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Simulation-Based Optimization for Performance Enhancement of Public Departments

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Abstract

This paper proposes an approach for enhancing the performance of public departments that are characterized by congestion and low efficiency. The proposed approach utilizes discrete-event simulation (DES) tools integrated with optimization, and employs the key performance indicator (KPI) concept. Applied to the citizen affairs and passports (CAP) department in Jordan as a case study, a DES model was developed with the aid of ARENA software. Optimization results using OptQuest showed that performance of the optimized CAP department was better in various aspects compared to the current department. Waiting time was reduced the most by 91.7% on average, while number of processed documents was increased by 8.2%. The total daily revenue for the optimized CAP department was higher by 19.7%.

Key words: Simulation; Optimization; Key Performance Indicator; Public Departments

1. Introduction

Enhancement of real-world production and business systems often entails solving complex and NP-hard optimization problems developed with noticeable formulation and modeling challenges. This is often attributed to three main characteristics of real-world performance; complexity, nonlinearity, and dynamic and stochastic behavior [1]. Hence, it is common among researchers to tackle real-world problems by developing representative mathematical and computer models and applying proper optimization and search methods. This applies to design problems of new systems as well as to enhancement problems of existing systems.

To compensate for the limitations of mathematical models in capturing the characteristics of real-world systems, simulation-based optimization methods were developed by applying a search algorithm on an optimization problem that is represented using a DES model [2]. In this representation, the complex structure of the often nonlinear, stochastic, and dynamic objective function and constraints are evaluated by computer simulation without the need to approximate a closed-form definition of the problem.

By utilizing computer capabilities in logical programming, random number generation, fast computations, and animation, DES is capable of capturing the characteristics of real world processes allowing analysts to estimate the performance measures of a system under a range of design parameter settings [3]. This performance is usually a complicated stochastic function of these parameters. To measure such performance, DES imitates the operation of the real-world system as it evolves over time and predicts the system's behavior without requiring a closed-form definition of the performance function. Such a capability makes DES superior to mathematical models, and more practical and less expensive than physical experimentation. Hence, the application of simulation studies in systems design and improvement has become common practice in the development of manufacturing systems, business operations, and the services sector [4-6].

Different approaches have been used in the literature to optimize or draw inferences from the output of a simulation model. Taguchi’s Experimental Design using Orthogonal Arrays (OA) was applied to many simulation studies to seek a system-level parameter settings based on certain response signal that is evaluated through simulation runs [7]. In addition to Taguchi's approach, some methods have utilized more efficient search engines from the field of Artificial Intelligence (AI). Common intelligent search methods in parameter design applications (combinatorial optimization) include genetic algorithms [8], Tabu search [9, 10], and neural networks [11]. A complete discussion of different simulation-based optimization methods is found in [12-14].

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As a reflection to these advancements in simulation-based optimization, simulation software vendors have integrated experimental design and optimization search modules into their simulation packages. Examples include AutoStat of AutoMod, Optimizer of Witness, and OptQuest of Arena.

The focus of this paper is on utilizing simulation-based optimization to enhance the performance of a real-world system as the citizen affairs and passports (CAP) department in Jordan. It presents an approach that employs the key performance indicator (KPI) concept to evaluate system performance. Arena simulation software is used to develop the DES model of the public service office and OptQuest is used for optimization.

2. Solution Approach

The proposed solution approach for simulation-based optimization is depicted in Figure 1. The developed framework comprises two parallel yet interrelated processes; the simulation process and the optimization process. The functionality of both processes eventually leads to obtaining a near-optimal solution (design changes) to enhance the performance of the underlying system. The implementation of this solution to the real-world system combined with the deployment of sustainability controls is expected to result in improving the KPI measures of system performance.

The simulation process starts from the definition of the enhancement or design problem at the selected production or business system. This includes a definition of the scope and objectives of the intended project. Specific problem definition results in correct problem formulation to start the optimization process. This includes defining decision variables (controls), objective function, constraints, and requirements. Problem definition also helps in directing the effort for collecting pertinent data. Collected data often includes system structure, logic, flow, cycle times, reliability of resources, etc. The collected data is used to set the parameters (coefficients and bounds) of the formulated optimization problem.

