor	2006	Operator-based relocation operations	Discrete-event simulation	One-way
Uesugi, Mukai and Watanabe	2007	User-based relocation operations	Simulation	One-way
Stillwater, Mokhtarian and Shaheen	2008	Environmental and demographic factors that affect the usage of carsharing	Regression analysis	Round-trip
Catalano, Lo Casto and Migliore	2008	Estimation of carsharing demand for carsharing	Random utility model	Not -defined
Fan, Machemehl and Lownes	2008	Trip selection	Optimisation	One-way
Zheng et al.	2009	Carsharing market	Regression analysis	Not defined
Kek, Cheu, Meng and Fung	2009	Operator-based relocation operations	Optimisation and Discrete-event simulation	One-way
Wang, Chang and Lee	2010	Operator-based relocation operations	Microsimulation and inventory replenishing model	One-way
Cucu, Ion, Ducq and Boussier	2010	Operator-based relocation operations	Optimisation	One-way
Febbraro, Sacco and Saeednia	2010	User-based relocation operations	Discrete-event simulation and Optimization	One-way
Lorimier and El-Geneidy	2011	Factors affecting vehicle usage and availability	Regression analysis	Round-trip
Morency, Trépanier and Agard	2011	Typology of carsharing users	Cluster analysis	Round-trip
Ciari, Schuessler and Axhausen	2011	Estimation of carsharing demand	Activity-based simulation	Round-trip
Papanikolaou	2011	Describing the functioning of one-way carsharing systems	System Dynamics	One-way
Li	2011	Performance of a carsharing system	Discrete-event simulation	One-way/Round-

				trip
Nair and Miller-Hooks	2011	Operator-based relocation operations	Optimisation	One-way
Morency, Habib, Grasset and Islam	2012	Behaviour of carsharing users	Random utility model	Round-trip
Barrios	2012	Level of service offered to users	Agent-based simulation model	One-way
Smith, Pavone, Schwager, Frazzoli and Rus	2012	Operator-based relocation operations	Optimisation	One-way
Correia and Antunes	2012	Trip selection and station location	Optimisation	One-way

Chapter 3

Problem Statement

Car sharing organizations are often posed with the problem of dynamic fleet management. There are times the demands of the customers are not known until the last minute and there are times when the customer does not return the vehicle on time causing a vehicle availability problem for the next customer. The major dilemma for most of the CSO is to decide which type of model to implement as part of their business model. Most car sharing organizations follow the round trip service model for car sharing, where in the customer picks the car from one station and returns it back to the same station. The advantage of having a round trip model is that at the end of the day the total number of cars at each station would be the same, there is no requirement for a vehicle relocation mechanism or an operator to make sure that the car returns to its original station. The disadvantage of this type of model is that the user does not have the flexibility to return the car to any station.

But nowadays more and more CSO's are offering the one way service model in order to provide flexibility to the customer of picking a car from any station. In a one way model the customer has the flexibility of picking the car from any station and returning the car back to any station, a vehicle relocation mechanism is used by operators in this type of model in order to bring the vehicle back to its original station. The advantage of having a one way model is that the user gets the flexibility of returning the car to any station. Also one way model allows more number of trips as compared to the round trip model which amounts to a very minimal use such as shopping or leisure trips (Barth and Shaheen, 2002). However, the disadvantage of a one way model is that the system is susceptible to being unbalanced due to the fluctuation in the demand throughout the day, such as high demand at popular stations could lead to no cars at those stations and excess of cars at stations with not as much demand. Also there has to be a manual intervention in order to return the car back to its original station which would add up to the fleet management costs. The CSO's make use of operators who have to manually transfer cars from one station to the other in order to meet the demand. Some organizations also make use of a fleet carrier, but the cost incurred is high. Therefore the problem investigated in this thesis is to evaluate the practical feasibility of one way model or the round trip model with regards to business as well as customer satisfaction. A case study with the CSO CommunAuto in the Montreal region is conducted.

Chapter 4

Solution Approach

This chapter presents our solution approach for addressing the fleet management issues in one-way vs round-trip model. Firstly, we provide a brief introduction to discrete event simulation and its various steps. Then, its application for addressing the fleet management problem followed by verification and validation of model results is provided.

1. **Problem formulation**: The first step in the simulation study is problem formulation. The problem formulation phase is divided into five activities which include defining the problem, defining the system, establishing the performance metrics, building the conceptual model and finally documenting modeling assumptions. The problem needs to be concisely and accurately defined so that the analyst and the stakeholders have a clear understanding of the problem. Once the problem is defined the system should be defined including the system boundaries, then we decide on the performance metrics and build the conceptual model while stating all the assumptions which were taken into consideration while building the model.
2. **Setting of objectives and overall project plan**: The objectives are all the questions that would be answered with the help of simulation. This step also defines why simulation is used as a substitute method of optimization for problem solving.
3. **Model conceptualization**: Before making the actual simulation model we first make the process map which would act as a blue print to the actual DES model. In this

phase we first define the basic model and then work towards building the complex and larger model. Conceptual model can be constructed either using a flow chart, a process map, an activity diagram or software engineering diagrams.

4. **Data collection**: In this step all the data that is required as an input for the simulation model is collected. Also the data which is not available but is required for the DES model would be generated using random number generation techniques.
5. **Model translation**: The conceptual model is converted into a complex DES model with the help of an advanced flowchart and algorithm. The conceptual model is realized into an actual DES model using the ARENA software. Model development would be done in this step of the simulation study.
6. **Verification**: In this step of the simulation study, the developed DES model is checked for any errors. There are various types of verifications such as visual checks, code checks, inspecting the output reports, model debugging and so on (Sargent, 2007). The verification process is conducted to make sure that the simulation model runs without any error.
7. **Validation**: Validation of the DES model is done by testing the model with different data sets while observing the changes in output. This is the most important step as it determines whether the simulation model represents the real system adequately. The various types of validation techniques are event validity, face validity, internal validity, parameter-variability sensitivity analysis, turing test, predictive validation and so on (Sargent, 2007). For the case of our simulation model we make use of the parameter-variability sensitivity analysis wherein we change the value of the

parameters and observe the effect of the same on the output, we also make use of the face validity which is basically an expert opinion for better judgement of the results.

The flow chart representing the various steps used in a simulation study is shown below:

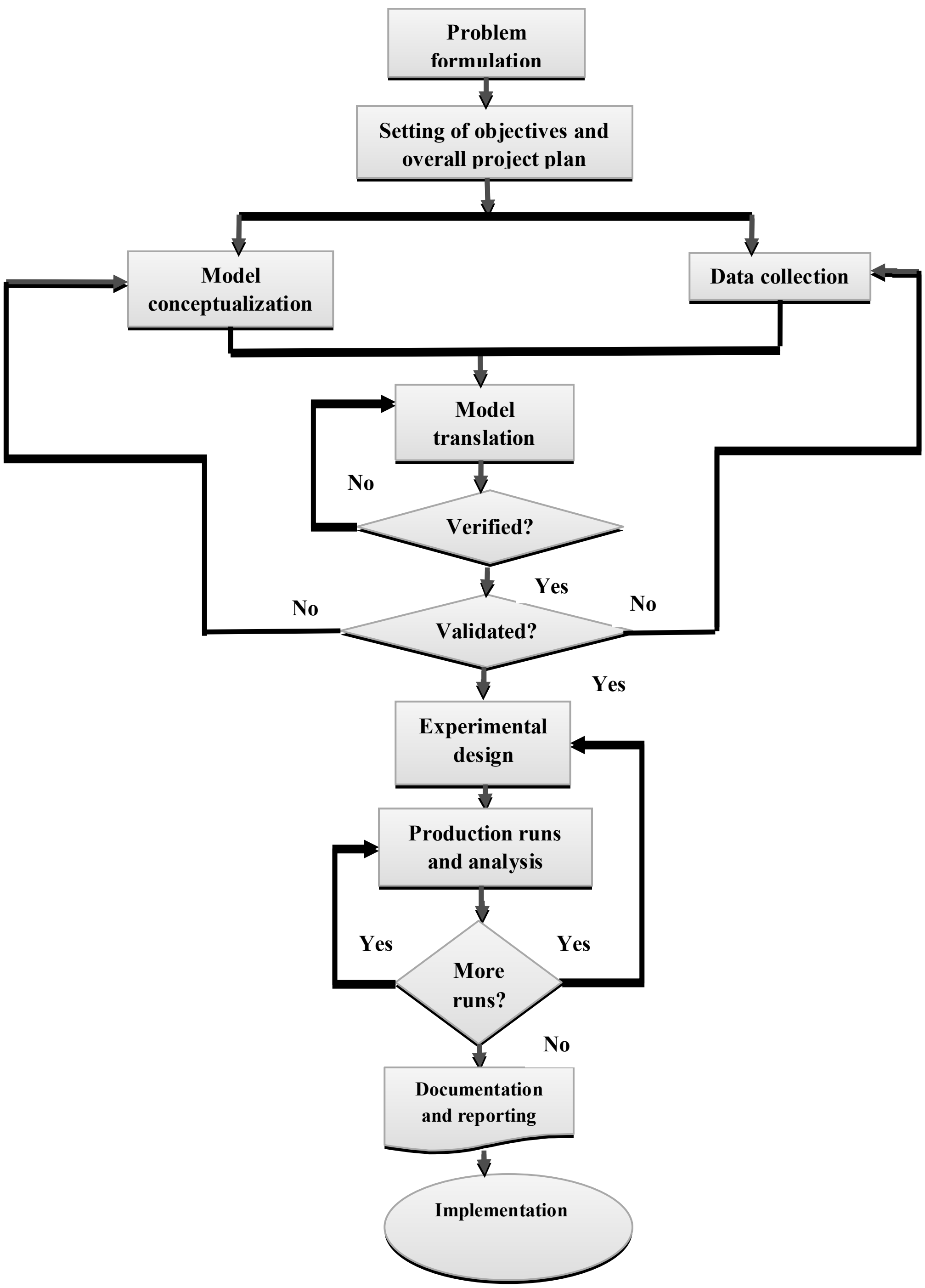

Figure 5: Steps in simulation study (Banks et al 2010)

4.1 Setting of objectives and overall project plan

The objective of our simulation model is to evaluate which type of model would be beneficial to the CSO with regards to business and customer satisfaction. It requires evaluation of both the one way model and the round trip model, without affecting its current operations. The most efficient way to model this real world system would be using simulation. A simulation model would be the closest representation of the actual system. The reason for using Arena™ in order to model the system is because it is very flexible. It provides a variety of user-created templates for simulation modeling and analysis modules which can be combined in order to build various simulation models. The advantages of using Arena™ is its flexibility of being fully hierarchical and providing the ability to combine low level modules from Blocks and Elements, with high level modules from other templates. Arena™ also has a provision to write complex decision algorithms in procedural languages such as Visual Basic or C/C++. All of this is shared on the same platform with a common graphical user interface. Also Arena™ helps in creating customized modules and save it in the template.

4.2 Input modeling

Input modeling is an important aspect of simulation because it provides the driving force for any simulation model. A faulty input model would derive output which could be misinterpreted and generate misleading recommendations. There are four steps while creating a useful model for input data which are presented as follows:

1. **Data Collection**: Data is collected from the real system or the system which is to be modeled. This step often requires a substantial amount of time. At some instances the real data is not easily available or not available at all, in such cases expert opinion and overall good knowledge of the process helps in making educated guesses.
2. **Identifying probability distribution**: Most of the time when data is available or provided it is used in order to create a histogram to review the type of distribution it follows. However, there are exceptions to trying to fit the data into a distribution especially when there are discrepancies with the data such as if the data is stale, the data is a time varying, or is dependent and so on.
3. **Choose parameters**: Parameters are estimated from the data and determine the specific instance of the distribution family.
4. **Goodness of fit**: The goodness of fit test is done in order to evaluate whether the distribution as well as the parameters which are chosen are a good fit with the data. It can be done using statistical tests or via graphical methods. Chi-square test and Kolmogorov-Smirnov test are common type of goodness of fit tests. Most of the times for evaluating the fit of the distribution, histogram is not that efficient. A quantile-quantile(Q-Q) plot is a useful tool when it comes to evaluating goodness of fit(Banks *et al.*, 2010).

4.2.1 Data collection

In this section we talk about the data obtained from CommunAuto which includes the total number of requests every month and the average number of hours per reservations on average. The graph below shows the average number of hours per reservation for the year 2011.

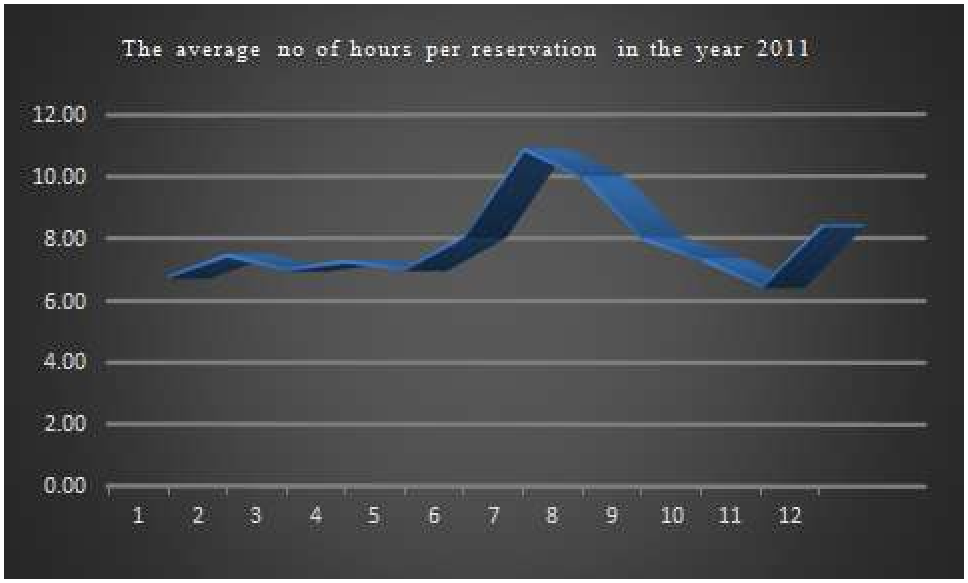

Figure 6: Average number of hours per reservation for the year 2011 for CommunAuto

It can be seen in the above graph that for the average number of hours per reservation for the year 2011, there is a peak in the average number of hours per reservation in July with the value reaching up to 10.86 hours. The mean of the average number of hours per reservation is 7.86 hours. This value would be used as the trip duration hour for our simulation model. Also the data provided by the CommunAuto includes the total number of reservations per month which can be segregated based on the number of requests per day. The data is as shown in the graph below:

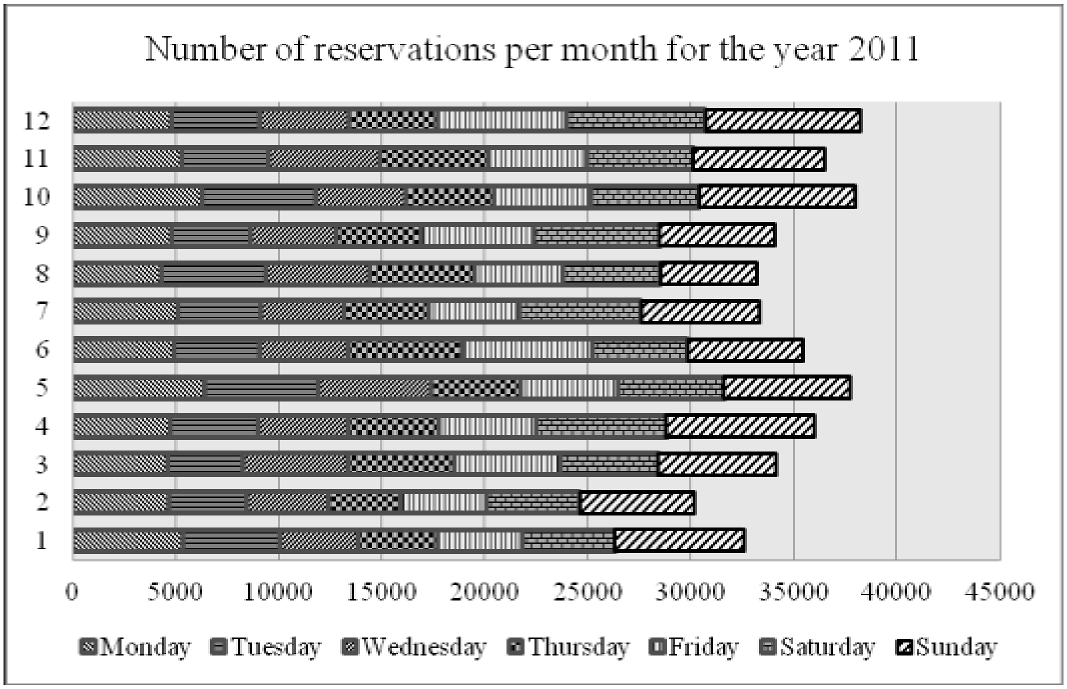

Figure 7:Number of reservations per month for year 2011 for CommunAuto

In figure 7 we can see that the peak reservations are on the weekend especially on Sunday. There is also a peak that is observed in the summer especially in the month of May and also at the end of the year especially in October and December.

Other important data which are used as input parameters within our DES model are as follows:

Total number of vehicles: The total number of vehicles is basically a summation of the cars present at each station. The number of cars at the time of development of the model is equal to the total number of actual vehicles in the fleet (881 cars).

Total number of stations: The total number of stations that CommunAuto has is more than 330 but at the time of data collection some of them were non-functional and hence were not included. So the total number of stations included in the simulation model is 273 stations.

Average number of hours per reservation: The average number of hours per reservation for the year 2011 is 7.86 hours. CommunAuto customers can book the car for a span of 1 hour to a maximum of a day and up to a week. However, while modeling the simulation system we have used the average hours per reservation based on the real data i.e. 7.86 hours. The variance is assumed to be 4 hours because if we keep the car busy for more hours or a day or a week, it would lead to big number of rejections at the station. In order to avoid this situation, the variance is assumed to be 4 hours.

4.2.2 Identifying probability distribution

In this step of input modeling we try to fit the input data into a distribution. However, as we observe from the data that is collected, that it is Time-varying data. Poisson distribution can be used in order to model the random events which occur within a fixed amount of time. However, in our case the arrival rate of requests varies per hour, per day and per month. In cases where there is a trend observed in the data, the trend has to be given more emphasis rather than a choice of distribution to represent the uncertainty in the system. Since the arrival rate function is not clearly defined, and it varies according to time or follows a certain trend, fitting a Nonstationary Poisson Process (NSPP) to arrival data could be difficult. The method used to solve this problem is to approximate the arrival rate as being constant over a period of time. The steps for solving the problem are as follows:

1. Model the arrivals over a time period, say [0, T].
2. Divide the period [0, T] into k equal intervals of length $\Delta t = T/k$.
3. Let the period of observations be n, let Cij be the number of arrivals occurred during the i^{th} time interval on the j^{th} period of observation.
4. The estimated arrival rate during the i^{th} time period, $(i-1)\,\Delta t < t < i\Delta t$ can be expressed as the average number of arrivals over the length of the time interval (Banks *et al,* 2010):

$$\hat{\lambda}(t) = \frac{1}{n\Delta t}\sum_{j=1}^{n} Cij$$

Based on the approximation technique we get the average number of reservations per month being 34958, which when further divided into days is 1165 requests per day, and further broken down into hours 48.55 requests per hour, which finally makes it 0.81 requests per minute. Hence, we would produce a constant request per 0.81 minutes.

However, the data that is required as an input is the total count of reservations per station. This data was not easily available and hence was not provided. Therefore we have created the data using Excel functions which would be explained in detail in the later sections. First we discuss the approach used for sampling and the sample size.

4.2.2.1 Sampling method

In order to reduce the number of errors caused by inspection of each and every item of the population, a sampling method is used as it provides a much complete census in a shorter period of time and with less cost. There are various methods of sampling. Some of the most commonly used sampling techniques are as follows:

1. **Simple random sampling:** In sample random sampling there is equal probability of each item being selected.
2. **Cluster sampling:** In cluster sampling technique a random sample is selected from each group.
3. **Systematic sampling:** In this type of sampling technique it selects the sample in sequence, for example every 10th item.
4. **Stratified sampling:** The population is divided into strata and the sample is selected from the stratum.
5. **Judgment sampling:** In this type of sampling technique an expert's opinion is taken into consideration in order to determine the characteristic and location of a definable sample group (Evans and Lindsay, 2005).
6. **Sampling with or without replacement:** In sampling with replacement the sample values are independent, the value we get on the first sample does not affect what we get on the second, and the covariance between the two samples is zero. While, in sampling without replacement the sample value aren't independent, the value we get on the first sample affects what we can get for the second one. (Sampling with/without replacement, 2013)

We would be making use of simple random sampling technique, as the request for a car could arrive to any station. Hence the probability of an item being selected is equal.

