Intensive Care Unit (ICU) Patient Monitoring Improvement Using Internet of Things (IOT) Based on BPR Approach

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Abstract

A small delay of the Intensive Care Unit (ICU) patient deterioration recognition can cause a permanent disability or even death. Therefore, patient monitoring is the most critical process in ICU. Human-related monitoring failures mostly cause delayed recognition of ICU patients. A higher workload in ICU leads to health professional burnout that could result in lousy healthcare quality. Internet of Things (IoT) implementation in the ICU monitoring process is expected to reduce the health workforce's workload and patient monitoring process time. This paper aims to improve the operational process of ICU monitoring through IoT implementation with the Business Process Reengineering (BPR) approach in one of Jakarta's private hospitals. The Complex Proportional Assessment (COPRAS) method is used to prioritize the risks of the current monitoring process to select the suitable IoT. This research proposes three business process models that utilize IoT-Based Patient Monitoring, Intelligent Monitoring Analytics, and a combination of both. A combination of IoT-Based Patient Monitoring and Intelligent Monitoring Analytics results the greatest process time reduction at 37.10%. Intelligent Monitoring Analytics results the smallest process time reduction at 11.56%.

Keywords
Patient Monitoring, Intensive Care Unit (ICU), Internet of Things (IoT), Business Process Reengineering (BPR), Multicriteria Decision Making (MCDM), Comparative Proportional Assessment (COPRAS).

1. Introduction
ICU is an important hospital unit that provides critical care and life support for patients who suffer a critical illness. The most crucial ICU activity is patient monitoring since the smallest delay of a patient's health deterioration can lead to death. Delayed recognition of ICU patients' deterioration is mostly caused by human-related monitoring failures (Van Galen et al., 2016). Numerous surveys demonstrate the high workload experienced by ICU health professionals, which is a cause of burnout. In 2015, Siloam Hospital Manado's number of deaths from 265 ICU patients was 49. One of the reasons was a medical error due to high workload, more than each staff can bear (Nursalim et al., 2015). There should be a solution to improve the ICU monitoring process to prevent delayed recognition and reduce ICU professionals' workload.

Internet of Things is a concept in which humans, objects, and everything connected via the internet are well integrated and can exchange information (Lee and Kim 2018). IoT has propitious advantages for the ICU monitoring process. It eases patient monitoring, reduces manual work, and reduces errors (Prajapati et al. 2017). Furthermore, IoT facilitates a proactive framework of medical practice and enables patient treatment's personalization (Ahouandjinou et al. 2017). Many countries have invested IoT in their healthcare system. Southern Hills Hospital, Las Vegas, was developing technology in the form of an IoT-based headband that is used to reduce pain in patients (GlobeNewswire 2015). China has invested heavily in healthcare industry IoT solutions, from digital health records to smartphone attachments reading EKGs and temperatures (D'mello 2020). Smart medical bed (Hillrom, 2020) and IoT-based patient monitoring (Prajapati et al. 2017) are examples of IoT systems suitable to be implemented in the ICU.

The use and adoption of IoT technology in healthcare keep increasing over the years because it is a new trend technology that can be utilized in the healthcare sector to improve healthcare quality, organizational performance, and healthcare society in general (Van Os et al. 2015). Indonesia is currently being emphasized to be able to compete with foreign hospitals with efforts to improve hospitality in hospitals. One of the efforts to improve hospital service is by implementing technology (Taufiqqurrahman 2019).

This study aims to design an improvement in ICU patient monitoring's operational processes through the adoption of IoT with the Business Process Reengineering approach. The data is obtained through in-depth interviews with ICU personnel, historical data, and questionnaire distribution to the experts who are involved in the ICU monitoring process. BPR is defined as the critical analysis and radical redesign of existing business processes to achieve breakthroughs (Teng et al. 1994). Previous researches had proved that BPR could improve healthcare processes (Arovah and Dachyar 2020, Dachyar et al. 2018, Dachyar and Novita 2016, Putro and Dachyar 2020, Salsabila & Dachyar 2020).

2. Literature Review

2.1. ICU

An intensive care unit (ICU) is an organized system for the provision of care to critically ill patients that provides intensive and specialized medical and nursing care, an enhanced capacity for monitoring, and multiple modalities of physiologic organ support to sustain life during a period of acute organ system insufficiency clinic (Marshall et al. 2017). Ministry of Health defined Intensive Care Unit as a part of the hospital building with critical service categories, apart from surgical installations and emergency departments (Ministry of Health 2010).