Using the environment (platform) of the selected simulation software, the DES model is built so that the realistic characteristic of the underlying system are captured using logical design and probabilistic models. The integrated optimization module is also developed using the variables and performance measures defined in the developed DES model. The behavior of the DES model is verified compared to the intended logical design and validated using actual performance data. Test runs are used to check the performance of the optimization module.

Finally, the optimization search engine is applied to the DES model to perform the optimization in iterations of developing controls combinations and simulation-evaluation until termination condition is reached. The optimal controls are validated using the DES model and set for implementation.

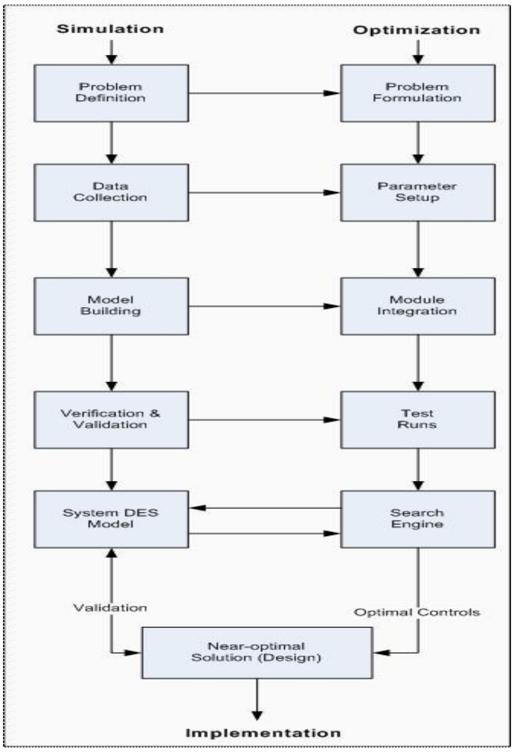

Figure 1. Framework for Simulation-based optimization

In this work, the proposed solution procedure depicted in Figure 1 is applied and demonstrated through a case study. The simulation aspect of the procedure is conducted with the aid of ARENA software. This includes data gathering and fitting, DES model building and model verification. Meanwhile, the optimization portion of this study is carried out with the aid of OptQuest optimizer. Relevant steps in this phase include determining system variables, defining objective function(s), and specifying linear constraints on system variables as well as certain performance measures (sometimes called goal functions). Then, a search algorithm is applied to search for the optimal solution. The last step occurs at the end of each run of the simulation model used for the evaluation of the objective and goal functions.

3. Case Study: Citizen Affairs and Passports Department

The citizen affairs and passports (CAP) department, which is adopted as the case study, issues four main documents to Jordanian citizens: Passports (PA), Birth Certificates (BC), Family Books (FB) and Identity Cards (ID). The floor layout for this department is represented in Figure 2. This figure shows the primary elements in the department (primary and secondary checking staff, cashiers, data entry staff and printers), which are used to issue the four documents, plus the queue lines and management

