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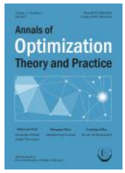

Optimizing hospital facility layout planning through process mining of clinical pathways

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Abstract During the recent years, demand for healthcare services has dramatically increased. As the demand for healthcare services increases, so does the necessity of constructing new healthcare buildings and redesigning and renovating existing ones. Increasing demands necessitate the use of optimization techniques to improve the overall service efficiency in healthcare settings. However, high complexity of care processes remains the major challenge to accomplish this goal. This study proposes a method based on process mining results to address the high complexity of care processes and to find the optimal layout of the various medical centers in an emergency department. ProM framework is used to discover clinical pathway patterns and relationship between activities. Sequence clustering plug-in is used to remove infrequent events and to derive the process model in the form of Markov chain. The process mining results served as an input for the next phase which consists of the development of the optimization model. Comparison of the current ED design with the one obtained from the proposed method indicated that a carefully designed layout can significantly decrease the distances that patients must travel.

Keywords Healthcare processes; Process mining; Optimization; Facility layout planning.

1. Introduction

Efficiency improvement is increasingly recognized as a serious concern for health organizations all around the world. Particularly, in developed countries, there has been a remarkable improvement in life quality factors during the last decades. This fact, in addition to development of new treatments, increased average longevity and hence dramatic demands for healthcare services have been observed.

As the demand for healthcare services increases, so do the need for new healthcare buildings as well as the need for redesign and renovating existing ones. Several studies

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have reported an unprecedented healthcare building boom and proven the importance of creating optimal physical environments to achieve the best possible outcomes for patients, families, and staff (see Kotzer *et al.* (2011); Ulrich and Zhu (2007), for example). Over the last decades, many healthcare managers have referred to the industrial sector and applied techniques and principles that have been developed in industrial processes to improve the performance of healthcare processes. However, high complexity of healthcare processes makes it challenging to apply these techniques in healthcare environments. Over the years, attention has gradually expanded from resource allocation and strategic planning to include operational issues such as resource scheduling and treatment planning Rais and Viana (2011). In particular, Discrete Event Simulation (DES) based approach has been extensively used by researchers to address problems generally faced by hospital`s managers. In addition, analytical approaches like queuing based models played a vital role in this area. Facility layout design, in particular, has received considerable critical attention. Studies showed that an efficient layout design can result in a remarkable reduction in the total costs of manufacturing and service industries. Difficulties arise, however, when an attempt is made to apply these approaches to real-world healthcare systems. This is mainly a consequence of high complexity of healthcare systems. As argued by Rebuge and Ferreira (2012), healthcare domain is considered to have complex models due to four characteristics: i) health care processes are highly dynamic, ii) health care processes are highly complex, iii) health care processes are increasingly multi-disciplinary, and iv) health care processes are ad hoc. Process mining techniques provide an opportunity to discover what is actually happening in the system. It aims at extracting process knowledge from event logs which may originate from all kind of systems like hospital information systems Mans *et al.* (2009). Taking benefits of wide range of available event logs in hospitals, these data can be used for improving the efficiency of care processes. In recent years, there has been an increasing growth on the number of papers addressing the applications of process mining in different disciplines and particularly, in healthcare domain. In a study by Mans *et al.* (2009), the gynecological oncology healthcare process within a university hospital has been analyzed. They analyzed the healthcare process from three different perspectives: (1) the control flow perspective, (2) the organizational perspective and (3) the performance perspective. Relevant event logs extracted from the hospital's information system and analyzed using the ProM framework. Rebuge and Ferreira (2012) proposed a methodology for the application of process mining techniques that leads to the identification of regular behavior, process variants, and exceptional medical cases. The approach is demonstrated in a case study conducted at a hospital emergency service. Based on process mining outcomes, Zhou *et al.* (2014) proposed a discrete event simulation model to analyze the clinical center. Sensitivity analyses have also been carried out to investigate the care activities with limited resources such as doctors and nurses. Analyzing and evaluating seven different process mining algorithms was done in Lang *et al.* (2008). Poelmans *et al.* (2010) argued that neither process nor data discovery techniques alone are sufficient for discovering knowledge gaps in particular domains such as healthcare. They showed that the combination of both gives significant synergistic results.

