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ORIGINAL PAPER

LAYOUT DESIGN OF OUTPATIENT DEPARTMENT: SIMULATION STUDY AND IMPLEMENTATION

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ABSTRACT. Background: Hospital layout is one important factor affecting hospital service quality and, consequently, patient satisfaction. Generally, the layout is designed based on the experience of the hospital specialists without any systematic approaches.

Purpose: Due to the increasing number of patients, the case study hospital has built a new multi-floor building to move its Outpatient Department (OPD) to operate there. Therefore, this study aims to apply the Activity Relationship Analysis (ARA) and simulation to design a new OPD layout.

Methodology: Data of the previous system were analyzed using the ARA. The results were then used to design three scenarios (A, C, and D) and the other three scenarios (B, E, and F) were proposed by hospital specialists. Then, six layouts were evaluated using simulation tests and the efficiencies of the designs were measured by an average total service time per patient.

Results: The simulation results showed that the average total service time of scenario A, D, E, and F were lower than scenario B and C. While the average total service time at the sub-service unit of D was the longest compared to scenario A, E, and F. These results demonstrated that scenario A, E, and F were the most efficient layouts. However, when considered thoroughly by the hospital specialists, scenario A was eventually selected.

Conclusion: This study can contribute to scientific literature as it demonstrates the application of the ARA and simulation in the design of the multi-floor layout, an aspect under-researched in existing studies. This study also provides the practical implication suggesting that these techniques should be used together in the layout designs because they can help to determine the correctness and efficiency of the layout design before actual implementation.

Key Words: activity relationship analysis, simulation, hospital layout design, outpatient department

INTRODUCTION

Hospital layout is one important factor affecting the hospital service quality [Arnolds and Gartner, 2018; Benitez et al., 2019; Elshafei, 1977; Gosavi et al., 2016; Jamali et al., 2020; Sower et al., 2001; Ward et al., 2005; Zhao et al., 2009], especially the Outpatient Department (OPD) layout that includes several service units. An efficient OPD layout can promote the efficient flows of staff and patients by minimizing distances of travel, making efficient use of spaces, and providing optimal functional adjacencies. Accordingly, the efficient OPD layout can reduce the patient's waiting time and increase the level of patient satisfaction with the hospital service quality [Boonmee et al., 2021; Luo et al., 2017; Tsui and Fong, 2018].

Many approaches are used in the facility layout design [Boonmee and Kasemset, 2019], for example, Activity Relationship Analysis (ARA), simulation, optimization, heuristics, lean manufacturing, decision-making analysis, SERVPERF theory, and SHELL model. In addition, some of these approaches have been combined to design the facility layout in many previous studies, for instance, optimization and simulation [Vahdat, 2019], lean manufacturing, SERVPERF theory [Soriano-Meier, 2011], and heuristics and ARA [Motaghi et al., 2009].

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The case study hospital of this research is a community hospital located in Chiang Mai province, Northern Thailand. The hospital provides healthcare services to approximately 600-700 patients per day. While the number of patients is constantly increasing, the hospital has built a new building to improve its services and prepare itself for the increasing number of patients. The hospital decided to move its OPD to operate in the new building and increased service capacity from single-floor to double-floor operation. This hospital previously designed its OPD layout based mainly on the experiences of the hospital specialists without any systematic methods. As a result, it wanted to apply systematic approaches in the design of its new OPD layout.

The hospital aimed to design its new OPD layout to minimize the service time and, subsequently, the waiting time of the patients. The design of the layout thus needs to consider the relations and share of resources (e.g., facilities and human resources) between service units. Among many design approaches, the ARA is a technique that considers the degree of closeness and relations between service units in the layout; therefore, this technique was selected and applied in the layout design in this research. This research also applied the simulation technique in the selection of the appropriate layout because the simulation technique can help to evaluate the efficiency of the alternative layouts before actual implementation.

Although the ARA and simulation are widely used in the facility layout design. Two main gaps can be identified. Firstly, the simulation is rarely applied in the hospital layout design because most studies use it mainly for evaluating the performance of the healthcare operational system [Boonmee et al., 2020; Gallagher et al., 2016; Günal and Pidd, 2011; Katsaliaki and Mustafee, 2011; Kasemset et al, 2021; Murphy, 2013; Sepúlveda, 1999]. Secondly, limited studies combine these two approaches in the design of the multi-floor layout, especially the hospital layout. Therefore, the objective of this research was to use the ARA and simulation to design, propose and evaluate the most efficient OPD layout for a case study hospital.

THEORY

Activity Relationship Analysis (ARA)

The ARA is one technique in Systematic Layout Planning (SLP) [Francis, et al., 1992]. It is often applied in the initial stage of the SLP to design the facility layout [Muther, 1955] and includes two main tools, namely Activity Relationship Chart (ARC) and Activity Relationship Diagram (ARD).