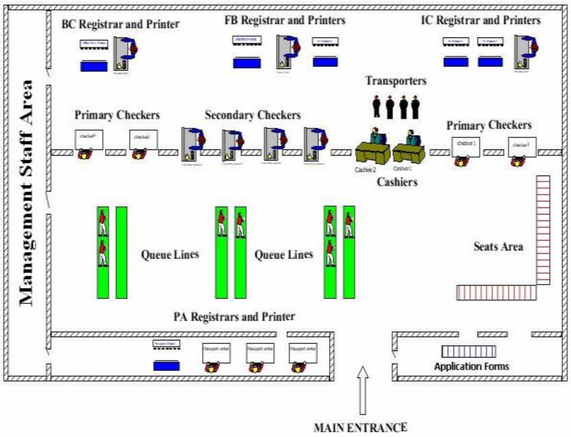

Figure 2. Floor layout of the actual CAP department

Customers who seek any of the four documents usually receive assistance from special preparers to complete the right application form outside the CAP department. Once the customer is in the department, several sequential steps must be taken to obtain the sought document, as shown in Figure 3. Firstly, the customer waits for one of the four primary checking staff to become available to get his application form checked for correctness and completeness and then stamped. If the application form was lacking correctness or completeness, the customer is asked to make the required changes and wait in line (or queue) again. Once the primary checking is complete, the customer turns to the secondary checking staff whom responsible for verification of the entered data through comparison with the supporting documents. The customer waits until one of the four secondary checking staff is available then gets the form verified and thus stamped. Then, the customer pays the fees required to issue the document at either of the two cashiers, whoever is available. The fee rates for the PA, IC, FB and BC documents are 20 JD, 2 JD, 2 JD and 1 JD, respectively.

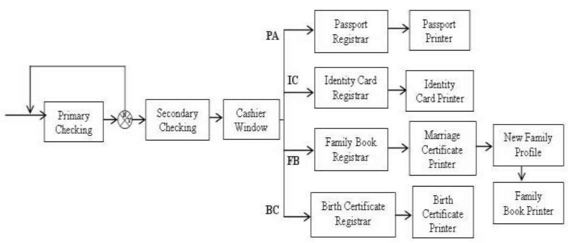

Figure 3. Schematic diagram for obtaining documents from CAP department

Up to this point, customers seeking one of the four documents go through the same steps of primary checking, secondary checking and paying fees at the cashiers. After paying the fees, the application forms are transferred by the four staff (transporters) responsible for delivering these forms to each of the four registrars, based on the type of the document required. As the passport registrars (three of them exist), identity card registrar, family book registrar and birth certificate registrar receive the application forms; they process these forms by entering the data into the computer and do the required editing. Finally, the PA, IC, FB and BC documents are printed and provided to the customer. However, in the case of the FB documents the family book registrar prompts printing a copy of the marriage certificate on a separate printer. The marriage certificate is then attached to create a new family record and the FB document is finally printed. One printer is available per each type of document except for the IC documents which have two printers.

3.1. Data Collection and Analysis

To simulate the operation of the CAP department, it is required to collect data to describe the arrival rates of the different customers at the department, the delay times at each stage within the department, and the times of transferring the application forms between the cashier and the four registrars through the transporters. Data were collected experimentally through observation of the various activities during the work hours of the CAP department. Data collected were then imported into Arena Input Analyzer to fit the probability distributions that will be used in the model in conjunction with random number generators (RNG) to simulate the stochastic operation of the CAP department. The results of data collection and analysis for the arrival rates of the customers at the CAP department and the delay times at each stage within the department are summarized in Table 1.

The transfer time of the application forms between the cashier and the four registrars was estimated based on the distances between the cashier and the registrars and the average transporter speed. The distances between the cashier and the PA, IC, FB and BC registrars were 20 m, 3 m, 6 m and 8 m, respectively. The average speed of the transporters is approximately 60 m/min. Therefore, the transfer time can be calculated as the distance to be traveled divided by the average transporter speed.

Table 1. Arrival rates and delay times at the CAP department

	Time (minute)	
Activity	Distribution	Parameters
PA arrival rate	Exponential	5.5
IC arrival rate	Exponential	13
FB arrival rate	Exponential	4.5
BC arrival rate	Exponential	8.5
PA primary checking	Triangular	(3,6,9)
IC primary checking	Triangular	(3,5,7)
FB primary checking	Triangular	(2,4,6)
BC primary checking	Uniform	(2,4)
PA secondary checking	Triangular	(4,6,10)
IC secondary checking	Triangular	(4,6,10)
FB secondary checking	Triangular	(4,6,10)
BC secondary checking	Triangular	(4,6,10)
PA fee payment	Uniform	(1,3)
IC fee payment	Uniform	(1,3)
FB fee payment	Uniform	(1,3)
BC fee payment	Uniform	(0.5,3)
PA data registering	Triangular	(15,18,25)
IC data registering	Uniform	(1,2)
FB data registering	Uniform	(4,6)
BC data registering	Triangular	(1,2,3)
Family profile registering	Triangular	(4,6,8)
PA printing	Triangular	(2,4,8)
IC printing	Triangular	(12,15,20)
FB printing	Uniform	(2,8)
BC printing	Triangular	(2,3,4)
Marriage cert. printing	Uniform	(2,8)