In light of high complexity of healthcare systems, we believe success requires a complete understanding of actual processes. Indeed, practical experiences showed a significant gap between what is prescribed to happen, and what actually happens. The only requirement for applying process mining techniques is availability of event log. Nowadays, clinical data are stored as a hospital information system. A hospital cannot operate without an information system and hence, a very detailed information about the executed activities is readily available. In addition, user-friendly environments of process mining software tools, such as ProM (open-source tool for process mining algorithms) and DISCO (Fluxicon process mining software), enable analysts and designers to provide new insights that facilitate the improvement of existing care processes without a complete understanding of the algorithms and techniques involved.

The aim of this study is to propose a method to help healthcare organizations to analyze complex hospital processes and find the optimal patient-centered layout based on real characteristics of the system in order to increase the efficiency of the care services. In order to do so, process mining techniques were applied to extract process related information, namely process model and pathway patterns, from event log of an ED in Seoul, South Korea. Based on the results obtained from process mining, number, age and acuity level of patients traveling between each two medical functions have been obtained. An architectural layout optimization model is then proposed in order to minimize patients traveling distance and length of stay by sensing sequence of activities. Up to now, far too little attention has been paid to facility layout optimization of hospitals. Moreover, existing studies have been mostly based on subjective judgments of patients` movement and relationship of medical functions. It is worth pointing out that the main advantage of a process mining-based method, however, is that the outcomes are based on real executions of processes rather than relying on subjective observations or opinions. Given the enormous cost of designing and constructing hospital buildings in addition to the significant impact of their layout on productivity and efficiency of hospitals, we believe the design process of hospital buildings is a challenging managerial problem which requires integration of architectural and operational management views.

The remaining part of the paper proceeds as follows: Section 2 describes the process mining-based method to discover the clinical patterns form the clinical records. As the main objective of this study, outcomes from process mining were used in a layout optimization problem in Section 3. Finally, Section 4 concludes the paper.

2. Patient movement analysis

The study uses a process log that consists of the care processes of 11357 patients of the ED of S Hospital in Seoul, South Korea. Treatment activities were collected during a period of 61 days. There are totally 9 activities that a patient might go through during his/her visit to the ED. Table 1 shows the details about the activities. Since patients correspond to cases in the log, 11357 cases, and 52250 events have been observed. We used the ProM framework to perform the study Van Dongen *et al.* (2005). ProM has been developed to support various process mining algorithms. Sequence clustering plug-in has been implemented to support the clustering goal. It allows to cluster patients in dataset and further apply other desire process mining techniques to each cluster Veiga (2009). However, in this study, sequence clustering plug-in is used for two reasons. First, it allows the user to apply preprocessing steps to clean the data set and to remove infrequent events. Second, the process model can be obtained in the form of Markov chain, which allows the user to understand the relations between activities.

During our investigations, we realized that those patient pattern behaviors, which occurred less than ten times, can be considered as infrequent sequences and can be eliminated from the dataset. After setting the minimum occurrence of a sequence to 10, information about 424 patients (less than 4 percent) deleted from the dataset (from 11357 instances, 10933 were kept). The resulting data set, consist of 10933 patients with 57 different activity patterns. Figure 1 and Figure 2 illustrate sequences and events present in the filtered event log receptively.

Table 1. Activities performed by patients.

Index	Activity	Index	Activity
A	Registration	F	CT (Brain)
B	Triage	G	CT (Other)
C	Blood test	J	Hospitalization
D	Chest PA or AP	I	Departure
E	Consultation		

