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Healthcare system simulation using Witness

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Abstract: Simulation techniques have a proven track record in manufacturing industry as well as other areas such as healthcare system improvement. In this study, simulation model of a health center in Malaysia is developed through the application of WITNESS simulation software which has shown its flexibility and capability in manufacturing industry. Modelling procedure is started through process mapping and data collection and continued with model development, verification, validation and experimentation. At the end, final results and possible future improvements are demonstrated.

1. Introduction

Over time, simulation tools and techniques are applied in problem detection and process improvement of many manufacturing and service systems. Popularity and flexibility of the simulation programs enable organizations to monitor the whole aspect of their systems and plan for business development prior to facing the real behavior of their industry or service [1].

Among various service organizations, healthcare industry has a fundamental and significant role in upgrading lifestyle standards. In this regard, usage of different tools and methods to enhance the capability of healthcare service providers to keep up with the growing changes of their industry is being increased. However, the process of migrating to the new or improved environment or methodology is not easily acceptable by healthcare staff and managers. Simulation allows for various types of assessments and examinations to be done. It does not burden managers with large amounts of money and it reduces any possible risk and danger in the healthcare performance [2]. Thus, this paper aims to assess the benefits and drawbacks of the current healthcare system of a health center in Malaysia and suggest recommendations to enhance the healthcare level in the supposed case study.

In the rest of this paper, a review of the current literature and WITNESS simulation software is presented. Then the case study is introduced and the simulation process is demonstrated. Next, model verification and validation is mentioned. After that, model experimentation and results are depicted as well as final conclusions.

1.1. Computer simulation of healthcare industry

Although simulation modelling has been widely used in manufacturing and logistics during the past four decades, healthcare is an issue that has not benefitted from the advancements and capabilities of simulation modelling [3, 4]. According to [5], application of simulation techniques in healthcare has noticeably increased after 2000 while before that only a handful of studies were conducted in this area. In this regard, application of simulation techniques in healthcare can be categorized into several areas including decision making for medical, administrative and operational issues [6], investigating control

programs, monitoring medical progress, forecasting future incidences, designing health care systems [7], improving the factors which affect the patients' flow such as waiting time, stay length, patient throughput and clinical overtime and allocating resources [8]. As an example, [9] applied lean manufacturing concepts through simulation techniques in healthcare and demonstrated its tangible results such as decreasing costs, errors and waiting time of patients. In addition, [10] presented some intangible results, for instance, increasing the customer and employee satisfaction as well as staff motivation. Assessing the impact of several scenarios, [11] reengineered a healthcare system using simulation techniques. [12] and [13] applied mathematical programming for scheduling of doctors of an emergency room and healthcare resource allocation of a health center respectively. [14] developed a simulation approach using multi-objective optimization for treatment of cancer in a health center. By combining design of experiments and simulation, [15] estimated the capacity of an emergency room. [16] merged discrete-event simulation and lean manufacturing concepts to develop a new approach for improving healthcare systems and depicted the impact of their approach through three examples.

1.2. Overview of WITNESS simulation software

In this paper, WITNESS simulation software is applied because of its strengths and flexible features as one of the powerful and popular Visual Interactive Simulation Modeling (VISM) systems [17] for discrete-event simulation. WITNESS is capable of designing complex processes of manufacturing enterprises and service industries through quick and accurate modeling and detailed mathematical support as well as comprehensive assessment and evaluation reports [18].

The modeling procedure in WITNESS is started using different basic entities called elements and after defining appropriate specifications, it is continued with relating the elements through using graphical and coded connectors. In addition, each element can be programmed using built-in codes.

2. Case study: a health center in Malaysia

A health center in the Johor Bahru city of Malaysia is considered. This medical center provides health services including medication, laboratory, dental services etc from 8:00 A.M to 10:00 P.M (regular time) and also during emergency time (from 10:00 P.M to 8:00 A.M). The scope of this case study includes the queuing systems associated with the treatment services (only Medical services) and supportive services (Pharmacy and Laboratory) which are provided by four doctors in regular time.

2.1. Process mapping and data collection

In the first step, the conceptual model of the case study, as one of the initial steps in a simulation process, is used to deeply understand the actual workflow of the system and determine how to design the simulation model (Figure 1). There are three counters in the arrival area of the health center that put the patients into a queue for scanning their barcode number and waiting for visiting doctors. Here, as patients go to the shortest queue behind the three counters, when they arrive in the health center, a decision-making entity has been defined before the counters' queues. In addition, based on the statistical study of patients, almost 13 % of them are advised to go to the laboratory. Thus, another decision-making entity is defined after seeing the doctors in order to separate patients which must go to the laboratory from the rest. Finally, all patients go to the pharmacy to receive their medicines.