3.2. System Modeling

The system was modeled using Arena with various modules that represent the different aspects of the CAP department, as shown in Figure 4. For example, customer arrival rates were modeled using CREATE and STATION modules which carry the information about the arrival probability distributions, given in Table 1. Primary checkers, secondary checkers, cashiers and registrars were represented using STATION and PROCESS modules which provide the delay time distribution information to the modeler. The four staff responsible for transferring the application forms from the cashiers to the registrars were modeled using LEAVE and ENTER modules supplemented by the destination distances and the number of transporters available and the average speed. Other types of modules were also required in the model to fully describe the behavior of the system such as DECIDE and ROUTE modules.

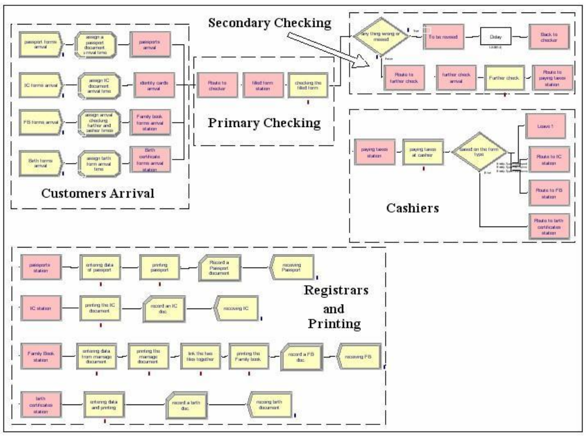

Figure 4. Arena Model structure of the CAP department

4. Simulation Results

4.1. Current System

Simulation of the current CAP department (shown in Figure 4) is useful for the validation of the developed system model and for evaluating the usefulness of any changes to be made to the current system. Due to the probabilistic nature of discrete-event simulation, the model was run 35 times, where each run represents one business day. Thus, all the simulation results presented in this study are based on the average of 35 runs. Unlike other systems characterized by continuous operation, the business day in the CAP department consists of a single shift starting from 8:00 AM and ending at 3:00 PM. Thus, the type of simulation used for this case is a terminating simulation.

Results of the model simulation for the present CAP department are presented for four selected key performance indices (KPIs), as shown in Table 2. A fifth KPI, which is the total daily revenue, is calculated by multiplying the number of processed documents by the fee per document for all document types and taking the total sum which gave 1,348 JD/day. Some of the results listed in Table 2 were compared to experimental data in terms of the total number of application forms processed and total time spent in the system. The simulation results were found in good agreement with the experimental data. Also, it can be seen in Table 2 that there are relatively significant amounts of incompletely processed application forms (Work-In-Process) remaining in the system at the end of the business day especially for passports. Also, it can be seen that a significant amount of the total system time that is required to issue a document (row 4) is due to non-productive waiting time (row 3). These two observations suggest a relatively poor performance for the present CAP department which requires some changes to be made to improve the system.

Table 2. Simulation results in terms of KPIs for the current CAP department

KPI	PA	IC	FB	BC
Work-In-Process	15.4	5	4.4	5.7
Number processed	57	42	28	68
Waiting time (min)	39.1	15	27.4	16
System time (min)	81.3	41.9	54.9	30

4.2. Optimized System

A group of changes in the current system are proposed by specifying a set of design variables that are iteratively varied until a feasible solution with the best system performance is achieved. Besides, a fixed change in the floor layout of the CAP department is proposed by relocating the PA registrars and printers to a new location which is closer to the cashiers. The design variables considered were in terms of the number of registrars, printers and cashiers, as shown in Table 3. This table also shows constraints on the lower and upper bound for each design variable within which the search algorithm attempts to find an optimal solution. These design constraints can be useful in increasing the efficiency of the search for optimal solutions.

