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Traffic Simulation Modeling for a Major Intersection

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Abstract

Nowadays, computer simulation is widely used in industries to support decision-making and performance enhancement. Real situations often require optimal solutions in the presence of multiple constraints. Present study aims to solve a transportation problem with the help of simulation modeling. Different kind of models are investigated using multiple iterations to reduce vehicle cycle and waiting time at roundabout intersection. Discrete Event Simulation (DES) is done to compare base model against two alternatives, while, ARENA soft ware is used for data analysis and computations. Results indicated that the alternative 2 of round about only is the best option considering cycle time, waiting time and number of vehicles transferred out of the system. Findings are beneficial to improve traffic flow at similar intersections, where commuters face long waiting time during peak hours.

Keywords: Traffic control, Traffic lights, Roundabout, Urban area, DES, Arena, Decision-making

1. INTRODUCTION

In the second half of 20th century, most of the major cities in Saudi Arabia were not crowded with people and vehicles. However, with the passage of time, number of people and cars were multiplied due to urbanization. As a result, Jeddah faces frequent traffic jams, creating lot of undue stress and safety concerns among drivers. Some people blame police officers for their lack of training, while others, shift this responsibility to the ministry of transportation and the municipality [1].

In order to improve safety and reduce traffic crowding, the city management made a plan to smooth traffic flow at intersections having both traffic lights and a roundabout structure. The system under study is a roundabout with four traffic lights. A roundabout is a one-way road around a checked focal island to improve traffic flow with typical flared ways to deal numerous vehicles. Fig. 1 shows the four main streets intersecting at the Aldarrajah roundabout. Each road leading to the roundabout is composed of four lanes with one extra lane dedicated for right turn making a total of five per road.

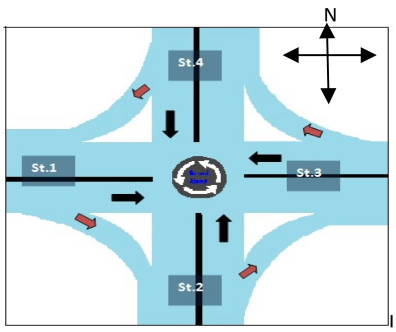

Figure 1. Illustration of the aldarrajah roundabout

The next section presents the simulation modelling practice. In Section 3, problem description is explained. The proposed input data, data sources and data

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collection methods are described in Section 4. The model building is presented in Section 5. The proposed alternative system designs are shown in section 6. The output analysis is presented in section 7. Conclusions and future suggestions are discussed in Section 8.

2. SIMULATION MODELING PRACTICE

Computer simulation is a powerful tool that enables decision-makers in business industry to enhance their operational readiness and objectivity [2]. Both objectives and specificity are better controlled in simulation modeling, thus, providing sufficient support to the decision-makers. Different types of simulation models are available that transforms inputs into outputs using multiple iterations. Discrete event simulation (DES) is a common method, which simulates the behavior and performance of a real-life process, facility or system. DES models the system as a series of events and support the decision-making process in organizations. It supports companies in better utilization of their resources and capabilities for competitive advantage. A surgical center in Belgium works on DES model. Real data is used for resource optimization and technical decision making by comparing different surgical procedures in atrial fibrillation. Major portion of the cost is consumed in managing the resources of operation room, besides choosing the best surgical procedure among different options. [3].

Airport operations used DES to model the landside processes of baggage drop-off, check-in, security check, security access, and immigration processes. The processes are optimized to allow greater number of passengers utilizing the services per hour [4]. Environmental impact of the hot in-place asphalt was studied using multiple recycling approaches with the help of DES model. Different iterations were done to compute fuel consumption, construction time, and air emissions for optimized settings [5]. A simulation model was developed using DES to optimize the assembly line of a television printed circuit board. The simulation model improved the workload balance and increase the throughput of the assembly line [6].

An event-driven stochastic process was modeled through conventional simulation for the analysis of unmanaged intersections. The analysis was done to improve the flow of traffic by reducing traffic delays and temporal gaps between two vehicles [7]. The Traffic Responsive Plan Selection (TRPS) was studied with the help of actual data to improve intersection's traffic control system and reduce the green time wastage. Researches developed the SimTraffic simulation model to evaluate traffic timings in different scenarios. Subsequently, the traffic response control mode was found to improve the performance of traffic network [8]. A sudy conducted in China reduced the load of traffic using a simulation model, which used congestion indicators to show traffic situations in different timings [9].