2.2. ICU Patient Monitoring

Monitoring is crucial for the daily care of ICU patients, as the optimization of hemodynamics, ventilation, temperature, nutrition, and metabolism of patients is the key to improving patient survival (Kipnis et al. 2012). The parameter that needs to be monitored is the vital signs of ICU patients, including temperature, blood pressure, heart rate, pulse, respiratory rate, and oxygen saturation.

2.3. Internet of Things

The Internet of Things (IoT) defined as the physical object network that is embedded with sensors, software, and other technology in order to communicate and exchange data over the internet with other devices or systems. IoT is based on integrations of various processes such as identifying, sensing, networking, and computation. It enables large-scale of technological innovations and value-added services which personalize users' interaction with various "things" (Farhan et al. 2018).

2.4. Business Process Reengineering

The critical analysis and radical redesign of existing business processes to achieve breakthrough (Teng et al. 1994). BPR has been one of the most discussed concepts in business and academic literature throughout the 1990s. BPR is known by many names, such as "core process redesign", "new industrial engineering" or "working smarter". BPR is commonly viewed as a top-down solution from a management perspective (AbdEllatif et al. 2018).

3. Methods

This research follows the BPR approach in three main stages. The first stage is mapping the as-is process. In mapping the as-is process, the current ICU patient monitoring model is created and simulated to know the particular process's flow and time. The second stage is analyzing the as-is process using Complex Proportional Assessment (COPRAS) to identify and rate the potential risks of the current process. The significant risks are the ones that are given the proposed IoT system that is expected to reduce those risks. The last stage is designing the to-be model by modifying the as-is model with three IoT implementation strategies. The model flow is created using Business Process Modeling Notation (BPMN) and simulated in iGrafx software.

4. Data Collection

Due to the hospital restriction regarding COVID-19, the process could not be observed on-site. The current monitoring process flow was defined through an in-depth interview with ICU personnel. The flow was mapped through Flow Process Chart that depicts process stages along with their process types that happen in the Intensive Care Unit. There are 14 operations, 1 movement, 5 inspections, and 1 delay. Two actors who are involved in ICU patient monitoring are nurse and doctor. The processes' times were based on the historical data. The distributions were identified using Minitab software. The processes time that were not documented were identified through questionnaire (see Table 1). The process time that had been determined might be overestimated or underestimated since it doesn't consider the allowance time for each process.

Table 1. Process Time & Distribution

Actor	No. Process	Process	Time (Minute)
Nurse	1	Set up the monitoring device	
	1.1	Set the upper limit for vital signs	Normal (0.73, 0.26)
	1.2	Set the lower limit for vital signs	Normal (0.63, 0.21)
	2	Attach device to patient's body	Triangular (1, 3, 1.5)
	3	Check the monitoring accuracy	Normal (1.91,0.81)
	4	Fix device installation on patient's body	Uniform (0.3, 4)
	5	Input monitoring results to medical health records	Uniform (1.5, 2.5)
	6	Evaluate patient's actual condition	
	6.1	Match the monitoring results with actual condition	Normal (1.37, 0.34)
	6.2	Compare each vital sign with another	Normal (1.74, 0.1)
	6.3	Determine whether the patient needs doctor or not	Lognormal (1.40, 0.27)
	7	Determine patient's handling	Normal (1.37, 0.04)
	8	Check where the responsible doctor is	Uniform (0.1-0.5)
	9	Call the doctor	Uniform (1, 1.5)
	10	Inform the doctor directly	Uniform (0.5, 1)
	11	Prepare equipments needed by doctor to examine patient	Triangular (2, 2.5, 2.2)
	12	Wait until the doctor arrives	Uniform (0.3, 1.5)
	13	Give the equipments to the doctor	Uniform (0.1, 0.5)
Doctor	14	Examine patient's health condition	Weibull(20.70,1.95)
	15	Analyze patient's health condition	Lognormal (2.45, 0.29)
	16	Determine response action	Lognormal (2.47,0.27)

The risk was assessed based on several criteria that were collected from several references. 4 nurses and 3 doctors are the experts for criteria validation. These are the criteria that had been validated by the experts to assess the risks (see Table 2).

