Industrial Engineering in public systems: Optimizing Hadath Motor Vehicle Inspection Station

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Abstract-Public institutions aim at providing citizens with better services to satisfy them and ensure their safety and wellbeing. In order to ensure car and road safety, the Lebanese Ministry of Interior performs annually motor vehicle inspections in four stations in Lebanon. The annual mechanical inspection checks the vehicles roadworthiness for conformity to technical standards and norms according to law 124. Lebanese citizens have been complaining about the long waiting queues while performing their annual motor vehicle car inspection especially at Hadath station. This station suffers from extensive congestion because it is the only station that serves citizens in the Beirut governorate. Also, the number of served cars has been increasing over the years without proper adjustments. Therefore, we decided to optimize the performance of this station and minimize queue times. In order to achieve our goal, we applied queuing theory on the current queue system upon arrival to assess its effectiveness and we designed a new queue system that is based on one queue, multiple servers that will minimize waiting time at this queue. Also, we used simulation in order to evaluate the performance of the current system, test the feasibility of different alternatives and design a new system that minimizes overall waiting time in system. Moreover, we investigated the possibility of using 'Psychology of Queuing' in order to reduce the impact of waiting time and to enrich citizens' experience. And, we analyzed the possibility of designing a system based on appointments in order to control the car arrival variability. The design of the new system will include differentiated lanes for old cars and new cars that will be determined by classifying a criterion using data analytics and RStudio depending on the model of the car to reduce congestion caused by older car models. Also, we aim to forecast the demand of car inspections in order to determine the required system capacity that will meet the increasing demand. Therefore, our project will improve the overall system efficiency and minimize waiting time.

I. INTRODUCTION/MOTIVATION

In Lebanon, there are four main stations that perform annual motor vehicle inspection for Lebanese registered cars: Hadath station, Tripoli station, Zahle Station and Saida station. In 2011, the four inspection stations of Motor Inspection Vehicle announced that they can serve up to 350,000 car inspections per year while the demand might reach around 800,000(Akl, 2011). In other words, they are only capable of satisfying 44% of the total number of Lebanese registered cars. The Hadath Station has the highest demand since it is the only station that provides car inspection services for Beirut governate. Therefore, we decided to focus our project on the most congested station which is Hadath station. In order to meet demand, the Hadath Station expanded its capacity in 2018. Now, citizens complete the whole service in the car. Upon arrival, customer service employees guide the driver into one of 11 lanes based on visual congestion which leads to the kiosk of a cashier that receives the required personal information. After passing the kiosks, he goes into one of the 26 servicing lanes. In each servicing lane, there are four servicing posts where each post inspects specific criteria. However, this new system did not accommodate the increasing car inspection demands as well as the needs of the Lebanese citizens. When we observed the process on ground, we still saw citizens complaining about long waiting times and endless queues. Thus, citizens consider it a waste of time to wait for long hours to get inspected. Some often prefer not to go at their scheduled month or give their car to a broker to get this service done. In order to provide a better experience for citizens coming annually for their car inspection, we decided to conduct our project in the Hadath station and to apply Industrial Engineering tools in order to assess the performance of the current system, propose new feasible solutions and decrease waiting time in the queue and in the system.

II. GOALS AND OBJECTIVES

Goal: Optimize Hadath Motor Vehicle Inspection station's system efficiency and minimize waiting time of Lebanese citizens

- **Aim 1:** Analysis of the performance of the current queue system at the Station upon arrival using queuing formulas and evaluating its performance by comparing it to another queue system

- **Aim 2:** Analysis of the current process waiting time using simulation on ARENA and test different alternative solutions assessing different decision criteria

- **Aim 3:** Forecast number of cars that require annual car inspection for the next 3 years in order to predict future car demand for the station

- **Aim 4:** Enhance customers' experience while waiting using Psychology of Queuing

- **Aim 5:** Design new car lanes layout by segmenting car lanes for old cars and new cars and find an optimal cut off of number of lanes for each type by using data analytics

III. BACKGROUND

In order to determine the optimal queue system, different queue systems such as systems with one queue and multiple servers can be compared with multiple servers and multiple queues system (Prasad, V.h, & Koka, 2015).With predefined parameters like arrival rate, service rate, numbers of customers in the system for each system design, we can get at the end the number of customers in queue and in the system and the waiting time in queue and in the system for each case. For example, the service rate for a one queue system is different than a multiple queue system because in the latter we divide service rate into the number of servers which results in a difference when computing. In our case, in order to design the optimal queue system in front of 11 kiosks upon arrival, we decided to follow this method by comparing the current system, which is 11 servers with 11 queues, with a system of 11 servers and one queue.