Another study used simulation modelling to balance the flow of traffic on double-lane roundabouts, where traffic congestion increased due to increase in the flow of heavy vehicles that also impact the flow of passenger cars [10]. DES model was developed in Indonesia optimizing the flow of traffic on a major road intersection. Arena used all different traffic light options against multiple traffic scenarios to reduce the queue of traffic during red lights [11].

IT experts frequently used DES and Arena for the simulation of diversified scenarios [12]. A study was conducted to improve operations at airport using simulation modeling. Arena was used to reduce congestion at the airport by optimizing passenger time between his entery and departure. Iterations were done for check-in procedures time, security search time and parking lot time. The software generated multiple combinations that were checked and verified in real time situations to reach the best possible combination [13]. Moreover, production of the rubber smoked sheets were enhanced using Arena simulation program. A Systematic Layout Planning (SLP) theory was used to eliminate redundant steps in the process of rubber sheet production. Simulation modelling is used to control air flow parameter, while the plant layout is optimized for better time and distance [14]. Likewise, traffic flow Simulation Model is developed using Arena for the waterway intersection seaport in China. Different inputs included the tidal window, traffic rules, different feet types and weather conditions. Results indicated that the capacity of the waterway was improved by reducing the waiting time [15].

Present paper considers the DES modelling by Arena to solve the traffic intersection problem [16]. The simulation modelling and analysis are done for the current and proposed scenarios in order to support the decision-making process.

3. PROBLEM DESCRIPTION

Number of vehicles waiting in queue at each traffic light is high, creating stress and loss of time among commuters. An optimum road design must be found in order to reduce the signal waiting time and total cycle time at the intersection. Table 1 indicates the calculations for travel time and road capacity.

Assumptions and descriptions, which are designed for system behavior, can be listed as follows.

- Because, each vehicle has to adopt a departure lane depending upon its destination. These destinations are randomly selected from a set using a uniform and normal distribution. Therefore, these vehicles are supposed to take corresponding lanes before time.
- A vehicle can enter the roundabout only, if light is green. If the light assigned to specific lane is red, vehicle has to stop.
- At the point of start, where the number of vehicles are entered into the system for counting, it is assumed that each vehicle will not change its lane with any another one.
- For alternative design 2, a vehicle's wait time before a stop sign is distributed from UNIF (0.0333 to 0.0833) minutes after consultaions and interviewing sessions with concerned experts.
- The roundabout is assumed as a perfect circle.
- Vehicles can enter into system at the point, where there is a possibility of only right turn.
- In order to calculate the road capacity, it is assumed that average length of a vehicle is 4.9 meters, which is approximately 16 feet.
- The capacity of lanes is assumed to hold certain number of vehicles based on defined road length and average vehicle length.
- Travel time for vehicles is defined on the basis of average road length along with average speed, which is assumed to be 15 km/h.

Table 1. Calculations for travel time and road capacity

	Average distance travelled (meters)	Average time in minutes at 15Km/h	Average road capacity assuming a vehicle is 4.9 meters
Right before Light	351.00	0.39	71.63
Right at Light	364.50	0.41	74.39
Straight	477.50	0.53	97.45
Left	571.00	0.63	116.53
U-Turn	660.75	0.73	134.85

3.1. Study Objectives

Present study aims to reduce the total waiting time of vehicles in an urban intersection, thus allowing maximum number of vehicles to utilize the roundabout at any given time. For this purpose, traffic control parameters need to be designed in an optimized way to improve the performance measures. It will be done by analyzing different configurations of traffic lights and use of roundabout. In addition, the factors affecting the vehicle queue time and total time consumed in the system will be studied.

3.2. Propsed Performance Measures

Below are the performance measures that will be used in the comparison of different alternatives.

1. *Time in system* (minutes): Since there is a single intersection under consideration, so, vehicles are simulated only, when they enter in one of the joining streets or when they leave the system. In between these stages, they are considered for alternative structures.
2. *Queue waiting time* (minutes): Vehicles have to wait, until they pass through the intersection. Vehicle waiting is due to traffic light or volume of the traffic. This measure can be further split into statistics such as "waiting time in queue of line A of street Y".
3. *Number of vehicles in system* (vehicles): Number of vehicles in system can show the efficiency of the proposed system at the intersection.

Apart from the performance measures, some response variables are also defined for the validation of model that includes average number of vehicles and average time of vehicles that are randomly selected in the following way:

- Average number of vehicles turning towards 'x' direction from street i (i=1,2,3,4)
- Average number of vehicles waiting in lanes of street 'i'

The simulation model will be validated by comparing the maximum and minimum values of these measures with the observed data.