Table 2. Risk Criteria

Criteria that Affect Risks	Reference
Probability of occurance	(Asefzadeh et al. 2013, Barcellos et al. 2016; Begum, 2017)
Impact on patient's safety	(Asefzadeh et al. 2013; Barcellos et al. 2016; Rodriguez-Paz & Dorman 2008)
Impact on hospital reputation	(BÜYÜKDOĞAN et al. 2017; De Cruppé and Geraedts 2017, Shan et al. 2016)
healthcare quality given	(Asefzadeh et al. 2013, Jensen et al. 2017, Shan et al. 2016)

The potential risks of ICU patient monitoring were also collected from various references. The following table shows the potential risks in ICU patient that had been validated by the experts to assess the risks (see Table 3). The experts who validated the risks are the same with criteria validation experts.

Table 3. Potential Risks

Potential Risk	Reference
Monitoring alarm malfunction (no alarm)	(Asefzadeh et al. 2013, Schmid et al. 2013, Stokes et al. 2017)
Failure to identify the type of alarm by the nurse	(Asefzadeh et al. 2013, De Silva et al. 2015, Salous et al. 2017)
Failure to assess and treat pain adequately	(Bambi et al. 2019, Olusegun et al. 2012, Vázquez-Valencia et al. 2018)
System disconnections	(Asefzadeh et al. 2013, Moyen et al. 2008, Vázquez-Valencia et al. 2018)
Late detection of patient deterioration	(Elliott and Coventry 2012, Keim-malpass et al. 2020, Moyen et al. 2008)
Lack of coordination among healthcare team members	(Asefzadeh et al. 2013, Miller et al. 2010, Valiee et al. 2014)
Delays in care / visit	(Chan et al. 2017, Corwin et al. 2017, Yousefinezhadi et al. 2016)
Wrong dose of Medication	(Bratu et al. 2019, Corwin et al. 2017, MacFie et al. 2016)
Medication administration error	(MacFie et al. 2016, Moatari-Kazerouni and Bendavid 2017; Shahin 2019)
Inadequate written or oral communication	(Asefzadeh et al. 2013, Hendel and Flanagan 2009, Meier 2006)
lack of proper equipment or equipment failure	(Asefzadeh et al. 2013, Ribeiro et al. 2018, Thomas and Galvin 2008)
Exhaustion due to the work pressure	(Colville et al. 2017, Khorasani et al. 2014, Tutiany et al. 2017)
Nurse & doctor negligence / carelessness	(Huang et al. 2015, Khorasani et al. 2014, Oyebode 2013)

5. Results and Discussion

5.1. Mapping As-Is Model

The ICU patient monitoring process (see Figure 1) starts when the nurse sets up the monitoring device by setting the patient's vital signs' limits. The device has to be connected to patients by attaching it to the patient's body to retrieve vital signs' real time data. Nurse gets notification and alarm through their screen when the condition of patient vital signs is abnormal or exceeds the limits specified. The nurse checks the monitoring accuracy. If the alarm is caused by an incorrect device installation, the nurse will fix the installation. The nurse inputs the monitoring results to the medical record system. She checks the patient's actual conditions by matching the monitoring results with the real patient condition, comparing every vital sign with the others, and determining whether the patient's condition requires a doctor's examination. If not, the nurse will determine which treatment is suitable for the patient's condition. If the patient needs a doctor, the nurse has to check the responsible doctor's location. If the doctor present in the room, the nurse will inform the doctor regarding the patient's condition directly. If the doctor is away, the nurse will tell the doctor through a phone call. After that, the nurse will prepare the equipment that is needed and give them to the doctor. The doctor will examine the patient's condition and analyze the results of the examination. Eventually, the doctor will determine the response action for the patient.