4.2.2.2 Sample size

Sample can be defined as a subset of objects which is taken from the population (Evans and Lindsay, 2005). In our case the population is the total number of reservations for the year 2011 (denoted as *N*) is equal to 419507. Since we are using a simple random sampling technique we make use of the Cochran technique for sample size (Cochran, 1977). Based on the Cochran technique the formula for sample size *n* is as follows:

$$n = \frac{Nz^2pq}{\mathrm{N}d^2 + z^2pq}$$

where for 95% confidence interval the critical *z* value is 1.96 , *p* and *q* are estimate of variance the standard value for which is 0.5, the population size $N = 419507$ and *d* is the acceptable margin of error, in our case the value of *d* is 0.015.

When we solve the equation with the given values for the parameters we find the value of *n* or the sample size as follows:

$$n = 4225$$

Therefore, the sample size used as an input to our simulation model or the total number of requests is 4225.

4.2.3 Data generation

The data required as an input for the DES model is the total number of requests at each of the individual stations. The origin and destination station number for each request is required as an input data for simulation of both round trip model as well as the one way model. However, due to the unavailability of this data, the total number of requests per station had been generated using excel function. The data is generated using the RANDBETWEEN function of excel, which generates a random integer number between the top and bottom values that you specify. As shown in the below figure, the function generates a random number between 1 and 330

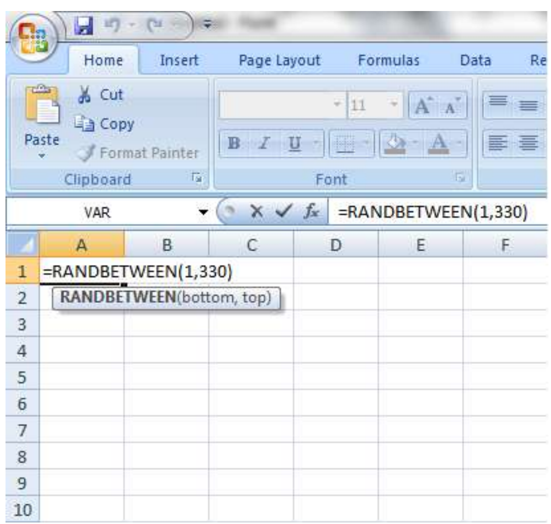

Figure 8: Random number generation in Excel

The random integer that is generated denotes the origin station and the destination station. The data that is fed for the round trip model and the one way model are different. The origin and the destination stations are same for the round trip model. The sample input table for the round trip model is shown in the table 2 below

Table 2: Sample input table for the round trip model

Origin	Destination
252	252
266	266
159	159
326	326
264	264
111	111
245	245

Similarly, the data for the one way model is created using similar function. However, in a one way model the origin and destination are different, as the user has the flexibility of taking the car from one station and drop it to another station. The sample input table for the one way model is as shown in the table 3 below

Table 3: Sample input table for one way model

Origin	Destination
252	131
266	265
159	324
326	279
264	122
111	219
245	210
159	19
88	238

The total number of cars present at each station is also fed as an input to the DES model. The list of number of cars present at each station is provided by CommunAuto which is also included in the appendix. The sample input table for the number of cars is shown in table 4 below:

Table 4: Sample input table for the number of cars at each station

Car_Origin (station number)	Number of cars at the station
110	3
110	
110	
111	2
111	
113	1

In the above table 4, the total number of cars, the Car_origin is the station origin number where the car is initially present. Based on the count of the stations within the excel file, it is easier to know the number of cars present at each origin station. For example there are three cars at station number 110, two cars at station 111 and one car at station 113 and so on.

4.3 Model conceptualization

We created a conceptual model for developing our DES model using process map. The process map (figure 9) explains how the customer can book a car through a request which can be made online or by a phone call. Once the request is sent there is a check for the availability of the car at the nearby stations. If there is a car available it is booked for the hour as requested by the customer and then the customer picks up the car from the station, utilizes it for the time it was booked for, and returns it back to the same station if it is a round trip model. However, if the request for the car is a one way model, the customer has the flexibility of dropping the car to any of the stations. The complete process map is shown in figure 9 below

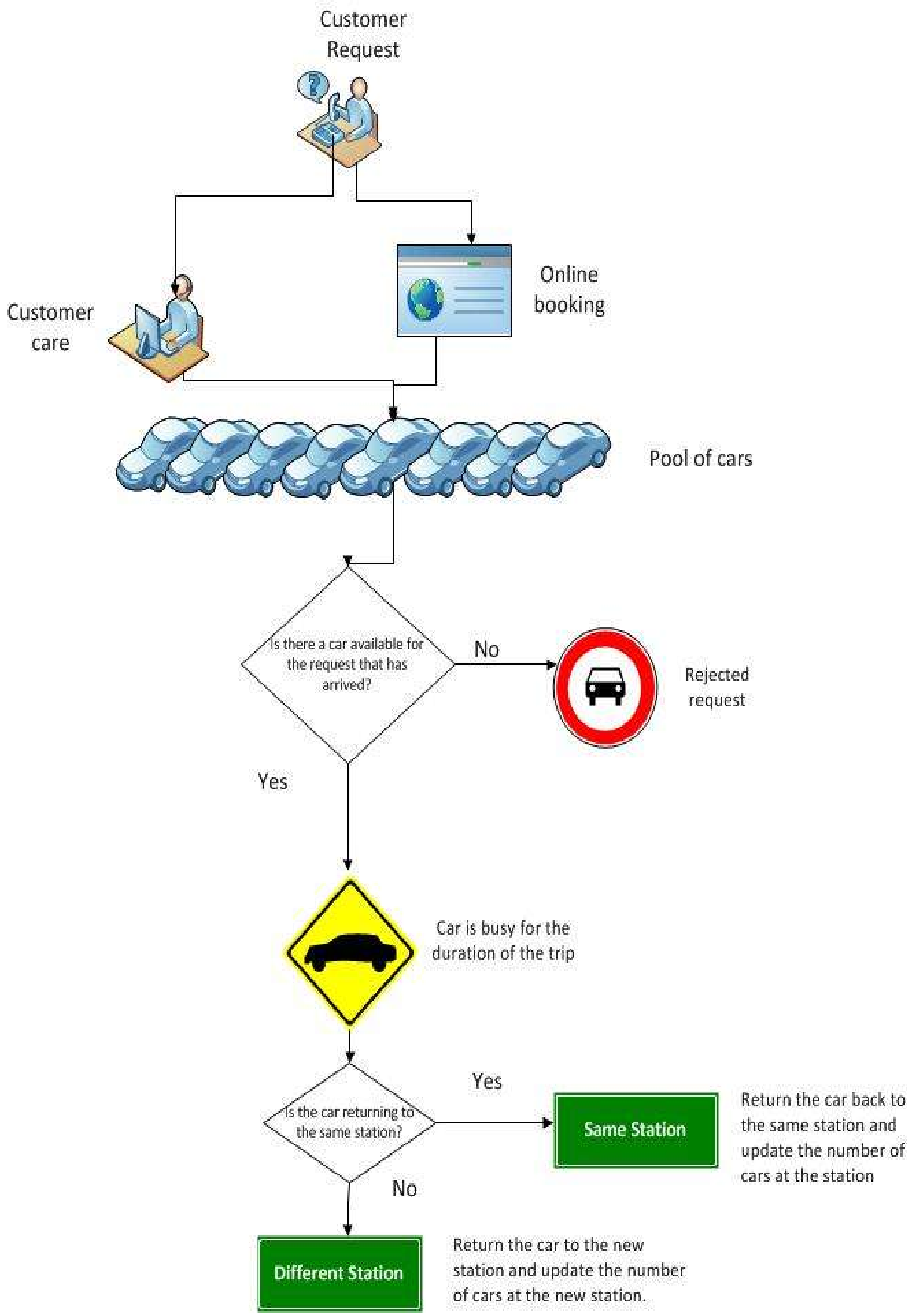

Figure 9: Process map

4.4 Model translation

In this section we translate the conceptual model (process map) into the actual DES model. First we develop an algorithm and then use it to develop the simulation model.

4.4.1 DES algorithm

The DES algorithm is designed based on the general process map of the system. It defines the various entities and the events of the DES model. The flow of the algorithm is explained as follows:

1. The car entities are first generated all together at once.
2. The car entities that are generated pick up their origin from the table which is provided as an input to the DES model.
3. Once the car entities are assigned their specific origin, they go to the respective station and wait for an incoming request entity.
4. The request entity is generated and is assigned the origin and destination attribute which is provided as an input to the DES model. The input file for the round trip model would be different from the one that is used for the one way model. However, the file with the origin data for the car entity would remain the same in both the entities.
5. The generated request entities are recorded.
6. Once the request entity is matched with the car entity, they are batched together.
7. The batched entities are delayed for the duration of the trip.

8. Upon trip completion, split the entities based on the original entity types which would separate the request entity and the car entity.
9. The destination of the request entity is saved into a variable.
10. The car entity is delayed for some time, this is done so that the destination of the request entity is first saved onto the variable and then it is assigned as the new origin for the car entity.
11. The new origin of the car entity is recorded.
12. The car entity is then sent back to the set of stations where it waits to be matched with a request entity.

The flow chart of the algorithm explained above is represented in the figure below:

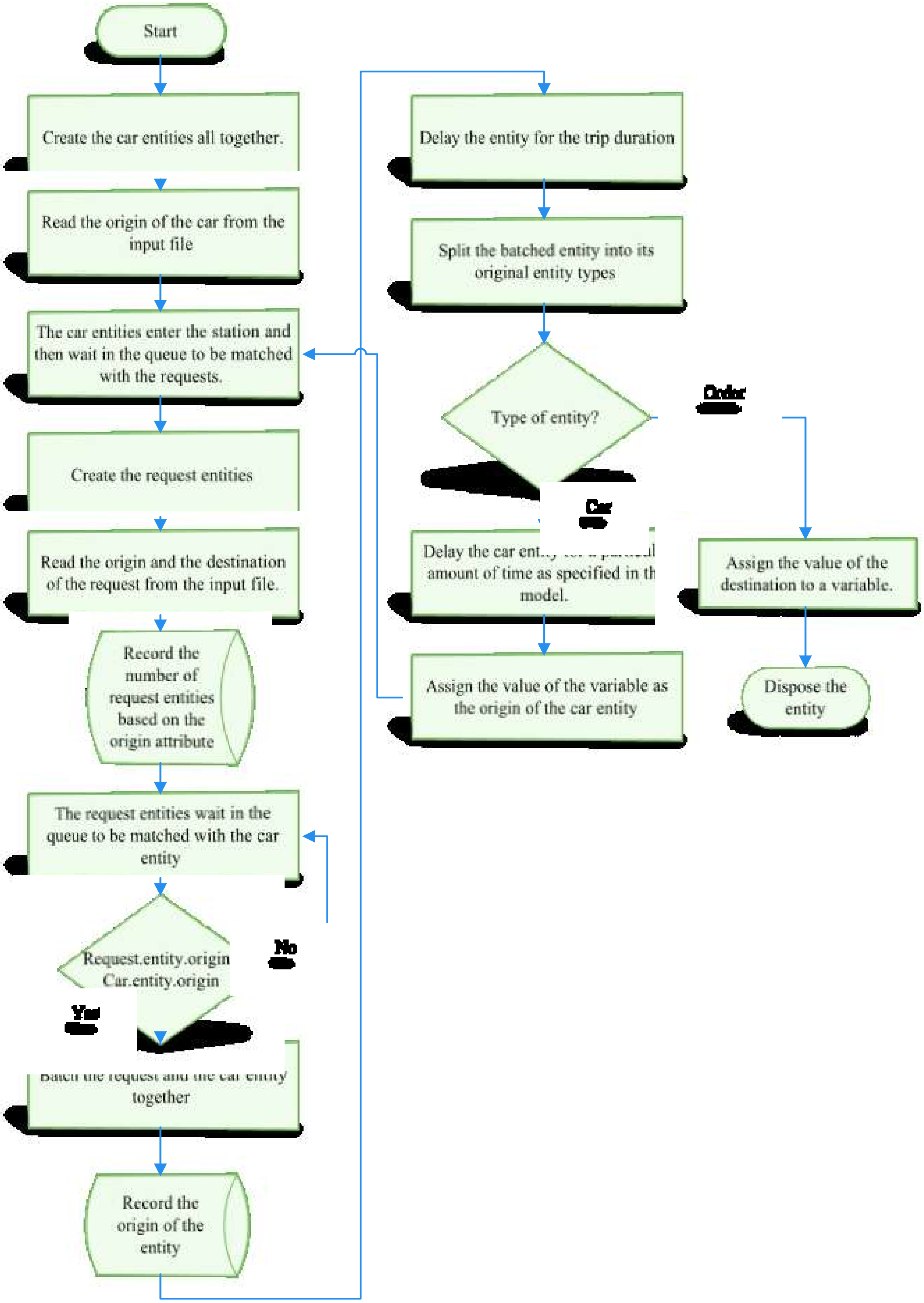

Figure 10: Flowchart for the DES algorithm

4.4.2 Elements of the DES model

This section explains the various elements used in DES. These elements are categorized as follows:

4.4.2.1 System

The system can be defined as collection of interrelated components that act together over time to accomplish a goal. In our case the car sharing organization is modeled as a system composed of various modules such as request creation, car creation and so on, that work in unison with each other.

4.4.2.2 Entity

The entity can be defined as an object or component, the movement of which within the system causes a change in the system. The entities within our research model are the individual cars at each station. The second entity in the model is the request entity; these entities represent each individual customer request that arrives at a particular instance of time.

4.4.2.3 Attribute

Attribute can be defined as the property of an entity. The attributes used in the DES model are the origin and the destination of the entities. These represent the station origin and destination. The request entity is assigned the origin and the destination attribute which represents the actual customer request of trip from one station and to the destination station. However, the car entity is assigned only the origin station initially. It later takes the value of the destination attribute from the request entity.

4.4.2.4 Variables

Variables can be defined as the quantitative property of the system which change or are determined by the relationship among the system components which evolves over time. The variable used in the model is the VCarTo variable which is used in order to assign the value of the destination of the request entity to the origin of the car entity, this is done so that the car goes to the respective destination station.

4.4.2.5 Set

Set is used in order to define various type of sets including entity type, entity picture, resources and so on. The set module is used as a set of stations in the model. The set is used as a counter in order to check the total number of requests per station, the total number of rejections per station, the total number of cars being used at each station and so on.

4.4.2.6 Events

Events can be defined as an action that changes the state of the system at an instance of time. There are various events happening in the DES model such as creation of the request/car entities, holding the entities in a queue, assigning the attributes to the entities, recording the value of the entities and so on.

The above listed elements are the basic process module elements. There are also elements in the advance process module which are explained as follows:

4.4.2.7 ReadWrite

The ReadWrite module is used in order to read data from an input file or using a keyboard. The data that is read can be then assigned values from a list of variables or attributes or using an expression. The ReadWrite module can also be used to write data onto a file or an output device (display the results on the screen). The ReadWrite module has been used in the DES model in order to read the data which is the number of requests from the requests input file as well as the number of cars read from the cars input file.

4.4.2.8 Delay

The delay module is used to delay an entity by the amount of time specified. Once an entity enters the delay module it remains in the module till the amount of time which is specified. The delay module is used as the trip duration in the research model, which holds the request entity and the car entity there by making both the entities wait in the module till the specified time.

4.4.2.9 File

The file module is used in unison with the readwrite module in order to access the external file through which the input data is read. The type of file has to be specified and so is the access type of the file. In the research module the files used are the requests file which are for the round trip as well as the one way and the file containing the list of cars.

4.5 Verification

Verification is done in order to ensure we are producing the right results. The input parameters as well as the logical structure of the model have been verified. The DES model is able to fully function with the given number of inputs. Also there have been no errors discovered at the time of execution. The input parameters do not change during the course of the execution and the total number of given input matches with the total number of output received at the end of the simulation. Using graphical representation of the simulation model makes it easy to track the number of requests, the number of cars being utilized at the station and the total number of cars present at each station. Hence at any course of time during the execution, these numbers can be verified from the simulation model.

Table 5 below shows sample verification results containing the input data for randomly selected stations which was fed to the simulation model, along with the observed results, and the expected results

Table 5: Sample data verification

Station number and name	Input(Number of requests arrivals)	Trip type	Expected number of requests arrivals	Observed number of requests arrivals
030- Iberville et MontRoyal	9	One-way	9	9
082- Berri et De Castelnau	13	Round trip	13	13
154-Parthenais et Logan	15	One-way	15	15
222 - Du Havre et La Fontaine	16	Round trip	16	16
176- Lajeunesse et Jarry	18	Round trip	18	18
289-Côte-des-Neiges et Van Horne	9	One way	9	9

The total number of requests which is read from the input file for both the individual models indicate the same value in the output of the simulation. Also the total number of cars present at each station which is read from an input file to the simulation shows the correct value in the output at the end of the simulation

Table 6: Sample data verification cars

Station number and name	**Input(Number of cars at station)**	**Trip type**	**Expected number of cars at station at end of simulation**	**Observed number of cars at station at end of simulation**
086 - Parc Père-Marquette	6	One-way	0	0
081 - St-Vallier et Jean-Talon	4	Round trip	4	4
229 - 43e Avenue et St-Zotique	2	One-way	4	4
191 - Square Dorchester	2	Round trip	2	2

4.6 Validation

Validation is performed to ensure that we are using the right method. There are various methods of validation such as face validity, historical data validation, predictive validation, internal validation, multistage validation and so on (Sargent, 2007). The types of validations used in our study are the Parameter- variability sensitivity analysis and Face validity. The parameter-variability sensitivity analysis is performed by changing the values of the input and observing the effect of the same on the output. The face validity is performed by consultation with experts.

4.6.1 Parameter-variability sensitivity analysis

In this type of validation we test both the models with three different sets of data. All the data sets are randomly generated and tested for the one way model as well as the round trip model. The results of the simulation for three different data sets generated in random are shown in the table 7 below. It can be seen that the average request acceptance rates are higher in round trip model and rejection rates are lower for all the three test cases.

Table 7: Number of tests and the corresponding results

Test name	Type of Model	Number of samples	Number of replication	Observed Average Acceptance rate	Observed Average Rejection rate
Test 1	Round trip	4225	10	92%	8%
	One way	4225	10	87%	13%
Test 2	Round trip	4225	10	92%	8%
	One way	4225	10	87%	13%
Test 3	Round trip	4225	10	92%	8%
	One way	4225	10	87%	13%

4.6.2 Face validity

In this type of validation technique an expert's opinion is considered in order to determine if the model adequately represents the real system and verify if the input output parameters are correct. For our simulation model, the output results were verified with the authorities of CommunAuto Montreal to check for high performing stations, the stations with higher rejection rates, and stations with greater acceptance rate. Table 8 and table 9 present the results of face validity for stations with high rejection and good acceptance rate:

Table 8: High rejection stations

Station
065 – Provost
171 - 75e Avenue et Parent
235 - Jean-Brillant et McKenna
316 - Hudson et de Kent
119-Cartier et Lavoisier

Table 9: Stations with good acceptance rate

Station
02-St-Sacrement
03-Garnier
04-Parc Lafontaine
124 - Henri-Julien et De Castelnau
181 - St-André et Bélanger

Chapter 5

Model development in Arena

In this chapter we discuss the development of the proposed DES model in Arena ™ simulation software, the various modules and components which are used within the model, the attributes of each blocks, and the working of the simulation model. We also state the assumptions which were taken into consideration before building the actual simulation model.

5.1 Assumptions

The assumptions used in our simulation model are listed below:

1. We have assumed that the requests are occurring at a constant rate of one request per 0.81 minutes based on the data provided by Communauto regarding the number of requests per day; it has been observed that there are 48.55 requests every hour which makes one request every 0.81 minutes.
2. The choices of the selection of the stations are randomly generated.
3. The customer does not wait more than 15 minutes at a station for a car. If the customer does not get the car within 15 minutes, the request is cancelled and that order counts as a rejection at that particular station.
4. All the cars are available and free at the start and the end of the simulation model.

5. The trip extensions and the car breakdowns haven't been taken into consideration. The actual trip breakdowns which was confirmed with CommunAuto was a very minimal percentage.
6. The parking space for the one way model is assumed to be flexible and not constant.
7. The trip duration is assumed to be a Normal distribution with mean of 7.86 hours and a variance of 4 hours (Based on the average number of hours per reservation for the year 2011 i.e. 7.86 hours collected from CommunAuto).

5.2 Model explanation

The model consists of various modules, first we look at the request generation module, followed by the car generation/car availability module, request rejection module and the main module.

