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Improvement of Public Cab Transportation System through Computer Simulation

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Authors' contributions

This work was carried out in collaboration among all authors. Authors SOCM, DSP and MFBM designed the study, performed the data analysis, developed the simulation model and wrote the first draft of the manuscript. Authors SOCM and DSP revised the final draft of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Aims: Public transportation is a dynamic problem which depends of different variables such as service schedules, route times, demand rates, and traffic density. Due to these features, mathematical modelling for improvement purposes is a difficult and complex task. Thus, computer simulation is proposed as a more comprehensive and efficient approach.
Study Design: A transportation case study is considered with the main feature variables. Data was obtained from a cab system within a town in Mexico. The reported problems consisted of economic losses due to low service level and cab utilization,
Methodology: The transportation problem consists of a cab system with four main routes which are served twice a day. Data associated to route times, demand rates, cab capacities, fleet size, service restrictions and fare costs was collected to develop a simulation model and analyze the current state of the real system. Once validated, an improvement approach was performed on the simulation model.
Results: The validated simulation model corroborated the problems reported by the case study. The proposals to improve performance, which consisted of reduction of cab fleet and route length led to reduce operative costs without affecting service level.
Conclusion: Simulation is an important tool to improve complex logistic systems which cannot be addressed by standard mathematical modelling.

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Keywords: Discrete-event simulation; transportation system; business analytics; operative costs.

1. INTRODUCTION

Public transportation systems are the main resource for mobility of people in urban and rural areas. Particularly in some towns in Mexico, where narrow streets are common, cabs are more suitable in contrasts to buses or large vehicles. Fig. 1 presents an example of these systems and street features.

In contrast to standard cab services which are hired for a single user or group, cabs in these systems are shared with other users and follow specific routes (just as a standard bus service would do). Each vehicle can load up to 5 passengers excluding the driver. A frequent problem, which is observed at busy times, is low service level which leads to economic losses.
Because cabs must serve specific routes through crowded and narrow streets, transportation or route times are variable and extensive. This reduces the availability of vehicles even though the cab fleet may be large. If routes are served at specific schedules, this reduces service levels and increases operative costs.

Transportation problems are frequently studied within the logistic and operational research fields through different tools such as mathematical programming and combinatorial optimization. However, these cab systems involve many dynamic and static variables such as route times, demand rates, cab capacities, fleet size, service restrictions and fare costs, which restrict the use of these tools for analysis and improvement purposes.

This is the reason to apply discrete-event simulation, which also enables the analysis of metrics such as resource utilization which is difficult to measure in the real system or through mathematical modelling. Computer simulation uses virtual elements to represent real life scenarios to test and validate specifications for decision-making. It significantly reduces design costs and provides immediate feedback on decisions, alternatives and performance for each individual element [1, 2, 3].

The application and results of this tool are described in the present work as follows: in Section 2 we describe the case study data (times, costs, user statistics, etc.). Then, in Section 3 we present the details of the simulation model. In Section 5 we present the results of the validated simulation model. In Section 6 these results are analyzed to support the changes to improve the system's performance. Finally, in Section 7 we present our conclusions.

2. METHODOLOGY

The study is formulated as follows: a company manages four routes within a community in Mexico. Each route is served by a fleet of 5 vehicles with a capacity of five passengers (excluding the driver). These vehicles are Tsuru type from the Nissan company. Table 1 presents the service schedules for these routes including the route times and length. Note that these times are already modelled with a probability function, and both times and length cover the route which starts and ends at the cab station.

Although the maximum load capacity is five passengers, sometimes the cab can start the route with less passengers. Once the cab arrives at the station, it waits up to 10 minutes. After this time, the cab starts the service route independently of the loaded passengers.

Table 1. Service schedule and route times

Route	Service Schedule	Service/Route Time (T, minutes)	Route Length (L, kilometers)
To Zone1	06:00 to 08:00 hours 14:00 to 16:00 hours	Normal (25, 2)	12.5
To Zone 2	08:00 to 10:00 hours 16:00 to 18:00 hours	Triangular (20,30,40)	20.2
To Zone 3	10:00 to 12:00 hours 18:00 to 20:00 hours	Uniform (30, 40)	16.7
To Zone 4	12:00 to 14:00 hours 20:00 to 22:00 hours	Exponential (30)	14.4

Fig. 1. Features of cab fleet and streets

Table 2. Passenger arrival rate at cab station (number of passengers per hour)

Time	Monday	Tuesday	Wednesday	Thursday	Friday
06:00-08:00	40	30	35	30	50
08:00-10:00	45	30	30	30	40
10:00-12:00	30	25	30	25	40
12:00-14:00	50	45	25	30	40
14:00-16:00	30	30	30	30	40
16:00-18:00	35	25	30	40	35
18:00-20:00	35	25	30	35	40
20:00-22:00	35	30	25	30	40

Regarding the passengers, Table 2 presents their arrival rates (demand) within a period of five days, considering Monday and Friday as the busiest.

