CONDUCTING EXPERIMENTAL DESIGN AND OPTIMIZATION ON AN INNOVATIVE CAR RENTAL BUSINESS

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ABSTRACT

This paper introduces an advanced 3D object-oriented discrete event simulation model, developed with SIMIO software, to optimize the design and operation of an innovative car rental service. The proposed simulation model is used to perform an exhaustive sensitivity analysis over the main process variables. The main goal is to determine the best system configuration, which allows maximizing the company profit while satisfying a suitable service level to the customers.

Keywords: Discrete-Event Simulation, Experimental Design, Car Rentals, Optimization.

1. INTRODUCTION

In order to represent and optimize the design and operation of modern real-world service processes, two solution strategies, among others, are typically used: (i) analytical methods based on linear / non-linear mathematical formulations (MILP / MINLP models) or (ii) discrete event simulation-based methods. On the one hand, exact mathematical optimization approaches may be able to rigorously find optimal or near optimal solutions to several interesting problems. However, for realistic complex decision-making processes, the problem representation may be usually highly simplified and the computational effort may be really significant. On the other hand, modern discrete event simulation packages provide a set of tools to easily generate a better representation of more complex systems. However, one of simulation's greatest disadvantages is that, on its own, it does not serve to estimate the optimality gap (Law at al. 2002). To mitigate this inherent drawback, a deep sensitivity analysis can be performed. This technique is used to easily evaluate how different values of a set of independent variables will impact a set of dependent variables under a given set of assumptions.

In the last years, the commercial simulation software has incorporated efficient optimization codes to automatically search for near optimal solutions. Simulation optimization can be defined as the process of testing different combinations of values for controllable values, aiming to find the combination of values which offers the most desirable output results for simulation models (Harrell and Mccomas 1996). Unfortunately, the performance of the method is highly affected by the number of variables being manipulated. This paper proposes a simulation optimization strategy to determine the best configuration of an innovative car rental business. The simulation model, developed with the SIMIO software, was used to analyze and evaluate the dynamic behavior of the process, considering different operative schemes and possible alternatives of investments. During this process, several types of experimental designs, e. g. multifactorial and fractional, were executed in order to select the most important variables of the model which directly impact on the response variables. The selected variables were then properly studied in order to find the best configuration for the car rental service.

2. DEVELOPING THE SIMULATION MODEL

This work is motivated by the challenging problem presented in the 2014 SIMIO Student Competition. The problem addressed is the design and operation of an innovative car rental system for travelers in an airport. In the next subsections, the system characteristics, model assumptions, and simulation model development will be discussed.

2.1. System Description

The system to investigate is based on a new airport business that allows passengers to drop-off their car at a parking facility at the airport, and in addition to free parking they may receive rental income for their cars while they are away. The company offers to its customers free transfer between parking facility and airport.

2.2. Model Assumptions

The following assumptions are considered for developing the simulation model:

- The company must operate a uniform fleet of vehicles. There are three size options: Mini, Small and Large.
- Each shuttle follows a fixed route (Figure 1) between the airport and the rental company to load and unload passengers. In addition, they are uniformly distributed over time in order to visit the collection points (airport and rental office) periodically.
- For both shuttle drivers and check-in clerks, there are three work shifts: Early, Midday and Late.
- A FIFO (First In First Out) queue policy is adopted.

- Arriving passengers can use a mobile application to select from the available cars.
- Arriving passengers, who could not find an appropriate car in the rental office, are returned to the airport.
- Both the parking arrivals and renting arrivals have a party size. These groups of passengers are not separated during the simulation.
- Rental cars are assigned in a specific category based on the model type.
- The owner of the car receives 50 % of the rental income.
- Cars entering the parking must be cleaned.
- Both the parking duration and rental duration are in integer days.
- Cars must be parked between a minimum and a maximum number of days.
- When a car is not accepted for parking, the customer is lost to competition.
- Parking passengers are expected to reach the airport in 15 minutes at most. Rented passengers expect to spend no more than 20 minutes to travel to rental facility and complete the check-in-process.

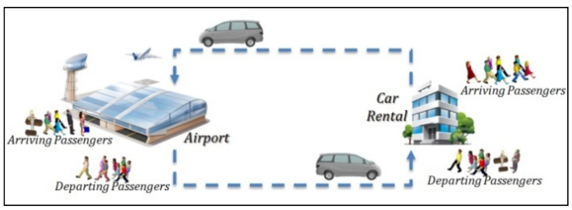

Figure 1: Shuttle routes

2.3. Simulation Model

The real system is represented as a discrete event simulation model by using the SIMIO software (Kelton et al. 2011, Thiesing et al. 1990). SIMIO is a modern simulation modeling framework based on intelligent objects. Actually, this software is used to represent a wide-range of production and service systems (Basán et al. 2013). 3D views of the simulation model for the car rental are given in Figure 2 and 3.