5.2.1 Request generation module

The request generation module consists of the Create block which generates the request entities constantly every 0.81 minutes up to a total of 4225 requests. These entities would go to the Read/Write block which would read the origin and destination from the request file which is generated and is used as an input parameter for the model. Figure 11 shows the request generation module blocks

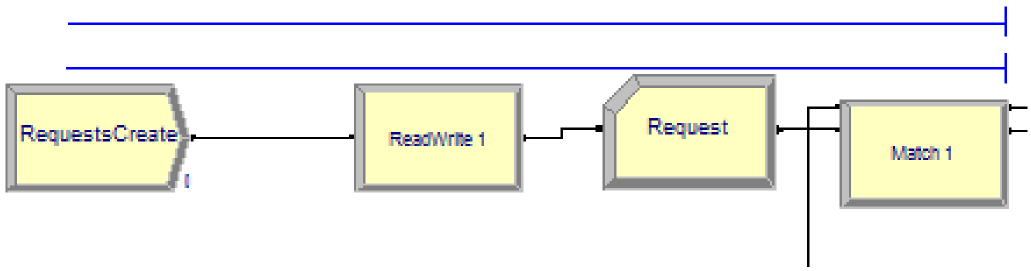

Figure 11: Request generation module blocks

The various attributes of the RequestsCreate block shown in figure 12 below are explained further. The Type attribute specifying Constant indicates that there would be a constant generation of entities which would then read from the input file, the Value attribute is used in order to specify the value/time when the entities would be generated which in this case is every 0.81 minutes, the unit of which is specified by the Units attribute. The Entities per Arrival determines the number of entities that are generated at once, the Max Arrivals is the total number of arrivals this create block will generate and finally the First Creation attribute defines when the first entity would be generated.

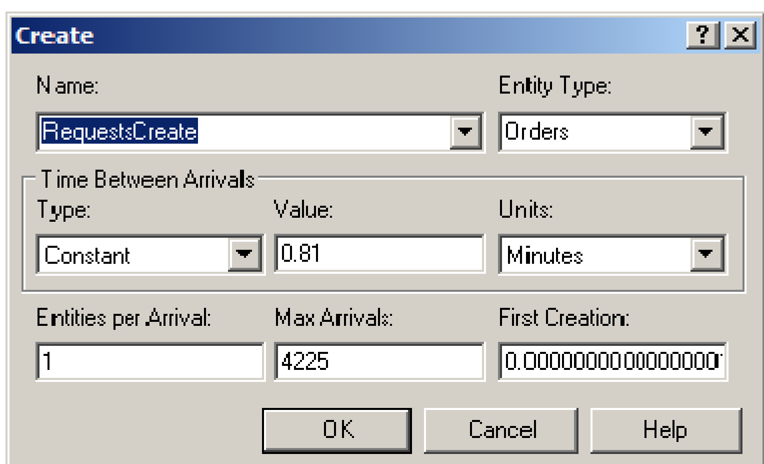

Figure 12: Create block attributes

In figure 13, the ReadWrite dialog is used to read from the file and in this case the file is Requests, the Type attribute specifies the action that has to be performed and in this case it is to Read from File. The Requests file has a recordset which is specified within the RecordsetID attribute and the content of the recordsets are assigned attributes Origin and Destination which is provided in the Assignments section.

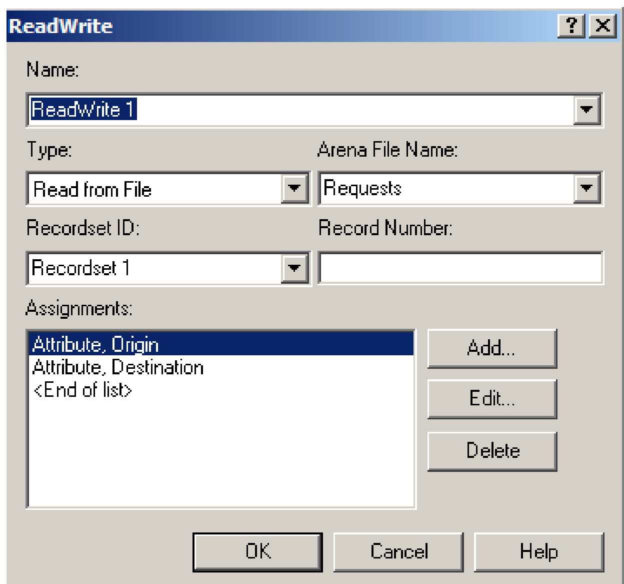

Figure 13: ReadWrite attributes for request create module

Once the entity is passed through the ReadWrite block and it reads the requests from the recordsets of the corresponding input file, it is then send to the Record block which counts the number of order entities and records it into the set with the origin of the entity recorded, which would be used at the output to verify the number of input requests. The dialog box of the Record block is shown in the figure 14 below

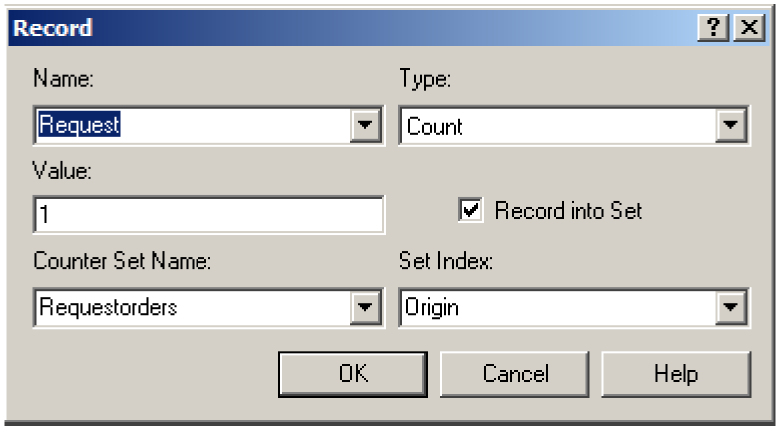

Figure 14: Record attributes for the request create module

5.2.2 Car Generation module

The car generation module consists of similar blocks as the request generation module. However, in this case the car entity is created which would be matched with the request entities generated from the requests generation module. The entities are send to the ReadWrite block which would read the Cars file which contains the total number of cars present at each station. These entities are then routed to a set of stations using the Route block which is as shown in figure 15 below:

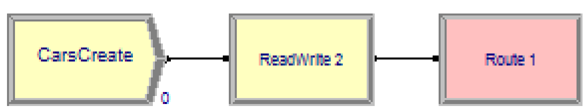

Figure 15: Car Creation module

The entities that are created in the "CarsCreate" create block would go to the ReadWrite block which would read the Cars file, which contains the recordsets with the total number of cars which are present at each station viz the Origin station. The create block used for the CarsCreate module is as shown in figure 16 below:

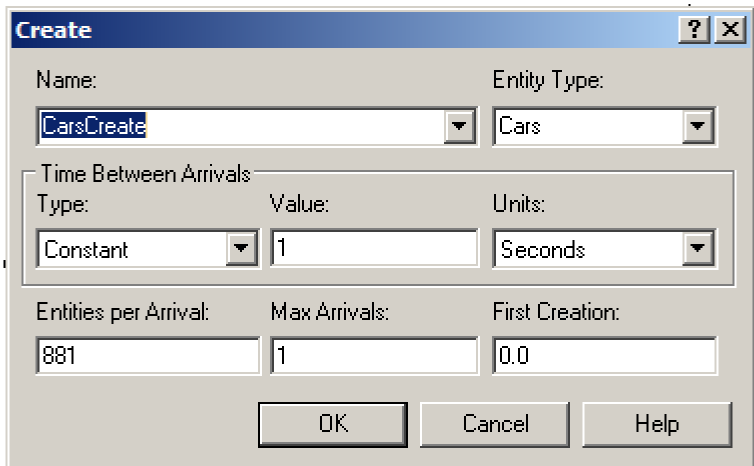

Figure 16: Create attribute for car creation module

In the CarsCreate create attribute we have the Type as Constant, the Entities per Arrival is 881 which corresponds to the total number of cars in the fleet, this means that at one instant there would be 881 entities that would be generated at time 0.0 which is specified by the FirstCreation attribute and the Max Arrivals is 1, hence only the total of 881 entities would be generated once throughout the whole simulation model.

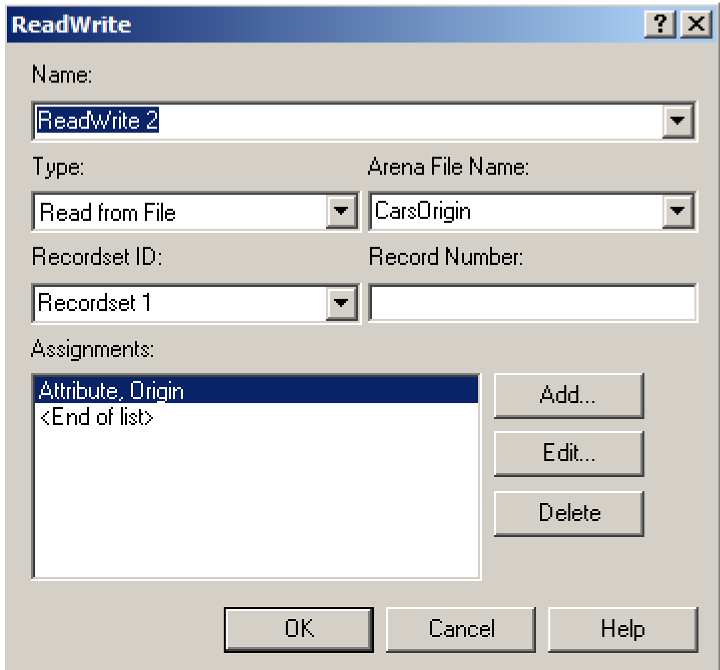

Figure 17: ReadWrite attributes for for car creation module

In figure 17 above, we can see the ReadWrite dialog box for the CarCreate module. It reads the input file CarsOrigin which contains the total number of cars in file which is read by Arena. The total number of cars present at each station is specified within the input file with the Origin which is specified as an Attribute as shown in the above dialog box. The entity is then routed to a set of stations using the Route block, the attributes for the route are as shown in figure 18 below.

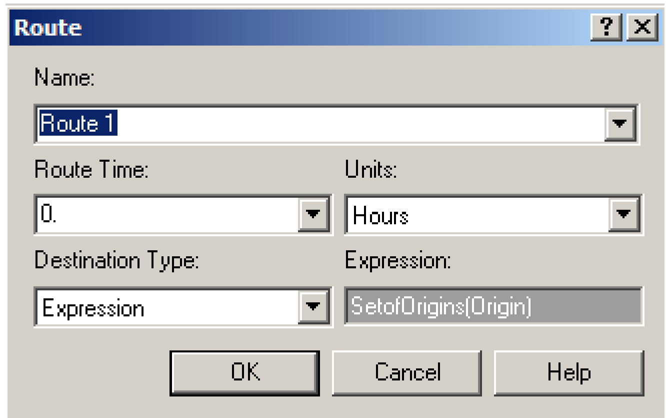

Figure 18: Route attributes for car creation module

As shown in the route dialog box above the entities are routed to a set of stations hence the Destination Type is Expression and the set of stations is specified within the Expression attribute. The route block sends all the 881 car entities that is generated by the create block to the set of station which would ensure that all the cars are available before the request entities arrive.

5.2.3 Request rejection module

The request rejection module as the name suggests is used in order to check and record the number of requests that are being rejected at the various stations. The request rejection module consists of a create block which creates an entity every 15 minutes in order to check if there are any requests in the queue and if there is it removes the first one waiting in line. The entity is then send to a decide block where it checks if there is a request entity waiting in the queue, if there is it is removed from the request queue using the Remove block from which the original entity is sent to the Dispose block which disposes the entity and the removed entity which is the removed request entity is sent to a Record block which records its origin and then sends the entity to the dispose block to dispose the entity. The Request reject module is shown in figure 19 below

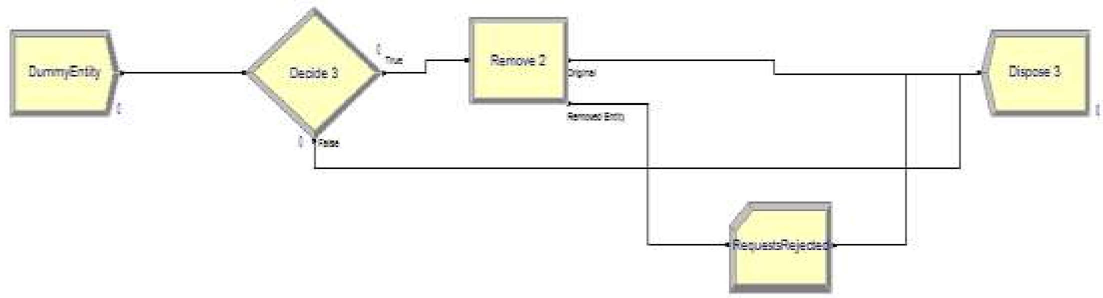

Figure 19: Request rejection module

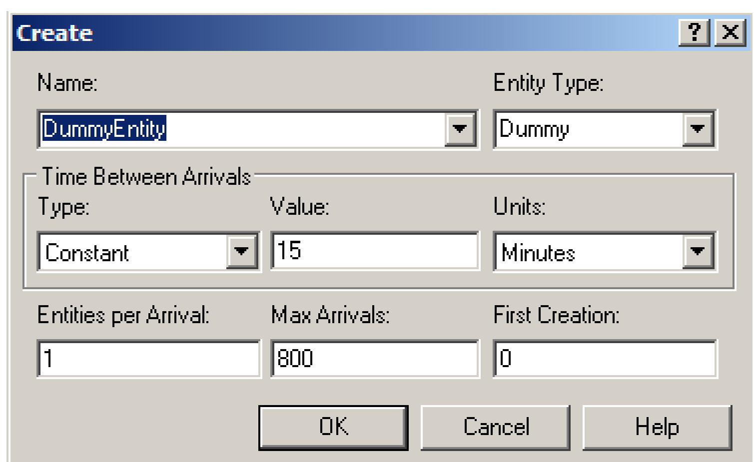

Figure 20: Create attribute for request rejection module

In figure 20 there is a DummyEntity which is constantly generated every 15 minutes which checks if there is any requests which are pending. The Max Arrivals is 800 as the simulation model is run for a total of 200 hours. The entity created is send to the Decide block, the dialog box for which is shown in the figure 21 below:

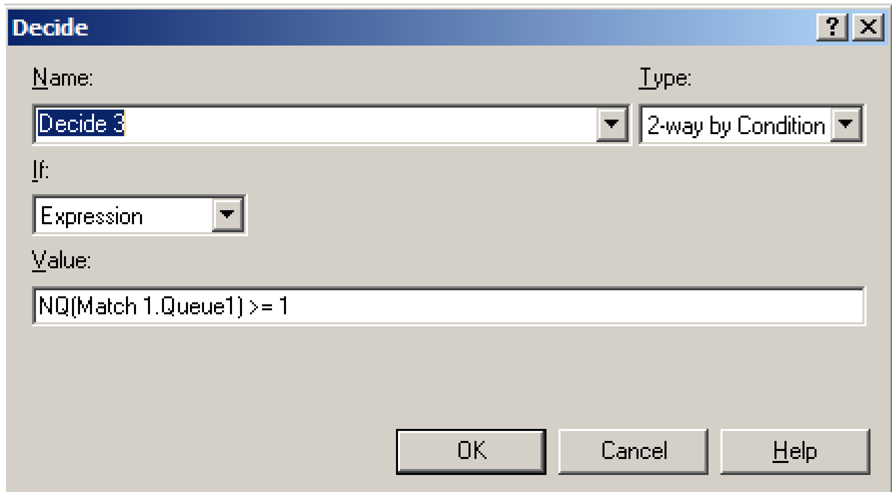

Figure 21: Decide dialog box attributes for request rejection module

Once the entity reaches the Decide block it looks for any requests which is waiting in the Match1.Queue1 which is the Match queue for the request entity, once it finds any request entity in the queue, it sends the entity to the next block which is the Remove block. The Remove block specifies the Queue Name from which the entity has to be removed, and it removes the first entity of the queue based on the Rank of Entity attribute which has the value 1 .However, Arena has a limitation of removing only 1 entity at a time using the Remove block, the attributes for the remove block are shown in figure 22 below

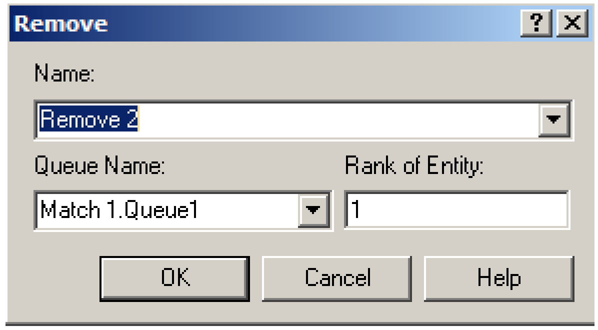

Figure 22: Remove dialog box attributes for request rejection module

The Remove block has two outputs Original and Removed Entity, the original is the entity which is given as the input to the remove block and the removed entity is the entity which is removed using the remove block. Finally the removed entity is send to the Record block which counts the number of removed entities with the origin of the removed entity which is specified in the Set Index as shown in the Record dialog box in figure 23 below

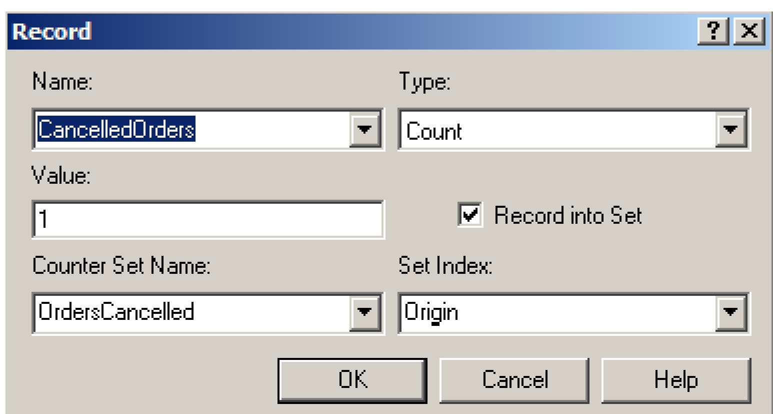

Figure 23: Record dialog box attributes for request rejection module

5.2.4 Main module

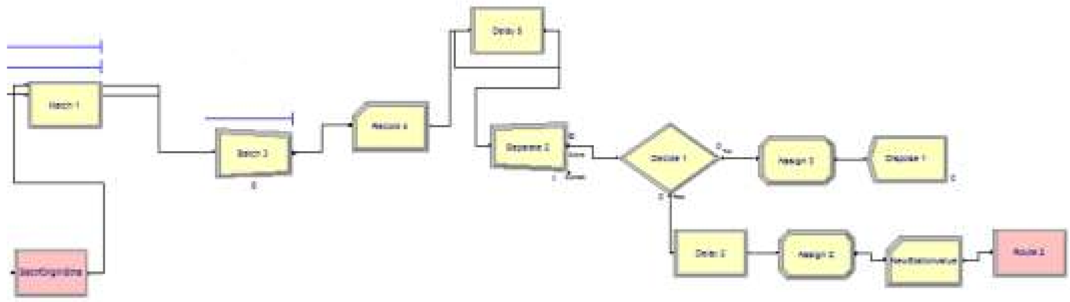

Figure 24: Main module

The main module block is the continuation of the request generation module and the car generation module. The car entities and the request entities are matched at the Match 1 block as shown in figure 24 above. The car entities arrive from the SetofOriginStns block which is a station block with a set of all the total number of stations. Once both the entities arrive, they are batched together using the Batch block, then the entities are forwarded to the Record 4 block which records the origin of the entities. The Record block is used in order to check the total number of cars which are busy at each station. The entities are then delayed for an average time of 7.86 hours using the Normal distribution function with a variance of 4 hours. That means the total travel time can be from 3.86 hours to 11.86 hours. This time is based on data provided by the company which is the average travel time (in hours). Then the entities are introduced to a Separate block which separates both the entities viz the request/order entity is separated from the car entity. The decide block segregates the car entity from the request entity. The request entity is forwarded to the Assign 3 block which assigns the value of the destination attribute to a variable named vCarTo, the destination attribute is read from the request entity. The car entity is forwarded to a delay block which delays the entity for 0.00000000001 seconds; the purpose of having the delay block is to delay the car entity so as to assign the value of the variable vCarTo to the origin attribute of the car entity. This step would ensure that the car entity would have the new origin which is basically the destination which is read from the request/order entity. The car entity is then routed back to the set of origin stations with the new origin attribute which is assigned from the request entity.

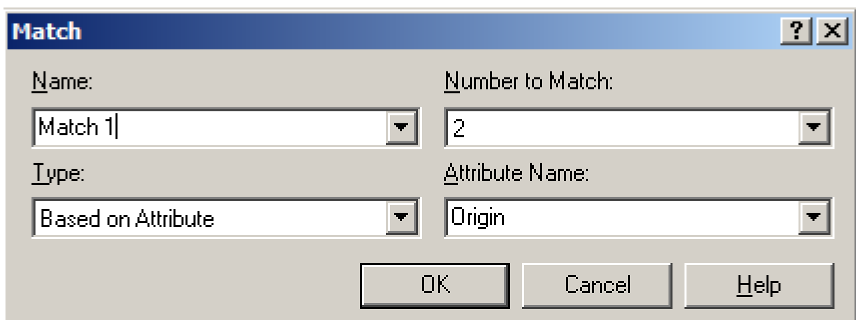

Figure 25: Match dialog box attributes for Main module

The Match block attributes shown in above figure 25 matches the request entity and the car entity, the match is based on the Type Based on Attribute which matches the entities based on the Origin attribute type which is specified in the Attribute Name and then sends them to the next block. The Number to Match specifies the number of entities to be matched.