4. PROPOSED INPUT DATA, DATA SOURCES, AND DATA COLLECTION METHODS

The data for the number of vehicles entered the intersection was collected by a team of students from the Civil engineering department of King Abdulaziz University (KAU) Jeddah, Saudi Arabia. The number of vehicles passing through the intersection were calculated for all four streets and their respective lane, at fixed intervals of 5 minutes for 18-hours, starting at 6:00 am. Arena's Input Analyzer is used for the analysis. Resultantly, a graph of the number of vehicles entered the system for all the intersections is plotted as seen in Fig. 2.

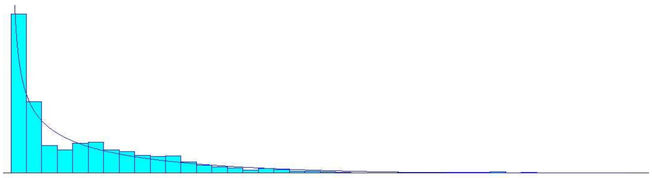

Figure 2. Distribution of number of vehicles entered the system for 18 hours

The Input Analyzer is used to perform the chi-square and Kolmogorov-Smirnov Tests. Similarly, the distribution with smallest MSE that fit into the data was considered as Beta distribution. Also, the MSE results for each distribution are tested.

However, after plotting the total number of vehicles versus diffrent day timings, it is realized that the arrival of vehicles are dependent on the time of the day. Fig. 3 shows the relationship of the number of vehicles in the system versus the time of the day. Peak loads are noticed around noon as well as late afternoon, due to school and office timings respectively.

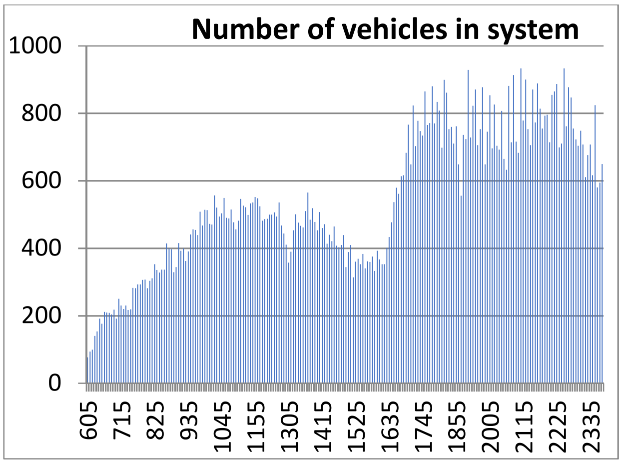

Figure 3. Histogram of data (number of vehicles in the system versus time of the day)

From the hypothesis results, enough evidence was not available to support the Beta distribution of data. Due to multi-mode nature of data set, it was decided to use discrete distribution of number of vehicles by dividing the data into 18 parts, which corresponds to hourly readings of data. More so, the probability of each vehicle to choose one of the possible directions was computed for each hour. Table 2 shows the average number of vehicles along with a probability of choosing a specific lane.

Table 2. Example data analysis

6:00 am to 7:00 am	Right after traffic light	Right before traffic light	Forw ard	Left	U-Turn	Total
Total number of cars	4	28	60	143	43	278
Average number of cars per 5 mins interval	0.34	2.34	5	11.92	3.58	23.17
Probability of choosing lane	0.02	0.10	0.22	0.51	0.15	1.00

5. MODEL BUILDING

Simulation model was developed on the basis of vehicles entering each street and going in different directions. The schedule of the route that a vehicle would travel was defined on the basis of data analysis, starting from 6:00 am until 12:00 pm. Each vehicle was assigned a path from the discrete distribution. Probabilities of these paths are derived from the data analysis and defined as a variable in the model.

The model logic and traffic light logic are built with the help of Arena. All models are run for 30 replications. The resulting confidence intervals are found to be satisfactory after their comparisons with mean values, in whichhalf width was much smaller than its mean value.

a. Model Verification

Animation of the base model was prepared to check the visual behavior of the model. Picture entities were assigned in the model to show the directions of vehicles. Be doing so, it became clear that a vehicle was choosing the right lane and following the correct path to cross the intersection. Fig. 4 and Fig. 5 shows the picture entities along with animation run before and after respectively.