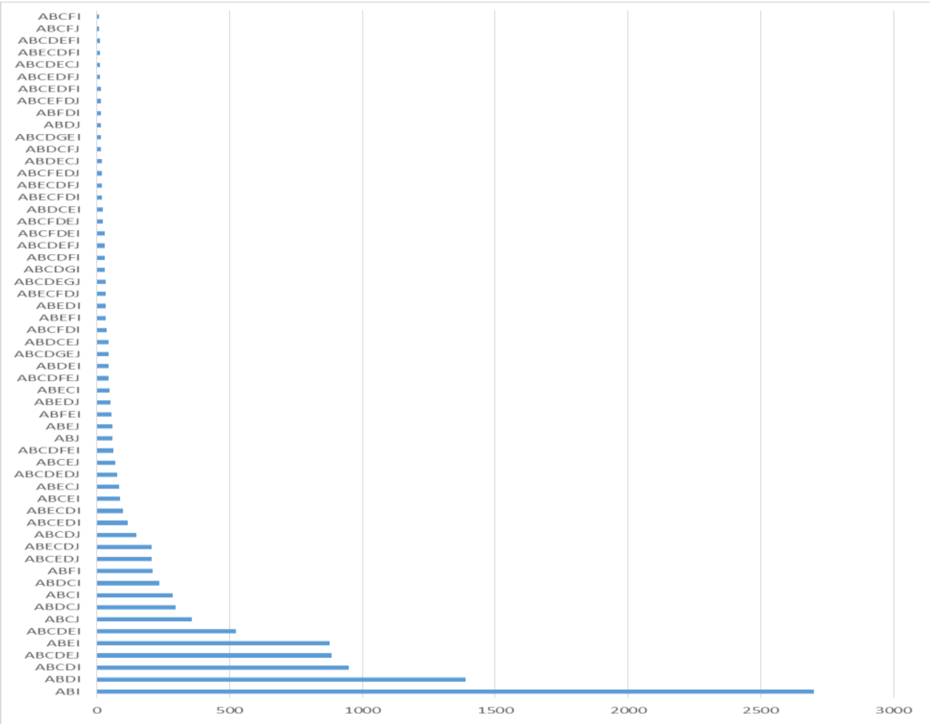

Figure 1. Activity patterns present in the filtered log.

In order to obtain the Markov chain for complete log without dividing it into clusters, the number of desired clusters must be selected equal to one. Figure 3 represents the discovered process model in the form of Markov chain (darker elements are more recurrent than lighter ones).

3. Layout optimization model

In this section, a mathematical optimization problem has been proposed to find the best layout of ED. Using the activity relations between medical centers inside the ED obtained by process mining techniques, the model attempts to maximize goodness of the functional interactions of the center with other centers.

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3.1. Mathematical model and notations

Let l be the numbers of available locations, and n denotes the number of required medical

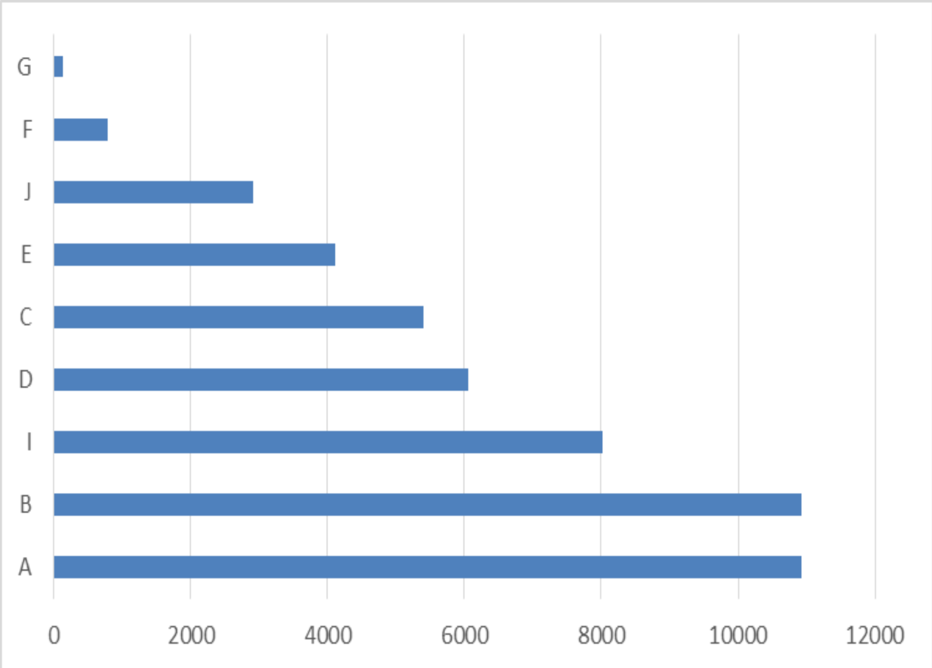

Figure 2. Events present in the filtered log.