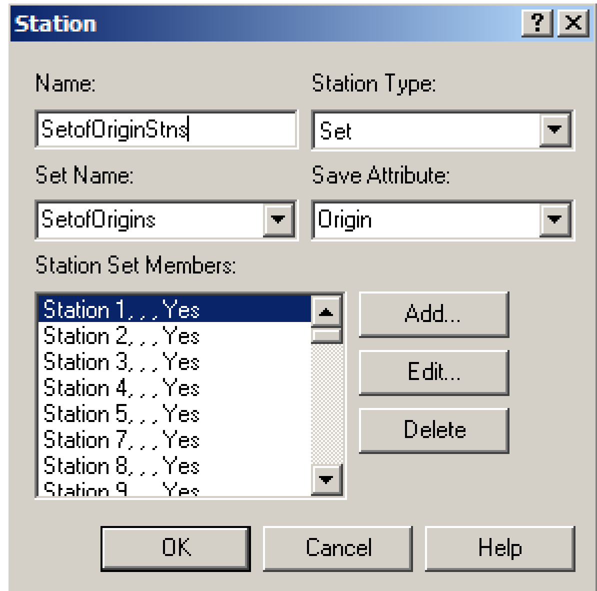

Figure 26: Station dialog box attributes for main module

The SetofOriginStns shown in figure 26 above is basically a station block which is used as a Set that is specified in the Station Type, which indicates that the station block has more than one station and it is a set of stations. The car entities are generated using the car generation module and the car entities which have completed the trip is routed to this set of stations, and the origin attribute is saved.

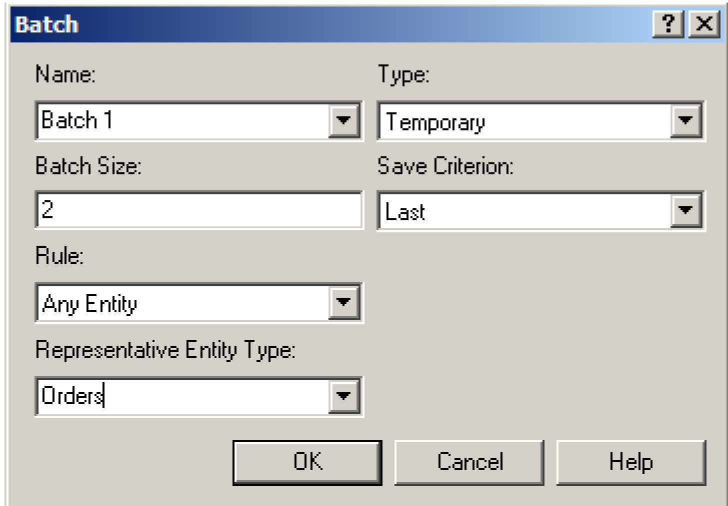

Figure 27: Batch dialog box attributes for main module

The batch block as the name suggests is used to batch the entities together, as shown in figure 27. The batch block is used in order to batch the car entity along with the request/order entity. The Batch Size 2 indicates that once both the entities have entered into the batch block it is batched as one and is send to the next block. The type of batch used is a temporary batch, the save criterion is used in case if there isn't anything specified in the representative entity type. However, in this case the representative entity type is Orders, which means that the batched entity would be represented as an Order entity until it is separated using a separate block after which the individual entities would have their respective characteristics.

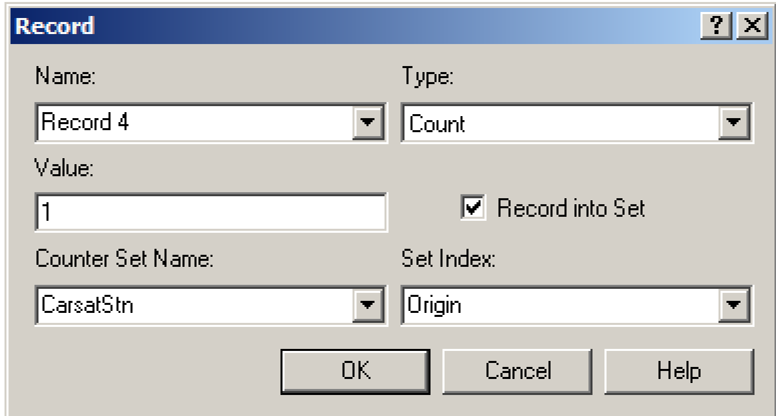

Figure 28: Record dialog box attribute for the main module

The Record block as shown in figure 28 is used in order to record the number of cars that are being utilized. The origin attribute of the entity is used in order to track the station number of the car that is currently busy and which is recorded into set which is later displayed at the end of simulation.

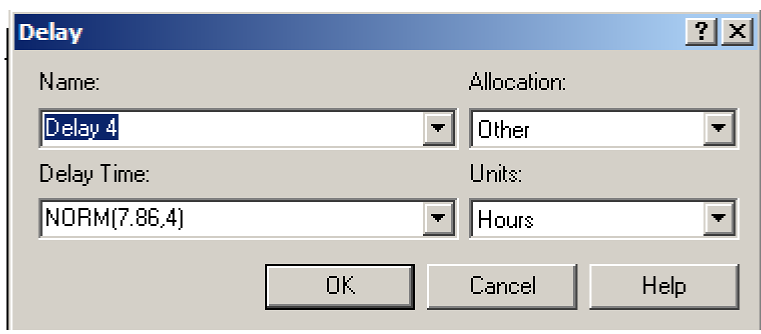

Figure 29: Delay dialog box attrtibutes for main module

The Delay block shown in figure 29 is used in order to delay the entities for the trip time. The total trip time that has been considered has a mean of 7.86 hours using Normal distribution with a variance of 4 hours.

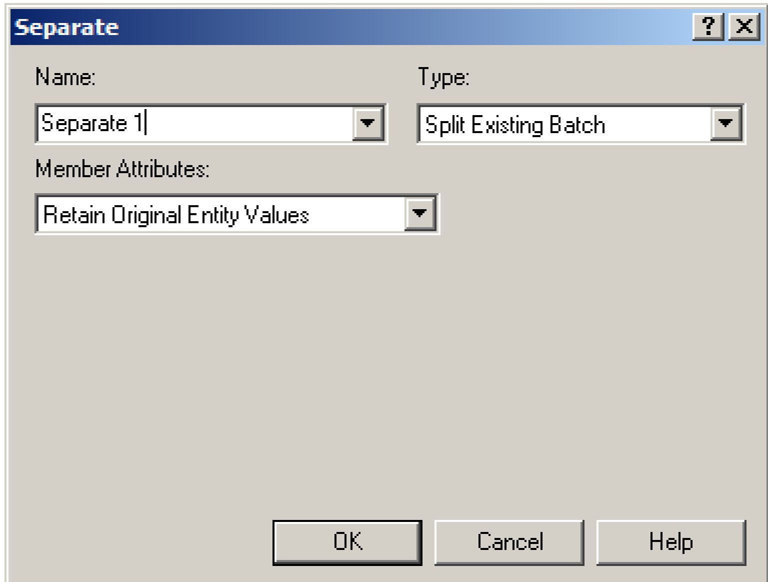

Figure 30: Separate dialog box attribute for main module

The Separate block (figure 30) is used in order to segregate the entities which is the car entity and the request/order entity that was batched using the type split existing batch. The member attributes with the value retain original entity values helps to retain the original attribute value of the entities before they were initially batched.

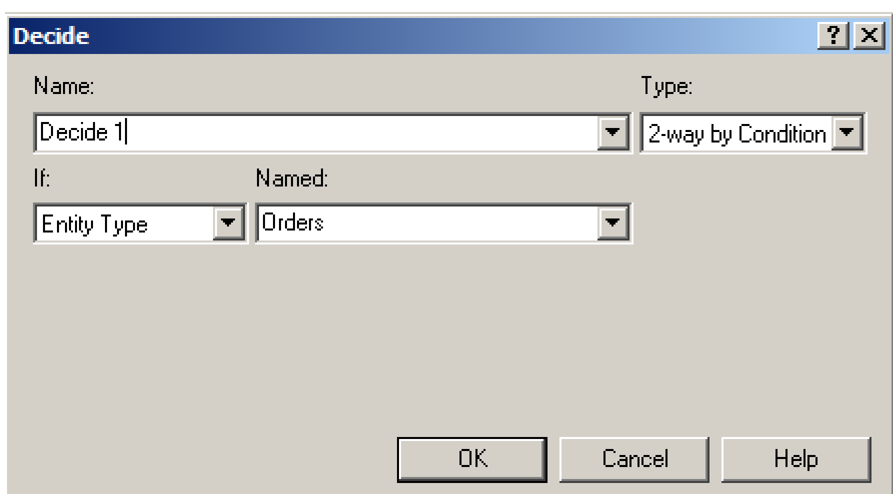

Figure 31: Decide 1 dialog box attribute for main module

The decide block (figure 31) used here is a 2-way by condition type, so if the entity type is named Orders it is true and is send to the Assign block, else it would be send to delay. In this case the entity being the car entity which would be then send to the delay block.

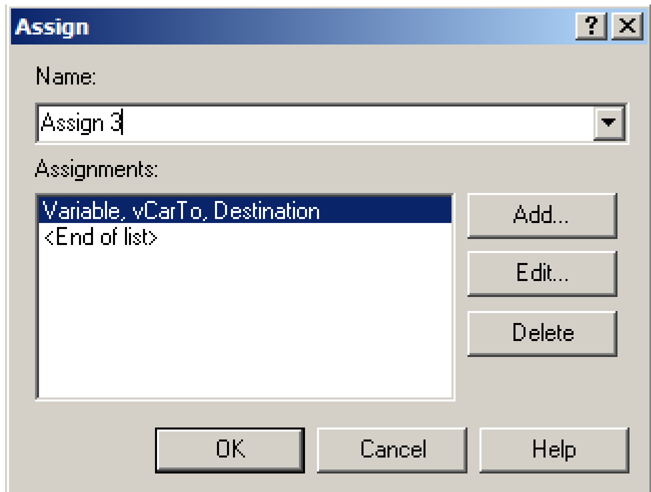

Figure 32: Assign 3 dialog box attributes for main module

The order entity which is send to the assign block (figure 32), the destination attribute from the order entity is stored into a variable named vCarTo, which would be in turn used to assign the new destination value to the car entity.

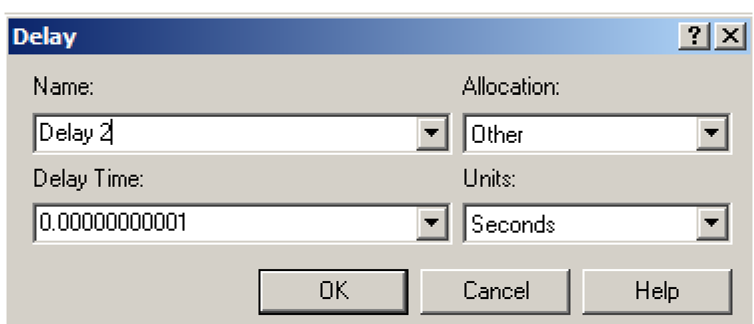

Figure 33: Delay 2 dialog box attributes for main module

Before the car entity is assigned a new destination it is delayed (figure 33) so that the variable vCarTo first receives the destination value from the order entity and then the same value can be assigned to the car entity.

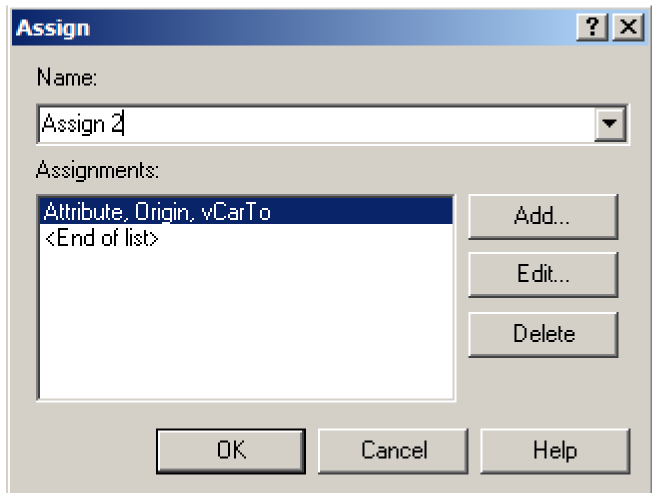

Figure 34: Assign 2 dialog box attributes for main module

As shown in the above figure 34, the value of the variable vCarTo has been assigned to the attribute Origin. Hence, the car that would now return back to the set of origin stations would have a new origin in case of a one way model and the same station for the round trip model.

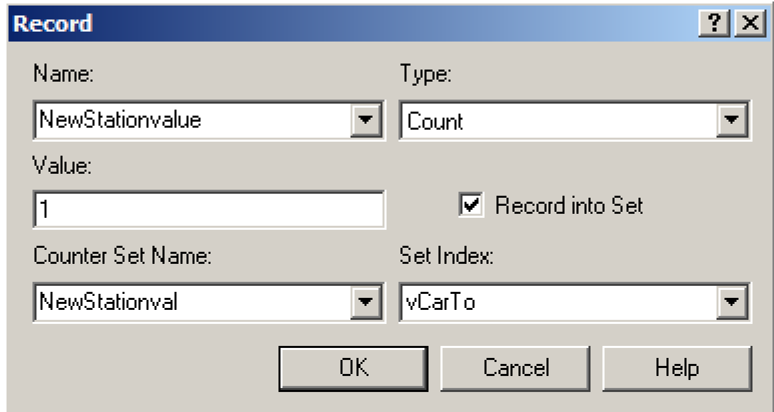

Figure 35: Record new car value dialog box attribute for main module

The new station value has been recorded into set in order to track the new destination of the car entity (figure 35). This record helps us determine the number of cars returning to the same station and the number of cars going to some other station which in turn helps us in determining the total number of cars at the end of simulation at each station. Finally the car entity is routed back to the set of origin stations block using a route block as shown in figure 36 below.

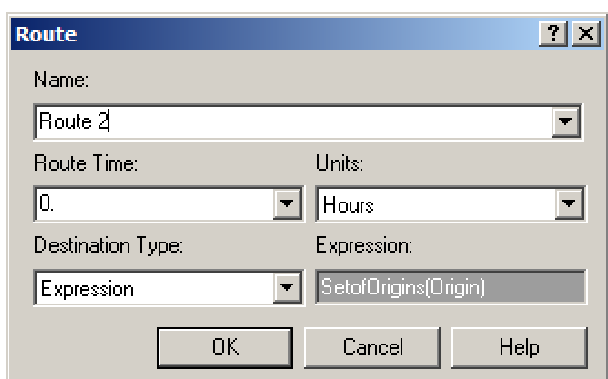

Figure 36: Route 2 dialog box attributes for main module

The destination type used is an Expression and the SetofOrigins(Origin) is specified in the expression so the car returns back to its origin station within the set of stations.

Chapter 6

Case Study for CommunAuto

In this chapter, we present the application of the proposed DES based solution approach through a case study for Communauto. The various steps of the model will be presented along with related input-output results. Based on these results, we will provide a set of recommendations to Communauto which can help it in deciding the deployment of right type of vehicle return strategy at the end of trip completion (one-way vs round trip).

6.1 Input parameters

The lists of input parameters for the DES model are presented as follows:

1. Total number of vehicles: The total number of vehicles at the time of development of the model is equal to the total number of actual vehicles in the fleet which is 881 cars.

2. Total number of stations: The total number of stations that CommunAuto has is more than 330 but at the time of data collection some of them were nonfunctional and hence were not included in the data used for the simulation model. So the total number of stations included in the simulation model is 273 stations.

3. Total number of requests generated: Both the models have been run for a total of 4225 requests that have been randomly generated using the excel function and each model has been run for a total of 10 replications.

4. Total number of order cancellations: Every 15 minute there is an entity that is generated that checks if there has been a request waiting in the queue. If there is one it is disposed from the model and the "Origin" of the request is recorded.

6.2 List of elements

The lists of elements which are used in the proposed simulation model are presented in table 10 below

Table 10: List of elements in DES model

Element type	**Name of element in the model**
Entity	Orders
	Cars
	Dummy
Variable	VCarTo
Attribute	Origin
	Destination
Create	RequestsCreate, CarsCreate, DummyEntity
Decide	Decide1, Decide2
Assign	Assign2, Assign3
ReadWrite	ReadWrite1,ReadWrite2
Match	Match1
Batch	Batch1
Delay	Delay2, Delay4
Separate	Separate1
Remove	Remove1
Record	Request,CarsatStation, NewStationvalue, CancelledOrders
Station	SetofOrigins
Route	Route1,Route 2
Dispose	Dispose1, Dispose3

6.3 List of input files

The lists of files which are used in the simulation model along with its range are mentioned in the table below:

Table 11: List of files in the DES model

Arena File Name	Recordset Name	Range Name
Requests	Recordset 1	origin_one
		origin_two
CarsOrigin	Recordset 1	Origin

6.4 Output Analysis

The output file which is generated by the Arena™ software is the .out file that has been compiled and formatted into a table which contains the number of requests per station, the number of accepted requests, the number of rejections per station, the total number of cars present at each station at the start of the simulation and the number of cars present at each station at the end of the simulation, the total acceptance ratio, the utilization ratio of the station, and finally the rejection ratio of each station. The DES model was run for a total of 200 hours. The output data has been organized based on the station numbers and the detailed results are presented in the Appendix B. A sample output table for a one way model is shown in the table 12 below:

Table 12: Sample output report table for one way model

Station	TV	TR	AR	RR	FVS	TUR	RR
002 - St-Sacrement	20	17	17	0	12	100%	0%
003 – Garnier	10	14	14	0	11	100%	0%
004 - Parc Lafontaine	13	16	16	0	4	100%	0%
005 - Jeanne D'Arc	3	15	15	0	7	100%	0%
008 - Plaza et Beaubien	3	12	12	0	10	100%	0%

(TV- Total Vehicles at station, TR- Total Requests, AR-Accepted Requests, RR-Rejected Requests, FVS- Final number of Vehicle at Station, TUR- Total Utilization Rate, RR-Rejection rate)

The contents and the acronyms used in the table 12 are explained below:

1. Station- The station refers to the CommunAuto list of actual station, the station's name is its geographical location.
2. TV (Total Vehicle) – This is the total number of vehicles present at the station.
3. TR (Total Requests) – This is the total number of requests that arrive at the station.
4. AR (Accepted Requests) – This is the total number of accepted requests at the station. This is calculated by the formula:

$$AR= \sum \text{Number of requests} - \sum \text{Number of rejections}$$

5. RR (Rejected Requests) – This is the total number of requests rejected at the station.
6. FVS (Final number of Vehicles at the Station) – The total number of vehicles at the station at the end of the simulation. As shown in the above sample table for the one way model, the final number of cars at the station differ from the total number of cars at the start of the simulation, this is because in a one way trip the user drops the car at

a destination station which differs from the origin station. For a one way model it is calculated by the

NVS= TV- AR+ New cars going to the station.

7. TUR (Total Utilization Ratio) – The total acceptance rate is calculated using the formula:

TUR= (AR/ TR) %

8. TRR (Total Rejection Ratio)- The total rejection rate is calculated using the formula

TRR= (RR/TR)%.

