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A Mathematical Model to Evaluate and Improve Lean Management of Healthcare System: A Case Study of Health Examination Center

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Abstract. Healthcare system plays an important role in our daily life. A well operated healthcare system not only can save lives but also provide good work environment to medical staffs. However, most of the healthcare systems suffer from high workload of medical staff and low customer satisfaction. In addition, the stochastic nature of healthcare services is hard to evaluate the performance. Therefore, this study aims to implement lean management in the healthcare system with lean techniques and a stochastic model to achieve both customer satisfaction and waste reduction simultaneously. The first step is analysis of the current process and collect data to clarify the current status by quality management practices and lean tools. Further, a stochastic mathematical programming model is developed to optimize the performance of this healthcare system. Simulation results show that the efficiency of process flow after leveling is improved about 19.97%, idle ratio of work station is improved about 41.64% and 22.47% and the average flow time is improved about 4 minutes. A health examination center case is applied to demonstrate the benefit of the proposed method. This study might be the first study which implement lean and stochastic characteristics of healthcare system in a mathematical model. This model can serve as a decision support system and can be apply to other service system in lean improvement.

Keywords. Lean management, Mathematical programming model, Simulation, Healthcare

Introduction

Healthcare system plays an important role in our daily life since more and more people become paid attention to health management and regular inspection. Institute of Medicine (IOM) emphasizes that the organization has a good patient safety culture. It needs to focus on systems and processes, re-engineering the work environment, adjusting the system, simplifying unnecessary processes, and proactively avoiding possible harm or adverse events in process [1,2,3].

Lean management is adopted from Toyota Production System [4] and the development of lean management is as Figure 1 [5]. Lean thinking is composed of five principles which is value, value stream, flow, pull, and perfection [6]. Seven wastes are

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transportation, inventory, motion, waiting, overproduction, overprocessing and correction and some examples in healthcare on Table 1 [7]. Use it to find the wastes on the process in hospital and eliminate waste and then upgrade the efficiency and quality in process and provide patients the safety and satisfactory healthcare environment [8].

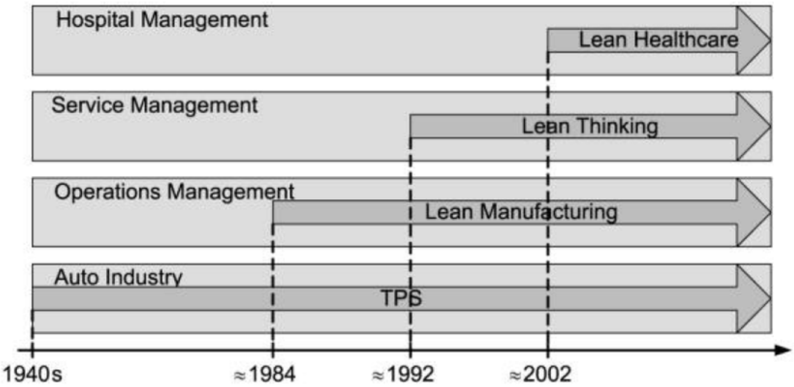

Figure 1. The development of lean management.

Table 1. Seven wastes and some examples in healthcare.

Wastes	Some examples in healthcare
transportation	• staff walking to the other end of a ward to pick up notes • central equipment stores for commonly used items instead of items located where they are used
inventory	• excess stock in storerooms that is not being used • patients waiting to be discharged • waiting lists
motion	• unnecessary staff movement looking for paperwork, eg drug sheets not put back in the correct place • storing syringes and needles at opposite ends of the room • not having basic equipment in every examination room
waiting	waiting for: – patients – theatre staff – results, prescriptions and medicines – doctors to discharge patients
overproduction	• requesting unnecessary tests from pathology • keeping investigation slots 'just in case'
overprocessing	• duplication of information • asking for patients' details several times • repeated clerking of patients
correction	• readmission because of failed discharge • adverse drug reactions • repeating tests because correct information was not provided

However, the high workload of medical staffs and low customer satisfaction become key issues in most healthcare systems. These issues lead us to implement lean management. In addition, a few healthcare systems can measure the performance of customer satisfaction after implementing lean management.