The system of car inspection is exclusive to Lebanon as other countries do it differently or they do not have stations for inspections, they do it at a licensed garage. However, in GCC countries, the government follows a similar system for car inspection regarding the use of servicing lanes. In order to analyze the performance of servicing lanes, a simulation model was used. After analyzing their results, they deduced that the main problem of waiting time in queues was the high variability of servicing times in lanes 1, 2, 3 and 4 that differs by 10 minutes maximum. This caused, for example, the cars in lane four to have the highest average waiting time and to wait more in lines than the cars in other queues. So, in order to improve performance of system, the government worked on decreasing variability between lanes.

Moreover, in order to minimize the burden of waiting, many techniques related to the "Psychology of Waiting" have been used. In fact, while waiting, the actual waiting time is not the issue, but the perception of that time by the customer which is Satisfaction, that is Perception minus Expectations, is the main problem behind bad experiences in waiting. So, in order to improve the experience of the customer while performing a service, we should focus on the perception of the customer while waiting. As waiting time increases, the customer becomes more likely to have a negative experience and become frustrated or angry (Davis & Heineke, 1994). In order to determine the experience of the customer whole waiting, there are mainly six cornerstone principles. But the principles that are most relevant to our project are the following:

- Customers who are unoccupied tend to perceive longer waiting times than customers who are occupied during their waiting time.
- People expect to get started directly upon their arrival. To simplify this, it is compared to going into a restaurant. The waiters usually give you the menu directly in order to keep you busy with looking through it.

In our case, customers wait the whole time in their car without being occupied by anything and the inspection process does not start until they reach the kiosk and pay. This waiting without doing anything increases the burden of waiting which makes them feel like they are waiting more than the actual waiting time. In order to enhance the customers' queue experience, we decided to occupy them with an activity.

There are very few or rare cases of countries that have a similar car inspection system as the Hadath Station. Usually, citizens go to a local licensed garage and get their annual inspection done. Thus, we had to improvise in finding creative solutions and to use our knowledge in industrial engineering tools to find exclusive techniques for this case.

IV. METHODS

A. Simulation Model

We performed the Arena simulation to the entire car inspection process. We collected data on the arrival rate as well as the inspection process. We fitted the distributions accordingly using software such as Input Analyzer and Expert Fit. As cars arrive, the customer service employees guide cars into the least congested lane out of the 11 kiosk lanes. It was simulated using a decision module of N-conditions in the form of If statements. If the number of cars in Queue in kiosk 1 is less than that of the number of cars in each of the other kiosk (2,3...11), then the arriving car will be sent to kiosk 1. These if statements were present for each specific queue and would send the car to the queue with the least congestion which is what the worker does visually in the Hadath Station. Then, after the kiosk service, the first six lanes are split into two inspection lanes which were simulated also using the same decision concept. In each of the inspection lanes, there are four process lanes corresponding to the four inspection steps. After the inspection process is finished, the cars are routed to the exit gate (considered a station). This simulation will be used as an evaluation tool to compare different possible solutions.