The output of the simulation model is also displayed using graphical presentation. The graphical presentation of the simulation model was made using the following steps:

1. The geographical locations of the stations was provided by CommunAutoInc. The latitude and longitude of the stations were given, using this information. The locations were mapped on Google Earth with the help of the website http://www.earthpoint.us/.
2. Once all the stations were mapped on google earth, a region of stations was selected. The image of the region of stations selected is shown in figure 37

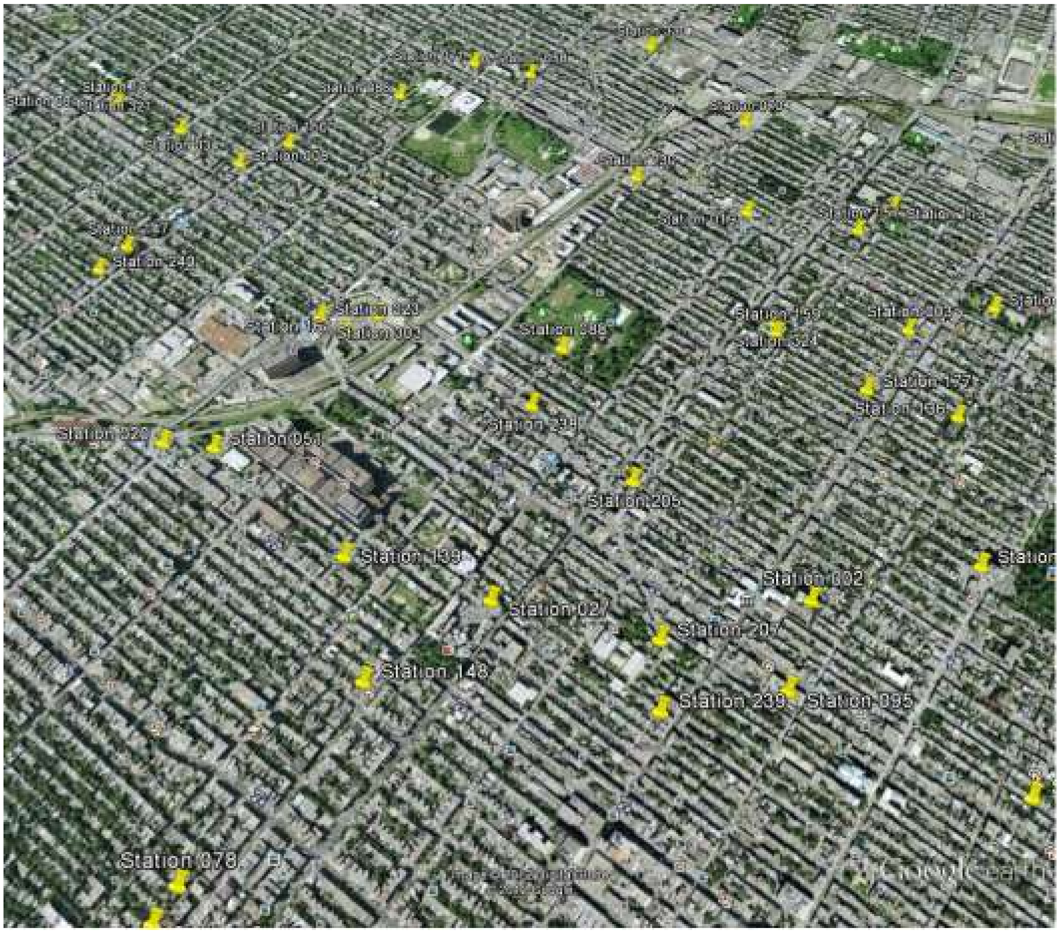

Figure 37: List of selected stations mapped on Google Earth

3. Once the set of stations were mapped, the image was saved onto the visio drawing and using Arena ™ built in function of exporting visio drawings. The image was exported on the model.
4. For representing the number of cars at each station at the start of simulation, the total number of cars at the end of simulation and the rejection at each station, the dialog box function in Arena ™ was used.
5. The end output with the dialog boxes and the visio drawing of the set of stations is shown in figure 38

As highlighted in figure 38, the total number of cars the station 020 has is 6, but the number of cars present at the station is 4 and the number of rejections at the station is 0. Similarly, the total number of cars at station 139 is 1, the number of cars present at station is 0, and the number of rejections at the station is 1.

Figure 38: List of stations with the output display parameters

We can see the various stations having display boxes which indicate the total number of vehicles at the station, the number of vehicles present at the station, and finally the number of requests rejected at the station. The corresponding display boxes are arranged in the output model as shown in table 13

Table 13: Dialog box format

<table>
<tr><td>Total number of vehicles at the station.</td><td>Number of vehicles present at the station.</td></tr>
<tr><td colspan="2">Total number of rejections at the station</td></tr>
</table>

6.4.1 Alternative Configurations

Based on the output file which is compiled and formatted into an excel table we can see the number of stations with their individual requests, the number of cars present at each station, the total number of rejections and so on. In this section we try an alternative configuration by moving the cars from station with less rejection to stations with less number of cars or more rejections. We can see in table 14 below, station 119 has 14 rejections out of the 23 requests and stations 251 and 061 each has 0 rejections out of 18 and 12 requests.

Table 14: Sample output for one way model

Station	TV	TR	AR	RR	TUR	RR
119 - Cartier et Lavoisier	1	23	9	14	39%	61%
251 - Valois et Ontario	3	18	18	0	100%	0%
061 - Berri et Notre-Dame	5	12	12	0	100%	0%

(TV- Total Vehicles at station, TR- Total Requests, AR-Accepted Requests, TUR- Total Utilization Rate, RR-Rejection rate)

However, when we move 2 cars from station 251 and 3 cars from station 061, and move the total 5 number of cars to station 119, we can observe the results shown in table 15 below:

Table 15: Sample output for one way model with alternative configuration

Station	TV	TR	AR	RR	TUR	RR
119 - Cartier et Lavoisier	6	23	15	8	65%	35%
251 - Valois et Ontario	1	18	16	2	89%	11%
061 - Berri et Notre-Dame	2	12	12	0	100%	0%

(TV- Total Vehicles at station, TR- Total Requests, AR-Accepted Requests, TUR- Total Utilization Rate, RR-Rejection rate)

As we can see the number of rejections at station 119 reduced from 14 to 8, and at the same time we can also see that even after moving 3 cars from station 061 the number of requests accepted are still the same. This indicates that station 061 has cars which are unutilized and moving them to station 119 helps reduce the number of rejected requests. Similarly, based on the output generated we listed out the stations with high rejections rates and also we have listed stations with 0 rejection rates with more than 12 cars. The table 16 below shows the stations with high rejection rates

Table 16: List of stations with high rejections

Station	TV	TR	AR	RR	TUR	RR
065 – Provost(One way model)	1	19	7	12	37%	63%
065 – Provost(Round trip model)	1	19	11	8	58%	42%
171 - 75e Avenue et Parent(One way model)	1	20	11	9	55%	45%
171 - 75e Avenue et Parent(Round trip model)	1	21	11	10	52%	48%
235 - Jean-Brillant et McKenna(One way model)	1	19	7	12	37%	63%
235 - Jean-Brillant et McKenna (Round trip model)	1	19	10	9	53%	47%
316 - Hudson et de Kent(One way model)	1	22	14	8	64%	36%
316 - Hudson et de Kent (Round trip model)	1	20	10	10	50%	50%

(TV- Total Vehicles at station, TR- Total Requests, AR-Accepted Requests, TUR- Total Utilization Rate, RR-Rejection rate)

Also, we list the stations with no rejections and more number of cars. The list of stations with more than 13 cars and 0 rejections are as listed in table 17

Table 17: List of stations with zero rejections

Station	TV	TR	AR	RR	TUR	RR
002 - St-Sacrement(One way model)	20	18	18	0	100%	0%
002 - St-Sacrement (Round trip model)	20	17	17	0	100%	0%
004 - Parc Lafontaine (One way model)	13	18	18	0	100%	0%
004 - Parc Lafontaine (Round trip model)	13	16	16	0	100%	0%
124 - Henri-Julien et De Castelnau (One way model)	16	15	15	0	100%	0%
124 - Henri-Julien et De Castelnau (Round trip model)	16	15	15	0	100%	0%
148 - Laurier et St-Urbain (One way model)	15	22	22	0	100%	0%
148 - Laurier et St-Urbain (Round trip model)	15	22	22	0	100%	0%

(TV- Total Vehicles at station, TR- Total Requests, AR-Accepted Requests, TUR- Total Utilization Rate, RR-Rejection rate)

Now we move the cars from the stations with less rejection rate to stations with higher rejection rate. The following table 18 shows the stations with the new results of the stations with the higher rejection rates:

Table 18: New value of stations after alternative configuration

Station	TV	TR	AR	RR	TUR	RR
065 – Provost(One way model)	7	19	14	5	74%	36%
065 – Provost(Round trip model)	7	19	19	0	100%	0%
004 - Parc Lafontaine (One way model)	7	18	16	2	89%	11%
004 - Parc Lafontaine (Round trip model)	7	16	16	0	100%	0%
171 - 75e Avenue et Parent(One way model)	11	20	20	0	100%	0%
171 - 75e Avenue et Parent(Round trip model)	11	21	21	0	100%	0%
002 - St-Sacrement(One way model)	10	18	18	0	100%	0%
002 - St-Sacrement (Round trip model)	10	17	17	0	100%	0%
235 - Jean-Brillant et McKenna(One way model)	8	19	13	6	68%	32%
235 - Jean-Brillant et McKenna (Round trip model)	8	19	19	0	100%	0%
148 - Laurier et St-Urbain (One way model)	8	22	18	4	82%	8%
148 - Laurier et St-Urbain (Round trip model)	8	22	22	0	100%	0%
316 - Hudson et de Kent(One way model)	9	22	22	0	100%	0%
316 - Hudson et de Kent (Round trip model)	9	20	20	0	100%	0%
124 - Henri-Julien et De Castelnau (One way model)	8	15	15	0	100%	0%
124 - Henri-Julien et De Castelnau (Round trip model)	8	15	15	0	100%	0%

(TV- Total Vehicles at station, TR- Total Requests, AR-Accepted Requests, TUR- Total Utilization Rate, RR-Rejection rate)

As shown in the above example Station 171, 75e Avenue et Parent has just 1 vehicle present at the station, we moved 10 cars from station 2, St-Sacrement to the station 171 and the rejection rate went from an average 45% to 0%. Also the total number of rejections at station 2 still remained the same. Based on the results, we can see the optimum number of cars that need to be present at each station in order to avoid higher rejections. Similarly, we moved cars from station 124 to station 316, from station 148 to station 235 and finally from station 04 to station 65. All of which show a tremendous decrease in the total number of rejections.

Hence we can see by analyzing the output file the CSO's can make more conscious decisions on relocating cars from the not so busy stations to stations with a lot of requests and fewer cars, and thereby reduce the number of request rejections. The output analysis can also help in deciding the adequate number of cars to be halted at each station.

6.4.2 Recommendations for Communauto

Based on the simulation tests for the one way model and the round trip model, we can observe that for the round trip model there are cars at some stations which are unutilized and for the one way model there is an imbalance in the number of cars at each station; some stations have excess cars and some have no cars at all. Using the alternative configuration method we can decide on the optimum number of cars to be stationed at each individual station in order to avoid rejections. Now, in order to move the unutilized cars to stations with greater demand for the round trip model, and distribute the cars evenly among the stations for one way model various vehicle return/relocation strategies need to be implemented. Vehicle return strategies can be of two types: operator based relocation strategy and customer based relocation strategy. In the customer based relocation strategy the customer is persuaded to relocate the vehicle to the specific station by an incentive technique, the incentives could range from lower rate to free rides. Another way of influencing the customer for relocation can be done by combining car sharing and car pooling technique together; sharing the ride with a fellow customer travelling to the similar location to get discounted rates. As well as offering free rides to customers via social media platforms to relocate the vehicle at the destination station. The advantage of having a customer based relocation technique is that it helps in reducing costs of hiring transporters to manually transfer the vehicles, also it is environmentally sustainable. The disadvantage of the customer based relocation technique is that the customer can only be persuaded/ influenced upto a certain degree, the decision of the acceptance solely depends on the customer.

In an operator based relocation strategy, it is initiated by the car sharing organization which includes a station manager and a transporter. The station manager would calculate the total number of cars to be positioned at each station at regular intervals and the transporter would relocate the vehicles to the specific station. The advantage of an operator based relocation technique is that there is no dependency on the customer to relocate the vehicle, as well as any maintenance work of the car can be reported to the station manager on time. However, the disadvantages include additional costs of staff, time consumption for moving the car after decisions taken by the station manager (Weikl and Bogenberger, 2012). CSO's are providing the flexibility to its users for using one way car model with an option to return the car at a parking zone within the given region, this type of system is known as the free floating system. In the future, CommunAuto can provide its customers the flexibility of using a one way car sharing model with a customer based relocation technique by providing lucrative incentives, and in order to avoid excess costs on rent for parking spaces within the city should opt for the free floating system.

Chapter 7

Conclusions and future work

7.1 Conclusions

A car sharing system has a small to a medium size fleet of vehicles which are available for its large group of members at designated stations spread over a city. Communauto has a total of 36000 members who are catered by 883 vehicles at 330 stations spread across the city of Montreal. The company currently works on a round trip model system; in which the customer takes a car from one station and returns it back to the same station. In order to check if a one way model could be implemented in the network of stations within the city of Montreal and, as well as to compare the existing round trip model with the one way model, we designed a Discrete Event Simulation(DES) based model. The DES model is a dynamic discrete stochastic model which consists of four modules, the request generation module where the requests are generated, the car generation module where the car are assigned to each station, the request rejection module tracks the number of requests rejected at each station, and finally the main module where the customer requests are matched with the car entities and the trip takes place. The input for the simulation model was generated using excel functions to randomly generate origin station and destination number using data provided by CommunAuto.

The simulation model was run for a total of 200 hours of simulation time for each replication and each model was run for 10 replications. Both the models were tested with three different sets of data, with the same number of replications and simulation hours. It was observed from the output results that the average acceptance rate for the roundtrip model was 92% which is higher than the one way model with 87%. Also, the average rejection rate for the round trip model was 8% while the average rejection rate for the one way model is 13%. The alternative configuration analysis for both the models shows the optimum number of cars to be maintained at the stations to reduce the rejection rate. The tests indicate that through alternative configuration the rejection rate can be reduced from an average 50% to a mere 12%. Based on the output analysis it can be suggested that even though the round trip model has less rejection rate as compared to the one way model, in order to utilize unused cars the one way model should be implemented along with a customer based vehicle relocation technique, in order to make sure that the number of cars at each station are balanced.

7.2 Future work

The future works to ameliorate the existing model are:

i. Use of actual number of requests per station to develop a more precise output.

ii. Various relocation techniques could be implemented in order to move the excess number of cars from the busy stations to the stations with no cars or less number of cars.

iii. Possibility of customer driven relocation techniques for vehicles could be explored.

iv. Having actual data on requests could help in making use of various other simulation tools such as Input Analyzer and Output Analyzer.

v. The model could also incorporate cost parameters which would help the CSO with better decision making, keeping in mind the cost value of every decision.

vi. Use of hybrid model which is a combination of a one way model as well as a round trip model.

vii. Models with cluster region classification could be used in order to promote a one way model within a small community while a round trip model could still be continued within the city.

References

Adelman, D. (2003) Price-directed replenishment of subsets: Methodology and its application to inventory routing. Manufacturing Service & Operations Management, 5, 348–371.

Adetiloye, T. (2012), Collaboration Planning of Stakeholders for Sustainable City Logistics Operations. Masters thesis, Concordia University.

Al-Deek H., Emam E.B. (2006), New methodology for estimating reliability in transportation networks with degraded link capacities, Journal of Intelligent Transportation Systems Technology ,Planning ,and Operations, 10(3), 117-129.

Andrew J, Douma, F. (2006), Developing a model for carsharing potential in Twin Cities neighbourhoods. Compendium of Papers for the 85th Annual Meeting of the Transportation Research Board, Washington D.C., 8.

Arnald, B., Cozot, R., Donikian, S. and Parent, M. (1996). Simulation Models for French Praxitele Project, Transportation Research Record: Journal of the Transportation Research Board, 1521, 118-125.

Bae S.H., Sarkis, J., Yoo, C.S. (2011), Greening transportation fleets: Insights from a two-stage game theoretic model, Transportation Research Part E: Logistics and Transportation Review, 47(6), 793-807.

Bandyopadhyay, S., Saha, S., (2013), Unsupervised Classification, DOI 10.1007/978-3-642-32451-2_2, Springer-Verlag Berlin Heidelberg 17-18.

Banks, J., Carson J.S., Nelson, B.L., Nicol, D.M., (2010) Discrete-Event System Simulation (5th Edition) , Prentice Hall.

Barrios J (2012) On the performance of flexible carsharing - a simulation-based approach.Working paper

Barth, M., Shaheen, S. (2002). Shared-Use Vehicle Systems: Framework for Classifying Carsharing, Station Cars, and Combined Approaches. Transportation Research Record: Journal of the Transportation Research Board, 1791,105-112.

Barth, M., Todd, M., (1999) Simulation model performance analysis of a multiple station shared vehicle system. Transportation Research Part C: Emerging Technologies 7(4), 237-259.

Barth, M. and Todd, M. (2001). User Behavior Evaluation of an Intelligent Shared Electric Vehicle System, Transportation Research Record: Journal of the Transportation Research Board, 1760, 145-152.

Barth, M., Todd, M. and Xue, L. (2004). User-Based Vehicle Relocation Techniques for Multiple-Station Shared-Use Vehicle Systems. Paper presented at the Transportation Research Board 83rd Annual Meeting, Washington DC.

Beaulieu M., Gamache M. (2006), An enumeration algorithm for solving the fleet management problem in underground mines Computers and Operations Research, 33 (6) , 1606-1624.

Bell, M.G.H. (2000), A game theory approach to measuring the performance reliability of transport networks, Transportation Research Part B: Methodological, 34(6),533- 545.

Bertsimas, D. J. (1988), Probabilistic combinatorial optimization problems. Ph.D. dissertation,Report No. 193, Operations Research Center, Massachusetts Institute of Technology, Boston, MA.

Bonsall, P.W. (1979), The simulation of organized car sharing - The simulation models and their calibration. TRRL Working paper SP/SRB8.

Bonsall, P. (1982). Microsimulation: Its application to carsharing, Transportation Research Part A: General, 16(5-6), 421-429.

Cassias, I., (2005) Project54 Vehicle Telematics for remote diagnostics, fleet management and traffic monitoring.

Cepolina EM, Farina A (2012) A new shared vehicle system for urban areas. Transportation Research Part C 21:230-243

Chen, A., Yang, H., Lo, H. K.,Tang, W. H. (1999), A capacity related reliability for transportation networks. J. Adv. Transp., 33, 183–200. doi:10.1002/atr.5670330207.

Cheung B.K.-S., Choy K.L., Li C.-L., Shi W., Tang J. (2008), Dynamic routing mode land solution methods for fleet management with mobile technologies International Journal of Production Economics, 113 (2) , 694-705.

Ciari F, Dobler C, Axhausen KW (2012) Modeling one-way shared vehicle systems: an agent-based approach. Proceedings of the 13th International Conference on Travel Behaviour Research

Cochran, W. G. (1977) Sampling Techniques, Third Edition, New York: John Wiley & Sons, Inc.

Crainic, T.G., Laporte, G.,(1998) Fleet Management and Logistics (Center for Research on Transportation 25th Anniversary Series, 1971–1996), 1st ed., Springer.

Crainic T., Gendreau M., Dejax P. (1993), Dynamic and stochastic models for the allocation of empty containers, Operations Research, 41, 102-126.

Danielis, R., Rotaris, L., Valeri, E. (2012), Carsharing for tourists. In: RIEDS – Rivista Italiana di Economia, Demografia e Statistica – Italian Review of Economics, Demography and Statistics. RePEc:ite:iteeco:122008.)

Dantzig G, Fulkerson D (1954) Minimizing the number of tankers to meet a fixed schedule. Naval Research Logistics Quarterly, 1, 217-222.

Dantzig, G. and Wolfe, P. (1960) Decomposition Principle for Linear Programs. Operations Research 8, 101-111.

Dejax, J. , Crainic T.G., (1987) Survey paper—a review of empty flows and fleet management models in freight transportation Transportation Science, 21, 227–248

Doherty M.J., Sparrow, F.T., Sinha K.C. (1987) Public use of autos: Mobility Enterprise Project J. Transp. Eng., 113, 84–97

Dror, M., Laporte G., Trudeau P. (1989), Vehicle routing with stochastic demands: Properties and solution frameworks. Transportation Science, 23, 166–176.

Dulai T., Jaskó S., Muhi D., (2008) Source: AIP Conference Proceedings. Vol. 1060(1), 410-413.

El Fassi A., Awasthi, A., Viviani, M.(2012) Evaluation of carsharing network's growth strategies through discrete event simulation, Expert Systems with Applications, 39(8), 6692-6705.

Evans, J.R., Lindsay W.M., (2005) An introduction to Six Sigma & process improvement. Thomson, South-Western. 99-101

Fan W. D., Machemehl R. B., Lownes N. E.. (2008) Carsharing: Dynamic decision-making problem for vehicle allocation. Transportation Res. Record: J. Transportation Res. Board 2063 97–104.

Fan, W., & Xu, Y. (2013). Managing Dynamic Vehicle Allocation for Carsharing Systems: Stochastic Programming Approach. In Transportation Research Board 92nd Annual Meeting (No. 13-0324).

Ferguson A., Dantzig G.B. (1955), The problem of routing aircraft-A mathematical solution. Aeronautical Engineering Review, 14, 51-55.

Fisk C.S., (1984), Game theory and transportation systems modeling Transportation Research Part B, 18 (4–5) 301–313

Frantzeskakis L and Powell WB (1990), A successive linear approximation procedure for stochastic dynamic vehicle allocation problems. Transportation Science, 24, 40-57.

Future of Car Sharing < http://futureofcarsharing.com/>

Gendreau, M., G. Laporte, R. Séguin. (1995), An exact algorithm for the vehicle routing problem with stochastic customers and demands, Transportation Science, 29,143–155.

Glockner G.D., Nemhauser G.L., (2000) A dynamic network flow problem with uncertain arc capacities formulation and problem structure Operations Research, 48, 233–242

Godfrey, G. A., Powell, W. B. (2002a), An adaptive, dynamic programming algorithm for stochastic resource allocation problems I: Single period travel times, Transportation Science, 36(1), 21-39.

Godfrey, G. A., Powell, W. B. (2002b), An adaptive, dynamic programming algorithm for stochastic resource allocation problems II: Multi-period travel times, Transportation Science, 36(1), 40-54.