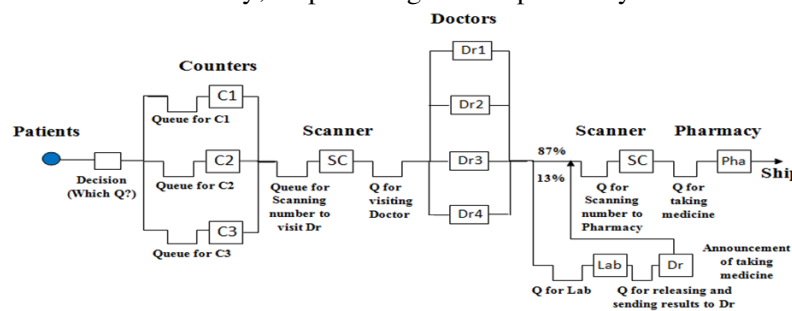


Figure 1. Conceptual model of the health center

Using the stop watch method, required data on cycle times, inter arrival times, setup times, waiting times, break down times, queue capacities and number of servers are collected from around 500

samples (Patients). For analyzing data, Easy Fit software is applied to estimate which distribution is best fitted to the collected data. In this software, the goodness of fit which is ranked by the Anderson Darling test is considered and among the results, the first distribution which exists in Witness software is accounted as the distribution of the data. As an example, the distribution function of the counters' service time is estimated as a Lognormal distribution with $\mu = 0.3$ minute and $\sigma = 0.05$ minute.

2.2. Model development

Based on the conceptual model, collected data, distribution functions of simulation parameters and actual behavior of the system, the simulation model of the health center is built using WITNESS simulation software. Figure 2 shows the simulation model of the health center.

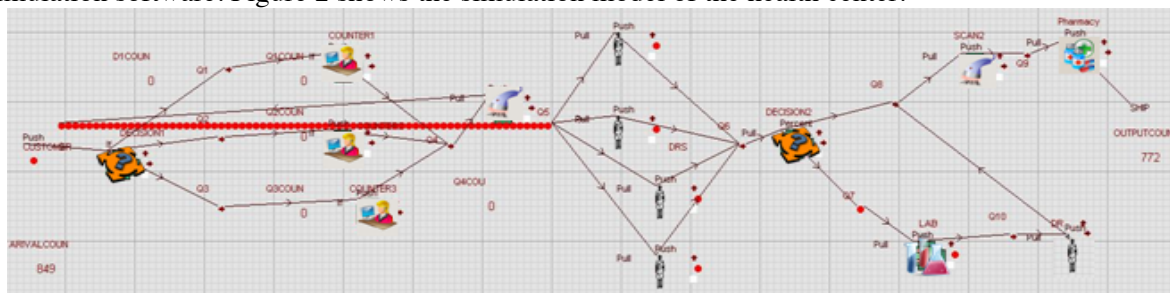


Figure 2. Simulation Model for the Health Center

2.3. Verification and validation of the model

To be confident whether a simulation model and its results are “correct” or not, model verification and validation methods must be applied. Referring to [19], the process of ensuring that the coding and logic of a computerized model and its execution are correct is named model verification; however, model validation is belonged to the concept of ensuring the consistency of the processes and results of the simulation model with the actual behavior of the real system. Using Witness simulation software, the next two parts present model verification and validation of the case study.

2.3.1. *Model verification.* In general, verification must be performed to ensure about the accuracy of the programmed model, its specifications and algorithms, and also its implementation. There are several ways to verify a simulation model such as incremental model building, expert evaluation, internal evaluation, consistency test and so on. In this study incremental model building is applied to verify the simulated model.

In the incremental model building method, the model should be built in small sizes and checked whether it is rightly and logically coded or not. Then it should be expanded to the final model. In this study, four steps are used to demonstrate the process of verification through the incremental model building method. First, the model is built from arrival of patients to taking numbers from counters and then checked whether the number of entered patients (e.g. 262) and output of the three counters (e.g. 262) are equal or not (Figure 3). After verifying the first step, the model is simulated from patients' arrival to visiting doctors (Figure 4). Here, 274 patients have arrived in which 254 of them have been visited by doctors, 4 of them are being visited and 16 of them are waiting for visiting doctors. The third step is building the model up to the stage of taking medicine without considering patients that should go to the laboratory (Figure 5). In the last step, the complete model is built.