Table 3. Defined design variables for optimization of CAP department

Design Variable	Lower Bound	Upper Bound
PA registrars	2	5
PA printers	1	3
BC registrars	1	3
BC printers	1	3
IC printers	1	5
FB registrars	1	3
Cashiers	1	3

In addition to the design constraints, another set of constraints was imposed on the waiting times of the four types of application forms, as shown in Table 4. These constraints are sometimes called response constraints because the waiting times are response variables in this case. Defining these response constraints is useful in ensuring customer satisfaction through less waiting times at the levels specified in Table 4.

Table 4. Bound constraints defined on the various waiting times

Response Variable	Constraint (min)
PA waiting time	< 10
IC waiting time	< 6
FB waiting time	< 6
BC waiting time	< 5

Improving the performance of the present CAP department requires also that an objective be defined as a measure of performance. This objective was defined as the maximum total daily revenue for the CAP department. This variable is considered as the most important KPI since it depends on all other KPIs. For example, the total daily revenue is directly proportional to the number of processed application forms per day, which is also influenced by the waiting time of each application form in the system. Waiting time itself contributes to the total time that an application form spends in the system.

Given the objective, design constraints and response constraints, OptQuest within ARENA was used to implement the optimization approach proposed in this study. This was done by firstly using the design variable values in the present system as an initial solution. The feasibility of this solution is determined by checking if the design constraints are satisfied, otherwise a new set of design variable values that satisfy the design constraints is searched at a given step size. After selecting appropriate values for the design variables, OptQuest must invoke Arena to run a simulation and determine whether or not the current trial solution is feasible with respect to the response constraints, otherwise a new solution that satisfies both the design and response constraints is searched. If a feasible solution is found, a new solution that yields better system performance results is sought. This process continues until all the design variable possibilities are exhausted or a predetermined time limit is reached. Ultimately, the best solution was reached when the values for the design variables listed in Table 3 were set at 5, 3, 3, 2, 4, 1 and 3.

Results of the model simulation for the optimized system given the new design variable values are presented for the four KPIs, as shown in Table 5. Comparing these results with the results of the current system listed previously in Table 2, the percentage improvement in each KPI value can be calculated for each type of document issued by the CAP department. A summary of these calculated percentages are listed in Table 6.

Table 5. Simulation results in terms of KPIs for the current CAP department

KPI	PA	IC	FB	BC
Work-In-Process	15.4	5	4.4	5.7
Number processed	57	42	29	68
Waiting time (min)	39.1	15	27.4	16
System time (min)	81.3	41.9	54.9	30

Table 6. Percentage improvement in KPI values for the optimized CAP department compared to the current department

KPI	PA	IC	FB	BC	Average
Work-In-Process	50.0%	34.0%	52.3%	50.9%	46.8%
Number processed	22.8%	4.8%	3.6%	1.5%	8.2%
Waiting time	90.0%	90.7%	96.0%	90.0%	91.7%
System time	49.4%	32.2%	48.1%	48.3%	44.5%

It can be seen from Table 6 that performance of the optimized CAP department has improved in all respects relative to the current CAP department. Work-in-process was reduced by 46.8% on average leading to an average increase by 8.2% in number of processed documents by CAP department. Waiting time and system time were significantly reduced by 91.7% and 44.5% on average, respectively. The total daily revenue for the optimized CAP department was also calculated as 1,614 JD/day. This translates to a 19.7% increase in total daily revenue compared to the current system.

Although the performance of the optimized system for the CAP department is expected to improve compared to the current system, this requires a new investment by inquiring five printers and hiring six more employees. The initial cost of the five printers can be considered negligible over a long period of time. Also, the average daily wage per CAP department employee in Jordan is about 10 JD, which totals 60 JD per day. Therefore, the proposed system can still be profitable compared to the current system since its estimated total daily revenue is higher by 266 JD than that of the current system.