Godfrey, G., Powell W. B.. (2002) An adaptive, dynamic programming algorithm for stochastic resource allocation problems I: Single period travel times. Transportation Science. 36, 21–39.

Harker P.T., (1988) Private market participation in urban mass transportation: application of computable equilibrium models of network competition Transportation Science, 22 (2) ,96–111

Harms, S., Truffer, B. (1998), The emergence of a nation-wide carsharing co-operative in Switzerland. A case study for the project "Strategic Niche Management as a tool for transition to a sustainable transportation system". EAWAG.

Health effects institute, (2010) Health effects institute Traffic-related air pollution a critical review of the literature on emissions, exposure, and health effects < http://pubs.healtheffects.org/getfile.php?u=553 />

Hollander Y.Z., Prashker J.N., (2006) The applicability of non-cooperative game theory in transport analysis Transportation, 33 (5), 481–496

Ichoua, S., Gendreau, M., Potvin, J-V. (2006) Exploiting Knowledge About Future Demands for Real-Time Vehicle Dispatching 40(2), 211–225.

Jordan W., Turnquist M. (1983), A stochastic dynamic network model for railroad car distribution. Transportation Science, 17, 123-145.

Jorge, D., Correia, G. (2013) Carsharing systems demand estimation and defined operations: a literature review 13(3), 201-220 ISSN: 1567-7141.

Juan, A., Faulin, J., Grasman, S., Riera, D., Marull, J., Mendez, C. (2011), Using safety stocks and simulation to solve the vehicle routing problem with stochastic demands, Transportation Research Part C: Emerging Technologies, 19(5), 751- 765.

Kek, A., Cheu, R. and Chor, M. (2006). Relocation Simulation Model for Multiple-Station Shared-Use Vehicle Systems, Transportation Research Record: Journal of the Transportation Research Board, 1986, 81-88.

Kek, A., Cheu, R., Meng, Q. and Fung, C. (2009). A decision support system for vehicle relocation operations in carsharing systems', Transportation Research Part E: Logistics and Transportation Review, 45(1), 149-158.

Kelton, W. D,. Sadowski, R.P., Swets, N.B. (2010), Simulation with Arena, 5th Edition Rockwell Automation, Rockwell Automation (retired) McGraw-Hill, ©2010.

Koch, H. (2001), "User needs report", MOSES (Mobility Services for Urban Sustainability) Project – Workpackage 2.2, European Commission, DG TREN. University of Bremen. 22-24.

Kochel P., Kunze S., Nielander U. (2003), Optimal control of a distributed service system with moving resources: Application to the fleet sizing and allocation problem International Journal of Production Economics, 81-82 , 443-459.

Kurauchi F., Sumalee A.(2008), Editorial: Evaluation and enhancement of transport network reliability: Network equilibrium based approach, Journal of Advanced Transportation, 42 (3) , 209-212.

Larsen, A., O. Madsen, M. M. Solomon. (2002) Partially dynamic vehicle routing Models and algorithms. Journal of Operational Research Society, 53, 637–646.

Lo, S.M., Huang, H.C. , Wang, P. , Yuen, K.K. , (2006), A game theory based exit selection model for evacuation, Fire Safety Journal, 41, 364-369.

Marcotte P., Zubieta L., Drissi-Kaitouni O. , (1990) Iterative methods for solving and equilibrium problem arising in transit deregulation Transportation Research Part B, 24 (1) 45–55

Massot, M., Lapierre, E.,(1999) Syndicat des Transports Parisiens. "PRAXITELE: THE MISSING LINK." Public transport planning and management: proceedings of Seminar E held at the European Transport Conference, Robinson College, Cambridge, 27-29. PTRC Education and Research Services Ltd. on behalf of the Association for European Transport.

Maxwell, M.S., Henderson, S.G., Topaloglu, H., (2009), Ambulance redeployment: An approximate dynamic programming approach, Proceedings of the 2009 Winter Simulation Conference (WSC), 1850, 1860, 1316 doi: 10.1109/WSC.2009.5429196.

Mitchell, W., Borroni-Bird, C., Burns, L. (2010). Reinventing the Automobile: personal urban mobility for the 21st century. Cambridge, Massachusetts: MIT Press, (Chapter 8).

Morton, D.P. (2002) Stochastic Optimization Class Notes, The University of Texas at Austin, Austin, Texas, U.S.A.

Muheim, P., (1996), Partner. Car Sharing Studies: An Investigation. Graham Lightfoot, Ireland.

Myerson R.B. (1991), Game Theory: Analysis of Conflict. Cambridge Mass.: Harvard University Press.

Nair R, Miller-Hooks E (2011) Fleet management for vehicle sharing operations. Transportation Science 45(4), 524–540

Nagurney A., Qiang, Q., Nagurney, L.S., (2010) Environmental impact assessment of transportation networks with degradable links in an era of climate change- International Journal of Sustainable Transportation, 4 (3). 154–171.

Nakayama, S., Yamamoto, T., Kitamura, R. (2001) A Simulation Analysis for the Management of an Electric-Vehicle Sharing System: The Case of the Kyoto Public-Car System, Transportation Research Board, Proceedings, 80th Annual Meeting, Washington, D.C.

Nance, R., (1993) A history of Discrete Event simulation programming languages SRC 93-003.

Pasquier M., Quek C., Tan B.T., Chee S. (2001), Opportunistic planning for a fleet of transportation robots Engineering Applications of Artificial Intelligence, 14 (3) , 329-340.

Powell, W. B. (1988), A comparative review of alternative algorithms for the dynamic vehicle allocation problem. B. L. Golden, A. A. Assad, eds. Vehicle Routing:Methods and Studies. North Holland, Amsterdam, The Netherlands, 249–291.

Powell, W. B., Topaloglu H. (2003), Stochastic programming in transportation and logistics. Stochastic Programming, Handbook in Operations and Management Sciences, 10. Elsevier, Amsterdam, The Netherlands, 555–635.

Powell, W.B., Topaloglu, H., (2005). Fleet management. In: Applications of Stochastic Programming, MPS/SIAM Series on Optimization, vol. 5, SIAM, Philadelphia, PA. 185–215.

Raviv, T., Tzur, M., Forma, I. A., (2012), Static repositioning in a bike-sharing system: models and solution approaches. EURO Journal on Transportation and Logistics, 1-43.

Regan, A., Mahmassani, H., Jaillet, P. (1998), Evaluation of Dynamic Fleet Management Systems: Simulation Framework Transportation Research Record: Journal of the Transportation Research Board, 1645(1), 176-184, doi:10.3141/1645-22.

Reyes, P.M. (2005), Logistics networks: A game theory application for solving the transshipment problem, Applied Mathematics and Computation, 168(2), 1419 -1431.

Sampling with/without replacement (2013) http:/www.ma.utexas.edu/users/parker/sampling/repl.htm

Sargent, R.G., (2007), Verification and validation of simulation models In WSC '07: Proceedings of the 39th conference on Winter simulation , 124-137.

Schrank, D., Lomax, T., (2007), The 2007 urban mobility report, p.p. 5-6 <http://www.ncga.state.nc.us/documentsites/committees/21stcenturytransportation/prioritizationbest%20practicesefficiency/presentations/mobility_report_2007_wappx.pdf>

Shaheen, S., Cohen, A., (2012), Innovative Mobility Carsharing Outlook: Carsharing Market Overview, Analysis, and Trends Fall-2012, Transportation Sustainability Research Center- University of Berkeley.

Shaheen, S., Sperling, D., Wagner, C. (1999) A Short History of Carsharing in the 90's. Journal of World Transport Policy and Practice, 5, 16-37.

Shouke W, Yang, H., Abbaspour, K., Mousavi, J., Gnauck, A., (2010), Game theory based models to analyze water conflicts in the Middle Route of the South-to- North Water Transfer Project in China, Water Research, 44(8), 2499-2516.

Simao H.P. , Day J., George A., Gifford T., Nienow J., Powell W.B., (2009) An approximate dynamic programming algorithm for large-scale fleet management a case application Transportation Science, 43, 178–197

Spivey, M., Powell, W.B. (2004) The dynamic assignment problem. Transportation Science, 38, 399–419.

Sumalee, A., Uchida, K., Lam, H.K.W. (2011), Stochastic multi-modal transport network under demand uncertainties and adverse weather condition, Transportation Research Part C: Emerging Technologies, 19(2), 338-350.

Sun L.J., Gao Z.Y. (2007), An equilibrium model for urban transit assignment based on game theory European Journal of Operational Research, 181 (1) 305–314

Tan C (29 February 2008) -The Straits Times End of the Road for Honda Car Sharing Scheme.

Taylor M.A.P. (1999), Dense network traffic models, travel time reliability and traffic management. I: General introduction Journal of Advanced Transportation, 33 (2), 218-233.

The Moses guide: Keys to car-sharing, Chapter 1: What's in it for the customer? <http://www.uitp.org/Working-Bodies/Car-Sharing/pics/moses -KeysToCarSharings.pdf />

Topaloglu, H. (2006) A parallelizable dynamic fleet management model with random travel times, European Journal of Operational Research, 175(2), 782-805.

Topaloglu, H., Powell, W. B. (2007), Sensitivity analysis of a dynamic fleet management model using approximate dynamic programming. Operations Research, 55(2), 319-331.

Traffic Congestion growing factor-< http://appian.tmwsystems.com/industry -news/traffic-congestion-growing-factor-fleet-routing-and-scheduling />

Trowbridge, M.J., Gurka, M.J., O'Connor, R.E. (2009) Urban sprawl and delayed ambulance arrival in the U.S Am J Prev Med, 37, 428–432.

Uesugi, K., Mukai, N. and Watanabe, T. (2007). Optimization of Vehicle Assignment for Car Sharing System, Knowledge-Based Intelligent Information and Engineering Systems, 4693, 1105-1111.

Viton P.A., Privately-provided urban transport services (1982) Journal of Transportation Economics and Policy, 16 (1982), 85–94

Viviani, M., (2012) Self Service Electric Vehicle in Canada http://www.emc-mec.ca/ev2012ve/proceedings/EV2012VE24T3s7-02 -MarcoViviani-Communauto_SelfServicesEVsInCanada.pdf

Wallace, S. (1986) Solving Stochastic Programs with Network Recourse. Networks 16, 295-317.

Wang, H., Cheu, R. and Lee, D.-H. (2010). Dynamic Relocating Vehicle ResourcesUsing a Microscopic Traffic Simulation Model for Carsharing Services, Computational Science and Optimization (CSO), 2010 Third International Joint Conference, Huangshan, Anhui, 108-111.

Weikl S, Bogenberger K (2012) Relocation strategies and algorithms for free-floating car sharing systems. In: IEEE conference on intelligent transportation systems, 355–360.

What is Car Sharing org < http://www.carsharing.org/about/what-is-car-sharing/>

White WW. (1972), Dynamic transshipment networks: An algorithm and its application to the distribution of empty containers. Networks 2: 211-236.

White WW., Bomberault A. (1969), A network algorithm for empty freight car allocation. IBM Systems Journal 8, 147-171.

Wiki optimization definition (2013) http://en.wikipedia.org/wiki/Mathematical_optimization

Wikipedia "List of Discrete Event simulation software" (2013) http://en.wikipedia.org/wiki/List_of_discrete_event_simulation_software

World Health Organization, (2005); World Health Organization, 2005 World Health Organization Health effects of transport-related air pollution, WHO Regional Office for Europe, Copenhagen, 125–165.

Yass, I. (2010) Delays Due to Serious Road Accidents Prepared by: April 2010 Report Number 09/106, <http://www.racfoundation.org/assets/rac_foundation/content/downloadab les/road%20accident%20delays%20-%20yass%20-%20april%20 -%20report.pdf />

Yoon B., Lee, S. (2013), An Operation Model of Carsharing Service: Application of Simulation Method, Journal of Traffic and Logistics Engineering, 1(1), 15-19, doi: 10.12720/jtle.1.1.15-19

Zeimpekis V., Tarantilis C.D., Giaglis G.M., Minis I., 2007, Dynamic fleet management : concepts, systems, algorithms and case studies, Operations Research / Computer Science Interfaces Series, Vol. 38

Zhang, K., Batterman, S. (2013) Air pollution and health risks due to vehicle traffic, Science of The Total Environment, Vol 450–451, 307-316.

Appendix A

Table 19: The actual list of CSO in the world (http://www.carsharing.net/where.html)

City / Region	Organization	Cost of 4 hr trip*	Fleet Size	$/NGO
Alexandria, VA	zipcar	~	large	for-$
Ann Arbor, MI	Zipcar	~	large	for-$
Arlington, VA	zipcar	~	large	for-$
Ashland, OR	Ashland CarShare	~	~	~
Aspen, CO	Roaring Fork Valley Vehicles	~	small	for-$
Atlanta, GA	zipcar	~	large	for-$
Austin,Tx	Austin CarShare	$27.00	small	NGO
Austin,Tx	Car2go	$48.00	large	for-$
Baltimore, MD	zipcar	~	large	for-$
Bellingham,WA	Community Car Share of Bellingham	~	small	NGO
Berkeley,CA	City CarShare	$30.27	large	NGO
Buffalo, NY	Buffalo CarShare	~	small	NGO
Boston, MA	ZipCar	$31.50	large	for-$
Boulder, CO	eGo Carshare (formerly Boulder CarShare)	$19.76	small	NGO
Burlington, VT	CarShare Vermont	$34.05	small	NGO
Calgary, AB	Calgary Alternative Transp. Co-op	~	small	co-op
Chicago, IL	i-go-cars	$34.69	large	NGO
Chicago, IL	Zipcar	~	large	for-$
Chapel Hill, NC	ZipCar	$20.56	large	for-$
Cleveland, OH	City Wheels	$32.00	small	for-$
Denver, CO	eGo Carshare	$19.76	small	NGO
Denver, CO	Occassional Car	~	~	~
East Bay, CA	City CarShare	$30.27	large	for-$
Edmonton, AB	Carsharing Co-op. Edmonton	~	small	co-op
Eugene, OR	Eugene Bio Car Share	~	small	NGO
Fairfax County, VA	Zipcar	~	Large	for-$
Fernie, BC	Kootenay Carshare Cooperative	~	small	co-op
Fort Wayne, IN	Fort Wayne Car Co-op	~	small	co-op
Gainsville, FL	Zipcar	~	large	for-$

Gatineau, PQ	CommunAuto	$18.05	large	for-$
Greenbelt,MD	ZipCar	$31.50	large	for-$
Halifax, NS	CarShare HFX	~	~	~
Hamilton, ON	Grand River Car Share	$28.67	small	co-op
Hoboken, NJ	Corner Car		large	PPP
Hoboken, NJ	ZipCar	$36.00	large	for-$
Ithaca, NY	Ithaca CarShare	~	small	NGO
Kaslo, BC	Kootenay Carshare Cooperative	~	small	co-op
Kimberley, BC	Kootenay Carshare Cooperative	~	small	co-op
Kingston, ON	Kelsey	~	small	for-$
Kitsap County,WA	Scoot	$34.00~	large	for-$
Kitch.Waterloo, ON	Grand River Car Share	$28.67	small	co-op
Los Angeles, CA	LAXcarshare	~	~	for-$
Madison, WI	Community Car	$29.22	medium	for-$
Madison, WI	U Car Share	$40.00	medium	for-$
Minn./St. Paul, MN	hOurcar	$36.16	medium	NGO
Minn./St. Paul, MN	ZipCar	$35.39	large	for-$
Montgomery Cty, MD	ZipCar	~	large	for-$
Montreal, PQ	Communauto	$18.05	large	for-$
Nanaimo, BC	Nanaimo CarShare Cooperative	~	small	co-op
NelsonKootenay Carshare Cooperative	~	small	co-op	
Nevada City, CA	ContactMike Foxfoot	~	small	ngo
New York, NY	Connect by Hertz	$40.00	~	for-$
New York, NY	Mint	$40.00	~	for-$
New York, NY	ZipCar	$44.00	large	for-$
Oakland, CA	City CarShare	$30.27	large	for-$
Oklahoma City, OK	Timecar	~	small	for-$
Ottawa, ON	Vrtucar	$30.60	medium	for-$
Philadelphia, PA	PhillyCarShare	$30.84	large	NGO
Philidelphia, PA	ZipCar	~	large	for-$
Pittsburg, PA	ZipCar	~	large	for-$
Portland, OR	ZipCar	$38.00	large	for-$
Portland, OR	U Car Share	$40.00	medium	for-$
Portland, ME	U Car Share	~	medium	for-$
Prince Grgs. Cty, MD	ZipCar	~	large	for-$
Princeton, NJ	ZipCar	$36.00	large	for-$
Quebec City, PQ	Communauto	$18.05	large	for-$

Regina, SK	Regina CarShare	~	small	co-op
Revelstoke, BC	Kootenay Carshare Cooperative	~	small	co-op
Rutledge, MO	Dancing Rabbit Vehicle Co-op	~	small	co-op
St. Louis, MO	Wecar	~	~	for-$
San Francisco,CA	City CarShare	$29.94	large	NGO
San Francisco,CA	ZipCar	$37.00	large	for-$
San Luis Obispo, CA	FunRide	$26	small	For-Profit
Saskatoon, SK	Dadro Car Sharing	~	~	for-$
Seattle, WA	Zipcar	~	large	for-$
Sebastopol, CA	SolarCarShare	~	small	~
Sherbrooke, PQ	Communauto	$18.05	large	for-$
Syracuse, NY	CuseCar	~	small	NGO
Toronto, ON	AutoShare	$34.53	large	for-$
Toronto, ON	Zipcar	$39.60	large	for-$
Vancouver, BC	Co-operative Auto Network	$23.08	large	co-op
Vancouver, BC	ZipCar	~	large	for-$
Vancouver Island, BC	Co-operative Auto Network	$23.08	large	co-op
Victoria, BC	Victoria Car Share Co-op	$19.63	small	co-op
Washington, DC	ZipCar	$31.50	large	for-$
Whistler, BC	Co-operative Auto Network	$23.08	large	co-op
In Planning				
Ann Arbor, MI	Ann Arbor Community Car Co-op	~	small	co-op
Columbus, OH	Mid-Ohio Regional Planning Commission	~	~	~
Dallas, TX	Oak Cliff Car Share	~	~	~
Eugene, OR	Lane Car Share	~	~	~
Guelph, ON	Contact Bill Barrett	~	~	~
Old Westbury, NY	c/o Michael Cellini	~	~	~
Orlando, FL	contact Andy Nicol	~	~	~
Portland, ME	c/o Matti Gurney	~	~	~
Regina, SK	Regina CarShare	~	~	~
Santa Barbara, CA	Santa Barbara Car Share	~	~	~
Wilmington, DE	RideShare Delaware	~	~	~
Winnipeg, MB	contact Bruce Berry	~	~	~
Closed etc..				
DC / SF / WA / OR	Flexcar	~	~	~

Atlanta, GE	eMotion Mobility	~	~	~
Chicago, IL	Ready Car	~	~	~
Denver, CO	~	~	~	~
Detroit, MI	Motor City Car Share	~	~	~
Detroit, MI	Via Car	~	~	~
Palo Alto, CA	CarLink II Demo Project	~	~	~
Portland, OR	Car Sharing Portland	~	~	~
Riverside, CA	U.C. Riverside Intellishare	~	~	~
Traverse City, MI	CarSharing Traverse	~	~	~
World Wide				
Mobility CarSharing Switzerland	Mobility Car Sharing*	~	~	~
Europe	European CarSharing*	~	~	~
Austria	DENZELDRIVE	~	~	~
Belgium				
5 cities	Cambio	~	~	~
Finland	City Car Club	~	~	~
France	AutoLibre	~	~	~
Paris	Caisse-Commune	~	~	~
Paris	Connect by Hertz	~	~	for-$
Germany	Bundesverband CarSharing*	~	~	~
8 cities	Cambio	~	~	~
Goettingen	stadt-teil-auto Goettingen	~	~	~
Kassel	Stattauto Kassel	~	~	~
Italy				
Milano	Milano Car Sharing	~	~	~
Netherlands	Green Wheels			
Norway				
Oslo	Bilkollektivet	~	~	~
Trondheim	BILRINGEN	~	~	~
Bergen	BilRingen	~	~	~
Portugal		~	~	~
Lisboa	Mob Carshaaring	~	large	for-$
Spain				

Barcelona	Catalunya CarSharing	~	~	~
Sweden	a list			
Goteborg	Majornas Bilkooperativ	~	~	~
various cities	Sun Fleet	~	~	~
Denmark ?	Andelsbil.dk			
Aarhus	Aarhus Delebilklub	~	~	~
UK	Carplus			
Brighton	Streetcar	~	large	for-$
Cranfield University	CampusCars	~	~	~
Edinburgh	Smart Moves	~	~	~
London	Connect by Hertz	~	~	for-$
London	Streetcar	~	large	for-$
London	Zipcar	~	large	for-$
Oxford	ITSM	~	~	~
Southampton	Streetcar	~	large	for-$
Australia / New Zealand				
Aukland, NZ	Cityhop	~	medium	For-$
Brisbane	GWhiz	~	small	For-$
Melbourne	Flexicar	~	Large	For-$
Melbourne	GoGet	~	Large	For-$
Perth	Nexus Car Share	$32	Small	For-$
Sydney	GoGet	~	Large	For-$
Asia				
Jerusalem	contact Gidon Ariel	~	~	~
Tel Aviv	Car2Go	~	~	~
Singapore	Honda ICVS	~	~	~
Singapore	NTUC INCOME Car Co-op	-	-	-
Singapore	Whizzcar	-	-	-
City/Region	**Organization**	**4 hr trip***	**Size**	**$/NGO**