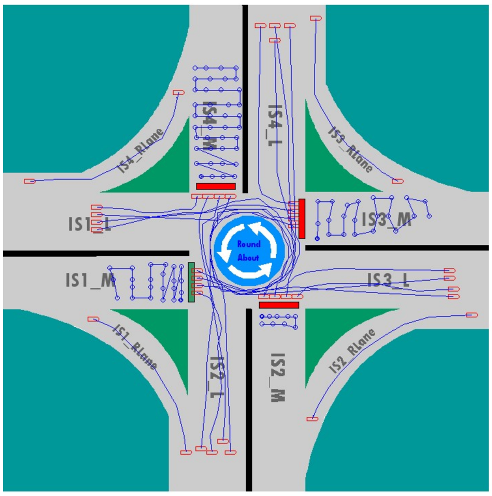

Figure 4. Animation before the run

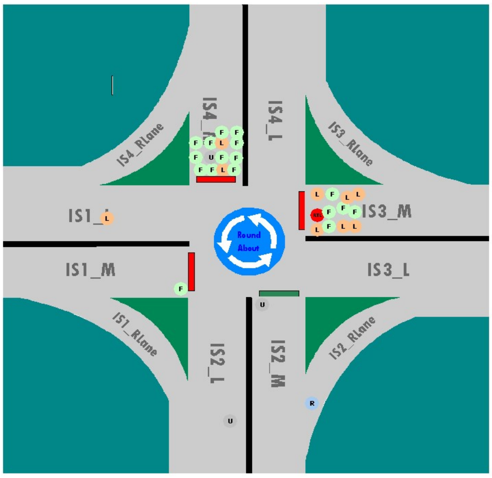

Figure 5. Animation during the run

Another method was used to generate only one entity with an objective to trace its path from beginning till end. In addition, multiple entities can also be generated to see the response of model in extreme conditions. However, this option cannot not be realized in present research due to the limit of maximum 150 entities for inuse academix version of the software. By using these techniques, it was verified that the model works error free.

b. Model Validation

For the validation purpose, some output measures from the model were compared with the observed real-life data. Actual system's values were checked to see their values within the confidence interval (CI) of simulation model or not.

CI for average number of cars entered into street 1 was (18940, 20580) in the simulation model consisted of 18-hour period with 30 replications, whereas it was recorded as 19,890 in real life scenario for the same period. While looking at the lane distributions, the CI of average vehicles that made U-turns from street 4 were reported as (1230, 1850) in the model whereas, the real-life data reported the number of these vehicles as 1,450.

Road lengths were calculated with the help of Google Earth and measurements were made on the map using the "path" tool. For the alternative design 1, which has no roundabout, the measurements were made according to virtual paths that were designed on the assumption that no roundabout existed in the map.

The average waiting time in queue was determined using an expert opinion. In the model, the durations for street 1, street 2, street 3 and street 4 was around 3 minutes, whereas, it was around 3 to 4 minutes in the real-life scenario. After comparing model outputs with real-life observations in the presence of experts, a high level of confidence on the validity of model was established.

6. PROPOSED ALTERNATIVE SYSTEM DESIGNS

Roundabouts are designed everywhere to streamline the flow of traffic at intersections without any stoppage. However, the current intersection uder study combined both traffic lights and a roundabout. After examining the intersection and doing the simulation modelling, two alternative solutions are considered for optimizing the flow of vehicles.

a. Propsed Design 1

The first alternative is to simulate the intersection on the assumption that only lights are present. This design requires the removal of roundabout as shown in Fig. 6 & Fig. 7, which also includes the cost of road modifications. Different sequence of the light's timings are used to find optimal settings that will streamline traffic flow.

The same set of data collected for the base model was further used to find arrival times and direction assignments. Alternative 1 used direction groups, which were different from the base model to signal green light for a given period of time. Referring to Fig. 6, the vehicles in lane 1, 2, 9 and 10, which were grouped in 1 direction, started crossing the intersection at the same time. In Fig. 7, the direction of group 3, consisted of lane 3, 4, 11 and 12 is shown. The same discussion is valid for street 2 and 4 as shown in Table 3.