Of the total number of passengers, approximately 60% are adult men, 30% are adult women, and 10% are children. The single trip fare is 0.30 USD for adults and 0.15 USD for children.

Although it is reported that vehicles leave with half capacity, which increases operative costs, many passengers remain at the station, unable to get a cab on their preferred schedule (i.e., if a passenger cannot get the cab to Zone 1 within 08:00 and 10:00 hours, the passenger must wait until the next schedule service at 14:00 to 16:00 hours, and if the passenger misses this service, then it must wait until the next day).

Each cab consumes approximately 1.0 liter of gasoline (95 octanes, regular) per 9 kilometers, and each liter has a cost of 1.2 USD. This leads to the following cost function for fuel consumption based on route length:

$$\text{Cost}(L) = (1.2 \text{ USD} / 9 \text{ km}) \times L. \quad (1)$$

Note that the maximum revenue of a cab unit is 0.3 USD × 5 passengers = 1.5 USD which is very similar to 1.2 USD which is the fuel cost of a 9 km trip. Thus, achieving full capacity is important to avoid economic losses. Also, the number of passengers who were unable to reach their preferred service is important to estimate the missed cab fares.

Here, there are two main concerns regarding the real economic impacts of these problems:

a) The level of utilization of each cab per route (all vehicles are at full capacity?) and overall service level of the fleet.
b) How many passengers (adults and children) are served and how many are not served (what are the revenues and losses in USD?).

A simulation model will be developed to address these concerns and estimate the economic benefits of measures to improve the current system.

3. SIMULATION MODEL

All simulation models must be developed based on a methodology with rigorous criteria [4]. This is because we must ensure that, within statistical parameters, it represents accurately the real process. Also, different versions of a same model may be conceived before obtaining the

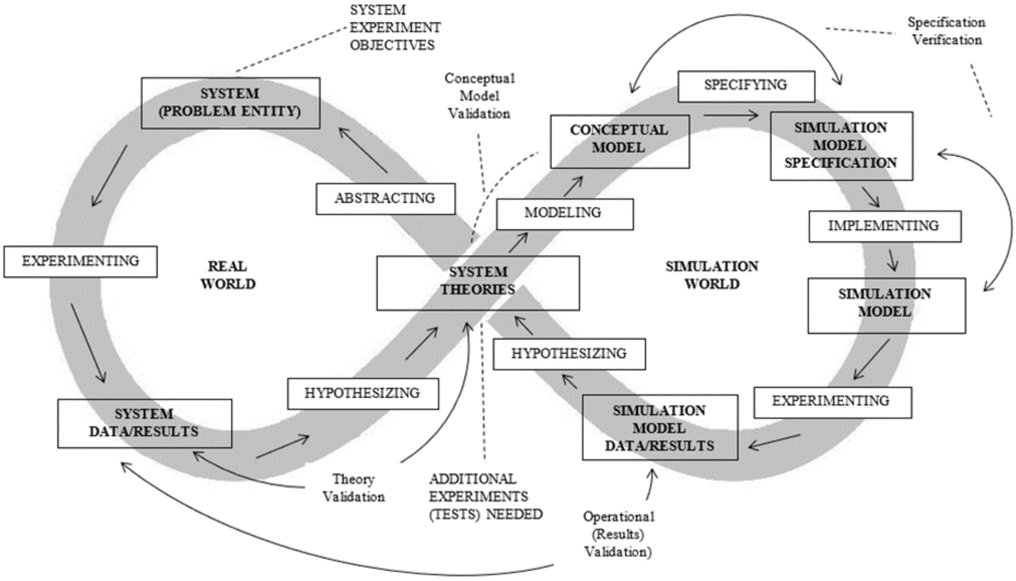


Fig. 2. Development of the Simulation model (adapted from [3]).

adequate, verified and valid one. Fig. 2 shows the relationship held through the modeling process. First, a conceptual model is born along its conceptual model validation, and this process is repeated until it is found a suitable conceptual model. Then, a computerized model is designed from the conceptual model, in addition to its computerized verification, which will be run until satisfactory. Once satisfactory, validation of the computerized model results takes place. If any changes on the conceptual or computerized models are needed, then verification and validation processes must be completed for all stages [5].

