Development of Supplier and Staff Organization Model of Hospital Pharmacy

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Abstract

In present study process of supplier arrivals and admission of deliveries in the hospital pharmacy was investigated. The study involved recording the arrival times of suppliers and the processing times for receipt and admission of deliveries. Expected number of supplier arrivals was estimated and modeled by an appropriate probability distribution. Differences in processing times for admission of deliveries were examined and tested. Distinct deliveries were clustered together, the probability of their arrival was calculated along with their respective probability distributions of processing times. Created Monte Carlo simulation model indicated a possibility of improving observed pharmacy processes with existing staff by changing work methods and policies. It was concluded that by combining industrial engineering methods with statistical modeling and simulations, it is possible to make an assessment of the current state of the process in conditions where data and information are scarce, which forms the basis for any improvement.

Keywords: pharmacy, process optimization, industrial engineering, statistical modeling, Monte Carlo method

1. INTRODUCTION

Initiatives and process improvement projects in the healthcare sector have become a standard in a large number of developed countries [1, 2]. The need for such projects is even more pronounced when considering circumstances such as the global financial crisis [3] that are reflected in the need to reduce all forms of losses, but also in a consequential reduction of investments in additional resources such as employees and new technologies. This trend did not avoid the Republic of Croatia, which set its goals for the healthcare sector in the National Reform Program [4], focusing in particular on public health institutions.

In a complex system of a public hospital, a large number of processes and activities affects the overall performance of the system. While improvement activities related to main hospital processes have been noted, as shown in work of Končar and Gvozdanović [5], in Croatian hospitals impact of supporting processes on the quality of patient services is often underestimated. Processes of hospital pharmacy are a good example of this attitude. The importance of optimizing activities of pharmacy and their impact on key performance indicators of a hospital, are identified in various scientific papers [6, 7]. Conditions in Croatian hospitals, where the possibility of investing in additional resources is very limited, and the requirements for efficiency are growing, are making improvement of work methods imperative.

The focus of this research were processes of supplier arrivals and admission of deliveries in pharmacy, and ways to understand and improve them. In literature, it was possible to find different approaches to problems concerning pharmacy operations and processes, some based on simulations [8, 9, 10], other based on queue theory and analytical models [11, 12]. Besides of those, there is a body of work related to pharmacy process improvements using Lean management or industrial engineering methods [13, 14]. Most of the examined papers are focused on issuing of goods from the pharmacy, there is a scarcity of papers about the processing of deliveries or supplier arrivals in hospital pharmacies, and possibilities of integrating different approaches for improving those processes.

The goal of our research was an assessment of the current state of processes of supplier arrivals and admission of deliveries in hospital pharmacy in circumstances where there is a lack of data and information about the process. If it is possible to assess the state of the observed processes, then it is necessary to propose improvements that will remove overlapping of the process delivery admission with the process of issuing orders of various clinics, which should have the effect of reducing the number of errors, reducing employee overburden and improving patient services. We try to give an answer to this question by combining industrial engineering methods with statistical modeling and simulation.

2. RESEARCH SETTING

The pharmacy whose processes were subject to research is part of the largest Croatian hospital, with approximately million medical cases per year of which 72000 are inpatient cases. Future expansion of hospital capacity, alongside with goals of National Development Plan for clinical hospital centers [4] highlighted the need for improvement of hospital processes, including those of the pharmacy. A limited amount of investment didn't allow the purchase of new technological solutions or employment of additional staff in pharmacy. Instead, the focus was put on the improvement of current work methods.

This research was part of a comprehensive project of implementation of lean principles [15, 16] in the subject hospital that started at the end of 2015, and it was one of two activities whose scope was limited to the pharmacy. Only resources assigned to research included existing employees and external consultants. At the time of research, there were 33 employees of whom nine pharmacists. On the tasks of issuing and storing of medications, two pharmacists, and three technicians were employed at any time. The medical consumables warehouse was staffed with two pharmacists, three technicians, and three support employees at any time. [15]. Storing of deliveries and issuing of goods happened during the basic eight-hour shift (8:00-16:00), while operating on-call rest of the time. Pharmacy operates with three available positions in the reception area for supplier deliveries. Technological capacities of the pharmacy were at very low level, with a high level of manual work in daily routines and processes, with infrastructure initially not design for purposes of pharmacy operations.