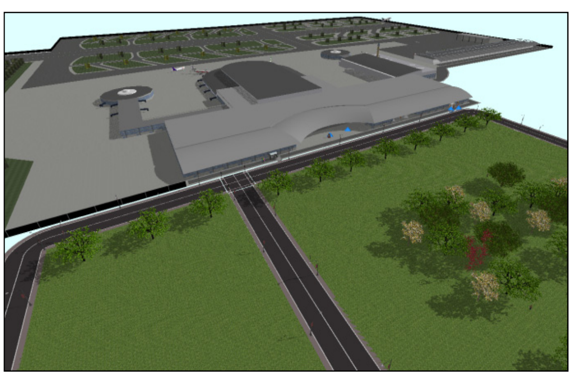
Figure 2: 3D graphical view of Airport


Figure 3: 3D graphical view of Car Rental

Each element and its behavior in the real system are modeled by specific objects and steps of the simulated software. The major characteristics of the computer model are presented below.

2.3.1. Model Entities

Two instances of Entity Object are defined into the model. They are:

- Car
- Group (parking and rental passengers)

A Batch Element is defined for combining both types of entities.

2.3.2. Parking and Rental Passenger

When a *Parking Passenger* arrives to the parking facility, he leaves his car at the cleaning station to then be transported from the parking facility to the airport by using the provided shuttle fleet. When returning from their trips, passengers are transported by means of the vans from the airport to the parking facility to find their cars.

We assumed that of the overall of *Rental Passengers* arriving at the airport: 50 % use the mobile app to reserve a car; 50 % go to check-in counter to reserve a car personally. For rental passengers using the mobile app:

- If the desired type of car is not available, the customer is not moved to the parking facility and is lost to competition.
- If the desired type of car is available, the customer reserves the car and then is moved from the airport to the parking facility by the shuttle fleet.

For rental passengers that do not use the mobile app:

- They are transported from the airport to the parking facility by the shuttle fleet.
- Then, they go to the check-in counter to reserve a car.
- If the preferred type of car is not available, they are lost to competition. Passengers use the van fleet to return to the airport.

2.3.3. Cars
New cars are accepted for parking only if:

- There are parking slots available.
- The number of cars that have been received by the company (parked + rented) is lower than the value of (*AcceptanceRelation*) * (*ParkingCapacity*).
- When a car is not accepted for parking is sent to *ParkingCompetition* (Sink Object).

2.3.4. Parking Slots
Parking slots are modeled by using a Station Element. The number of parking slots available is determined by variable *ParkingCapacity.*

2.3.5. Check-in
The Check-in Counter is modeled as a Server Object with the following properties:

- Capacity is supposed to be Infinity.
- Processing Time sets to a triangular distribution between the largest and smallest possible values, with a peak at the most likely value: Random.Triangular(1, 2, 3) minutes. Three resources are included into the model to represent the check-in staff (early, midday and late clerks).

2.3.6. Shuttle Fleet
Vans are modeled as instances of the Van Object (subclass of Vehicle Object). The Vehicle Object has an additional state variable named *RideQueueContents* which allows determining the quantity of travelers that is being transported on the shuttle. The additional variable is needed because of each arrival have a party size that varies between 1 and 4 travelers.
Vans follow a fixed route defined by the Sequence Table *VanRoute*. At each visited node, the vehicles for passenger pickups wait for a specified "dwell" time which is dependent of van type.
When the vans are off-shift, they park at Home Node named *VanParking*.
When the vans go on-shift, an add-on process is triggered to establish a suitable arrival frequency of the vehicles to pickup / drop off nodes. The above strategy allows a better utilization and distribution of the shuttle fleet and reduces the waiting time.

3. EXPERIMENTAL DESIGNS AND RESULTS
After carrying out an exhaustive verification and validation of the proposed simulation model, a comprehensive sensitivity analysis was conducted following next stages:

1. Factorial Design,
2. Full Factorial Design,
3. Optimization.

3.1. Experimental Scheme
In the experimental design, the input parameters and structural assumptions composing the simulation model are called factors. In this case, the identified input factors are:

1. Staffing level for the rental check-in counters for each of the three shifts: early clerks (EC), midday clerks (MC) and late clerks (LC),
2. Staffing level for the shuttle drivers for each of the three shifts: early drivers (ED), midday drivers (MD) and late drivers (LD),
3. Number of parking slots (PS),
4. Type of shuttle (TS),
5. Dwell Time (DT),
6. Acceptance Relation (AR).