Source: http://www.carsharing.net/where.html

Appendix B

Table 20: Detailed results of the One way model for Test_1

Station	TV	TR	AReq	RReq	FCS	TUR	RR
002 - St-Sacrement	20	17	17	0	12	100%	0%
003 – Garnier	10	14	14	0	11	100%	0%
004 - Parc Lafontaine	13	16	16	0	4	100%	0%
005 - Jeanne D'Arc	3	15	15	0	7	100%	0%
008 - Plaza et Beaubien	3	12	12	0	10	100%	0%
012 – Lajeunesse	3	12	12	0	5	100%	0%
013 - 6e Avenue	9	14	14	0	11	100%	0%
014 - Rachel et Papineau	4	22	21	1	2	95%	5%
016 - Jean-de-Brébeuf	6	22	18	4	0	82%	18%
018 - Beaudry et Robin	5	16	16	0	2	100%	0%
019 - Laurier et Papineau	6	15	15	0	4	100%	0%
020 - Bernard et Saint-Laurent	6	22	21	1	0	95%	5%
021 – Coolbrook	6	8	8	0	13	100%	0%
022 - Place St-Henri	10	17	17	0	2	100%	0%
023 - Métro Rosemont	7	11	11	0	13	100%	0%
024 - Centre St-Pierre	3	15	11	4	0	73%	27%
025 - Christophe-Colomb et Rachel	7	11	11	0	12	100%	0%
027 - St-Joseph et De Bullion	8	13	13	0	5	100%	0%
028 - St-Antoine et Atwater	4	17	17	0	0	100%	0%
030 - Iberville et Mont-Royal	3	8	8	0	5	100%	0%
032 - Van Horne et Dollard	5	10	10	0	7	100%	0%
034 - Boyer et St-Zotique	9	9	9	0	7	100%	0%
037 - Goyer	2	18	10	8	0	56%	44%
038 - Chambord et Fleury	7	13	13	0	12	100%	0%
041 - Métro Angrignon	5	17	15	2	0	88%	12%
042 - Plantagenet	3	13	13	0	3	100%	0%
043 - Remembrance et 32e avenue	2	22	12	10	0	55%	45%
044 - Nicolet et Hochelaga	6	15	15	0	3	100%	0%
045 - Evelyn	3	13	13	0	4	100%	0%
047 - Peel et Dr Penfield	4	11	11	0	7	100%	0%
048 - St-Jacques et St-Jean	1	10	10	0	2	100%	0%
049 - Monk et Jolicoeur	7	10	10	0	9	100%	0%
050 - Parc Ahuntsic	9	14	14	0	13	100%	0%

051 - Aréna St-Louis	4	12	12	0	15	100%	0%
052 - Old Orchard	6	10	10	0	12	100%	0%
056 - Hutchison et Milton	3	20	16	4	0	80%	20%
058 - Cartier et Rosemont	4	20	20	0	1	100%	0%
059 - Tour Penfield	2	13	13	0	4	100%	0%
060 - Victoria et 17e avenue	1	15	14	1	2	93%	7%
061 - Berri et Notre-Dame	5	12	12	0	12	100%	0%
062 - 4e avenue et Wellington	5	17	17	0	6	100%	0%
064 - Métro Sauvé	7	12	11	1	2	92%	8%
065 - Provost	1	19	7	12	0	37%	63%
068 - Métro Longueuil-Port-de-Mer	4	17	17	0	3	100%	0%
069 - Bossuet et Sherbrooke	3	16	13	3	0	81%	19%
070 - Masson et De Lorimier	9	11	11	0	7	100%	0%
071 - Papineau et Bellechasse	1	22	15	7	1	68%	32%
073 - Grant et LeMoyne	1	11	11	0	10	100%	0%
074 - St-Jean et St-Laurent	2	17	9	8	0	53%	47%
076 - Bernard et de L'Épée	4	13	13	0	6	100%	0%
077 - Bernard et Wiseman	4	16	16	0	6	100%	0%
078 - Laurier et Durocher	2	15	15	0	3	100%	0%
080 - Napoléon et St-Dominique	9	20	20	0	3	100%	0%
081 - St-Vallier et Jean-Talon	4	21	19	2	0	90%	10%
082 - Berri et De Castelnau	3	13	13	0	6	100%	0%
083 - Aréna Jean Rougeau	5	19	14	5	0	74%	26%
084 - Centre St-Mathieu	6	11	11	0	7	100%	0%
085 - François-Perrault	3	12	12	0	0	100%	0%
086 - Parc Père-Marquette	6	14	14	0	3	100%	0%
087 - Parc Beaubien	5	17	17	0	4	100%	0%
088 - Parc Laurier	3	16	16	0	4	100%	0%
090 - Sewell et des Pins	5	16	16	0	5	100%	0%
091 - Lucien-L'Allier	3	19	17	2	0	89%	11%
092 - Laprairie et Centre	3	18	18	0	3	100%	0%
093 - Appartements Rockhill	2	17	17	0	0	100%	0%
094 - La Fontaine et Pie-IX	2	19	18	1	0	95%	5%
095 - Drolet et Marie-Anne	6	16	16	0	6	100%	0%
096 - Collège Notre-Dame	5	15	15	0	13	100%	0%
097 - Roland-Therrien et De Gentilly	2	10	10	0	1	100%	0%
099 - Hochelaga et Préfontaine	1	19	15	4	0	79%	21%
100 - St-Clément et Adam	9	12	12	0	7	100%	0%
101 - Métro Radisson	2	17	16	1	0	94%	6%
102 - Métro Longueuil-Terminus	4	16	16	0	1	100%	0%
104 - Dézéry et Ontario	2	11	11	0	5	100%	0%

105 - Centre St-Donat	4	14	13	1	0	93%	7%
106 - Centre productions Jeun'Est	4	8	8	0	3	100%	0%
107 - Iberville et Ontario	6	15	13	2	1	87%	13%
109 - Ethel	3	8	8	0	6	100%	0%
110 - Aréna Cartier	3	16	15	1	0	94%	6%
111 - Ouimet et de L'Église	2	13	13	0	1	100%	0%
113 - Jardin De Lorimier	2	12	12	0	8	100%	0%
115 - Chez Magnan	2	11	10	1	0	91%	9%
116 - Riverside et Birch	3	14	13	1	0	93%	7%
119 - Cartier et Lavoisier	1	23	9	14	0	39%	61%
120 - Concorde et De Callières	1	18	17	1	4	94%	6%
121 - Notre-Dame-de-Grâces et Perrault	1	19	17	2	0	89%	11%
122 - Wolfe et Lavallée	1	22	16	6	4	73%	27%
123 - Woodland et de Verdun	5	14	13	1	0	93%	7%
124 - Henri-Julien et De Castelnau	16	15	15	0	13	100%	0%
125 - Technopôle Angus	2	8	8	0	6	100%	0%
127 - St-Florent et St-André	1	13	12	1	8	92%	8%
128 - Collège Ahuntsic	5	19	19	0	4	100%	0%
129 - Parthenais et Sherbrooke	3	14	13	1	4	93%	7%
130 - Émery et Sanguinet	5	9	9	0	15	100%	0%
131 - Benny et Monkland	6	11	11	0	8	100%	0%
132 - Beaumont et de l'Acadie	2	24	19	5	0	79%	21%
133 - Tansley et Dorion	3	17	17	0	0	100%	0%
134 - Gare de Westmount	2	16	16	0	2	100%	0%
135 - Victoria Hall	1	18	16	2	0	89%	11%
136 - De Lanaudière et Marie-Anne	2	20	16	4	0	80%	20%
137 - 13e Avenue et Beaubien	1	17	15	2	6	88%	12%
138 - Hamelin et Henri-Bourassa	2	9	9	0	11	100%	0%
139 - Maguire et St-Dominique	1	13	10	3	11	77%	23%
140 - Rachel et de Chambly	2	15	15	0	2	100%	0%
141 - Everett et de Bordeaux	2	20	16	4	2	80%	20%
143 - Towers et Ste-Catherine	1	16	10	6	0	63%	38%
144 - 13e Avenue et Laurier	6	11	11	0	1	100%	0%
147 - Drolet et Beaubien	2	11	10	1	0	91%	9%
148 - Laurier et St-Urbain	15	21	21	0	3	100%	0%
149 - St-Joseph et Henri-Valade	6	11	11	0	8	100%	0%
150 - Beaubien et Christophe-Colomb	2	16	12	4	2	75%	25%
152 - Tolhurst et Sauvé	2	14	12	2	0	86%	14%
153 - Boyer et Villeray	4	13	13	0	12	100%	0%
154 - Parthenais et Logan	2	15	11	4	0	73%	27%
155 - Panet et Larivière	2	10	10	0	8	100%	0%

156 - Alexandre-De-Sève et Ontario	2	15	15	0	5	100%	0%
157 - Chabot et Gilford	3	17	14	3	0	82%	18%
158 - Métro Crémazie	3	13	13	0	6	100%	0%
159 - De Lanaudière et Gilford	1	16	7	9	2	44%	56%
160 - Napoléon et de Mentana	2	13	13	0	6	100%	0%
161 - Rosemont et Saint-Denis	6	16	13	3	0	81%	19%
162 - Champagneur et Jean-Talon	2	13	13	0	8	100%	0%
163 - Dublin et Wellington	4	10	10	0	10	100%	0%
164 - Coursol et Georges-Vanier	2	19	18	1	2	95%	5%
165 - De Marseille et Du Quesne	2	20	9	11	0	45%	55%
166 - Jarry et Papineau	2	16	16	0	5	100%	0%
167 - St-Timothée et De Maisonneuve	3	22	16	6	0	73%	27%
168 - Fullum et Larivière	5	14	14	0	7	100%	0%
169 - Hôtel de Ville de LaSalle	1	23	13	10	0	57%	43%
170 - Aréna Jacques-Lemaire	1	11	10	1	8	91%	9%
171 - 75e Avenue et Parent	1	20	11	9	0	55%	45%
172 - Aquadôme	1	12	12	0	8	100%	0%
173 - Centrale et Raymond	1	13	10	3	0	77%	23%
174 - 5e Avenue et Édouard	1	19	16	3	0	84%	16%
175 - 5e Avenue et Centrale	2	15	12	3	0	80%	20%
176 - Lajeunesse et Jarry	4	18	18	0	2	100%	0%
177 - De Lanaudière et Mont-Royal	10	13	13	0	6	100%	0%
178 - Dézéry et Hochelaga	6	13	13	0	14	100%	0%
179 - Decelles et Côte-Ste-Catherine	4	9	9	0	8	100%	0%
180 - Métro Square-Victoria	2	21	15	6	0	71%	29%
181 - St-André et Bélanger	12	14	14	0	10	100%	0%
182 - Jarry et Boyer	2	10	10	0	6	100%	0%
183 - Gascon et Sherbrooke	2	17	16	1	3	94%	6%
184 - St-Denis et Sherbrooke	2	17	17	0	3	100%	0%
185 - Marché Maisonneuve	4	9	9	0	4	100%	0%
186 - Centre de commerce mondial (Électrique)	2	12	10	2	0	83%	17%
187 - Aréna Mont-Royal	6	18	18	0	3	100%	0%
188 - McGill et du Président-Kennedy	3	14	14	0	4	100%	0%
189 - Parc Nicolas-Viel	2	13	12	1	3	92%	8%
190 - 13e Avenue et de l'Ukraine	3	21	12	9	0	57%	43%
191 - Square Dorchester	2	14	14	0	2	100%	0%
194 - Brennan et Duke	2	11	11	0	4	100%	0%
195 - Préfontaine et Rachel	3	9	9	0	12	100%	0%
196 - 1re Avenue et de Verdun	4	15	15	0	1	100%	0%
197 - Hickson et Ross	2	14	13	1	1	93%	7%
198 - Métro Bonaventure	2	13	13	0	1	100%	0%

199 - Notre-Dame-de-Grâce et Prud'homme	2	17	12	5	0	71%	29%
200 - Westminster et Curzon	2	15	13	2	0	87%	13%
201 - Milton et du Parc	1	19	11	8	0	58%	42%
202 - Clark et de Liège	3	14	14	0	1	100%	0%
203 - Hampton et Monkland	2	14	12	2	0	86%	14%
204 - De Lévis et Notre-Dame	2	11	11	0	3	100%	0%
205 - Resther et Gilford	1	8	8	0	10	100%	0%
207 - Henri-Julien et Gilford	1	12	12	0	4	100%	0%
209 - Émile-Journault et Henri-Julien	3	12	12	0	0	100%	0%
210 - Outremont et Ducharme	4	16	16	0	1	100%	0%
211 - De Chateaubriand et Mistral	2	17	9	8	0	53%	47%
212 - 21e Avenue et Beaubien	3	13	8	5	0	62%	38%
213 - 15e Avenue et Bélanger	3	14	9	5	0	64%	36%
214 - Aréna Doug-Harvey	3	14	13	1	0	93%	7%
215 - Aréna Bill-Durnan	2	20	11	9	0	55%	45%
216 - Bourget et St-Jacques	3	7	7	0	7	100%	0%
217 - Campus Loyola	2	17	16	1	3	94%	6%
218 - Métro Jean-Talon	7	14	14	0	0	100%	0%
219 - Hôtel de ville de St-Laurent	2	11	11	0	7	100%	0%
220 - Hôtel de Ville de Mont-Royal	2	14	14	0	2	100%	0%
221 - De l'Esplanade et Beaubien	5	22	17	5	0	77%	23%
222 - Du Havre et La Fontaine	2	16	16	0	2	100%	0%
223 - Sherbrooke et Baldwin	1	11	11	0	3	100%	0%
225 - Rosemont et Lacordaire	3	18	14	4	0	78%	22%
227 - 35e Avenue et de Bellechasse	2	10	8	2	1	80%	20%
228 - 41e Avenue et St-Zotique	2	18	14	4	0	78%	22%
229 - 43e Avenue et St-Zotique	2	14	11	3	4	79%	21%
230 - St-Grégoire et Marquette	4	15	15	0	4	100%	0%
231 - Côte-des-Neiges et Côte-Ste-Catherine	2	18	16	2	0	89%	11%
232 - Métro Jarry	3	14	12	2	5	86%	14%
233 - St-Gérard et Jarry	4	14	14	0	4	100%	0%
234 - CEPSUM	2	15	15	0	6	100%	0%
235 - Jean-Brillant et McKenna	1	19	7	12	0	37%	63%
236 - Brown et Bannantyne	2	15	15	0	1	100%	0%
237 - Island et Richardson	2	17	14	3	0	82%	18%
238 - Resther et Boucher	4	14	14	0	2	100%	0%
239 - Mont-Royal et De Bullion	3	17	17	0	0	100%	0%
240 - Henri-Julien et Beaubien	5	17	15	2	1	88%	12%
241 - Place Bonaventure	1	15	12	3	0	80%	20%
242 - Rosemont et D'Iberville	3	12	11	1	10	92%	8%

244 - Querbes et Laurier	1	14	14	0	0	100%	0%
245 - De l'Épée et Van Horne	2	11	11	0	2	100%	0%
246 - Dollard et Ducharme	2	14	14	0	1	100%	0%
247 - St-Just et Outremont	2	10	10	0	3	100%	0%
248 - Jeanne-Mance et Sherbrooke	2	24	12	12	0	50%	50%
250 - Cuvillier et Ontario	2	11	11	0	6	100%	0%
251 - Valois et Ontario	3	18	18	0	0	100%	0%
252 - Sherbrooke et Benny	2	13	13	0	3	100%	0%
253 - Parc des Hirondelles	2	18	16	2	0	89%	11%
254 - Frontenac et Marie-Anne	1	8	8	0	11	100%	0%
255 - Trans Island et Queen-Mary	2	21	19	2	0	90%	10%
256 - Allard et Beaulieu	2	7	7	0	12	100%	0%
257 - 40e Avenue et Rosemont	2	19	13	6	0	68%	32%
258 - De Maisonneuve et St-Mathieu	2	20	18	2	0	90%	10%
259 - Brébeuf et Curé-Poirier	2	16	8	8	0	50%	50%
260 - Quai de l'Horloge	2	21	14	7	0	67%	33%
261 - Vieux-Port et De Callière	3	15	13	2	1	87%	13%
263 - Bibliothèque Belleville	2	7	7	0	7	100%	0%
264 - Hôtel de Ville de Saint-Bruno	1	18	12	6	0	67%	33%
265 - Maison des arts de Laval	1	17	7	10	0	41%	59%
266 - Hôtel de Ville de Laval	1	10	8	2	7	80%	20%
267 - Lionel-Groulx et Vinet	2	18	12	6	0	67%	33%
268 - Rachel et de Bordeaux	2	17	16	1	1	94%	6%
269 - Calixa-Lavallée et Sherbrooke	4	12	12	0	7	100%	0%
270 - De Maisonneuve et De Bleury	4	9	9	0	5	100%	0%
272 - D'Orléans et de Rouen	2	15	15	0	6	100%	0%
273 - Joliette et Hochelaga	2	22	16	6	0	73%	27%
274 - Sicard et Hochelaga	2	18	14	4	0	78%	22%
277 - Gordon et Wellington	2	18	14	4	2	78%	22%
278 - 18e Avenue et Dandurand	3	15	15	0	5	100%	0%
279 - 30e Avenue et Bélanger	2	20	13	7	0	65%	35%
280 - St-Hubert et du Rosaire	2	13	8	5	0	62%	38%
281 - De Verdun et Caisse	2	15	13	2	0	87%	13%
282 - Lajoie et Deacon	2	20	9	11	0	45%	55%
283 - Crémazie et Fabre	1	17	14	3	0	82%	18%
284 - Jarry et Henri-Julien	2	15	14	1	2	93%	7%
285 - Bourret et Lavoie	2	18	11	7	1	61%	39%
286 - Gladstone et Dorchester	2	14	14	0	0	100%	0%
287 - De l'Assomption et Sherbrooke	2	20	15	5	0	75%	25%
288 - Sauvé et Papineau	3	20	20	0	1	100%	0%
289 - Côte-des-Neiges et Van Horne	2	9	9	0	5	100%	0%

290 - St-André et Ste-Catherine	1	18	12	6	0	67%	33%
291 - Gare de Saint-Lambert	2	15	13	2	4	87%	13%
293 - Bélanger et D'Iberville	4	23	13	10	0	57%	43%
294 - St-Zotique et Papineau	2	18	14	4	0	78%	22%
295 - De Grosbois et Pierre-Bernard	2	16	15	1	4	94%	6%
296 - Isabella et Victoria	3	17	15	2	2	88%	12%
297 - Sherbrooke et du Fort	2	18	12	6	0	67%	33%
298 - Baldwin et Ste-Claire	2	13	13	0	9	100%	0%
299 - Jeanne-d'Arc et Sherbrooke	2	19	16	3	1	84%	16%
302 - Panet et Ontario	4	18	13	5	0	72%	28%
303 - De Chateaubriand et Rosemont	2	15	15	0	2	100%	0%
305 - 6e Avenue et de Bellechasse	2	14	4	10	0	29%	71%
306 - Montcalm et Ontario	2	22	14	8	0	64%	36%
307 - Papineau et Sherbrooke	2	15	15	0	3	100%	0%
308 - De Châteauguay et Ropery (Électrique)	1	15	11	4	0	73%	27%
309 - William et Queen	4	25	17	8	0	68%	32%
310 - Fullum et Rachel	1	15	14	1	0	93%	7%
311 - De Maisonneuve et Décarie	2	21	12	9	0	57%	43%
312 - Plessis et Ste-Catherine	4	14	14	0	3	100%	0%
313 - Pierre-Bernard et Hochelaga	2	18	13	5	0	72%	28%
315 - Notre-Dame et Côte-St-Paul	1	16	16	0	3	100%	0%
316 - Hudson et de Kent	1	20	15	5	0	75%	25%
317 - 21e Avenue et Rosemont	3	12	12	0	2	100%	0%
319 - Complexe Desjardins (Électrique)	4	18	16	2	0	89%	11%
320 - Place Ville Marie (Électrique)	2	13	12	1	4	92%	8%
321 - St-André et Bélanger (Électrique)	2	11	11	0	4	100%	0%
322 - Stade Olympique	2	14	13	1	0	93%	7%
323 - Jean-Brillant et McKenna (Électrique)	2	15	15	0	0	100%	0%
324 - De Lanaudière et St-Joseph	3	15	14	1	4	93%	7%
325 - Berri et Ontario (Électrique)	4	12	12	0	0	100%	0%
326 - Beaubien et 29e Avenue	1	11	10	1	5	91%	9%
327 - Île-des-Sœurs et Berlioz	2	8	8	0	12	100%	0%
328 - Rivard et Duluth	2	16	14	2	0	88%	13%
329 - Tillemont et D'Iberville	1	22	14	8	0	64%	36%
330 - Holt et des Érables	1	17	17	0	0	100%	0%