3. METHODOLOGY

The methodology we were using in order to achieve our research goals consisted of three parts: 1. collection of data by carrying out time study, 2. analysis of data and statistical modeling and 3. development of simulation model. The motivation for this type of approach was the fact that there was no structured data concerning supplier arrivals and processing time necessary for admission of deliveries.

3.1. Time study

For this step of research, we developed time study form which included information such as date of delivery, the name of a supplier, type of goods delivered, time of arrival, and time of departure from reception area, as shown in table 1. In order for time study sample to be a good representation of monthly supplier arrivals and deliveries, we decided to collect data during five work days, and criterion was to select two days at the beginning of a month, two in the middle and one at the end of the month. Data was recorded in a time period from 8 AM to 2 PM, a decision that was based on our agreement with pharmacy employees, who claimed that deliveries after 2 PM are highly unlikely.

Table 1 – Time study form

#	Name of supplier	Type of goods delivered	Date of delivery	Time of arrival t_p [h:min]	Time of departure t_k [h:min]	Delivery processing time $t_{dob} = t_p - t_k$ [h:min]
1.	Supp1	Medications	Day1	11:00	11:04	0:04
2.	Supp1	Medications	Day2	10:49	10:51	0:02
3.	Supp2	Medical consum.	Day1	10:22	10:43	0:21
4.	Supp2	Medical consum.	Day2	10:07	10:09	0:02

Types of goods delivered were divided into three groups: medications, medical consumables, and mixed deliveries. We calculated delivery processing time as a difference between arrival time, which is a moment that supplier parked his vehicle in one of three available positions of the reception area, and the time he left the reception area. Activities necessary to process deliveries, that are included in processing time, are presented in the figure 1.

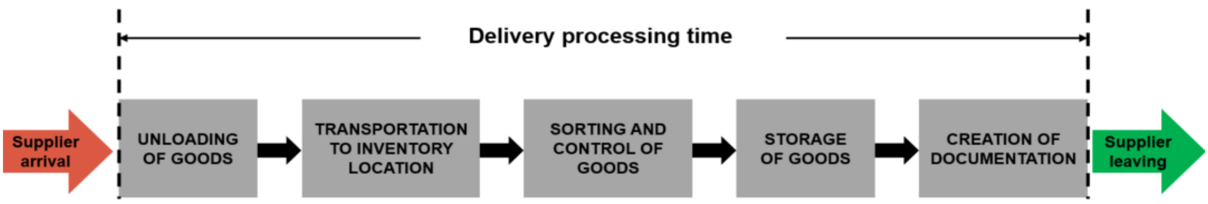


Figure 1 – Activities included in delivery admission process

3.2. Data analysis and statistical modeling

From data obtained through time study, we calculated sample statistics regarding a number of supplier arrivals during observed days. Population probability distribution of supplier arrivals was estimated and tested via χ^2 goodness of fit test. Information regarding processing times of deliveries was used to make initial analysis and clustering of deliveries into separate groups. Clustering was carried out by the k-means method [17, 18]. We varied a center parameter of a k-means algorithm between values of 2, 3 and 4 while setting a maximum number of iterations to 20. The algorithm was started 5 times for each selected value of the center parameter with a purpose of ensuring a stable solution, i.e. to see if we get approximately same cluster structure and centers. Differences in delivery processing times of formed groups by k-means method were formally tested by Mood's median test. This type of test was used because recorded data didn't correspond to the normal distribution, the variances across the groups were not equal, and a number of outliers were also detected [19]. Finally, we fitted theoretical probability distributions to every type of delivery. Fitted distributions to distinct groups were also tested by χ^2 test.

3.3. Development of simulation model

Monte Carlo method was chosen for the development of simulation model of the observed process. The reasoning behind this decision was our need to obtain estimates of process operating characteristic in short time span using a limited amount of data that we gathered [20, 21]. Idea was to simulate supplier arrivals and necessary processing times for admission of delivered goods that occur in one typical work day of pharmacy. To get good estimates of population parameters, 10000 iterations were conducted during the simulation process.

Simulation process was divided into four stages:

- Stage 1: by using distribution parameters of supplier arrivals, the number of supplier arrivals per day was simulated.
- Stage 2: simulation of types of deliveries per day was done using proportion information of formed groups of deliveries that we got by k-means algorithm. Simulated delivery types were then passed to supplier arrivals from stage 1.
- Stage 3: distribution parameters of processing times for different types of deliveries were used to simulate processing times of deliveries simulated in stage 2.
- Stage 4: total processing time of every iteration was calculated. Total processing times of iterations were averaged to get point estimate of the population mean processing time per day and to create confidence intervals at the level of significance of 5%. A similar procedure was done to estimate an expected number of supplier arrivals per day.