Firstly, the ARC is a tabular means of displaying the degree of closeness among all pairs of activities, areas, or departments [Muther, 1955]. The degree of closeness can be evaluated using quantitative data – such as frequency of movements – or qualitative data – such as perspectives of specialists [Affifah, 2019]. The symbols, including A, E, I, O, U, and X, are used to represent the degree of closeness, where A is Absolutely necessary; E is Especially important; I is Important; O is Ordinary closeness; U is Unimportant; and X is Undesirable.

Secondly, the ARD is a block diagram developed from information in the ARC [Tompkins, 2010; Sugandhi and Bharule, 2016]. It reflects the strength of the relationship between activities, areas, or departments to be placed into the layout by a number of joining lines [Muther, 1955]. For instance, four joining lines (degree of closeness = A) indicated a need to have two activities located close together, while one line (degree of closeness = O) indicates a lesser priority on placing the activities close to each other.

Simulation

A simulation is a process of designing a model of a real-world system and conducting experiments to evaluate the model performance before actual implementation [Law 1998; Boonmee and Kasemset, 2019]. The simulation is often used in improvement activities because it helps to deal with complicated systems and requires few assumptions [Nanda and Sudhir, 1996]. It is also used to learn non-existing systems to predict the outputs of actions and developments that are expensive to conduct experiments in the real world [Lagergren, 1998; Boonmee et al., 2020]. The steps of the simulation are as follows: formulate the problem and plan the study; collect the data and formulate the simulation model; check the accuracy of the simulation model; select the simulation software and construct a computer program; test the validity of the simulation model; plan the simulation to be performed; conduct the simulation runs and analyze the outputs statistically; and present recommendation to management [Hillier and Lieberman, 2015].

The output analysis is one important step in the simulation study [Kelton et al., 2010]. The simulation results are simply the observed samples of the random variables. This inference or predictions about a system can be done either by hypothesis testing or confidence interval (CI). CI indicates the range of likely value of the measure at any significant level (α) [Hillier and Lieberman, 2015]. The output from the simulation runs provides statistical estimates of the desired performance measure for each system configuration of interest. (1- α) % CI on mean is calculated based on equation (1) (Montgomery and Runger, 2014).

$$\bar{x} - t_{\frac{\alpha}{2},n-1} {}^{S}/_{\sqrt{n}} \leq \mu \leq \bar{x} + t_{\frac{\alpha}{2},n-1} {}^{S}/_{\sqrt{n}} \quad (1)$$

Where α = Significant level, n = Sample size, $\bar{x}$ = Sample mean, μ = Population mean, S = Sample standard deviation, $t_{\frac{\alpha}{2},n-1}$ = the upper bound $100\alpha/2$ percentage point of the t distribution with n-1 degree of freedom, the lower bound of mean is $\bar{x} - t_{\frac{\alpha}{2},n-1} {}^{S}/_{\sqrt{n}}$, and the upper bound of mean is $\bar{x} + t_{\frac{\alpha}{2},n-1} {}^{S}/_{\sqrt{n}}$.

The comparison can be conducted at any α-level when intervals of outputs are not overlapped, compared situations can be claimed that they are significantly different.

METHODS

Data collection

The OPD service system of the case study hospital is separated into two main groups: medical and supporting service units. The medical unit consists of examination rooms for six departments, including Pediatric (PED), General Practitioner (GP), Medicine (MED), Ear nose and throat (ENT), Surgical (SUR), and Orthopedic (ORTHO). While supporting service units include pre-checking, registration, Vital Sign (V/S) checking, history taking, X-Ray, laboratory (Lab), medical procedure room, payment, and pharmacy. Data of the existing service system were collected, including service- operation flows, operation time, number of patients and arrival rates, number of officers (including doctors, nurses, technicians, and support operators), existing OPD layout (one floor), and related limitations. Data of the new area were considered, including the new floor plan of the OPD area (two floors), the number of rooms, and the distance between each unit. The patient's operation flow was presented in Figure 1.

Simulation Model

Collected data were used to develop the simulation model using Arena software. Data input to the simulation model mainly applied 3 standard statistical distributions: constant (CONS), triangular (TRIA), and uniform (UNIF) distributions for each operation time as presented in Figure 1. For example, one patient at pre- checking may spend one of three operation times as 5 (min), 10 (mode), or 15 (max) seconds as TRIA distribution. The characteristic of each standard distribution can be found in Kelton et al. (2010).

The simulation model is separated into four sections (shown in Figure 1) as follows:

Section 1: This section represents the general primary operations when patients arrive at the hospital for OPD. The patient arrival rate is different depending on each period from 7:00 AM to 4:00 PM. To create patients for the simulation model, the arrivals are created based on exponential distribution with different mean values for each hour.