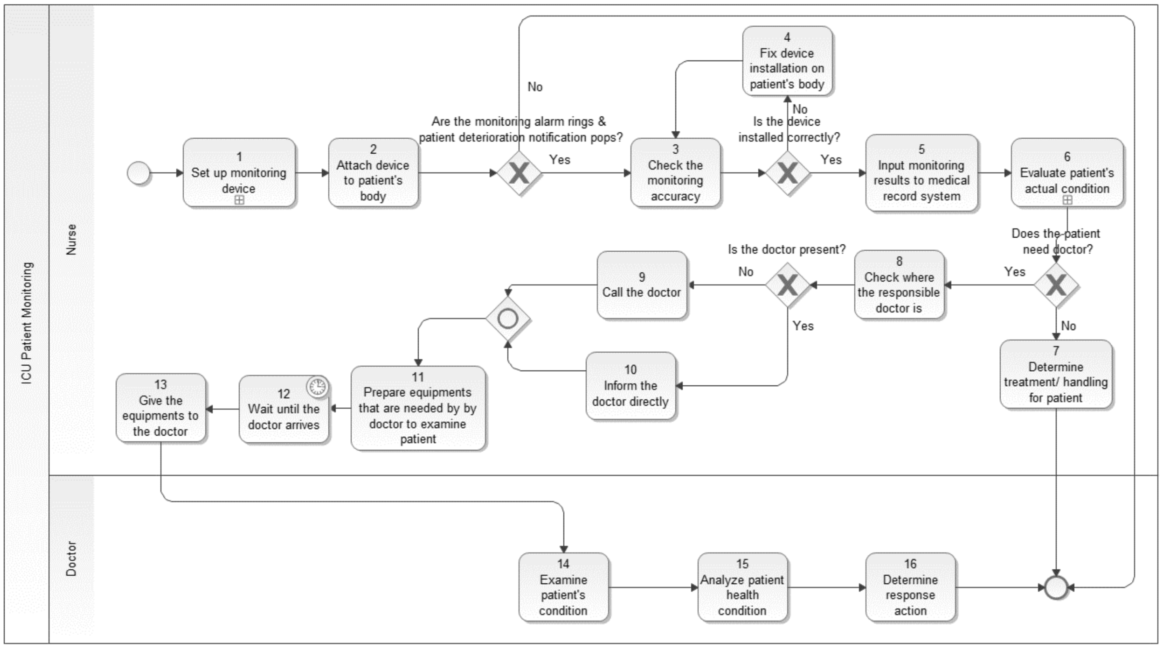

Figure 1. As-Is Model of ICU Patient Monitoring

The model was simulated to know the time taken to perform patient monitoring from end to end. The simulation result shows that it takes 28.12 minutes to complete monitoring for ICU patients, on average. The process times of the nurse and the doctors are 21.59 minutes and 6.53 minutes, respectively. Nurse's activities take more time than doctors since most activities in this monitoring process are performed by the nurse (see Table 4). The doctor has more focus on the patient handling process as a follow up for this monitoring process.

Table 4. As-Is Model Simulation Result

Process	Swimlane	Avg Cycle (Minute)
ICU Patient Monitoring	Nurse	21.59
	Doctor	6.53

5.2. Analyzing As-Is Model

The simulation result shows that it takes 28.12 minutes to monitor the patient in ICU. ICU personnel said that the monitoring time might be longer if there are many patients whose health conditions deteriorate simultaneously. In such a situation, the patient's waiting time to be treated becomes longer. It endangers the critically ill patients since their deteriorations must be given the follow-up actions in a fast and correct manner. There are 5 criteria used as the aspects to assess the risks in ICU patient monitoring: the probability of occurrence, impact on patient's safety, impact on patient's satisfaction, impact on hospital reputation, and healthcare quality. Impact on patient satisfaction was eliminated since it is not considered the top priority for the hospital in providing healthcare. The possible risks in the as-is process or affected by the as-is process were identified. Through a literature review, 18 potential risks were determined, and 13 potential risks were validated by the experts, consisting of doctors and nurses involved in ICU patient monitoring. Every criterion to assess the risks was weighted using the AHP method, whereas the potential risks were prioritized using COPRAS to determine their significances.

The potential risks with a score that exceeds the geomean out of all the risks score were processed further. They were given proposed IoT technologies that are expected to reduce those risks, if there is an available IoT that have the capabilities needed. If one of the values is below the overall geomean value or there is no IoT technology that is able to reduce the risk, the risks will be eliminated. Relative Priority (Qi) represents the priority score for individual risks, and Absolute Priority (Ui) is the comparison between individual score and maximum score in percentage.

The 7 risks that were accepted occurred in both of nurse and doctor lanes. There were 2 risks that were not given the IoT improvement since there is no available IoT that is able to reduce such risks' probability of happening in the particular ICU. As a result, the IoT technologies which have suitable functions to reduce the significant risks are IoT-based patient monitoring and intelligent monitoring analytics (see Table 5).

