APPLYING PRODUCTION RELATED KNOWLEDGE WHEN ANALYZING HEALTHCARE PROBLEMS USING SIMULATION APPROACHES

Ass. Prof. Dr. Bojan Jovanoski, Prof. Dr. Robert Minovski, Prof. Dr. Delco Jovanoski, dipl, eng, Krste Nikoloski
Faculty of Mechanical Engineering, Ss. Cyril and Methodius University in Skopje, Macedonia
bojan.jovanoski@mf.edu.mk

Abstract: *The focus of this paper is the knowledge gained from the engineers when solving production related problems and how this can be utilized when solving issues in the healthcare. Based on this, a research has been made where engineers have conceptualized and developed a simulation model for one polyclinic using real data. The simulation model is a hybrid one using Discrete Event Simulation and Agent Based Modelling approaches. It is created applying the basic principles of the queuing theory that is unavoidable even in the simplest production systems. The model simulates the patient flow in the polyclinic. By using experiments and analysis, what is the ideal number of resources with whom the waiting time of the patient would be under a certain time limit is suggested. This research showed that the possibilities of the application of simulations in healthcare and the benefits of their use are endless.*

Keywords: simulation, model, healthcare, discrete event simulation, agent based modelling, hybrid model

1. Introduction

Interdisciplinarity is becoming a very usual thing these days. Already found solutions in one industry/field are being translated in completely different one – and this has proven to be working. In this way the already gained experience and knowledge is being further enriched and resources for new research are being reduced. The paper consists of overview of the healthcare industry, given through the eyes of the engineers, using their experience from the manufacturing industry.

Why the healthcare industry? The spending of one country for the healthcare has some really big numbers: OECD countries 8.9, USA 16,4%, Japan 10,2% etc. [OECD statistics 2013]. All have dramatically increased since 2000 by nearly 50% for each country, no exception. Meanwhile, the life expectancy for one population is not proportional with the expenditure in the health sector. Here, Switzerland, Spain and Japan top the list. Some call it “the largest industry in the world”. These are one of the reasons why this industry has drawn a lot of attention, especially from experts outside of it.

Employment opportunities for Industrial Engineers in Healthcare are enormous. Healthcare is the largest and fastest-growing industry in the United States. According to the U.S. Department of Labor, wage and salary employment in the healthcare industry is projected to increase twice as fast as all industries combined through 2016. Hospitals, healthcare consulting companies, medical device manufacturers, and healthcare information technology firms, etc. are looking to Industrial Engineers to help them get their share of this growth in a cost-effective, well-coordinated, patient oriented, and profitable fashion, (n.a., 2012).

2. Industrial Engineers in Healthcare Management

In the recent decades, the healthcare management has been seen as a very interesting field for the industrial engineers (IE). The Institute of Industrial Engineers <www.iienet.org> have classified Healthcare Management with the same importance as Lean & Six Sigma, Supply Chain Management, Ergonomics, Quality systems etc. Some universities have a special IE curriculum for Healthcare management, e.g. TU Eindhoven <www.tue.nl>, School of Industrial Engineering at Perdue University <engineering.purdue.edu/IE>; at UW-Madison College of Engineering more than a half of the professors in the department Industrial and Systems Engineering conduct some kind of healthcare research <www.engr.wisc.edu/ie>.

The interest for this research sparked when a presentation was found titled “Operations Research in Health Care or Who Let the Engineer Into the Hospital?” by Michael W. Carter from Mechanical and Industrial Engineering, University of Toronto. IE helps integrate people, equipment, facilities, and other resources to improve work results. An IE uses skills learned in IE (Process Design, Flowcharting, Layout Optimization, Forecasting Methodologies, etc.) and performs cost-saving & quality improvement projects, (Salvendy, 2001). When talking about engineers in healthcare, there are plenty of areas to be included, but generally the term “optimisation” should be the umbrella above all. Optimising the cost per visit or on annual level; maximising the quality of life, service.