There are three types of patients: (1) New Patient (NP), (2) Registered Patient with Appointment (RPA), and (3) Registered Patient without Appointment (RPOA). All patients have to pass three operations: pre-checking, registration, and V/S checking, respectively.

Section 2: In this section, each type of patient is assigned to different operation flows. RPA have the highest priority and they are sent to three possible operations – diagnosis, lab testing, or X-ray – following the detail of their appointment records. While NP and RPOA are sent directly to do history taking.

Section 3: This section is the diagnosis section at the OPD. Patients are assigned to a specific diagnosis separately based on each medical unit, including PED, GP, MED, ENT, SUR, and ORTHO. After finishing the diagnosis by doctors, patients may be assigned to have more lab testing, X-ray, or medical procedures, then they might return to have diagnosis again.

Section 4: When patients finish their medical service at OPD following section 3, they normally go to carry out the payment, receive medicine at the pharmacy, and then go out of the system. In case of additional treatment is needed, patients may be admitted to the In- Patient- Department (IPD) or transferred to other hospitals for further treatment.

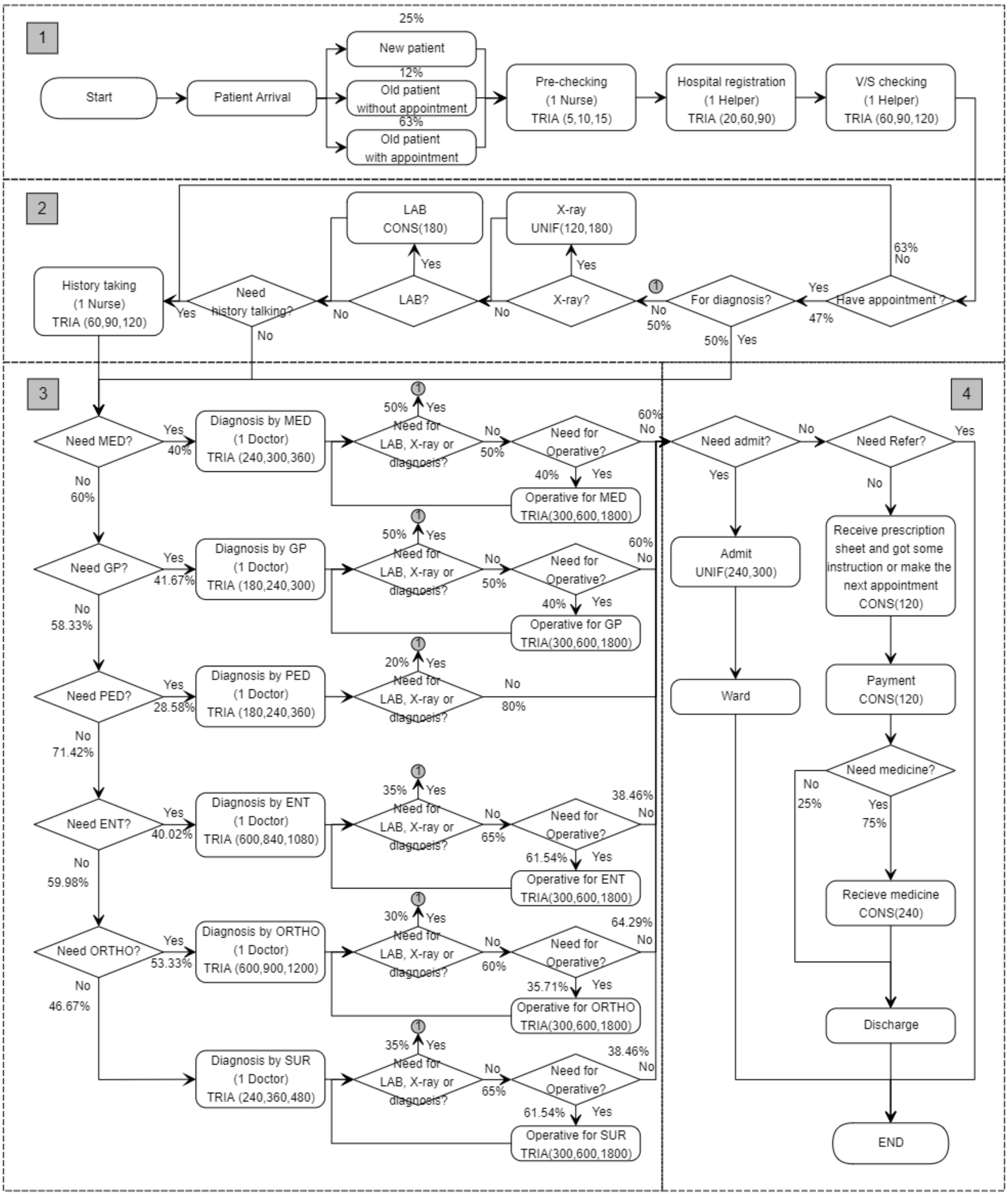

Fig. 1. Operational flow chart at OPD (time unit: second)