Table 5. Accepted Risks & Proposed IoT Improvement

Reference	Potential Risk	Qi	Ui (%)	Decision	Suitable IoT
(Asefzadeh et al., 2013; Schmid et al., 2013; Stokes et al., 2017)	Monitoring alarm malfunction (no alarm)	0.808	87.981	Accept	IoT-Based Patient Monitoring
(Asefzadeh et al., 2013; De Silva et al., 2015; Salous et al., 2017)	Failure to identify the type of alarm by the nurse	0.824	89.826	Accept	No suitable IoT
(Bambi et al., 2019; Olusegun et al., 2012; Vázquez-Valencia et al., 2018)	Failure to assess and treat pain adequately	0.828	90.189	Accept	Intelligent Monitoring Analytics
(Asefzadeh et al., 2013; Moyen et al., 2008; Vázquez-Valencia et al., 2018)	System disconnections	0.867	94.485	Accept	No suitable IoT
(Elliott & Coventry, 2012; Keim-malpass et al., 2020; Moyen et al., 2008)	Late detection of patient deterioration	0.841	91.635	Accept	IoT-Based Patient Monitoring
(Asefzadeh et al., 2013; Miller et al., 2010; Valiee et al., 2014)	Lack of coordination among healthcare team members	0.827	90.135	Accept	IoT-Based Patient Monitoring
(Chan et al., 2017; Corwin et al., 2017; Yousefinezhadi et al., 2016)	Delays in care / visit	0.781	85.117	Reject	-
(Bratu et al., 2019; Corwin et al., 2017; MacFie et al., 2016)	Wrong dose of Medication	0.730	79.586	Reject	
(MacFie et al., 2016; Moatari-Kazerouni & Bendavid, 2017; Shahin, 2019)	Medication administration error	0.737	80.267	Reject	
(Asefzadeh et al., 2013; Hendel & Flanagan, 2009; Meier, 2006)	Inadequate written or oral communication	0.918	100.000	Accept	IoT-Based Patient Monitoring

Reference	Potential Risk	Qi	Ui (%)	Decision	Suitable IoT
(Asefzadeh et al., 2013; Ribeiro et al., 2018; Thomas & Galvin, 2008)	lack of proper equipment or equipment failure	0.787	85.705	Reject	-
(Colville et al., 2017; Khorasani et al., 2014; Tutiany et al., 2017)	Exhaustion due to the work pressure	0.767	83.559	Reject	
(Huang et al., 2015; Khorasani et al., 2014; Oyebode, 2013)	Nurse & doctor negligence / carelessness	0.753	82.021	Reject	

5.3. Designing To-Be Model

The formulation of the to-be model was carried out based on the proposed improvement results based on significant risks. Based on the proposed improvements from data processing previously, there were two proposed IoT technologies: IoT-based patient monitoring and intelligent monitoring analytics. Three are three strategies proposed as follows (see Table 6).

Table 6. To-Be Scenarios

Code	Scenario	IoT-Based Patient monitoring	Intelligent Monitoring Analytics
S1	Scenario 1	✓	
S2	Scenario 2		✓
S3	Scenario 3	✓	✓

IoT-based patient monitoring system that was proposed by Prajapati et al. (2017) can help speed up communication, identify emergencies, ease communication with healthcare staff, and initiate proactive and quick treatment. This proposed system gathers data through bedside patient monitors. The data will then be processed further to produce output, notification, or signal to a particular monitoring cell or nurse and doctor. IoT-based patient monitoring can improve monitoring data record and the flow of monitoring information (Prajapati et al. 2017).

da Costa et al. (2018) developed intelligent monitoring analytics system that processes the monitoring data collected through a monitoring device. It consists of interconnected objects with the capacity of exchanging and processing data to improve patients' health. IoT based monitoring analytics involves four distinct layers which are acquisition, storage, processing, presentation. It uses intelligent algorithms based on machine learning techniques that are expected to perform advanced data fusion and predictive analytics to facilitate a better inference of patient health deterioration. It can improve the analysis process of patient's health (da Costa et al. 2018).

The improved process was created for each scenario by implementing the chosen IoT technologies (see Figure 2). Circle outline indicates the eliminated processes, whereas the rectangle outline suggests that there's a time reduction in those particular processes. IoT-based patient monitoring can simplify the monitoring process by eliminating 5 processes. Intelligent monitoring analytics only managed to reduce the time of 2 processes and eliminate 1 process.