Nowadays, different software is available for simulation, among these, the following can be mentioned: SIMIO, Rockwell Arena, PROMODEL, etc. In this case we used the Arena platform due to its use in the improvement of manufacturing and logistics systems [6,7,8]. Figure 3 presents the baseline simulation model which was built with the latest version of Arena [9].

The general description of each section of the model is presented as follows:

A. The arrival of customers for each route X (entities passengersX) is modelled by using “Create” modules. As these arrivals are dependent of time windows, these are modelled by using “Schedules”. Fig. 4(a) presents an example of both elements for route 1 (Zone 1). Other elements which are restricted to time windows are the cabs. Fig. 4(a) also presents the schedule for each cab associated to the fleet for route 1 (Zone 1).
B. The percentage of adults and children are defined by using a “Decide” module which separates the incoming entities (passengersX) based on probabilities (90% and 10% respectively). Fig. 4(b) presents an example of this element for route 1 (Zone 1).
C. Once the incoming entities are separated, these are labelled as “adult” and “children” by using “Assign” modules. This is important to address the second concern of the analysis. An example of these elements is presented in Fig. 4(c).
D. After all entities are labelled, these are batched to comply with the load features of each cab. For this purpose, an “Adjustable Batch” module is considered. This element enables batching based on a maximum number, and, if a waiting time is reached, batching is performed with the available entities in the module. Fig. 4(d) presents an example of this element considering the 10-minute waiting time and the maximum load capacity of 5 passengers.
E. Because cab service is restricted to certain time windows throughout the day, passengers who arrive at times out of these windows are considered to miss the service. As presented in Fig. 5(a), this is modelled by using another

“Decide” module where batches are separated based on the availability of resources (cabs). Note that the availability of each cab is based on its schedule as presented in Fig. 4(a).

F. Once that all batches are processed, and those missing the service are identified, the route time is represented. This is performed with “Process” modules which use the sets of cabs as resources. Note that each fleet is modelled as a “Set” and each one is filled with the independent cabs associated to each route. This was performed to address the first concern of the analysis. Fig. 5(b) presents an example of this element for route 1 (Zone 1).

G. After the transport service time is completed, the batches are separated to obtain the independent entities (single passengers labelled as “adult” and “children”). This is performed with a “Separate” module which is presented in Fig. 5(c).

Finally, the model is terminated with “Dispose” modules. Validation of the model was performed with service data (number of passengers served) through a two-week period.

4. RESULTS OF THE BASELINE SIMULATION MODEL

The simulation model was run through a five-day period. To address the two concerns presented in Section 2 we report on the following data: resource (cab) utilization, and number of passengers served within their preferred time window (adults and children), and number of passengers not served. Table 3 presents the statistics regarding the number of passengers served with the associated income and loss (in case of not served passengers). The service level is also computed. Table 4 presents the utilization of each cab on the fleet which serves each route. Total Operative Cost (TOC) is estimated based on the function (1) and considering the fleet size, the five-day run, and twice a day services as described in Table 1.