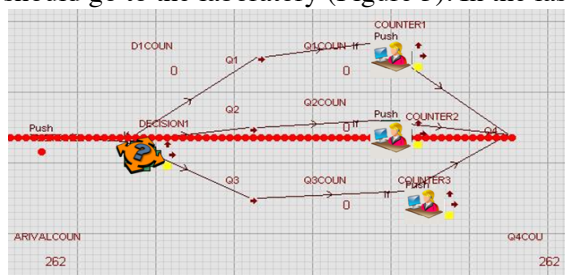


Figure 3. First Step of Verification

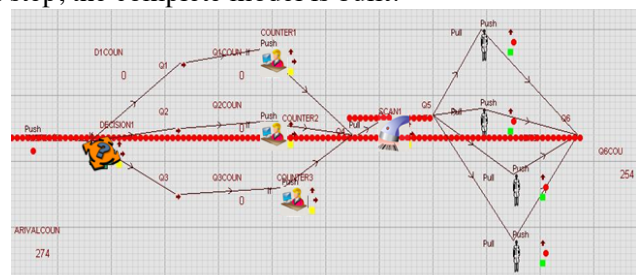


Figure 4. Second Step of Verification

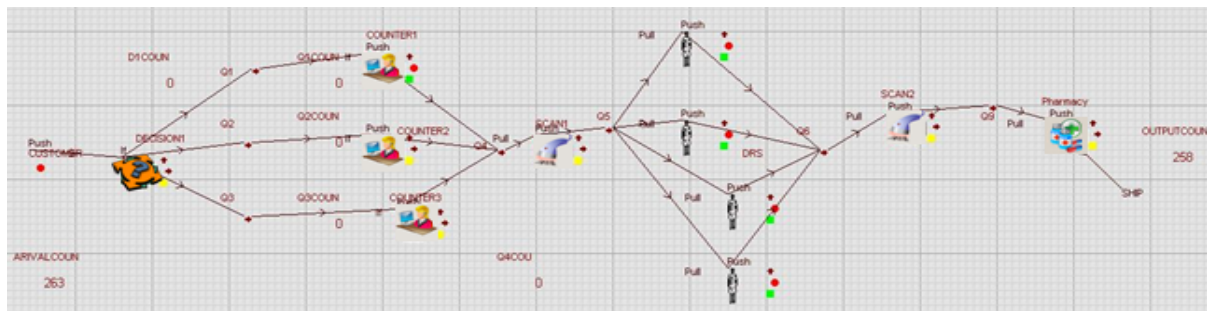


Figure 5. Third Step for Verification of the simulation model

In addition to the incremental model building method, most of the transactions of the simulated model are tested to check whether they are the same with what we have expected or not. For instance, the results of one random run of the model are depicted in Table 1 to demonstrate that the busy time of the pharmacy is 35.11 % when serving 257 patients in 14 hours (840 minutes). On the other hand, the mean value of the distribution function of the pharmacy service time is 1.13 minutes, and the busy time of the pharmacy is 294.92 minutes (840* 0.3511) which brings the expectation of serving almost 261 patients into account (294.92/1.13). Comparison of the results of the simulation model (257) and statistical calculation (261) depicts very little difference (around 1.5 %) which shows the strength of the model in terms of verification.

Table 1. Verification data of the simulated model

| Parameter | Pharmacy |
|----------------------|----------|
| Idle Time (%) | 64.89% |
| Busy Time (%) | 35.11% |
| Number of Operations | 257 |

2.3.2. Model Validation. The crucial role of model validation can be stated as making the model development team confident about the adoption of the simulated model to the actual situation of the system and its problems in a sensible manner. According to [19] there are four main approaches for model validation. The first approach is making the decision by simulation team members. The second approach is checking the model by different tests and evaluations during the simulation model building process to reach a subjective decision. The third approach which is frequently called “independent verification and validation” (IV&V), validates the model by applying the decision of a third party team. Using a scoring model can be mentioned as the fourth approach.