Therefore, the aim of this study is to implement lean management in the healthcare systems with lean techniques and create a stochastic mathematical programming model to achieve both customer satisfaction and waste reduction simultaneously. Furthermore, this model can serve as a decision support system and can be apply to other service system in lean improvement.

This study is organized as follows. Section 1 discusses lean management in healthcare systems and the stochastic programming model. We identify the problem and create a stochastic programming model (section 2). The case study and the simulation results is presented in Section 3 and the conclusion is discussed in Section 4.

1. Literature Review

Lean management is implemented in both manufacturing industry and service industry. We widely apply lean management to the healthcare systems in our daily life. Use value stream mapping to redesign patient flow to decrease waiting time and eliminate overcrowding [9]. Use Kaizen, standard work and single minute exchange of die to minimize waste, reduce turnover time, and decrease physician and patient waiting time [10]. Apply standard work, 5S, and visual management to reduce cycle time and eliminate waste [11]. Increase patient satisfaction and staff morale by implementing value stream mapping and 5S [12]. Improve patient flow and patient satisfaction by implementing value stream mapping and Kaizen [13]. Therefore, we apply lean techniques to improve both customer satisfaction and waste in the healthcare systems.

Optimization is to maximum utility or minimum lose on the conditions of limited resources. How to use the limited resources to maximum utility is an important issue in healthcare system. A model was formulated to simulate for scheduling on operating room [14]. A queuing model for ICU Griffiths was created and use simulation to solve [15]. A stochastic mathematical overbooking model was proposed to maximize the total expected profits in the healthcare systems by determining the optimal number of appointments to be scheduled [16]. A new stochastic general repair model was developed and it is better than the existing models because of giving faster, more accurate estimation results without relying on time-consuming Monte Carlo simulations [17]. A stochastic multilevel model was created and it can capture cost variations at different kinds of hospitals [18]. Thus, we can create a stochastic programming model in the healthcare systems to maximum customer satisfaction and use simulation to find the optimal or approximate optimal solution.

By literature review, both lean management and optimization can improve the customer satisfaction in the healthcare systems. In this study, we will implement lean management in the healthcare systems and use it to formulate a stochastic programming model to simulate and find the optimal solution, and then apply on Health Examination Center.

2. Methodology

In this section, we introduce the lean tools applied in the healthcare systems and a stochastic programming model.

Value stream mapping (VSM) is to describe the material and information flow in the process. It can help us know the operation is value-added or not in the healthcare systems. Different operations can separate into three types which are value-added, necessary waste and unnecessary waste. The target of drawing VSM is to eliminate unnecessary waste and reduce necessary waste. The following is the steps of implementing VSM. First, draw a current VSM and find the improvement points, and then propose the improvement actions and draw a future VSM for expected results.

Leveling is to eliminate, merge, simplify and rearrange the steps of the process and help the process more smooth. Use the equation (1) to determine cycle time and then do leveling.

$$\text{cycle time} = \frac{\text{working time}}{\text{service people}} \quad (1)$$

1. Problem definition

The goal is to maximize the efficiency of the process. In this section, we will introduce random variables and notations and build the corresponding stochastic programming model.

2. Define the random variables and notations (Table 2)

Table 2. Random variables and notations.

No.	Random variables and notations.	Definition
1	CT	Cycle time of the process
2	N	Number of the work stations
3	t_i, i = 1,2,…,9	Operation time which follows an unknown distribution
4	$X_{ij} = \begin{cases}1,\\0,\end{cases}$ i = 1,2,…,9 , j = 1,2,…,N	Operation i in work station j Otherwise
5	$Y_j = \begin{cases}1,\\0,\end{cases}$ j = 1,2,…,N	Work station j has operation Otherwise