Table 21: Detailed results of the Round_trip model for test 1

Station	TV	TR	AReq	RReq	FCS	TU	RR
002 - St-Sacrement	20	17	0	17	20	100%	0%
003 – Garnier	10	14	0	14	10	100%	0%
004 - Parc Lafontaine	13	16	0	16	13	100%	0%
005 - Jeanne D'Arc	3	15	0	15	3	100%	0%
008 - Plaza et Beaubien	3	12	0	12	3	100%	0%
012 – Lajeunesse	3	12	0	12	3	100%	0%
013 - 6e Avenue	9	14	0	14	9	100%	0%
014 - Rachel et Papineau	4	22	0	22	4	100%	0%
016 - Jean-de-Brébeuf	6	22	0	22	6	100%	0%
018 - Beaudry et Robin	5	16	0	16	5	100%	0%
019 - Laurier et Papineau	6	15	0	15	6	100%	0%
020 - Bernard et Saint-Laurent	6	22	0	22	6	100%	0%
021 – Coolbrook	6	8	0	8	6	100%	0%
022 - Place St-Henri	10	17	0	17	10	100%	0%
023 - Métro Rosemont	7	11	0	11	7	100%	0%
024 - Centre St-Pierre	3	15	0	15	3	100%	0%
025 - Christophe-Colomb et Rachel	7	11	0	11	7	100%	0%
027 - St-Joseph et De Bullion	8	13	0	13	8	100%	0%
028 - St-Antoine et Atwater	4	17	0	17	4	100%	0%
030 - Iberville et Mont-Royal	3	8	0	8	3	100%	0%
032 - Van Horne et Dollard	5	10	0	10	5	100%	0%
034 - Boyer et St-Zotique	9	9	0	9	9	100%	0%
037 – Goyer	2	18	0	18	2	100%	0%
038 - Chambord et Fleury	7	13	0	13	7	100%	0%
041 - Métro Angrignon	5	17	0	17	5	100%	0%
042 – Plantagenet	3	13	0	13	3	100%	0%
043 - Remembrance et 32e avenue	2	22	2	20	2	91%	9%
044 - Nicolet et Hochelaga	6	15	0	15	6	100%	0%
045 – Evelyn	3	13	0	13	3	100%	0%
047 - Peel et Dr Penfield	4	11	0	11	4	100%	0%
048 - St-Jacques et St-Jean	1	10	1	9	1	90%	10%
049 - Monk et Jolicoeur	7	10	0	10	7	100%	0%
050 - Parc Ahuntsic	9	14	0	14	9	100%	0%
051 - Aréna St-Louis	4	12	0	12	4	100%	0%

052 - Old Orchard	6	10	0	10	6	100%	0%
056 - Hutchison et Milton	3	20	0	20	3	100%	0%
058 - Cartier et Rosemont	4	20	0	20	4	100%	0%
059 - Tour Penfield	2	13	0	13	2	100%	0%
060 - Victoria et 17e avenue	1	15	3	12	1	80%	20%
061 - Berri et Notre-Dame	5	12	0	12	5	100%	0%
062 - 4e avenue et Wellington	5	17	0	17	5	100%	0%
064 - Métro Sauvé	7	12	0	12	7	100%	0%
065 – Provost	1	19	9	10	1	53%	47%
068 - Métro Longueuil-Port-de-Mer	4	17	0	17	4	100%	0%
069 - Bossuet et Sherbrooke	3	16	0	16	3	100%	0%
070 - Masson et De Lorimier	9	11	0	11	9	100%	0%
071 - Papineau et Bellechasse	1	22	11	11	1	50%	50%
073 - Grant et LeMoyne	1	11	2	9	1	82%	18%
074 - St-Jean et St-Laurent	2	17	2	15	2	88%	12%
076 - Bernard et de L'Épée	4	13	0	13	4	100%	0%
077 - Bernard et Wiseman	4	16	0	16	4	100%	0%
078 - Laurier et Durocher	2	15	0	15	2	100%	0%
080 - Napoléon et St-Dominique	9	20	0	20	9	100%	0%
081 - St-Vallier et Jean-Talon	4	21	0	21	4	100%	0%
082 - Berri et De Castelnau	3	13	0	13	3	100%	0%
083 - Aréna Jean Rougeau	5	19	0	19	5	100%	0%
084 - Centre St-Mathieu	6	11	0	11	6	100%	0%
085 - François-Perrault	3	12	0	12	3	100%	0%
086 - Parc Père-Marquette	6	14	0	14	6	100%	0%
087 - Parc Beaubien	5	17	0	17	5	100%	0%
088 - Parc Laurier	3	16	0	16	3	100%	0%
090 - Sewell et des Pins	5	16	0	16	5	100%	0%
091 - Lucien-L'Allier	3	19	0	19	3	100%	0%
092 - Laprairie et Centre	3	18	0	18	3	100%	0%
093 - Appartements Rockhill	2	17	0	17	2	100%	0%
094 - La Fontaine et Pie-IX	2	19	2	17	2	89%	11%
095 - Drolet et Marie-Anne	6	16	0	16	6	100%	0%
096 - Collège Notre-Dame	5	15	0	15	5	100%	0%
097 - Roland-Therrien et De Gentilly	2	10	0	10	2	100%	0%
099 - Hochelaga et Préfontaine	1	19	11	8	1	42%	58%
100 - St-Clément et Adam	9	12	0	12	9	100%	0%
101 - Métro Radisson	2	17	0	17	2	100%	0%
102 - Métro Longueuil-Terminus	4	16	0	16	4	100%	0%
104 - Dézéry et Ontario	2	11	0	11	2	100%	0%
105 - Centre St-Donat	4	14	0	14	4	100%	0%

106 - Centre productions Jeun'Est	4	8	0	8	4	100%	0%
107 - Iberville et Ontario	6	15	0	15	6	100%	0%
109 – Ethel	3	8	0	8	3	100%	0%
110 - Aréna Cartier	3	16	0	16	3	100%	0%
111 - Ouimet et de L'Église	2	13	0	13	2	100%	0%
113 - Jardin De Lorimier	2	12	0	12	2	100%	0%
115 - Chez Magnan	2	11	0	11	2	100%	0%
116 - Riverside et Birch	3	14	0	14	3	100%	0%
119 - Cartier et Lavoisier	1	23	12	11	1	48%	52%
120 - Concorde et De Callières	1	18	6	12	1	67%	33%
121 - Notre-Dame-de-Grâces et Perrault	1	19	10	9	1	47%	53%
122 - Wolfe et Lavallée	1	22	11	11	1	50%	50%
123 - Woodland et de Verdun	5	14	0	14	5	100%	0%
124 - Henri-Julien et De Castelnau	16	15	0	15	16	100%	0%
125 - Technopôle Angus	2	8	0	8	2	100%	0%
127 - St-Florent et St-André	1	13	5	8	1	62%	38%
128 - Collège Ahuntsic	5	19	0	19	5	100%	0%
129 - Parthenais et Sherbrooke	3	14	0	14	3	100%	0%
130 - Émery et Sanguinet	5	9	0	9	5	100%	0%
131 - Benny et Monkland	6	11	0	11	6	100%	0%
132 - Beaumont et de l'Acadie	2	24	3	21	2	88%	13%
133 - Tansley et Dorion	3	17	0	17	3	100%	0%
134 - Gare de Westmount	2	16	1	15	2	94%	6%
135 - Victoria Hall	1	18	9	9	1	50%	50%
136 - De Lanaudière et Marie-Anne	2	20	0	20	2	100%	0%
137 - 13e Avenue et Beaubien	1	17	6	11	1	65%	35%
138 - Hamelin et Henri-Bourassa	2	9	0	9	2	100%	0%
139 - Maguire et St-Dominique	1	13	4	9	1	69%	31%
140 - Rachel et de Chambly	2	15	0	15	2	100%	0%
141 - Everett et de Bordeaux	2	20	1	19	2	95%	5%
143 - Towers et Ste-Catherine	1	16	6	10	1	63%	38%
144 - 13e Avenue et Laurier	6	11	0	11	6	100%	0%
147 - Drolet et Beaubien	2	11	0	11	2	100%	0%
148 - Laurier et St-Urbain	15	21	0	21	15	100%	0%
149 - St-Joseph et Henri-Valade	6	11	0	11	6	100%	0%
150 - Beaubien et Christophe-Colomb	2	16	4	12	2	75%	25%
152 - Tolhurst et Sauvé	2	14	0	14	2	100%	0%
153 - Boyer et Villeray	4	13	0	13	4	100%	0%
154 - Parthenais et Logan	2	15	0	15	2	100%	0%
155 - Panet et Larivière	2	10	0	10	2	100%	0%
156 - Alexandre-De-Sève et Ontario	2	15	0	15	2	100%	0%

157 - Chabot et Gilford	3	17	2	15	3	88%	12%
158 - Métro Crémazie	3	13	0	13	3	100%	0%
159 - De Lanaudière et Gilford	1	16	5	11	1	69%	31%
160 - Napoléon et de Mentana	2	13	0	13	2	100%	0%
161 - Rosemont et Saint-Denis	6	16	0	16	6	100%	0%
162 - Champagneur et Jean-Talon	2	13	0	13	2	100%	0%
163 - Dublin et Wellington	4	10	0	10	4	100%	0%
164 - Coursol et Georges-Vanier	2	19	1	18	2	95%	5%
165 - De Marseille et Du Quesne	2	20	0	20	2	100%	0%
166 - Jarry et Papineau	2	16	1	15	2	94%	6%
167 - St-Timothée et De Maisonneuve	3	22	0	22	3	100%	0%
168 - Fullum et Larivière	5	14	0	14	5	100%	0%
169 - Hôtel de Ville de LaSalle	1	23	14	9	1	39%	61%
170 - Aréna Jacques-Lemaire	1	11	3	8	1	73%	27%
171 - 75e Avenue et Parent	1	20	11	9	1	45%	55%
172 – Aquadôme	1	12	5	7	1	58%	42%
173 - Centrale et Raymond	1	13	3	10	1	77%	23%
174 - 5e Avenue et Édouard	1	19	11	8	1	42%	58%
175 - 5e Avenue et Centrale	2	15	0	15	2	100%	0%
176 - Lajeunesse et Jarry	4	18	0	18	4	100%	0%
177 - De Lanaudière et Mont-Royal	10	13	0	13	10	100%	0%
178 - Dézéry et Hochelaga	6	13	0	13	6	100%	0%
179 - Decelles et Côte-Ste-Catherine	4	9	0	9	4	100%	0%
180 - Métro Square-Victoria	2	21	2	19	2	90%	10%
181 - St-André et Bélanger	12	14	0	14	12	100%	0%
182 - Jarry et Boyer	2	10	0	10	2	100%	0%
183 - Gascon et Sherbrooke	2	17	2	15	2	88%	12%
184 - St-Denis et Sherbrooke	2	17	0	17	2	100%	0%
185 - Marché Maisonneuve	4	9	0	9	4	100%	0%
186 - Centre de commerce mondial (Électrique)	2	12	1	11	2	92%	8%
187 - Aréna Mont-Royal	6	18	0	18	6	100%	0%
188 - McGill et du Président-Kennedy	3	14	0	14	3	100%	0%
189 - Parc Nicolas-Viel	2	13	2	11	2	85%	15%
190 - 13e Avenue et de l'Ukraine	3	21	0	21	3	100%	0%
191 - Square Dorchester	2	14	0	14	2	100%	0%
194 - Brennan et Duke	2	11	0	11	2	100%	0%
195 - Préfontaine et Rachel	3	9	0	9	3	100%	0%
196 - 1re Avenue et de Verdun	4	15	0	15	4	100%	0%
197 - Hickson et Ross	2	14	0	14	2	100%	0%
198 - Métro Bonaventure	2	13	0	13	2	100%	0%

199 - Notre-Dame-de-Grâce et Prud'homme	2	17	0	17	2	100%	0%
200 - Westminster et Curzon	2	15	0	15	2	100%	0%
201 - Milton et du Parc	1	19	10	9	1	47%	53%
202 - Clark et de Liège	3	14	0	14	3	100%	0%
203 - Hampton et Monkland	2	14	0	14	2	100%	0%
204 - De Lévis et Notre-Dame	2	11	0	11	2	100%	0%
205 - Resther et Gilford	1	8	0	8	1	100%	0%
207 - Henri-Julien et Gilford	1	12	1	11	1	92%	8%
209 - Émile-Journault et Henri-Julien	3	12	0	12	3	100%	0%
210 - Outremont et Ducharme	4	16	0	16	4	100%	0%
211 - De Chateaubriand et Mistral	2	17	0	17	2	100%	0%
212 - 21e Avenue et Beaubien	3	13	0	13	3	100%	0%
213 - 15e Avenue et Bélanger	3	14	0	14	3	100%	0%
214 - Aréna Doug-Harvey	3	14	0	14	3	100%	0%
215 - Aréna Bill-Durnan	2	20	2	18	2	90%	10%
216 - Bourget et St-Jacques	3	7	0	7	3	100%	0%
217 - Campus Loyola	2	17	4	13	2	76%	24%
218 - Métro Jean-Talon	7	14	0	14	7	100%	0%
219 - Hôtel de ville de St-Laurent	2	11	0	11	2	100%	0%
220 - Hôtel de Ville de Mont-Royal	2	14	0	14	2	100%	0%
221 - De l'Esplanade et Beaubien	5	22	0	22	5	100%	0%
222 - Du Havre et La Fontaine	2	16	1	15	2	94%	6%
223 - Sherbrooke et Baldwin	1	11	2	9	1	82%	18%
225 - Rosemont et Lacordaire	3	18	0	18	3	100%	0%
227 - 35e Avenue et de Bellechasse	2	10	1	9	2	90%	10%
228 - 41e Avenue et St-Zotique	2	18	0	18	2	100%	0%
229 - 43e Avenue et St-Zotique	2	14	0	14	2	100%	0%
230 - St-Grégoire et Marquette	4	15	0	15	4	100%	0%
231 - Côte-des-Neiges et Côte-Ste-Catherine	2	18	2	16	2	89%	11%
232 - Métro Jarry	3	14	0	14	3	100%	0%
233 - St-Gérard et Jarry	4	14	0	14	4	100%	0%
234 – CEPSUM	2	15	2	13	2	87%	13%
235 - Jean-Brillant et McKenna	1	19	10	9	1	47%	53%
236 - Brown et Bannantyne	2	15	0	15	2	100%	0%
237 - Island et Richardson	2	17	0	17	2	100%	0%
238 - Resther et Boucher	4	14	0	14	4	100%	0%
239 - Mont-Royal et De Bullion	3	17	0	17	3	100%	0%
240 - Henri-Julien et Beaubien	5	17	0	17	5	100%	0%
241 - Place Bonaventure	1	15	7	8	1	53%	47%
242 - Rosemont et D'Iberville	3	12	0	12	3	100%	0%

244 - Querbes et Laurier	1	14	7	7	1	50%	50%
245 - De l'Épée et Van Horne	2	11	0	11	2	100%	0%
246 - Dollard et Ducharme	2	14	0	14	2	100%	0%
247 - St-Just et Outremont	2	10	0	10	2	100%	0%
248 - Jeanne-Mance et Sherbrooke	2	24	2	22	2	92%	8%
250 - Cuvillier et Ontario	2	11	0	11	2	100%	0%
251 - Valois et Ontario	3	18	0	18	3	100%	0%
252 - Sherbrooke et Benny	2	13	0	13	2	100%	0%
253 - Parc des Hirondelles	2	18	0	18	2	100%	0%
254 - Frontenac et Marie-Anne	1	8	2	6	1	75%	25%
255 - Trans Island et Queen-Mary	2	21	1	20	2	95%	5%
256 - Allard et Beaulieu	2	7	0	7	2	100%	0%
257 - 40e Avenue et Rosemont	2	19	3	16	2	84%	16%
258 - De Maisonneuve et St-Mathieu	2	20	2	18	2	90%	10%
259 - Brébeuf et Curé-Poirier	2	16	0	16	2	100%	0%
260 - Quai de l'Horloge	2	21	1	20	2	95%	5%
261 - Vieux-Port et De Callière	3	15	0	15	3	100%	0%
263 - Bibliothèque Belleville	2	7	0	7	2	100%	0%
264 - Hôtel de Ville de Saint-Bruno	2	18	8	10	2	56%	44%
265 - Maison des arts de Laval	1	17	8	9	1	53%	47%
266 - Hôtel de Ville de Laval	1	10	1	9	1	90%	10%
267 - Lionel-Groulx et Vinet	1	18	2	16	1	89%	11%
268 - Rachel et de Bordeaux	2	17	0	17	2	100%	0%
269 - Calixa-Lavallée et Sherbrooke	2	12	0	12	2	100%	0%
270 - De Maisonneuve et De Bleury	4	9	0	9	4	100%	0%
272 - D'Orléans et de Rouen	4	15	1	14	4	93%	7%
273 - Joliette et Hochelaga	2	22	0	22	2	100%	0%
274 - Sicard et Hochelaga	2	18	2	16	2	89%	11%
277 - Gordon et Wellington	2	18	1	17	2	94%	6%
278 - 18e Avenue et Dandurand	2	15	0	15	2	100%	0%
279 - 30e Avenue et Bélanger	3	20	0	20	3	100%	0%
280 - St-Hubert et du Rosaire	2	13	0	13	2	100%	0%
281 - De Verdun et Caisse	2	15	1	14	2	93%	7%
282 - Lajoie et Deacon	2	20	1	19	2	95%	5%
283 - Crémazie et Fabre	2	17	5	12	2	71%	29%
284 - Jarry et Henri-Julien	1	15	0	15	1	100%	0%
285 - Bourret et Lavoie	2	18	2	16	2	89%	11%
286 - Gladstone et Dorchester	2	14	0	14	2	100%	0%
287 - De l'Assomption et Sherbrooke	2	20	2	18	2	90%	10%
288 - Sauvé et Papineau	2	20	0	20	2	100%	0%
289 - Côte-des-Neiges et Van Horne	3	9	0	9	3	100%	0%

290 - St-André et Ste-Catherine	2	18	6	12	2	67%	33%
291 - Gare de Saint-Lambert	1	15	2	13	1	87%	13%
293 - Bélanger et D'Iberville	2	23	0	23	2	100%	0%
294 - St-Zotique et Papineau	4	18	0	18	4	100%	0%
295 - De Grosbois et Pierre-Bernard	2	16	1	15	2	94%	6%
296 - Isabella et Victoria	2	17	0	17	2	100%	0%
297 - Sherbrooke et du Fort	3	18	0	18	3	100%	0%
298 - Baldwin et Ste-Claire	2	13	0	13	2	100%	0%
299 - Jeanne-d'Arc et Sherbrooke	2	19	0	19	2	100%	0%
302 - Panet et Ontario	2	18	0	18	2	100%	0%
303 - De Chateaubriand et Rosemont	4	15	0	15	4	100%	0%
305 - 6e Avenue et de Bellechasse	2	14	0	14	2	100%	0%
306 - Montcalm et Ontario	2	22	3	19	2	86%	14%
307 - Papineau et Sherbrooke	2	15	0	15	2	100%	0%
308 - De Châteauguay et Ropery (Électrique)	2	15	6	9	2	60%	40%
309 - William et Queen	1	25	0	25	1	100%	0%
310 - Fullum et Rachel	4	15	7	8	4	53%	47%
311 - De Maisonneuve et Décarie	1	21	3	18	1	86%	14%
312 - Plessis et Ste-Catherine	2	14	0	14	2	100%	0%
313 - Pierre-Bernard et Hochelaga	4	18	1	17	4	94%	6%
315 - Notre-Dame et Côte-St-Paul	2	16	6	10	2	63%	38%
316 - Hudson et de Kent	1	20	10	10	1	50%	50%
317 - 21e Avenue et Rosemont	1	12	0	12	1	100%	0%
319 - Complexe Desjardins (Électrique)	3	18	0	18	3	100%	0%
320 - Place Ville Marie (Électrique)	4	13	0	13	4	100%	0%
321 - St-André et Bélanger (Électrique)	2	11	0	11	2	100%	0%
322 - Stade Olympique	2	14	0	14	2	100%	0%
323 - Jean-Brillant et McKenna (Électrique)	2	15	1	14	2	93%	7%
324 - De Lanaudière et St-Joseph	2	15	0	15	2	100%	0%
325 - Berri et Ontario (Électrique)	3	12	0	12	3	100%	0%
326 - Beaubien et 29e Avenue	4	11	1	10	4	91%	9%
327 - Île-des-Sœurs et Berlioz	1	8	0	8	1	100%	0%
328 - Rivard et Duluth	2	16	0	16	2	100%	0%
329 - Tillemont et D'Iberville	2	22	9	13	2	59%	41%
330 - Holt et des Érables	1	17	6	11	1	65%	35%