Verification and validation of the model were conducted when the simulation test ran with a run length of 9 hours and 64 replications. Test results were also discussed together among the researchers and the hospital management team. From September to November 2019, the number of patients served at OPD was approximately 660 persons per day, so the results from simulation presented the number out as 652 to 663 persons per day using a 95% CI of the mean. The results from the simulation were not significantly different compared with the real data at the significance level (α) 0.05 because the 95% CI of mean included the value from the real system. In conclusion, the proposed simulation model can be used to represent the real system.

Test scenarios and limitations of the new area

The layout of the OPD in the new area is separated into two floors. The first floor consists of seven examination rooms, one Lab, one X-ray, two medical procedure rooms, one registration centre, one pharmacy, and one financial counter. The second floor consists of eight examination rooms, one Lab, and two medical procedure rooms. Examination Rooms need to be assigned exactly to each department as follows: 4 rooms for MED; 2 rooms for GP; 2 rooms for ENT; 2 rooms for ORTHO; 1 room for PED; and 1 room for SUR.

To assign examination rooms, ARC and ARD were used to evaluate the relationship between rooms. The relationships between rooms were rated using the degree of closeness: A, E, I, O, and U. A means that two rooms have to be located close to each other. E means that two rooms should be located close to each other, but after putting A. I and O are considered after E respectively, while U shows an unimportant relationship which can be last considered, and the rooms can be located independently.

From Figure 2, considering all departments, pairs of departments with relationships can be ranked as MED-GP (E level), MED-PED (O level), PED-GP (O level), SUR-ORTHO (O level), SUR-ENT (O level), and ORTHO-ENT (O level). Accordingly, MED and GP should be located close to each other, but ignoring this is still acceptable. In addition, all departments can be classified into two groups: MED-PED-GP and SUR-ORTHO-ENT. Not only the degree of closeness was considered, but the discussion among hospital specialists was also taken into account for designing test scenarios. Subsequently, six scenarios were designed in Table 1.

Table 1. Detail of each test scenario.

Scenario	1st Floor (7 rooms)	2nd Floor (8 rooms)	Note
A	**MED – 4 rooms*** **GP – 2 rooms*** **PED – 1 room**	**SUR – 1 room** **ENT – 2 rooms** **ORTHO – 2 rooms**	MED – 4 rooms GP – 2 rooms ENT – 2 rooms ORTHO – 2 rooms SUR – 1 room PED – 1 room - **Bold letters** indicate the plan according to the results from relationship analysis. - (*) indicates pair of MED and GP. - Scenario B, E, F were designed based on the hospital specialists' perspectives.
B	MED – 3 rooms* GP – 2 rooms* ORTHO – 2 rooms	MED – 1 room SUR – 1 room ENT – 2 rooms PED – 1 room	
C	MED – 2 rooms **ENT – 2 rooms** **ORTHO – 2 rooms** **SUR – 1 room**	**MED – 2 rooms*** **GP – 2 rooms*** **PED – 1 room**	
D	GP – 2 rooms **ENT – 2 rooms** **ORTHO – 2 rooms** **SUR – 1 room**	MED – 4 rooms PED – 1 room	
E	GP – 2 rooms ENT – 2 rooms ORTHO – 2 rooms PED – 1 room	MED – 4 rooms SUR – 1 room	
F	GP – 2 rooms ORTHO – 2 rooms SUR – 1 room PED – 1 room	MED – 4 rooms ENT – 2 rooms	