3. Stochastic programming model

$$\max \frac{E_\xi(\sum_{i=1}^{k} t_i)}{N*CT} \quad (2)$$

Such that

$$\sum_{j=1}^{N} X_{ij} = 1 \text{ , i} = 1,2, \dots .\text{k} \quad (3)$$

$$E_\xi(\sum_{i=1}^{9} t_i \times X_{ij}) \leq CT \text{ , } j = 1,2, \dots , N \quad (4)$$

$$\text{N} = \sum_{j=1}^{N} Y_j \quad (5)$$

$$\sum_{j=1}^{N} j \times X_{ij} \geq \sum_{j=1}^{N} j \times X_{1j} \text{ , } i = 2,3, \dots , k \text{ , } j = 1,2, \dots , N \quad (6)$$

$$\sum_{j=1}^{N} j \times X_{8j} \geq \sum_{j=1}^{N} j \times X_{ij} \text{ , } i = 1,2, \dots , k-2, j = 1,2, \dots , N \quad (7)$$

$$\sum_{j=1}^{N} j \times X_{9j} \geq \sum_{j=1}^{N} j \times X_{ij} \text{ , } i = 1,3, \dots , k-1 \text{ , } j = 1,2, \dots , N \quad (8)$$

$$X_{ij} \text{ , } Y_j \in \{0,1\} \text{ , } i = 1,2, \dots , k \text{ , } j = 1,2, \dots , N \quad (9)$$

The equations (2) ~ (8) represent a stochastic programming model. Equation (2) is the objective function which maximizes the efficiency of the process. Equations (3) ~ (8) are the constraints. Equation (3) means that any operations can only in a work station. Equation (4) means that the operation time of any work station have to be less than the cycle time of the process. Equation (5) means the number of the work station. Equation (6) means that operation 1 is the first operation in the process. Equation (7) means that operation 8 is the 8th operation in the process. Equation (8) means that operation 9 is the last operation in the process. Equation (9) means that X_{ij}, Y_j are 0-1 variables when i equals to 1 to 9 and j is equal to 1 to N.

3. Case Study

The case is conducted in a health examination center. First, we construct a current VSM. Second, we analyze the problem which is that the customer's waiting time is too long. Third, we use the simulation to find a better solution to operations configuration. Finally, we apply the simulation result to future VSM and then implement the improvements. VSM of health examination center is as Figure 2. We only consider one of the health examination sets which is general.

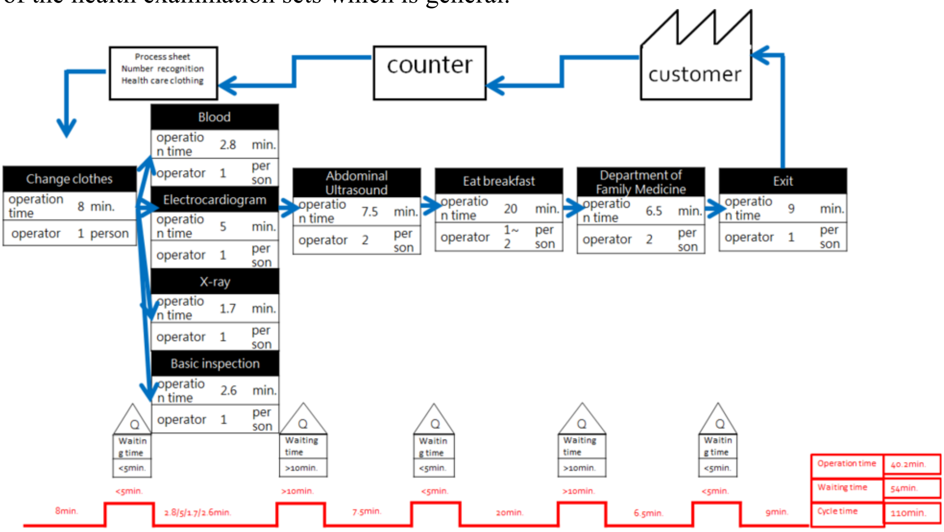

Figure 2. current VSM of health examination center.