Whole simulation procedure was executed in a program for statistical computing R 3.4.0.

4. RESULTS

4.1. Time study

During time study, 162 deliveries from 48 different suppliers to the pharmacy were observed. In 119 observations type of goods delivered was medical consumables, 21 delivery contained medications, and there were 22 mixed deliveries. The number of arrivals varied between observed days as shown in figure 2a. We also noticed a variation in a number of arrivals between fixed 30 minute time intervals (Figure 2b), were the most frequent number of deliveries was 2 per 30 minutes.

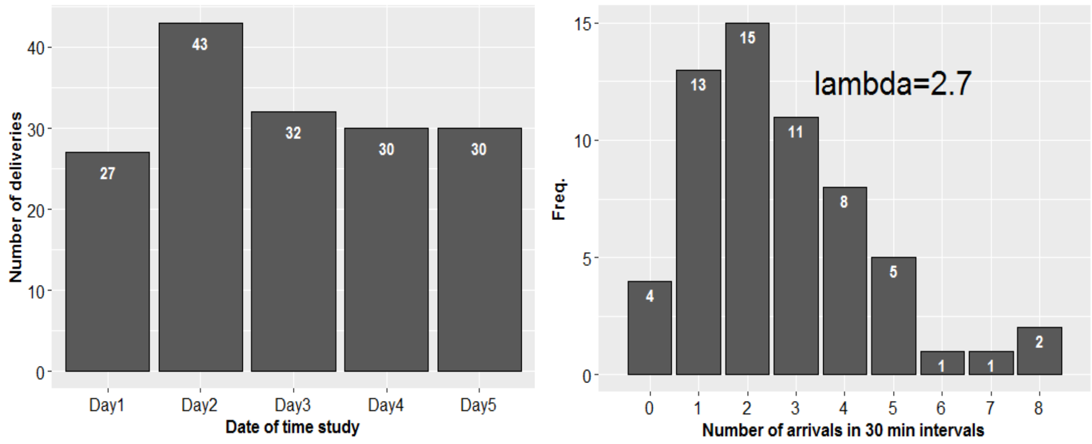


Figure 2 – a) Number of arrivals in observed days **b)** Number of arrivals in 30 min intervals

A number of supplier arrivals were modeled to follow Poisson probability distribution (parameter λ=2.7) and a p-value of 0.84 given by χ^2 test showed that we could not reject this hypothesis.

4.2. Data analysis and statistical modeling

The processing time of deliveries, which was an input to the k-means algorithm, gave most stable results when the center parameter was set to 3. Formed delivery groups were defined as small, medium and large, based on a magnitude of group center mean. Group of small deliveries included 123 observations from collected sample, group of medium deliveries consisted of 33 deliveries, and 6 deliveries were classified as large, as presented in figure 3.