According to (Linenberger, 2015), facilities that have incorporated management engineering in their pre-design and design stages enjoy substantially lower operational costs across the board, particularly in personnel, equipment and supply utilization. Process engineering techniques are becoming increasingly popular in the conceptualization, pre-design and design of new hospitals across the USA. Some hospital facilities use multiple methods and employ management engineers on staff to support implementation, while others are using a hybrid approach. “Engineering methodologies… such as Lean and Six Sigma… have radically improved manufacturing in the last few decades; there is no comparison to what manufacturing was like before they were developed. As our economy spends more money on healthcare, both in absolute terms and relative terms, it is becoming extremely important to streamline our health systems and delivery utilizing these methods,” - Hari Srihari, PhD., Chairman of Systems Science and Industrial Engineering, State University of New York at Binghamton.

Healthcare engineers are engaged in knowledge and hypothesis generation, predictive modelling, decision sciences, robust device design, and optimization – all of which should be very familiar to the Industrial Engineering. In addition, Healthcare engineers develop computational algorithms to implement the tools and calibrate them to healthcare data. This multidisciplinary field integrates knowledge from a variety of different areas, such as computer science, communication, public policy, management and all aspects of industrial engineering.

Apart from the positive sides of why an IE fellow should engage him/herself in healthcare management, there is also a study whit astonishing results, (Schuster, McGlynn, & Brook, 1998). The survey indicates that 30% from the patients with acute illness and 20% from the patients with chronic illness received contraindicated treatments. Inadequate levels of safety and inconsistent quality result from clinical uncertainty which in turn results from an increasingly complex healthcare environment, rapidly exploding medical knowledge, lack of valid clinical knowledge (poor evidence) or over reliance on subjective judgment.

Some of the projects that are stated and can be useful for the healthcare, but run by industrial engineers are Emergency Department Simulation, Patient Centered Care, Queueing model for CBS blood inventory, Clinical Managers workload measurement, OR scheduling & peri-operative simulation, Fracture clinic scheduling, Diagnostic imaging scheduling, HIV/AIDS funding allocation in Africa, Bed allocation, Ambulance drop-off delays, Surgical equipment processing, etc.

Simulation modeling offers significant advantages in that making the model, and analyzing the problem with the aim of better understanding it, does not rely on the initial collection of data. As such, it offers considerable benefits for those involved in the decision-making process. Expert opinion is used to first establish the relationships which, in this study, concern the treatment and side effects and recurrences after treatment. Analysis can then be used to better understand what data does, in fact, need to be collected at a later stage. It also allows analysis and exploration of different decisions, and the impact of these decisions on future action. Simulation allows for discussions of 'better' solutions to the given probabilities, taking into account the previous history and or facts. It allows for identification of the key variables early in the process, and as such is a powerful tool to aid decision making. The wide range of durations of health states suggests that a discrete event simulation approach is an appropriate choice. Similarly, the fact that health state changes on the basis of patient history means that a modeling technique that can represent this is desirable. Again, discrete event simulation modeling appears to satisfy this requirement. Another factor in the choice of discrete event simulation modeling to support economic evaluation is the sophistication of software that exists to implement and experiment with such models.

Discrete event simulation is one of the most widely used operations research method in healthcare and its usage has increased over the years indicated by literature survey articles by Jun (1999), Gunal (2010) each citing more than 100 articles that use discrete event simulation modeling in healthcare. Roberts (2011) recognizes that in healthcare it is often difficult to define a single performance characteristic. Especially in healthcare further investigation is often needed to understand how a change in the process leads to downstream impact. Hence simulation is considered an ideal technique to be used. Literature also indicates that most researchers find value in using discrete event simulation to validate process improvement or re-engineering efforts as well as to provide support for operational decision making in relatively confined environments such as outpatient clinics, call centers, pharmacy, ICU, and Emergency Departments. Most simulation modeling literature describes the process of conducting extensive scenario analysis to find an optimal balance between staff, capital and facilities/equipment (Mustafee 2010, Caberara 2011). However, there are several potential disadvantages of resorting to iterative analysis that is required by simulation. Law and McComas (2000) pointed out that one of the problems with simulation is that historically it wasn't considered an optimization technique. The inability of simulation to provide a single optimal solution, unlike other analytical modeling approaches, is not always appealing to customers or decision makers. The trial and error method is time consuming and decision makers particularly in healthcare; do often not appreciate tedious iterative review of output data. (Lowery 1996). In addition, Wilson (1981), Lane (2003), Brailsford (2009) point out the conundrum of implementing the simulation results in practice and highlight that model turnaround time and accuracy play a significant role in gaining customer buy–in, which suffers in the iterative approach. In order to take advantage of the benefits of computer simulation modeling while trying to avoid some of the tedious nature of choosing the best solution or policy using a set of candidate parameter settings(inputs) we explore the nature of simulation based optimization in healthcare problems. Simulation based optimization is an emerging filed that integrates optimization into simulation analysis. Although this technique has been applied in other industries (Law 2000, Jung 2004, Schwartz 2006), simulation still not very popular in healthcare. Recent examples of application of this method in healthcare include study of Sundaramoorthi (2010), where this technique was used to plan nurse resource allocation to patients based on workload needs. Ahmed (2009) used simulation based optimization to design a decision support tool to determine the optimal number of doctors and other staff to maximize the number of patients seen. Most recently, Zhang (2012) applied this integrated approach to determine the staffing requirements of a long term care facility. With the continually increasing ability of computers to run complex simulations in a reasonable time and the rise in optimization algorithms, along with the fact that most discrete event simulation vendor packages are now offering this capability built into their simulation tools; the ability to perform simulation optimization is becoming a more a viable method of analysis.