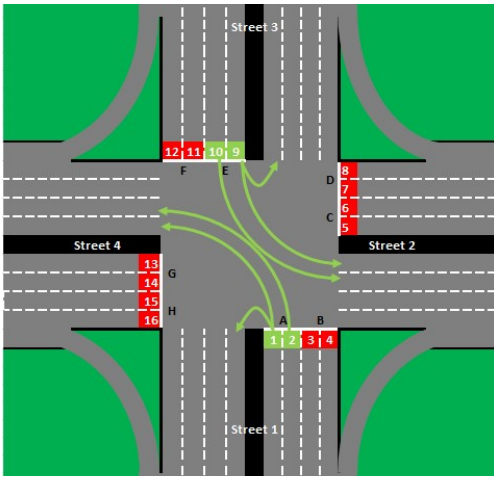

Figure 6. Group 1 direction

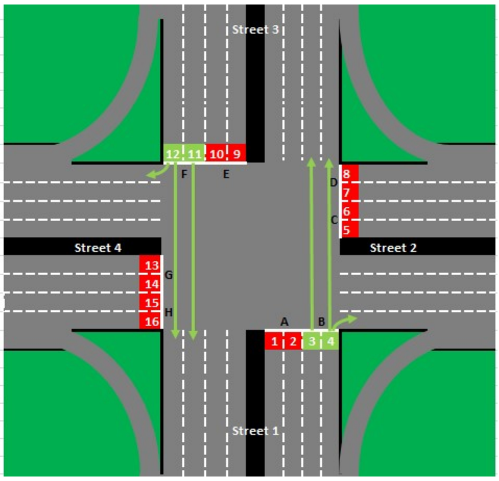

Figure 7. Group 3 direction

Table 3. Direction groups

Street	Green light for
1 & 3	Forward and Right
2 & 4	Forward and Right
1 & 3	Left and U-Turn
2 & 4	Left and U-Turn

b. Propsed Design 2

A study of 23 Roundabouts conducted by the Insurance Institute for Highway Safety (IIHS) in 2001 in the USA found that roundabouts not only reduced crashes by 40% but also decreased injury crashes by 80% as compared to intersections having traffic lights [17]. Therefore, the second alternative model simulated the roundabout without traffic lights. The modifications for alternative 2 are based on removal of traffic lights as shown in Fig. 8. The results are compared with the results of both alternative 1 and base model to ascertain the effectiveness of roundabouts without traffic lights.

Figure 8. Alternative model 2 design

7. OUTPUT ANALYSIS

ARENA's output analyzer was used to compare different models. Statistics of cycle time and waiting times of the vehicles entering each street has been determined as a performance measure. Hypothesis testing was performed at α=0.05 level. For simplicity, performance measures were numbered as 1; 2; 3; 4 corresponding to Street 1; Street 2; Street 3; Street 4. Also, CRN is used in the model as a variance reduction option.

a. Comparison of Three Models

During comparison of the three models, it is revealed that base model has the poorest cycle time, whereas alternative 1 has the best cycle time. Regarding waiting times, alternative 2 performs better than the base model whereas alternative 1 is slightly poorer than the base model. All results indicated that there is not enough evidence to support the respective means as they are same between base model - alternative 1 and base model- alternative 2.

For further testing, waiting time and cycle time of alternative 1 and alternative 2 are compared with each other. It is found that Alternative 2 performed better than alternative 1 in all measures.

Table 4 shows the average number of vehicles moving out of the system at the end of each replication.

Table 4. Average number of vehicles left the system

	Base Model	Alternative 1	Alternative 2
Average Number Out	115,660	115,790	116,200

b. Comparisons with Different Trafic Light Durations on Base Model and Alternative 1

Another comparison is done between base model and alternative 1, because traffic lights are only employed in these two designs. Different combinations of time durations for green signal were tested as (2, 1, 2, 1), while the real life conditions are reflected as (1, 2, 1, 2); (1, 0.5, 1, 0.5); (2.5, 1.5, 2.5, 1.5) for street 1 to 4 in the base model and direction groups 1 to 4 in alternative 1 respectively.

From the results, it is observed that alternative 1 reduced the cycle time of vehicles, whereas base model performed better regarding the waiting time of vehicles. Also, it is observed that (1-0.5-1-0.5) combination gave the best improvement in waiting times and cycle times for both models. These comparisons were based upon vehicle cycle time and vehicle waiting time with the help of ARENA output analyzer.

8. CONCLUSION AND FUTURE WORK

The alternative 2 of round about only is found to be the best solution among all options considering the cycle time, waiting time and number of vehicles transferred out of the system. On the other hand, the results indicated that the use of round abouts along with traffic lights was the last option in terms of performance measures. Two variables of moving time and waiting time significantly affecte the results.

Similarly, the cycle time of vehicles was reduced in alternative 1 for different traffic light durations. However, the average waiting time was increased. Therefore, it is concluded that removal of roundabout was the most critical factor in reducing the cycle time of vehicles at intersection crossing. It is found to have more impact on cycle time than traffic light durations.

Future study can be done at a larger scale for bigger network of roads in the city. Optimization of vehicular traffic using simulation modeling can be helpful in better utilization of resources.

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