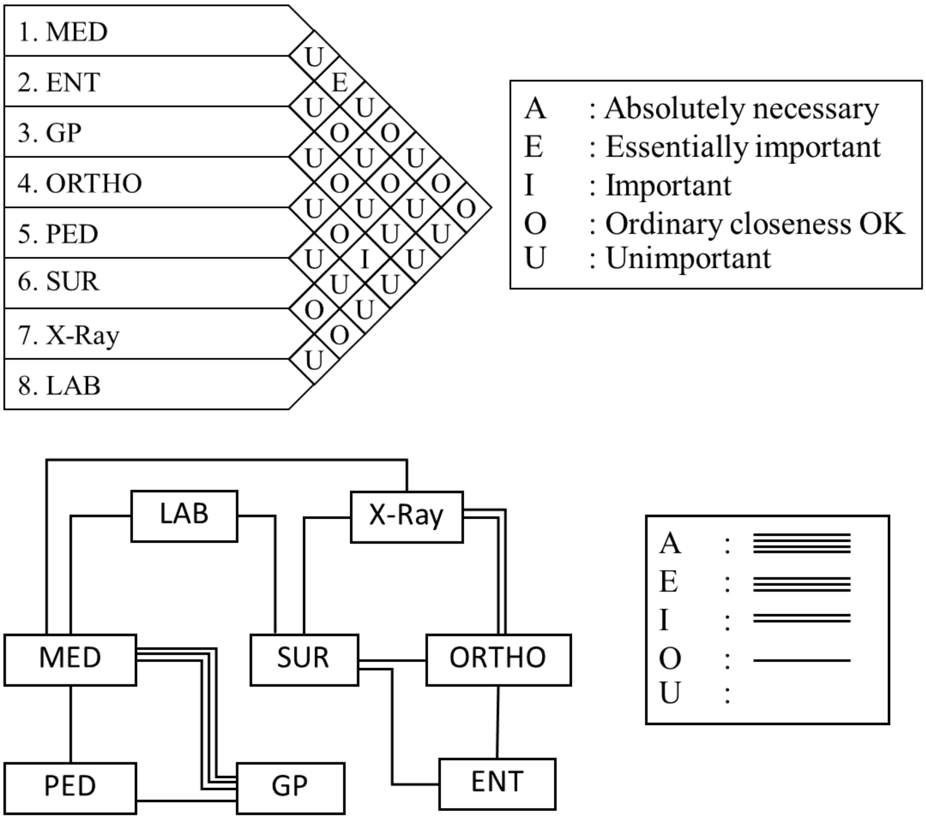

Fig. 2. Activity relationship chart and relationship diagram of OPD

RESULTS

Simulation tests were conducted with the same initial parameters, 9 hours per day with 64 replications, 95% CI of mean total time in the system of all scenarios, as compared in Figure 3.

As shown in Figure 3, scenarios B and C were dominated by F because F has less mean time than B and C significantly, scenarios B and C can thus be eliminated. While scenario A, D, E, and F were further considered because their intervals overlapped (which means they are not significantly different). Then, performance measurements for all departments were compared using 95% CI of mean comparison as in Figure 4.

The comparison results (shown in Figure 4) presented no significant differences among A, D, E, and F for most departments excluding PED. If considering only PED, the mean time of scenario D is longer than the scenario A, E, and F significantly. Hence, the scenario D was dominated. Thus, the appropriate solutions were A, E, or F.

Considering A, E, and F, similar design issues can be noticed as follows.

- 4 rooms of MED should be located on the same floor.
- PED should be located on the 1st floor.

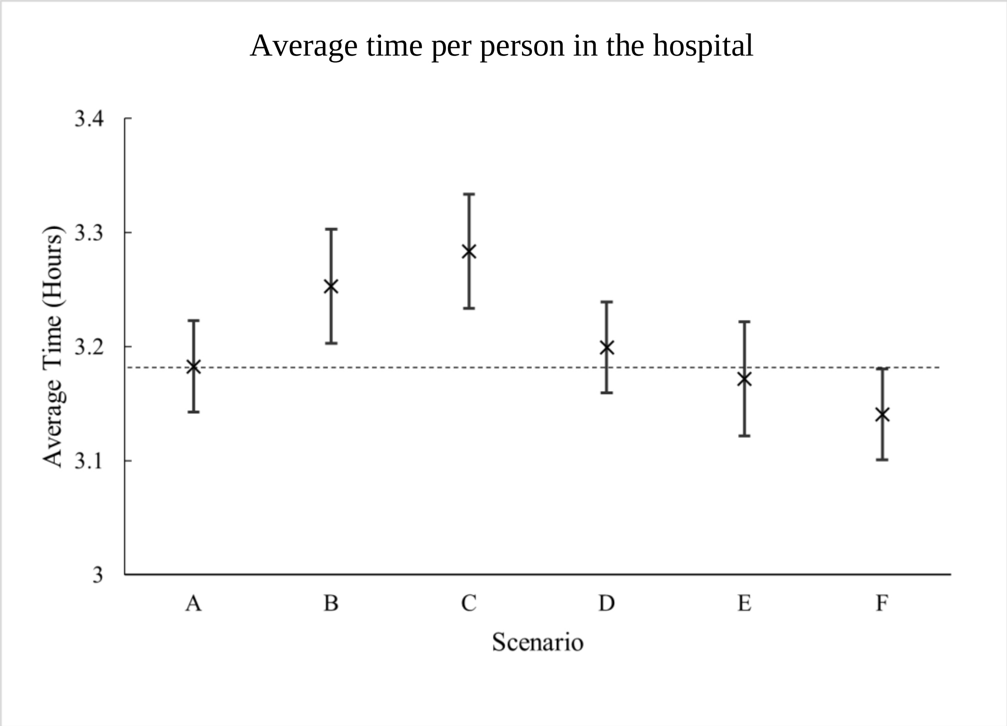

Fig. 3. 95% CI of mean total time in system comparison.