B. Queuing System

One of the main problems of the system is car congestion in the 11 queues in front of 11 cashier kiosks. In order to analyze the current performance of the system including waiting times in the queue, we applied queuing theory to the system. We assessed the current waiting time in th queue which is based on a multiple queue and multiple server system and we compared its effectiveness to a system of one queue and multiple servers using Little's Law and queuing formulas:

$$P0 = [\sum (1/n!) * (\lambda/\mu)^{n} + (1/s!) * (\lambda/\mu)^{s} * (s\mu/(s\mu-\lambda))]^{-1} \quad (1)$$

$$Lq = [(1/(s-1)!) * (\lambda\mu)^{s} * (\lambda\mu (s\mu-\lambda)^{2})] P0 \quad (2)$$

$$Ls = Lq + \lambda / \mu \quad (3)$$

$$Lq = \lambda * Wq \quad (4)$$

Indexes of queuing system:

n = Number of customers in the system
λ = Mean arrival rate
μ = Mean service rate per busy server
ρ = Expected fraction of time for which server is busy
Pn = Steady state probability of exactly n customers in the system
Lq = Expected number of customers waiting in the queue (i.e. queue length)
Ls =Expected number of customers in the system (waiting + being served)
Wq= Expected waiting time for a customer in the queue
Ws= Expected waiting time for a customer in the system (waiting + being served)

C. *Forecasting Cars' Demand*

In order to predict the number of cars coming annually to the Hadath Station, we decided to use forecasting tools like trend analysis. This tool will allow us to know the required capacity of the station so that it can meet the increasing demand of the upcoming years. In order to do so, we will base our analysis on historical data showing the number of cars that have annual inspection for each year for the past five years and apply trend analysis in order to determine the pattern of increasing demand for future years. Once demand is predicted, the station can know how much resources and lanes it will need for the upcoming years and will be able to adjust the scheduling system accordingly.

D. *Data Analytics*

In the current system, we noticed that old cars (typically 20 years or older) take more time in inspection than new cars. Therefore, we decided to design a new system that differentiates servicing lanes for old cars and new cars. In order to know the optimal cut-off for lanes and how many lanes to allocate for old cars and new cars, we decided to use data analytics. In this section, we will collect data on the number of cars of each production year along with the inspection time. This information will allow us to classify servicing lanes by determining a range of production years that distinguishes between old models (long inspection time) and new models (fast inspection time). Older car models will be provided more service lanes while newer car models will be provided with less service lanes. Hence, this system reduces the total average time spent in system.

E. *System based on appointments*

Throughout the project, we noticed that the arrival rates are stochastic and do not have a specific distribution throughout the week (each day the arrival rate is different) and workers can't estimate the exact number of cars coming each day. For example, Saturdays always have higher arrival rates than other days. Therefore, in order to reduce the variability of arrivals, we decided to implement a new system based on appointments. This system will allow us to control arrivals of cars per day according to the capacity of the station. First, we collected data to determine the available capacity per day of each servicing lane and each kiosk. Then, we schedule appointments accordingly in order to have the least waiting time and the greatest number of cars inspected.
In order to decrease the variability of arrivals, we considered to include incentives in this system to encourage citizens to come for their car inspection during weekdays rather than Saturdays. The incentives include a new pricing strategy where weekday fees are cheaper than Saturday fees.

F. *Strategy Development*

In order to compare alternatives based on several decision criteria, we will formulate a strategy by focusing on measurable results and following these steps: building the list of alternatives, organizing the objectives, determining the importance of objectives, evaluation of alternatives based on the decision criteria, and then the final ranking that aggregates relative importance of criteria and alternatives evaluations.

V. RESULTS

A. *Queuing Formulas*

After applying queuing formulas, we obtained the following results:

Table1: Performance Measures Comparison between one queue, multiple servers system and multiple queues, multiple servers queue system

	λ	Lq	Ls	**Wq**	**Ws**
One queue, Multiple Servers	5.208 customer/mins	14.38 customers in queue	24.8 customers in system	2.76 mins	4.76 mins
Multiple Queues, Multiple Servers	0.473 customer/ mins	16.57 customers in queue	17.51 customers in system	31.33 mins	35.07 mins

According to the queuing formulas, we notice that waiting time in queue for one queue, multiple servers' system is 2.76 mins which is much lower than the current system having a waiting time in queue of 31.33 mins. Therefore, we recommend having one queue, multiple servers queue system in front of the 11 kiosks queues.