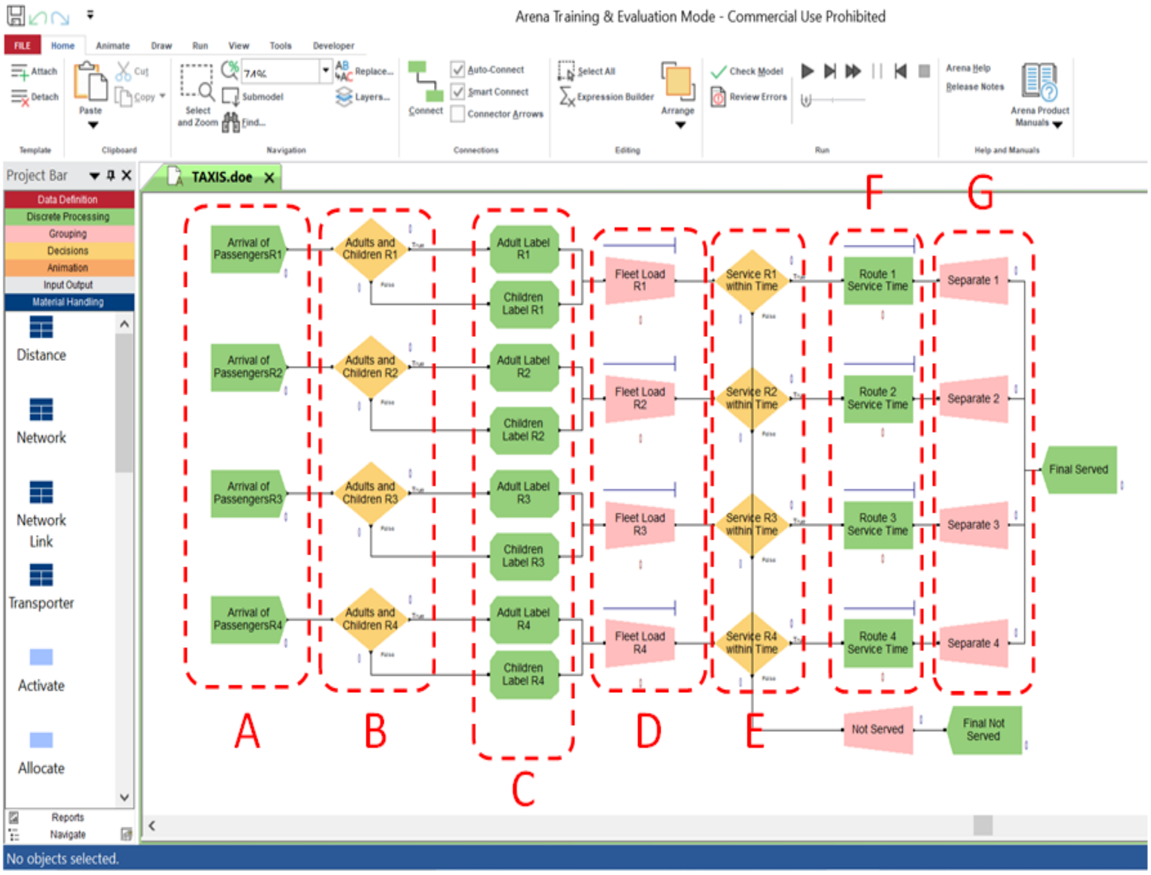
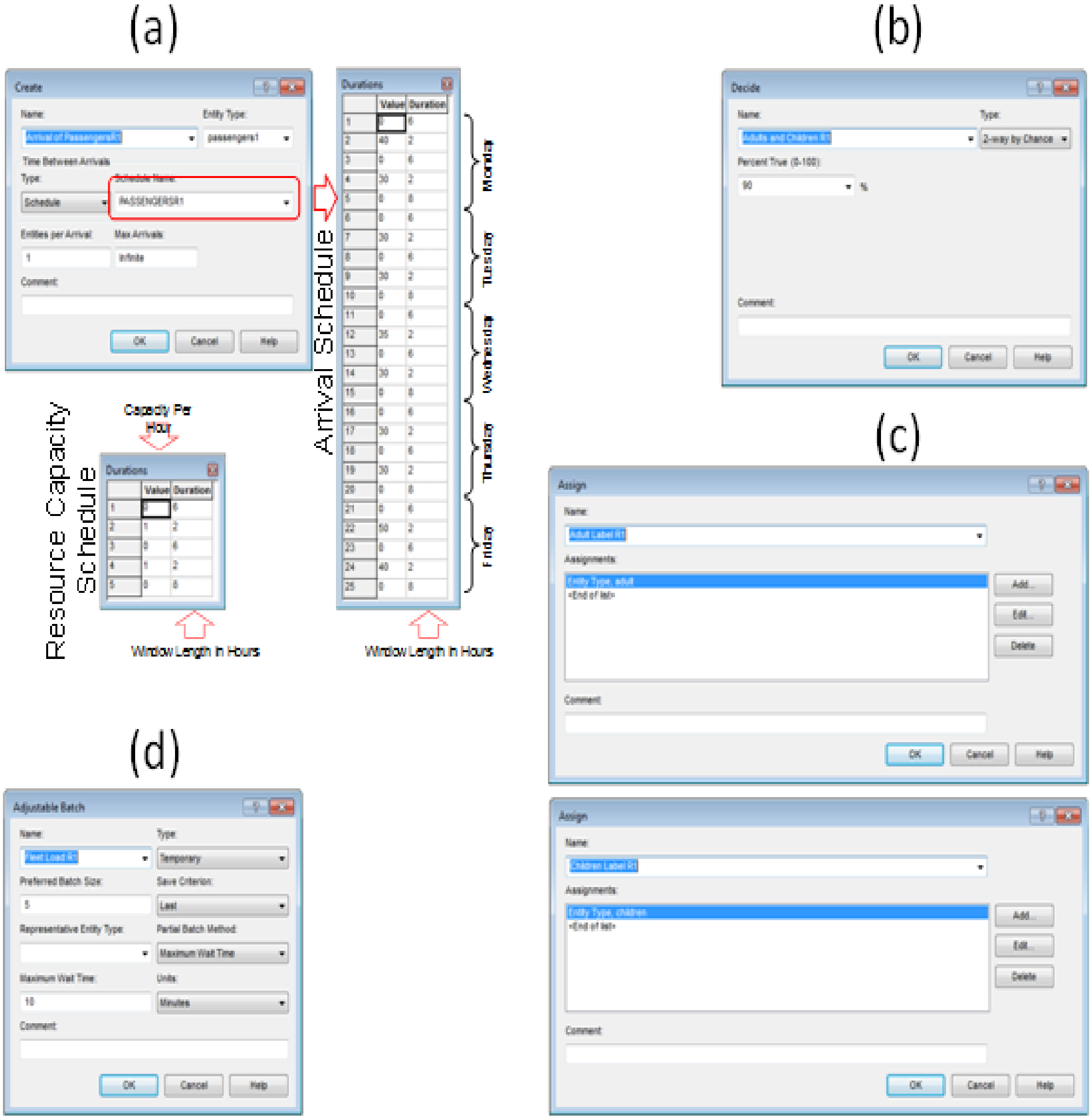