centers. The problem is to locate n distinct centers $N = \{1,2,3, \dots ,n\}$ in l distinct available locations $L = \{1,2,3, \dots l\}$. Where l is at least equal to the number of required centers n. It must be mentioned that the two cases "$l = n$" and "$l > n$" essentially are equivalent since $l - n$ dummy centers can be added. For clarity, we shall use indices q and r for available locations, and i and j for required centers. We denote by δ_{qr} the inversed normalized distance between positions q and r (closer locations have higher weight). For center i, the feasible (potential) set of locations is denoted by P_i. The position of center i is described by the binary variables x_{iq}'s such that the value of x_{iq} is 1 if center i is moved to position q and 0 otherwise. Finally, r_{ij} represents the movement relation between centers i and j. The movement relationship between different centers of ED plays a vital role in the optimization process. The outcomes of the process mining are used in this model as inputs of optimization model. Basically, to medical functions with high logical relationship (i.e., large rij) must be located close to each other in order to decrease the patients' moving distances. Having obtained the Markov chain for process model, it is also possible to provide a matrix representation which makes it more tractable for further analysis (Figure 4).

The objective of the model is to maximize goodness of the functional interactions of the center with other centers.

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$$Max\ Z = \sum_i \sum_j \sum_q \sum_r x_{iq} x_{jr} \grave{\delta}_{qr} r_{ij}$$

subject to

$$\sum_{q \in P_i} x_{iq} = 1 \qquad \forall\, i \qquad (1)$$

$$\sum_{i=1}^{n} x_{iq} \leq 1 \qquad \forall\, q \text{ and } q \neq 0 \qquad (2)$$

Constraint (1) claims that centers must be assigned to one of its potential positions. Constraint (2) claims that available position can hold at most one center.

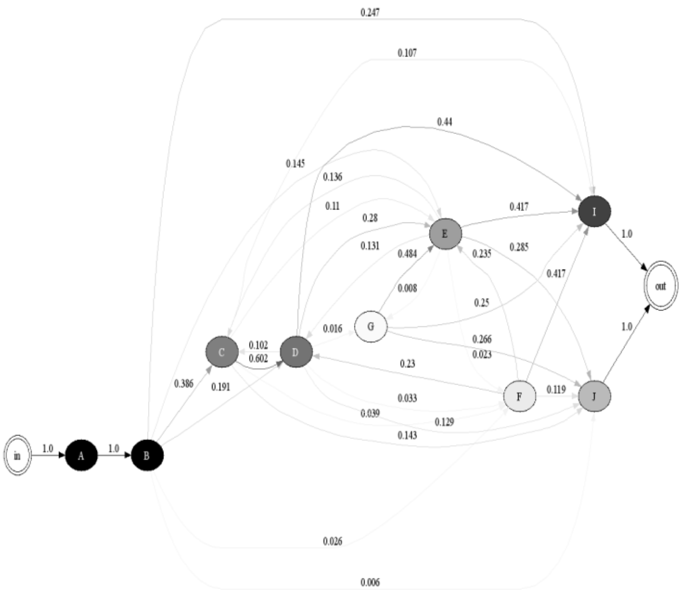

Figure 3. Markov chain model for the complete log.

3.2. Results and discussion

Figure 5 represents the current arrangement of medical centers inside the ED. The problem is to relocate required medical centers to available locations in order to decrease the total distance traveled by patients and hence decrease the length of stay. Our model was implemented in OPL and solved by CPLEX 12. The optimum layout obtained by proposed model (Figure 6) showed 37.95 percentage of improvement in comparison with current layout regarding total walking distance of patients (changed from 256203 to 158999). The needed CPU time is about 1 min. However, designing hospital units do not happen very often in practice. Therefore, it is acceptable to spend some hours of computational effort.

Having obtained the optimal layout using the proposed method, simulation modeling can be used to assist decision makers to adjust the obtained layout with respect to various

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considerations. The reasons may include adjusting the layout for qualitative objectives such safety and security. Other reasons may include some quantitative goals which are difficult to express using mathematical formulation. It must be pointed out that the layout obtained from the proposed model is the best layout possible considering distances traveled by patients and should be applied in the early design stage to determine the most efficient layout. The obtained layout may be tuned further according to any aspects that are not included in the formulation presented here.