These control variables can affect output performance measures of the model, which are called responses variables. In the simulation model, several different responses or performance measures of interest are used:

1. Company Profit,
2. Shuttle Fleet Utilization,
3. Check-In Counter Utilization,
4. Parking Slots Utilization,
5. Service Times,
6. Customers that are lost to competition.

The optimization objective is to maximize the company profit having into account the following constraints:

- Services times for parking passengers should be less than 15 minutes.
- Services times for rental passengers should be less than 20 minutes.
- Services times for returning passengers should be less than 15 minutes.
- The number of times that a car is returned by a rental passenger and there is not parking slot available should be cero.

Simulation is a useful tool to determine the sensitivity of a model to changes in input parameters. In this way, the factor identified above were combine to define and simulate alternative system configurations. After conducting a sensitivity analysis of controlled process variables, the range of input values for the control variables was determined as follows:

- Check-in clerks for each shift: 1 to 2.
- Shuttle drivers for each shift: 1 to 3.
- Number of parking slots: 600 to 800.
- Type of shuttle: Mini (4), Small (8) or Large (12).
- Dwell time: 1 to 4 minutes (depending of the type of shuttle).
- Acceptance relation variable: 2 to 3.

3.2. Results

In the simulation model 10 replicates for each scenario were run and their results were compared. The same test was replicated multiple times in order to create a variation in each response variable which then was utilized to evaluate experimental error. The proposed system configurations were tested on the simulation model during 105 days with a warming-up period of 15 days. Table 1 shows the average results for the top six alternatives.

Table 1: The best alternative system configurations

	Scenario					
	1	**2**	**3**	**4**	**5**	**6**
EC	1	1	2	1	2	1
MC	1	1	1	1	1	1
LC	1	1	2	1	2	1
PS	600	700	700	800	800	800
TS	8	8	8	8	8	12
ED	2	2	2	2	2	3
MD	1	2	2	2	2	1
LD	2	2	2	2	2	3
DT*	2	2	2	2	2	3
AR	2.9	2.6	2.6	2.5	2.5	2.5
CP**	2.21	2.17	2.13	2.12	2.10	2.09
PT*	11.6	10.6	9.9	10.7	9.9	9.4
RT*	16	14.6	12.7	14.8	12.7	13.2

* Dwell time (DT), parking service time (PT) and renting service time (RT) were measured in minutes.
** Company profit (CP) variable was measured in millions of dollars.

From Table 1, it follows that the best system configuration, which allows maximizing the company profit, is determined by the input values shown in Table 2.

Table 2: Proposed configuration system

Number of Parking Slots	600		
Maximum Number of Accepted cars	1740*		
Type of Shuttle	Small Van (8 seats)		
Van Quantity	3		
Dwell Time	120 seconds**		
Drivers Quantity	Early	Midday	Late
	2	1	2
Rental Check-In Counters Quantity	Early	Midday	Late
	1	1	1

* A new car is accepted whether (2.6 * PS ≥ current parked cars + current rented cars). This is due to that the company is able to offer parking to more customers than the available parking spaces.
** In order to improve the use of the van fleet, a minimum dwell time is required in each pickup point visited by the vehicles.

3.2.1. Company Profit

Table 3 shows the benefits and costs of the resources for the best found scenario. The confidence level used to calculate confidence interval half-width statistics for result averages across replications is 95 %.

Table 3: Company profit

+Gross Profit ($)	2,759,774
-Parking Spot Cost($)	385,714
- Van Operation Cost($)	13,500
-Shuttle Fleet Drivers Cost($)	104,400
-Rental Check-in Counters Cost($)	45,360
Average Net Profit($)	**2,210,800**
Confidence Interval of the Mean	**2,146,650 ≤ u ≤ 2,186,097**

3.2.2. Resources and Parking Utilization

The average utilizations of each resource are given in Table 4. For parking facility, the maximum quantity of cars parked in simultaneous was 580 lots while the average utilization was 72 %.

Table 4: Resources utilization

	Early	**Midday**	**Late**
Vans	45.0%	45.6%	40.6%
Check-in Counters	29.0%	19.4%	24.7%
Cleaning	75.7%		

3.2.3. Passenger Arrivals

On one hand, if parking customers arrive when the lot is full are lost to competition. On the other hand, the renting passengers are lost to competition when the desired type of car is not available. Figure 5 shows on the total the customers arrivals, the percent of arrivals lost.