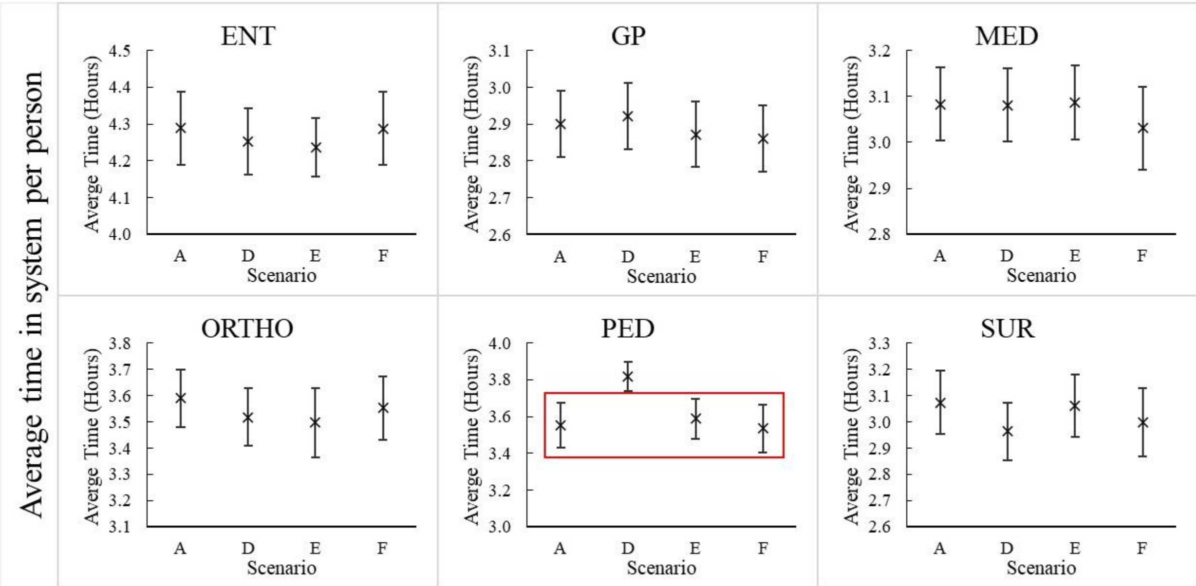

Fig. 4. The interval plot of average time in a system A, D, E, and F (95% CI).

DISCUSSION

From the simulation tests, scenarios A, E, and F were selected to be the appropriate solutions. Therefore, these three layouts were presented to the hospital management team for final decision and selection. From the meeting among researchers and the hospital team, layout A was selected to be implemented. It is because in scenario A, MED and GP – the units that work together highly frequently – were placed close to each other on the same floor. Then, the 1st floor includes MED (4 rooms), GP (2 rooms), and PED (1 room), while the 2nd floor includes SUR (1 room), ENT (2 rooms), and ORTHO (2 rooms).

For the real implementation of the scenario A, the following issues were considered:

(1) The proportion of patients between the 1st and 2nd floors were imbalanced at a ratio of 75.2% and 24.8%.

(2) All rooms on the 1st floor are occupied and three rooms on the 2nd floor are available for future service extension.

(3) Support units including X- ray, registration centre, pharmacy, and financial counter were set on the 1st floor. When the number of patients increases, some supporting units should be added, especially X-ray, which currently operates with high utilization (more than 95% from simulation results).

Practice Implementation

Since the end of 2019, the new building of the hospital case study has been operated and scenario A was implemented. Nevertheless, the hospital has more service data of OPD, the plan was therefore adjusted from scenario A as follows:

(1) For the 1st floor, the rooms for GP were increased from 2 to 4 rooms and the rooms of MED were decreased from 4 to 3 rooms because every patient who comes to the hospital without obvious symptoms will be served at GP before they are sent to other departments. Thus, GP was determined to have more examination rooms on the first floor. PED with a less strong relationship compared to GP and MED was moved to the 2nd floor due to the limited number of rooms on the 1st floor (7 rooms).

(2) For the 2nd floor, the rooms for SUR and ENT were the same as scenario A, which were 1 and 2 rooms, respectively. The rooms for ORTHO were increased from 2 to 3 rooms. Including 1 relocation room of PED, the 2nd floor utilized 7 of 8 rooms. The remaining one room was occupied for the new department since the hospital extended the OPD service unit.

(3) In addition, to reduce the overcrowding problem, support units including the registration centre and financial counter were set up on the 2nd floor to serve the patients.