In this study, the process of checking whether or not the model represents the actual situation of the health center is made by comparing the average number of patients served by the health center during a 14 hours working time and the average number of patients served through the simulation model during a run of 840 minutes. This length of the run is used because the simulation model is a terminating system. In the next step, we should determine the number of replications, which should be large enough to make us confident about the results. Since the distribution of the study’s population is not clear, we use the t distribution to determine the number of replications with a 95% confidence level. For estimating number of the replications, the formula presented by [20] $n_m = \left((s * t_{m-1, \frac{(1-\alpha)}{2}}) / (\bar{x} * k) \right)^2$, is applied where n =number of simulation runs to achieve the desired accuracy level, \bar{x} = the mean estimate of an initial m number of runs, s = the standard deviation estimate of m number of runs, α = confidence level, k =permissible percentage of error, and $t_{m-1, \frac{(1-\alpha)}{2}}$ = critical value of the two-tailed t-distribution at a level of significance, given m-1 degrees of freedom. Here, the model has been run for six times and the mean and standard deviation are calculated (Table 2). Using $t_{6-1, 0.025} = 2.571$ and $k = 0.05$, the number of replications should be 3 or above ($n = 2.26$). The final step is comparing the results of at least 3 replications with the actual

average number of patient arrivals which is 281 (Table 3). It is clear that the average number of patient arrivals using the simulation model (276) is very near to the actual one (281).

Table 2. Initial runs for estimating the number of replications

| Simulation runs | Patient arrivals |
|------------------------|------------------|
| 1 | 273 |
| 2 | 284 |
| 3 | 270 |
| 4 | 263 |
| 5 | 281 |
| 6 | 268 |
| Mean (\bar{x}) | 273.17 |
| Standard deviation (s) | 7.99 |

Table 3. Validation data of the simulation model

| Simulation | | Average Actual arrivals |
|------------------------|------------------|-------------------------|
| Replications | Patient arrivals | |
| 1 | 273 | 281 |
| 2 | 284 | |
| 3 | 270 | |
| Mean (\bar{x}) | 275.67 | |
| Standard deviation (s) | 7.37 | |

3. Model experimentation and results analysis

After completing the verification and validation of the model, the results of the model experimentation are obtained. In the service sector, one of the most important factors in performance measurement is the average time each customer is in the system. In this study, the average time each patient spends in the health center is around 44 minutes which is a long time. In addition, the average number of patients in the system is around 25 patients which is relatively large (Table 4). However, analysis of data in Table 4 shows that the average utilization of the system is more than 86 percent.

Table 5 depicts the percentage of working and inactiveness of the different entities of the simulation model. As shown, one counter is 100% idle and the other two are idle most of the time. The utilization of doctors in the system is an important factor. As we can see, all of the doctors are almost always busy (more than 98 %). However, Laboratory and Pharmacy are busy for around 65 % and 35% of the working hours.

Table 4. Simulation report of the verified and validated model

| Performance factor | Value | |
|---|--------------------|---------|
| Number of entered patients | 284 | |
| Number of shipped patients | 257 | |
| Number of patients in the system | 27 | |
| Average number of patients in the system | 25.06 | |
| Average time spent by each patient in the system (Minute) | 43.21 | |
| System Utilization | Mean | 86.74 % |
| | Standard Deviation | 13.64 % |

Table 5. Report of simulation results for various model entities

| Simulation Entity | Idle Time (%) | Busy Time (%) | Operations Number | |
|-------------------|---------------|---------------|-------------------|-----|
| Counters | 1 | 83.38 | 16.62 | 282 |
| | 2 | 99.87 | 0.13 | 2 |
| | 3 | 100 | 0 | 0 |
| Doctors | 1 | 0.84 | 99.16 | 64 |
| | 2 | 1.02 | 98.98 | 63 |
| | 3 | 1.85 | 98.15 | 65 |
| | 4 | 1.66 | 98.34 | 65 |
| Scanners | 1 | 96.74 | 3.26 | 284 |
| | 2 | 97.05 | 2.95 | 257 |
| Laboratory | 35.53 | 64.47 | 42 | |
| Pharmacy | 64.89 | 35.11 | 257 | |

4. Conclusions

In this study, the queuing system of a Malaysian health center is studied to determine the strengths and weaknesses of services offered to patients. According to the scope of study, it can be concluded from the simulation model that although the system utilization is more than 86%, the average time each patient spends in the system (around 44 minutes) and the average number of patients in the system (25 patients) are large amounts that reveal the inappropriate service level in the health center. One reason

is a long queue of patients waiting to get visited by doctors which often bothers patients. Here, adding one doctor, if possible, can be considered as an improvement to decrease the waiting time of patients in the whole queuing system. Furthermore, there are some amounts of idle time in the counter service which can be reduced by the deduction of one counter.

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