After we observe several times in the health inspection center, we can find that the way that medical staffs manage the customers and the relative position of the clinics affect customer's waiting time. The analysis of the problem which is that the customer's waiting time is too long is as Figure 3.

After leveling, we combine Electrocardiogram and Blood to work station 2 and combine X-ray and Basic inspection to work station 3 and work station 1 is Change clothes, work station 4 is Abdominal Ultrasound, work station 5 is Department of Family Medicine and work station 6 is Exit. Then, we use ARENA to simulate the result of the process before and after leveling. The models are created as Figure 4 and Figure 5. The comparison between process flow before leveling and after leveling which contain process time is as Table 3.

We assume that three scenarios of customer arrival time follow exponential distributions which parameters are one person per 7, 8, 9 minutes (i.e. exp(7)). After simulating the model which are process flow before leveling and after leveling, we can summery the average three scenarios results of the efficiency of process flow, idle ratio of work station, throughput and the average flow time as Table 4 and show the difference as Figure 6 and Figure 7.

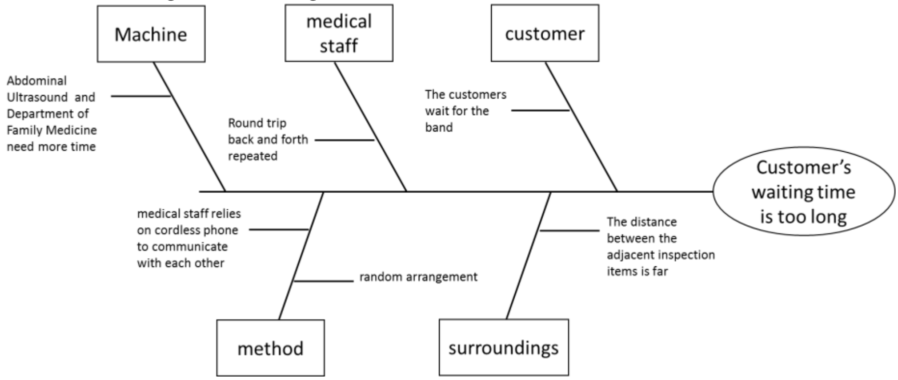

Figure 3. Fishbone diagram analysis of customer's waiting time

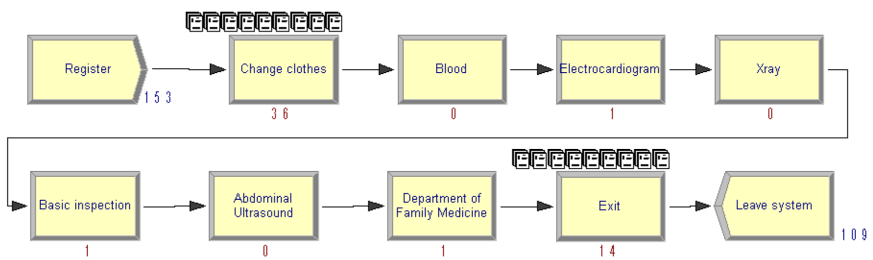

Figure 4. Process flow before levelling.

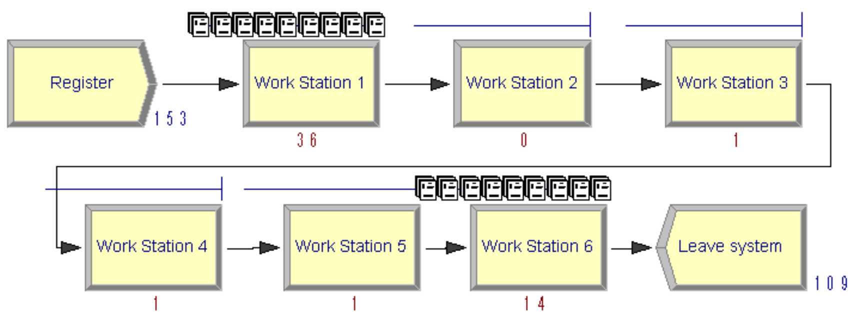

Figure 5. Process flow after levelling.