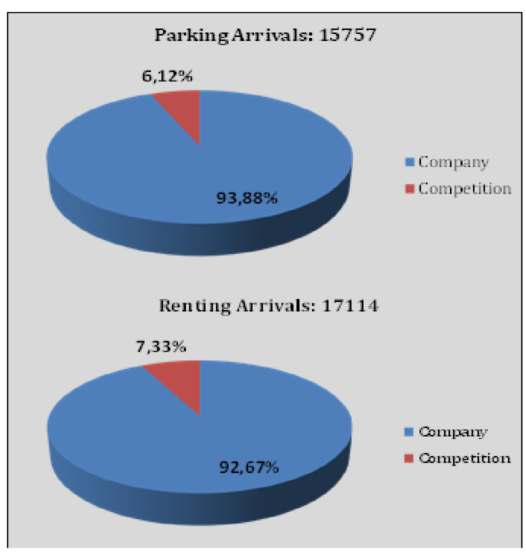

Figure 5: Customers lost

3.2.4. Service Times

Service times required for each passenger transported between parking and airport are detailed in Figures 6 and 7. These graphs show the service times computed in one replication of the proposed configuration. The mean and confidence interval were calculated considering 10 replications. The confidence level used was 95 %. Based on confidence intervals, the proposed configuration is able to satisfy the required level of service to customers.

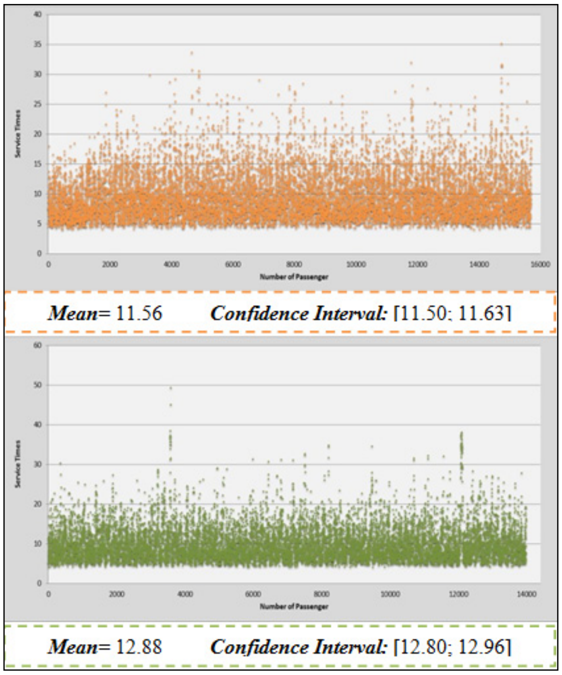

Figure 6: Services times for transporting parking passengers from parking facility to airport and vice versa

4. CONCLUSIONS

In this paper, a novel discrete event simulation modeling tool has been used to evaluate different configurations and operating modes for an innovative car rental business. The computer model was developed together with an attractive user friendly 3D interface to expedite the validation and illustration of simulation results. The proposed simulation model was used to evaluate the performance of alternative system designs and operation modes and, at the same time, to estimate the expected service quality and profitability of a realistic complex business. In this stage of the simulation project, an exhaustive sensitivity analysis was carried out to evaluate how different values of a set of critical independent variables will impact on a particular set of performance variables under a given set of assumptions. The sensitive analysis process was very useful to find the configuration system that allows maximizing the company profit while satisfying a suitable service level to the customers.

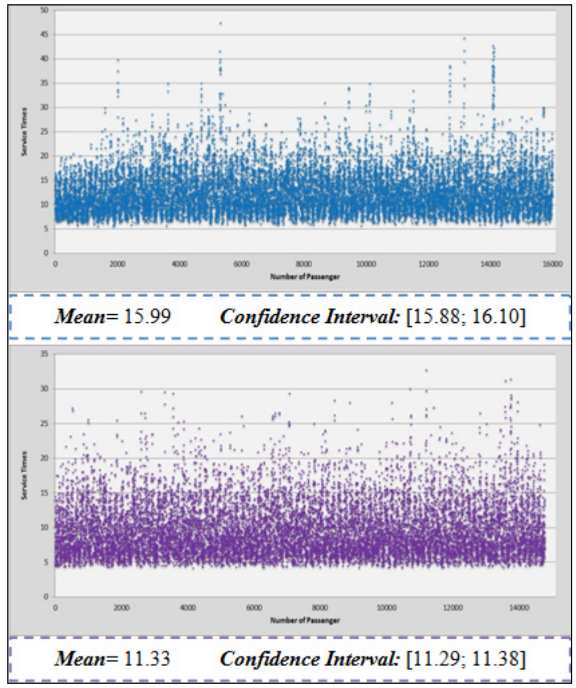

Figure 7: Services times for transporting renting passengers from airport to parking facility and vice versa

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