Brailsford (2007) defines three main types of models in healthcare: human body modelling, operational models and strategic, system level models. The model presented in this study involves primarily operations modelling, but consists of strategic modelling as well.

3. Research Model

Due to the type of the polyclinic, and the analysis made, the simulation model consists of five different sections: general practice, dental medicine, radiology, gynecology and laboratory. These were found to be of most importance for the general management. The methodology from (Banks, 1998) was utilized in order to create the model.

Figure 1 presents the patient flow for the general practice treatment. It encompasses activities such as entering the polyclinic, waiting, administrative procedures, walking, treatment, finalizing the appointment, etc. Much of these activities are parallel to a production process where a part (material) has to be taken from a storage, identified through the information system, pass through several operations, waits for a machine to be idle, be entered in a finished parts storage and be identified there, etc. Sub-models for the other four treatments were developed as well and combined in a final model. This one was laid over the general map of the polyclinic and the flow of the patients was modeled.

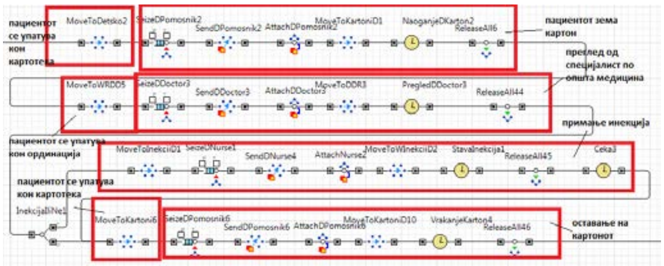

Fig. 1 *Model for the patients seeking general practice treatment*

The idea behind this model was to see the effectiveness of the polyclinic. What was measured? These three indicators where crucial for the outcome of the simulation project:

- Resources' utilization,
- The time the patient spends in the polyclinic and the
- Waiting time of the patient.

Through simulation modelling and experimentation, the goal was to develop different feasible scenarios, analyze them and choose the optimal set of parameters for the polyclinic. By parameters we mean number of doctors, number of assistants and number of offices.

It was decided that no patient should wait more than 3 minutes. In addition, for every treatment, a scenario of epidemics was modeled, increasing the patient number by 50%, thus giving the polyclinic a stress test. The later was modeled so that we can compare if the suggested parameters are suitable even in uncomfortable situations for the polyclinic. Figure 2 presents the result analysis for the general practice treatments. The upper part is for the normal conditions and the lower part when there is an epidemics. In both cases, the waiting time is much lower than the goal (58 s and 68 s, compared to 180 s). Parallel to that, the utilization of the doctors is around 80%, and for the nurses that assist them is around 85%. The same kind of analysis is performed for very treatment, with every change of the parameters (Table 1).