According to simulation results, the efficiency of process flow after leveling is improved about 19.97%, idle ratio of work station is improved about 41.64% and 22.47% and the average flow time is improved about 4 minutes. They imply that work efficiency is raised and maybe serve more people. But throughput is the same. The possible reason of that throughput is the same is enter parameter of simulation model is close to cycle time. Thus, we can know that leveling applied to the health examination center is better. The limitation is that use leveling results to do simulation. On the next stage, we will break this limitation.

Table 3. Comparison between before and after leveling.

Work station	Inspect item before leveling	Time(min.)	Inspect item after leveling	Time(min.)
1	Change clothes	8	Change clothes	8
2	Blood	2.8	Electrocardiogram Blood	7.8
3	Electrocardiogram	5	X-ray Basic inspection	4.3
4	X-ray	1.7	Abdominal Ultrasound	7.5
5	Basic inspection	2.6	Department of Family Medicine	6.5
6	Abdominal Ultrasound	7.5	Exit	9
7	Department of Family Medicine	6.5		
8	Exit	9		

Table 4. Results.

Item	Process flow before leveling	Process flow after leveling	Difference
the efficiency of process flow	59.86%	79.83%	19.97%
Idle ratio of work station	Electrocardiogram :46.53% Blood : 69.9%	work station 2 : 16.58%	-41.64%
	X-ray :81.82% Basic inspection : 71.38%	work station 3 : 54.13%	-22.47%
the average flow time	101.51 min.	97.51 min.	4 min.
throughput	122	122	0

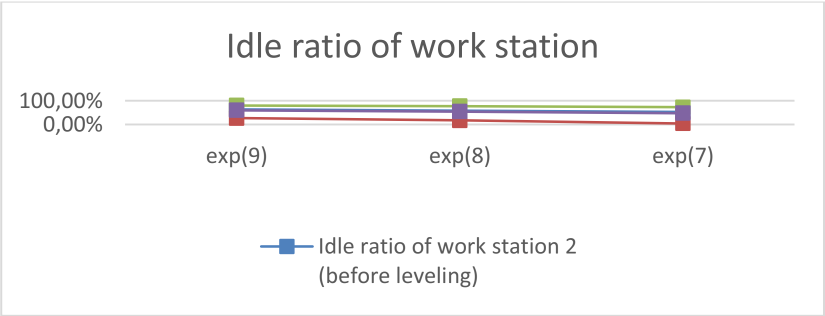

Figure 6. Comparison of idle ratio of work station.

4. Conclusions

We have formulated a stochastic programming model which can balance the process flow of health examination center and use simulation to solve it. From the result, we can know that the efficiency of process and customer's waiting time after leveling are better. Otherwise, this study might be the first study which implement lean and stochastic characteristics of healthcare system in a mathematical model. For future research, we add some variables and constraints to the stochastic programming model and solve it to find the approximate optimal solution to apply to the health examination center. Otherwise, we need to find a method to verify it is correct.

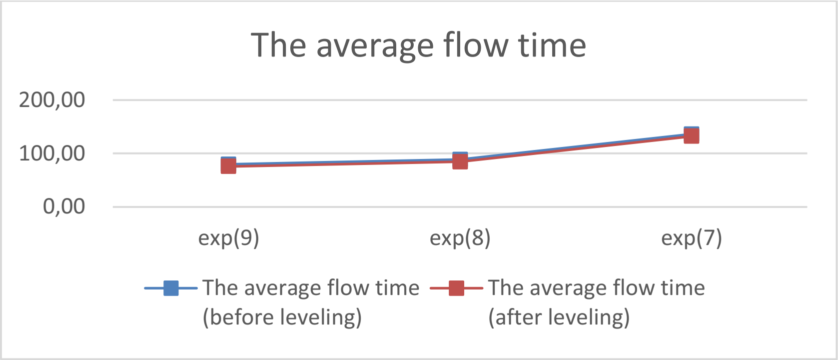

Figure 7. Comparison of the average flow time.

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