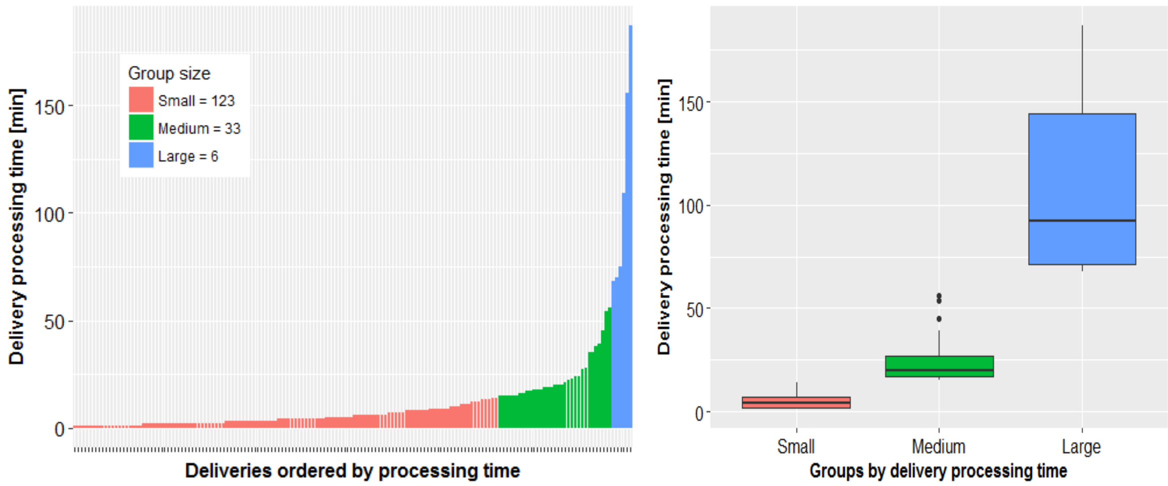


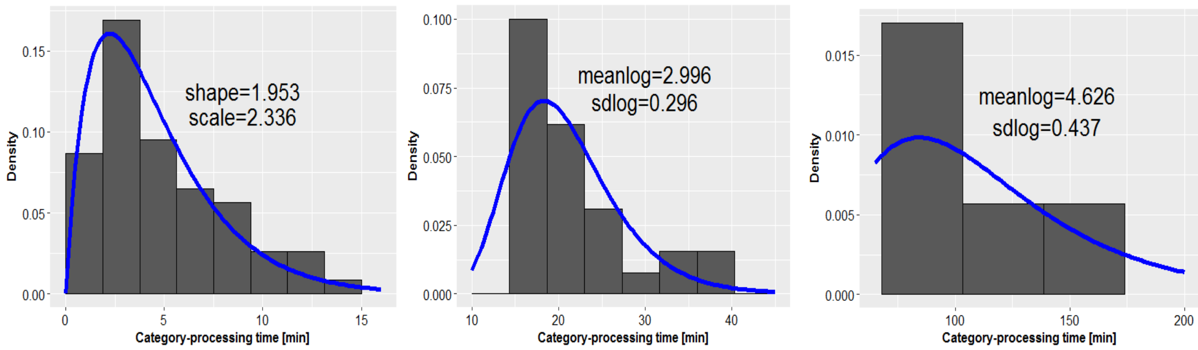
Figure 3 – Types of deliveries according to processing time

Mood's median test confirmed that there are significant differences in processing times between clustered delivery groups and post-hoc tests implied that all groups are considerably different according to p-values of pairwise comparisons (*small-medium p-value*=$2.87\cdot10^{-13}$, *small-large p-value*=$5.71\cdot10^{-3}$, *medium-large p-value*=$8.32\cdot10^{-3}$). Statistically significant differences of groups indicated that deliveries are from different populations, so their processing times needed to be modeled separately. Parameters of group centers (Table 2), acquired by clustering method, were used to estimate population parameters of processing times for each group.

Table 2 – Parameters of group centers

Parameter \ Group	Small	Medium	Large
Mean	4.715	21.433	110.833
Std. deviation	3.474	7.065	50.261
Range	1 – 14	15 – 56	68 – 187

Gamma distribution was the best fit for processing time of small deliveries with obtained p-value of 0.43 in the goodness of fit test. Processing times of medium deliveries have been modeled as lognormal because this hypothesis could not be rejected in $\chi2$ test as suggested by the p-value of 0.26. The goodness of fit test for large deliveries was inconclusive, because of a small number of observations belonging to this group. It was decided to fit large deliveries to the lognormal distribution, based on prior experiences in modeling this type of processes. Population parameters of fitted distributions are as shown in figure 4.



a) **small** b) **medium** c) **large**

Figure 4 – Fitted distributions of delivery processing times for each group

4.3. Simulation model

The first stage of simulation resulted in 10000 iterations of supplier arrivals (Figure 3) that were generated by the Poisson process with parameter lambda=2.7, and t=12 (12 thirty minute intervals in 6 hours that were observed during a day).

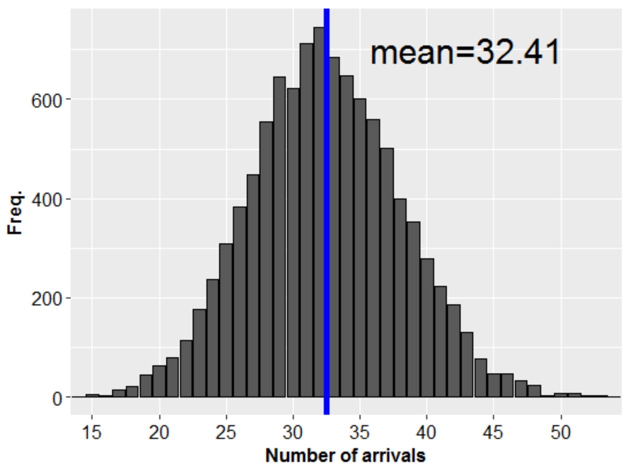


Figure 5 – Supplier arrivals in simulation model

Next stage connected delivery types with supplier arrivals using proportions of delivery types, through random number generator. In the third stage randomly generated processing times were added to matching delivery types from stage 2. I final stage total processing times of every iteration was calculated and analyzed (figure 6).