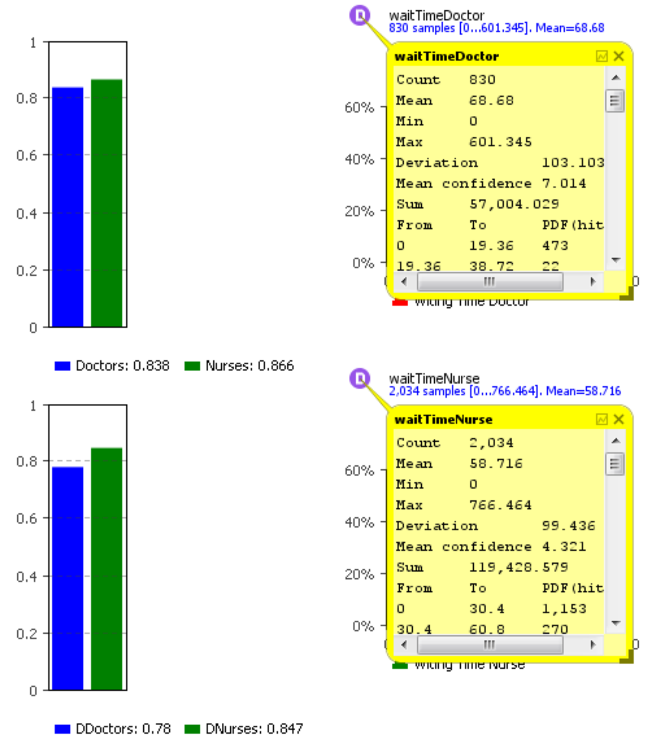

Fig. 2 Output data from a single simulation run for the general practice (normal conditions and with epidemics)

4. Results of discussion

Table 1 presents the results from the experiments and through it the discussion about the solution will be presented.

For the general practice treatments it was concluded that reducing the number of doctors from 13 to 12 will still leave the patients waiting under 3 minutes. Further reducing the number of doctors will generate results above the desired level. The patients going to the gynecologist will still have to wait longer because increasing the number of doctors and their assistants is not effective due to the fact that their current utilization percentage is only 33 %. That is why for these treatments it is suggested that there should be a scheduling mechanism implemented where each patients comes at a previously booked appointment. For the radiology department, it is suggested that the second assistant is not needed and even without him the defined goals will be met, without disturbing the utilization percentage too much. In the case of the laboratory and when there is epidemics, increasing the number of specialists will ensure stable work and waiting time for the patients that is still under the level of three minutes. For the patients asking for dental care treatment, who wait the most, adding another office with doctor and nurse does not solve the problem completely (460 s waiting time). In normal cases, another office should be added, but due to the limits in space in the polyclinic that is not possible and five is the maximum number of offices that can be allocated for the dental medicine. Here, like with the case of the gynecologists, scheduling the patients could solve the problem.

Table 1: *Detailed analysis of the performed experiments (the parameters of experimentation and the results).*

Experiment	Department	Epidemics	Number of			Utilization (%)		Mean waiting time for the patient [s]
			Spec.	Ass.	Office	Spec.	Ass.	
Normal conditions	GP (specialists)	no	13	13	13	54	/	22,5-
	GP (assistants)	no	13	13	13	/	58	14,3
	Dental medicine	no	4	4	4	69	69	814
	Radiology	no	1	2	1	39	6	36,8
	Gynecology	no	1	1	1	33	33	389,3
	Laboratory	no	2	4	1	66	42	35,2
GM with epidemics	GP (specialists)	yes	13	13	13	81	/	68,6
	GP (assistants)	yes	13	13	13	/	85	58,7
GP with 12 offices	GP (specialists)	yes	12	12	12	84	/	103
	GP (assistants)	yes	12	12	12	/	89	83,4
GP with 11 offices	GP (specialists)	yes	11	11	11	87	/	186,2
	GP (assistants)	yes	11	11	11	/	91	224,1
Radiology with 1 assistant	Radiology	yes	1	1	1	48	16	80,48
Laboratory with epidemics	Laboratory	yes	2	4	1	78	54	572
Laboratory with 3 spec.	Laboratory	yes	3	4	1	58	59	148,2
Dental medicine with 5 offices	Dental medicine	no	**5**	**5**	**5**	66	66	460

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5. Conclusion

This paper gives an overview of how to deal with healthcare problems, from an Industrial Engineer perspective. The knowledge gained in solving production related problems, can be utilized when solving problems in this industry. Although many tools and approaches were mentioned, the authors focus on simulation and its application in the healthcare management. At the end, a brief overview has been given of the pilot research project of this kind.

With the simulation project, the work of the polyclinic was analyzed through the utilization of the staff, waiting time of the patients and the time the patients spend in the polyclinic. Using the results from the experiments, a set of different scenarios were developed by changing different parameters and an optimal number of offices, doctors and assistants were suggested.

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