B. *Simulation*

For the current system, the end results included a waiting time of 20.0592 mins with a maximum of 179.12 mins. The total time of the car in the system is 31.8395 mins with a maximum of 191.01minutes. The number of cars served in the system is 2199 cars which supports the expert's opinion of serving up to 2,500 cars. We also determined certain bottlenecks in some of the lanes and a high variability of waiting time between the lanes.

C. *System based on appointments*

After performing calculations to determine the basis of scheduling appointments, we got the following results:
Cars served by servicing lanes = 80 cars/hour < Car Demand on average = 313 cars/hour < Cars served by kiosks = 330 cars/hour
In order to avoid congestion at servicing lanes (service rate of kiosks is higher than servicing lanes), we decided to schedule appointments as follows: for each hour, 29 car slots are assigned to have their inspection. The appointments will be hourly scheduled instead of quarterly in order to reduce system failures if the customer defaults to come on time. Currently, we are considering the possibility of designing an application to facilitate the booking process of appointments for annual car inspection.

VI. DISCUSSION

After applying queuing formulas, the results show that the current queuing system is not efficient and suffers from longer waiting time in several queues compared to a system with one queue, multiple servers. The methodology used in the literature review helped us in assessing the performance of the current system by comparing it to another system (Prasad, V.h. & Koka, 2015). This article helped in defining parameters, such as arrival rate and service rate for each system, in order to get performance measures for each system. Indeed, as the article shows, we obtained better results and less waiting time with this system which indicated that the current design of the queue can be changed in order to enhance the performance of the system.

In order to enhance customer experience, we conducted several interviews with the customers waiting in queue for their annual car inspection. We also performed an experiment by observing the arrival time of the customer, then waiting 15 mins and then asking the customer how long they have been waiting. Almost 80% answered that they have been waiting between 40 minutes and an hour, although they only waited for 15 minutes. These results conform with the theories of the article “The Psychology of Waiting in lines” (Maister,1985) that showed that a bad experience in servicing is based on perception and not the actual time waiting. Therefore, in order to decrease the impact of waiting, we decided to follow the article’s strategy to enhance customer experience by occupying the customer with a task while waiting. As a result, we decided to occupy the customer with filling their own data while waiting so that they can be distracted by a useful tool and at the same time decrease service time for kiosks.

Moreover, the simulation results showed high variability in waiting time, across all lanes that ranged from on average 20 mins to a maximum of 180 mins. Thus, this shows that in our model that includes 26 lanes, there is a high variability of waiting time across the lanes. This was also shown in the study of GCC countries’ car inspections, where cars in lane four had to wait more time than the cars in other lanes. As a result, in order to enhance the performance of the system, we should enhance the performance of the specific bottleneck lanes by decreasing their variability and enhancing work standardization. In our case, the waiting time variability is mainly due because of the cyclical shape of waiting queues and the different models of the car.

Currently, we are in the process of applying data analytics and forecasting tools. The data analytics would be useful to differentiate the lanes depending on the model of the car. The forecasting tools would serve to update the scheduling system as demand increases each year. Also, we are still in the process of evaluating different alternatives using Arena simulation in order to choose the alternatives with the least waiting time. The end solution will have a proposed cost benefit analysis to validate if the solution is worth implementation.

As for the limitations that we faced, the current situation in Lebanon has been our biggest limitation so far. This national situation led to road closures, inspection stations closure and university closure which delayed our set schedule. Due to this factor, we had limited time to visit the facility and collect data for our project. In our case, collecting data requires site visits since due to privacy issues, some previous data cannot be shared. On the other hand, there were also the problems and bugs in the ARENA software. Our project is mainly based on this software and it was crashing sometimes in the labs. Moreover, due to the complexity of the simulation, we could not use the student version in our laptops. Actually, because of the current inaccessibility to campus to get the full ARENA version and to retrieve all the required simulation files, we got delayed in testing the different solution alternatives on ARENA. Moreover, when suggesting new solutions, the layout of the station was one of our main limitations. Since the layout is fixed, we could not suggest any changes in the locations of the inspection stations. We can mainly change the number of lanes and their overall shape and process.

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