Fig. 3. Baseline Simulation model built with the Arena software

Table 3. Passengers served and not served: Income and loss estimation

Served			**Not Served**		
Adult	2189	0.30×2189	Adult	305	0.30×305
Children	234	0.15×234	Children	44	0.15×44
Total	2423		Total	349	
	Income ($)	691.80 USD		Losses ($)	98.10 USD
Service Level	85.6%				



Create

Name: Arrival of PassengersR1

Entity Type: passengers1

Time Between Arrivals

Type: Schedule

Schedule Name: PASSENGERSR1

Entities per Arrival: 1

Max Arrivals: Infinite

Comment:

Durations

	Value	Duration
1	0	6
2	40	2
3	0	6
4	30	2
5	0	6
6	0	6
7	30	2
8	0	6
9	30	2
10	0	6
11	0	6
12	35	2
13	0	6
14	30	2
15	0	6
16	0	6
17	30	2
18	0	6
19	30	2
20	0	6
21	0	6
22	50	2
23	0	6
24	40	2
25	0	6

Durations

	Value	Duration
1	0	6
2	1	2
3	0	6
4	1	2
5	0	6

Decide

Name: Adults and Children R1

Type: 2-way by Chance

Percent True (0-100): 90 %

Comment:

Assign

Name: Adult Label R1

Assignments:

Entity Type, adult
<End of list>

Comment:

Assign

Name: Children Label R1

Assignments:

Entity Type, children
<End of list>

Comment:

Adjustable Batch

Name: Fleet Load R1

Type: Temporary

Preferred Batch Size: 5

Save Criterion: Last

Representative Entity Type:

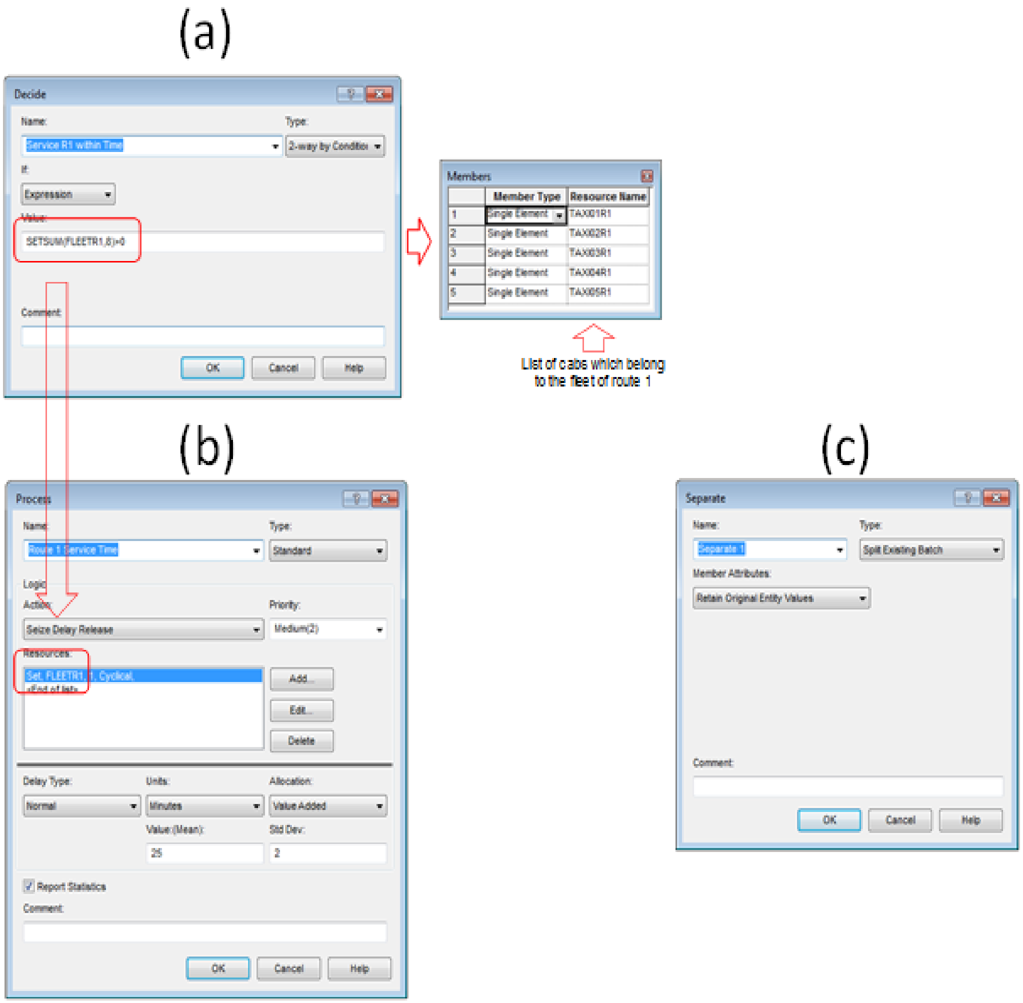
Partial Batch Method: Maximum Wait Time

Maximum Wait Time: 10

Units: Minutes

Comment:

Fig. 4. Description of the Arena modules used for the simulation of the cab system (part I): (a) “Create” module for arrivals, (b) “Decide” module for separation of entities based on probabilities, (c) “Assign” modules for labelling of entities as “adult” and “children”, and (d) “Adjustable Batch” module for batch creation based on maximum size and waiting time



(a) Decide

Name: Service R1 within Time

Type: 2-way by Conditio

If: Expression

Value: SETSUM(FLEETR1,6)>0

Comment:

Members

	Member Type	Resource Name
1	Single Element	TAX01R1
2	Single Element	TAX02R1
3	Single Element	TAX03R1
4	Single Element	TAX04R1
5	Single Element	TAX05R1

List of cabs which belong to the fleet of route 1

(b) Process

Name: Route 1 Service Time

Type: Standard

Logic

Action: Seize Delay Release

Priority: Medium(2)

Resources:
Set, FLEETR1, 1, Cyclical,
<End of list>

Delay Type: Normal

Units: Minutes

Allocation: Value Added

Value (Mean): 25

Std Dev: 2

☑ Report Statistics

Comment:

(c) Separate

Name: Separate 1

Type: Split Existing Batch

Member Attributes: Retain Original Entity Values

Comment:

Fig. 5. Description of the Arena modules used for the simulation of the cab system (part II): (a) "Decide" module for separation of entities based on availability of resources, (b) "Process" module for representation of route service time, and (c) "Separate" module for separation of batches