5. Conclusions

This paper has presented an approach for enhancing the performance of public departments such as the citizen affairs and passports department in Jordan. The CAP department system was represented by a DES model developed with the aid of ARENA software and supplemented with the gathered and fitted experimental data. OptQuest of ARENA was used to implement the optimization for the selected design variables to improve performance of the current system in terms of the defined KPIs. The optimization process included defining a suitable objective function, i.e. maximum daily revenue, and imposing linear constraints on the design variables (the number of registrars, cashiers and printers) and response variables (the four waiting times).

Results of model simulation and optimization showed that performance of the optimized CAP department was better overall compared to the current department. Waiting time was reduced the most by 91.7% on average, while number of processed documents was increased by 8.2%. Consequently, the total daily revenue for the optimized CAP department was increased by 19.7%.

References

[1] Q. Wang, C.R. Chatwin, "Key issues and developments in modelling and simulation-based methodologies for manufacturing systems analysis, design and performance evaluation". International Journal of Advanced Manufacturing Technology, Vol. 25, No. 1, 2005, 1254-1265.

[2] Y. Hani, L. Amodeo, F. Yalaoui, H. Chen, "Simulation based optimization of a train maintenance facility". Journal of Intelligent Manufacturing, Vol. 19, No. 1, 2008, 293-300.

[3] Law A., Kelton D. Simulation Modeling and Analysis. 3rd edition. McGraw-Hill, Inc, Lewis, PA, USA, 2000.

[4] T. Yang, P. Chou, "Solving a multi response simulation-optimization problem with discrete variables using a multiple-attribute decision-making method". Mathematics and Computers in Simulation, Vol. 68, No. 1, 9-21.

[5] R. Al-Aomar, "A methodology for determining system and process-level manufacturing performance metrics". SAE Transactions - Journal of Materials and Manufacturing, Vol. 111, No. 5, 2002, 1043-1050.

[6] R. Marasini, N. Dawood, "Simulation modeling and optimization of stockyard layouts for precast concrete products". Proceedings of the 2002 Winter Simulation Conference, 2002, 1731-1736.

[7] C. Ying, L. Derong, "An orthogonal array optimization for the economic dispatch with nonsmooth cost functions". Proceedings of the 44th IEEE Conference on Decision and Control - European Control Conference, 2005, 1264-1269.

[8] S.G. Lee, L.P. Khoo, "Optimising an assembly line through simulation augmented by genetic algorithms". International Journal of Advanced Manufacturing Technology, Vol. 16, No. 1, 2000, 220-228.

[9] J. Bachut, P. Smith, "Tabu search optimization of externally pressurized barrels and domes". Engineering Optimization, Vol. 39, No. 8, 2007, 899-918.

[10] V.P. Eswaramurthy, A. Tamilarasi, "Tabu search strategies for solving job shop scheduling problems". Journal of Advanced Manufacturing Systems, Vol. 6, No. 1, 2007, 59-75.

[11] M. Ercsey-Ravasz, T. Roska, Z. Néda, "Cellular neural networks for NP-hard optimization". Eurasip Journal on Advances in Signal Processing, 2009, doi:10.1155/2009/646975.

[12] F. Azadivar, "Simulation-optimization methodologies". Proceedings of the 1999 Winter Simulation Conference, 1999, 93-100.

[13] J. Swisher, P. Hyden, S. Jacobson, L. Schruben, "A survey of simulation optimization techniques and procedures". Proceedings of the 2000 Winter Simulation Conference, 2000, 119-128.

[14] O. Bataineh, H. Abdulla, A. Abu-Saif, "Development and application of a metaheuristic optimization procedure integrated with simulation for a bus transit system". IEEE International Conference on Industrial Engineering and Engineering Management, Singapore, 2008, 1749-1753.