CONTRIBUTION, IMPLICATIONS AND LIMITATIONS

This study can contribute to academic literature because it demonstrates the application and combination of the ARA and simulation technique in the design of a multi-floor OPD layout. This aspect is limited in existing studies because most studies focus mainly on the application of these techniques in a single floor layout design.

In terms of the practical implication, the results of this study show how the ARA and simulation successfully help to design the hospital layout which can be applied in other contexts. As known, to design the hospital layout based mainly on the experience of the hospital specialists, all important aspects may not be included in the design, such as the relations and flows between different service units. Once the layout is implemented and not suitable for the hospital, it is difficult to modify and, if modified, it is costly. On the other hand, when the design techniques, such as the simulation and ARA, are applied, all aspects are considered systemically. In addition, the simulation can help to determine the correctness and efficiency of the design before actual implementation. The simulation can further help to investigate any effects resulting from the change of some conditions. For example, if the number of patients increases, the simulation runs can demonstrate whether or not the designed layout is still suitable for those number of patients or it needs to be modified.

In hospitals, especially in developing countries like Thailand, the patients normally go to the hospital without appointments with the doctors and they sometimes need medical investigation and treatment from different healthcare service units at a time. This situation may lead to a high unplanned number of patients in the hospital waiting for medical treatment. Hence, the ARA technique that considers the relations between different service units and the use of hospital resources is suggested to be used in the layout design of this kind of hospital, as demonstrated in this research.

Different hospitals may have differences in the relations between healthcare service units, the use of resources, and the limitations of areas. The OPD layout designed in this research was also based on those of the case study hospital. According to these different conditions, further studies that apply approaches similar to this research may have different layouts depending on the conditions of the hospitals they consider.

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REFERENCES

Affifah, G., 2019, Redesign of office layout using activity relationship chart (ARC) at the "X" department administration office of a "Y" university. In IOP Conference Series: Materials Science and Engineering, 528(1), 12056.

Arnolds, I.V., Gartner, D., 2018, Improving hospital layout planning through clinical pathway mining. Annals of Operations Research, 263(1), 453- 477, https://doi.org/10.1007/s10479-017-2485-4

Benitez, G.B., Da Silveira, G.J., Fogliatto, F.S., 2019, Layout planning in healthcare facilities: a systematic review. HERD: Health Environments Research and Design Journal, 12(3) , 31- 44, https://doi.org/10.1177%2F1937586719855336

Boonmee, C., Kasemset, C., 2019, The improvement of healthcare management in Thailand via IE tools: A survey, In Proceeding of the 2019 International Conference on Industrial Engineering and Operations Management, Bangkok, 264-274.

Boonmee, C., Kosayanon, A., Chitapanarux, I., Kasemset, C, 2020, Radiotherapy service improvement: simulation study. Industrial Engineering and Management Systems, 19(4), 758-773 https://doi.org/10.7232/iems.2020.19.4.758

Boonmee, C., Pisutha-Arnond, N., Chattinnawat, W., Muangwong, P., Nobnop, W., Chitapanarux, I., 2021, Decision Support System for Radiotherapy Patient Scheduling: Thai Cancer Center Case Study. In 2021 5th International Conference on Medical and Health Informatics, 168-175, https://doi.org/10.1145/3472813.3473185

Elshafei, A. N., 1977, Hospital layout as a quadratic assignment problem. Journal of the Operational Research Society, 28(1), 167-179, https://doi.org/10.1057/jors.1977.29

Francis, R.L., McGinnis, L.F., White, J.A., 1992, Facility layout and location: an analytical approach. Pearson College Division.

Gallagher, T.H., Etchegaray, J.M., Bergstedt, B., Chappelle, A.M., Ottosen, M.J., Sedlock, E.W., Thomas, E.J., 2016, Improving communication and resolution following adverse events using a patient-created simulation exercise. Health Services Research, 51, 2537- 2549, https://doi.org/10.1111/1475-6773.12601

Gosavi, A., Cudney, E.A., Murray, S.L., Masek, C.M., 2016, Analysis of clinic layouts and patient- centered procedural innovations using discrete-event simulation. Engineering Management Journal, 28(3), 134-144, https://doi.org/10.1080/10429247.2016.1195664

Günal, M. M., Pidd, M., 2011, DGHPSIM: generic simulation of hospital performance. ACM Transactions on Modeling and Computer Simulation (TOMACS), 21(4), 1-22, https://doi.org/10.1145/2000494.2000496

Hillier, F., Lieberman, G, 2015, Introduction to Operations Research, 10th ed., McGraw-Hill, Singapore.