Table 4. Utilization of each cab and estimation of total operative cost (TOC) per route: DW = week salary of the cab driver which is estimated as 40 USD

Cab	R1	Cost(L)	R2	Cost(L)	R3	Cost(L)	R4	Cost(L)
01	0.49	1.67	0.67	2.69	0.64	2.23	0.63	1.92
02	0.58	×5 cabs	0.68	×5 cabs	0.73	×5 cabs	0.73	×5 cabs
03	0.60	×2 trips	0.62	×2 trips	0.69	×2 trips	0.59	×2 trips
04	0.60	×5 days	0.70	×5 days	0.63	×5 days	0.54	×5 days
05	0.55	+DW	0.71	+DW	0.64	+DW	0.57	+DW
	TOC	83.5 +40 = 123.5	TOC	134.5 + 40 = 174.5	TOC	111.5 + 40 = 151.5	TOC	96.0 + 40 = 136.0

By considering all cost data, we can estimate the global profit as 691.80 USD - (123.5+174.5+151.5+136.0) = 691.80-585.5 =106.3 USD with a virtual loss of 98.10 USD due to missing services. This leads to estimate the profits as 15.3% of all incomes with a potential loss of 14.18%.

Table 5. Service levels, incomes, TOCs and Profits with Improvement Actions

Scenario	**1**	**2**	**3**	**4**
Served				
Adults	2003	1987	2229	2162
Children	198	217	246	238
Not Served				
Adults	458	408	197	323
Children	52	33	21	43
Service Level	76.8%	80.0%	91.2%	84.8%
Income	630.6	628.7	705.6	684.3
Losses	145.2	127.4	62.3	103.4
TOC	500.3	470.4	548.0	506.3
Profit	130.3	158.3	157.6	178.1

5. CHANGES FOR IMPROVEMENT

From the utilization data reported in Table 4, it is observed that there is availability of resources, particularly for route 1. Thus, the first change to test is to reduce the cab fleet to four units per route.

While this may affect the number of clients served, based on the loss analysis, it is observed that operative costs are higher (585.5 USD vs. 98.10 USD). Another aspect to be considered is to improve the service route. Although in practice this is a difficult task due to the current street infrastructure and traffic density, a reduction of 3.4 km (16.8 km) and 2.2 km (14.5 km) were obtained for routes 2 and 3 respectively with *Google Maps* ®. With the same tool, throughout the day, we estimated route times and the following expressions were obtained for routes 2 and 3: Uniform (25, 32) and Normal (24, 3). By following the same analysis described in Tables 2 and 3, we report the expected incomes and losses with four main scenarios (see Table 5):

1. Reduce the fleets to four cabs and keep routes 2 and 3 unchanged;
2. Reduce the fleets to four cabs and consider the reduced routes 2 and 3;
3. Keep the fleets unchanged and consider the reduced routes 2 and 3;
4. Keep routes 1 and 4 with five cabs, and routes 2 and 3 (the routes with higher TOC) with four cabs. Consider the reduced routes 2 and 3.

Considering the baseline profit of 106.3 USD all scenarios represent an improvement. Scenarios 1 and 2 are the less suitable if the baseline service level of 85.6% is considered. As presented in scenario 4, reducing the fleet for routes with the higher TOC can improve the profits without significantly affecting the service level

6. DISCUSSION AND CONCLUSIONS

Discrete-event simulation is an important tool to improve logistic systems. In the present case study, a significant reduction in operative costs can be achieved if reassignment of resources is performed. Such actions do not require additional investment and their suitability can be addressed by the simulation model which reduces the cost risks of early implementation.

These positive results must be considered with caution. This is due to the limitations of the case study as partial and estimated data were considered and no real implementation was performed. Also, redesign of the transportation routes was not addressed through specialized methods which may lead to more significant savings. Among these methods, the Traveling Salesman Problem (TSP) or Capacitated Vehicle Routing Problem (CVRP) can be suitable options [10]. Note that this approach may involve hybrid simulation modelling with operational research which is an emerging research field [11].

Nevertheless, the present work describes the main steps that must be followed to develop a simulation project to analyze and improve a real dynamic system. This includes the modelling of the economic aspect as function of the system’s variables, and guidance regarding the use of the simulation software for a transportation problem. This is important for the objective assessment of the current and improved conditions of the system, and for the appropriate use of the software.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors."

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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