	In	A	B	C	D	E	F	G	I	J	out
In	0	1	0	0	0	0	0	0	0	0	0
A	0	0	1	0	0	0	0	0	0	0	0
B	0	0	0	0.386	0.191	0.145	0.026	0	0.247	0.006	0
C	0	0	0	0	0.602	0.110	0.039	0	0.107	0.143	0
D	0	0	0	0.102	0	0.280	0.033	0.016	0.440	0.129	0
E	0	0	0	0.136	0.131	0	0.023	0.008	0.417	0.285	0
F	0	0	0	0	0.230	0.235	0	0	0.417	0.119	0
G	0	0	0	0	0	0.484	0	0	0.250	0.266	0
I	0	0	0	0	0	0	0	0	0	0	1
J	0	0	0	0	0	0	0	0	0	0	1
out	0	0	0	0	0	0	0	0	0	0	1

Figure 4. Matrix representation of the movement relations.

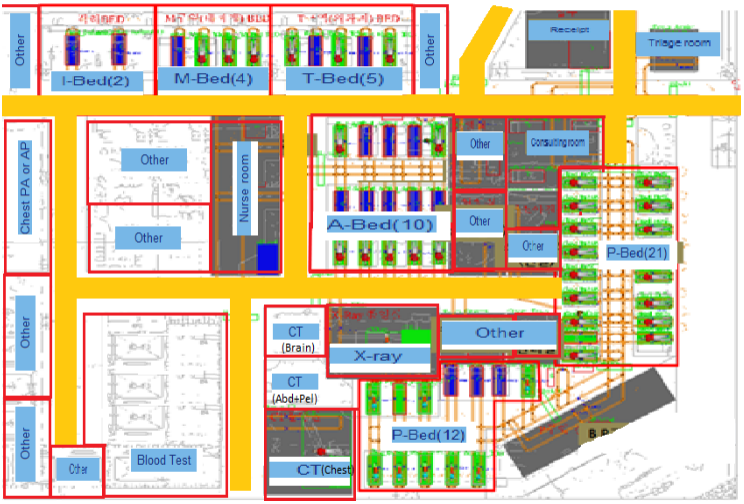

Figure 5. Current layout of ED.

4. Conclusions

In this study, a process mining-based method proposed to discover process model and clinical pathway patterns of an ED. Process mining can be used as a reliable tool to enhance care process analysis and to discover the pathway patterns from the clinical records. The process model is then used to find the best layout of medical functions in ED. The objective was to decide upon the location of the various clinical centers so as to reduce the effort spent by the patients while moving from one unit to another. It was found that a carefully designed layout could significantly decrease the distances that

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patients must travel, as well as related complications. The most important limitation of this study lies in the fact that there are many factors, such as patient and personnel's safety and security that must be taken into account when designing a hospital building. Future studies need to be carried out in order to determine the best layout of hospital buildings by considering multiple layout planning objectives simultaneously. Work in this direction is in progress.

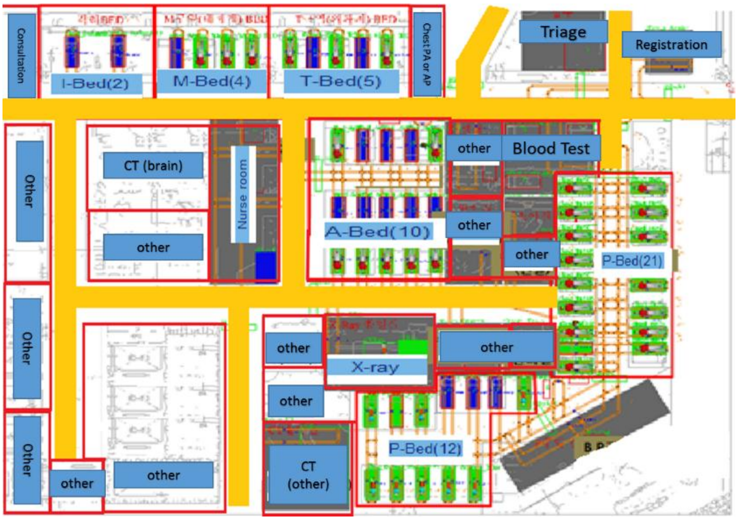

Figure 6. Optimum layout of ED.

Acknowledgment

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