Jamali, N., Leung, R.K., Verderber, S., 2020, A review of computerized hospital layout modelling techniques and their ethical implications. Frontiers of Architectural Research. 9(3), 498-513, https://doi.org/10.1016/j.foar.2020.01.003

Kasemset, C., Pangsuta, T., Boonmee, C., 2021, The application of revenue management in chilled storage area allocation: simulation study. CMUJ. Nat. Sci, 20(2), e2021029, https://doi.org/10.12982/CMUJNS.2021.029

Katsaliaki, K, Mustafee, N., 2011, Applications of simulation within the healthcare context. Journal of the Operational Research Society, 62 (8), 1431-1451, https://doi.org/10.1057/jors.2010.20

Kelton, W. D., Sadowski, R. P., Swets, N. B., 2010, Simulation with Arena, 5th ed., McGraw Hill.

Lagergren, M., 1998, What is the role and contribution of models to management and research in the health services? A view from Europe, European Journal of Operational Research, 105(2), 257-266, https://doi.org/10.1016/S0377-2217(97)00233-6

Law, A. M., McComas, M. G., 1987, Simulation of manufacturing systems. In Proceedings of the 19th conference on Winter simulation, 631-643, https://doi.org/10.1145/318371.318675

Lin, Q., Wang, D., 2019, Facility layout planning with SHELL and Fuzzy AHP method based on human reliability for operating theatre. Journal of Healthcare Engineering, 2019, https://doi.org/10.1155/2019/8563528

Luo, L., Luo, L., Zhang, X., He, X., 2017, Hospital daily outpatient visits forecasting using a combinatorial model based on ARIMA and SES models. BMC Health Services Research, 17(1), 1-13, https://doi.org/10.1186/s12913-017-2407-9

Mikell, P. G., 2014, Work systems. the methods, measurement and management of work. Pearson.

Montgomery, D. C., Runger, G. C., 2014, Applied statistics and probability for engineers, 6th ed., Wiley, Singapore.

Motaghi, M., Hamzenejad, A., Riyahi, L., Soheili, K. M., 2011, Optimization of hospital layout through the application of heuristic techniques (Diamond Algorithm) in Shafa hospital (2009). International Journal of Management and Business Research Summer 2011, 1(3), 133-138.

Murphy, D.R., Klein, R.W., Smolen, L J., Klein, T.M., Roberts, S.D., 2013, Using common random numbers in health care cost - effectiveness simulation modeling. Health Services Research, 48(4), 1508-1525, https://doi.org/10.1111/1475-6773.12044

Muther, R., 1955, Practical plant layout. McGraw-Hill College.

Nanda, S., Miller, A., 1996, Risk analysis in the valuation of medical practices, Health Care Management Review, 21(4), 26-32, https://www.jstor.org/stable/44950790

Sepúlveda, J. A., Thompson, W. J., Baesler, F. F., Alvarez, M. I., Cahoon, L. E., 1999, The use of simulation for process improvement in a cancer treatment center. In 1999 Winter Simulation Conference Proceedings. 'Simulation- A Bridge to the Future`, 1541-1548, https://doi.org/10.1109/WSC.1999.816890

Soriano-Meier, H., Forrester, P. L., Markose, S., Garza-Reyes, J.A., 2011, The role of the physical layout in the implementation of lean management initiatives. International Journal of Lean Six Sigma, 2(3), 254-269, https://doi.org/10.1108/20401461111157204

Sower, V., Duffy, J., Kilbourne, W., Kohers, G., Jones, P., 2001, The dimensions of service quality for hospitals: development and use of the KQCAH scale. Health Care Management Review, 26(2), 47-59, https://www.jstor.org/stable/44951016

Sugandhi, S. D., Bharule, A., 2016, Fine blanking plant layout improvement using systematic layout planning. International Journal of Scientific Engineering and Research (IJSER), 4(4), 1-4, https://www.ijser.in/archives/v4i4/IJSER15735.pdf.

Tompkins, J. A., White, J. A., Bozer, Y. A., Tanchoco, J. M. A., 2010, Facilities planning. John Wiley and Sons.

Tsui, Y.M., Fong, B.Y., 2018, Waiting time in public hospitals: case study of total joint replacement in Hong Kong. Public Administration and Policy, 21(2), 120-133, https://doi.org/10.1108/PAP-10-2018-009

Vahdat, V., Namin, A., Azghandi, R., Griffin, J., 2019, Improving patient timeliness of care through efficient outpatient clinic layout design using data-driven simulation and optimization. Health Systems, 8(3), 162-183, https://doi.org/10.1080/20476965.2018.1561160

Ward, K.F., Rolland, E., Patterson, R.A., 2005, Improving outpatient health care quality: understanding the quality dimensions. Health Care Management Review, 30(4), 361-371.

Zhao, Y., Mourshed, M., Wright, J., 2009, Factors influencing the design of spatial layouts in healthcare buildings. In Proceedings of the 25th Annual ARCOM Conference. Association of Researchers in Construction Management, 1041-1049.

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