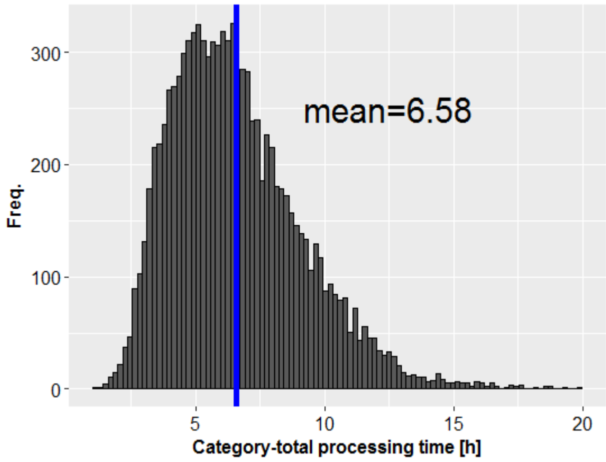


Figure 6 – Total processing time per iteration in simulation model

Estimated total daily processing time for deliveries and expected daily number of supplier arrivals, with their respective confidence intervals, is presented in the table 3.

Table 3 – Total daily delivery processing time and supplier arrivals in simulation model

Parameter	Mean	Std. deviation	Range	Conf. interval 95 %
processing time [h]	6.581	2.548	1.078 – 19.838	6.531 < μ < 6.631
arrivals	32.4137	5.629	14 – 54	32.303 < μ < 32.524

5. DISCUSSION AND CONCLUSION

Understanding the current state of the processes, and constraints in the form of infrastructure, existing staff, and other pharmacy activities and processes opens up room for improvement suggestions. It could be interpreted by observing mean total processing time for admission of daily deliveries, that each position of the reception area is occupied on average 2.2 hours per day, assuming equal occupancy of positions. Going further in these lines of interpretation, it could be hypothesized that each employee working in a basic eight-hour shift (8-16 h), excluding pharmacists, works on average 43 minutes per day on the admission of deliveries. Because in the current state all pharmacy processes are carried out simultaneously, there is a high probability of errors, especially in the case of delivery admission and issuing orders, which are caused by overlapping of input flow of goods from supplier deliveries and output flow from pharmacy to clinics which are not physically separated. Other observed problems include a constant need for pharmacy employees to switch from one activity to the other, which results in overburdening and causes employee absenteeism. Taking all these things in consideration, agreed improvement suggestion was to create dedicated time intervals for admission of deliveries and issuing of orders to clinics. Delivery admissions are to be split into two different time intervals (8-10h and 12-14h), and issuing of goods can be performed in between those intervals. One of the prerequisites of such work organization is defined policy for emergency issuing of goods that can happen during delivery admission intervals. This improvement should lead to a reduction of errors and a better balance of employees work.

During this research, differences between suppliers with regard to the type of goods they are delivering were not taken into account, as well as the differences in the delivery admission times with regard to the type of goods delivered. Also, it is necessary to check the impact of the availability of reception area positions on the total time of necessary for the admission of deliveries. Because the simulation model is based on 5 days of a single month, it would be important to check the adequacy of the model throughout the year, i.e. the potential impact of seasonality on the number of supplier arrivals and admission time. The aforementioned weaknesses will be the subject of future research that will focus on the development of a more complex model of pharmacy work organization

This paper contributes to the field of improvement of the pharmacy processes through research of the processes of supplier arrivals and delivery admission, because research of these processes is rarely presented in the literature. The approach used enables the assessment of initial process status in conditions of the small amount of data and information, through the integration of industrial engineering, statistical modeling, and simulation. In addition, this could form the foundation for the development of a more complex model of staff organization necessary for delivery admission, which will take into account a greater number of input factors. The implementation of proposed improvements based on the current state analysis, to the specific problem is the following test of the usefulness of this approach.

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