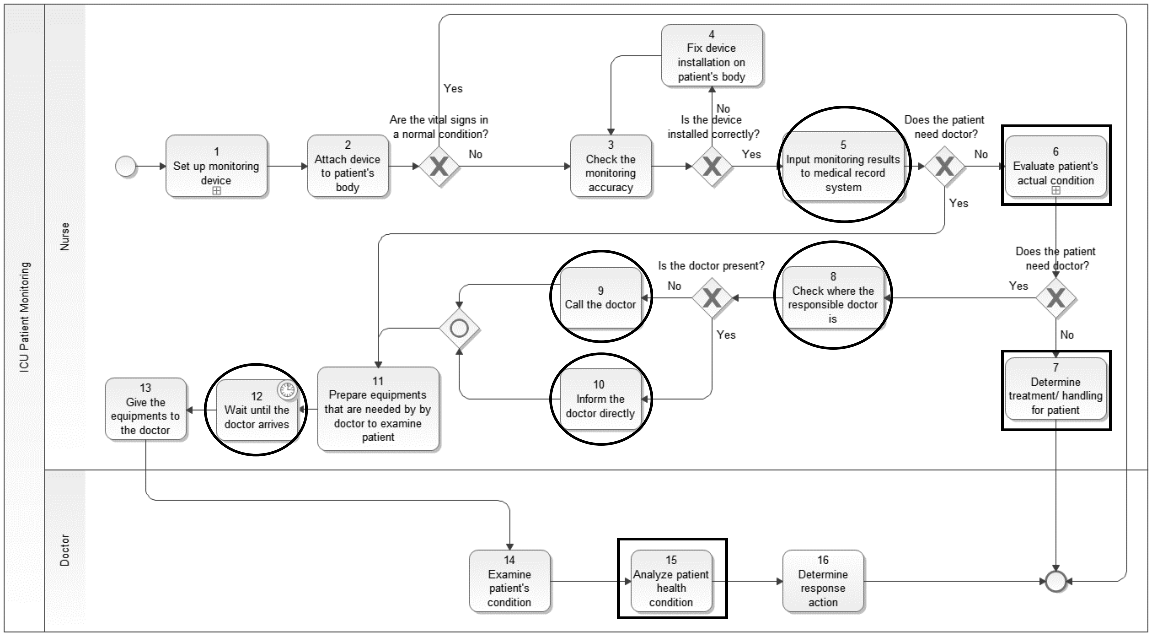

Figure 2. To-Be Model of ICU Patient Monitoring

There are several changes in to-be model as compared to the as-is model (see Table 7).

Table 7. Changes in To-Be Model

IoT Technologies	Lane (Actor)	Changes in The Model
IoT-Based Patient Monitoring	Nurse	Eliminate manual monitoring result input. The result will be recorded automatically by the system.
		Eliminate determine whether the patient need doctor or not. Intelligent software agent will determine patient's need.
		Eliminate doctor location check, the doctor will be notified directly by the system.
		Eliminate inform the doctor, the doctor will be notified directly by the system.
		Eliminate wait for the doctor since the doctor is expected to get ready after being notified.
Intelligent Monitoring Analytics		Eliminate manual monitoring result input. The result will be recorded automatically by the system.
		Reduce the time of patient's handling determination since the system will perform patient's data analytics
	Doctor	Reduce the time of patient's condition analysis, since the system will perform patient's data analytics.

Scenario 3, which implements both IoT technologies, results in the greatest time reduction. Simulation results recapitulation of all scenarios (see Table 8) shows that scenario 1 & 3 results in a significant time reduction compared to scenario 2, which only caused a small-time decrease in the overall process time. The notable time reductions are due to IoT-based patient monitoring implementation both in scenario 1 and scenario 3. Nonetheless, both IoT-based patient monitoring and intelligent monitoring analytics can improve ICU patient monitoring time efficiency and decrease the likelihood of human error that may occur.

Table 8. Simulation Results Recapitulation

Process	As-Is Model	To-Be Model					
	Avg Cycle (min)	Avg. Cycle (min)			% Change		
		S1	S2	S3	S1	S2	S3
Total	28.12	18.93	24.87	17.70	32.68%	11.56%	37.10%

Implementing IoT-based patient monitoring in the ICU will prevent delayed patient deterioration and reduce patients' waiting time to be treated. It is also will decrease the workload of ICU professionals significantly. On the other hand, implementing intelligent monitoring analytics will only shorten patients' waiting time to be treated. Implementing both of the IoT technologies at the same time costs a great deal of money, and it is likely for the system to be hindered due to the difficulties faced by ICU personnel in adapting two new technologies concurrently.

6. Conclusion

This research proposed improving the ICU monitoring process by preventing delayed patient deterioration recognition and reducing patient's waiting time to be treated by applying IoT technology. The improved processes were designed based on the BPR approach through three kinds of scenarios. The research proved that prioritizing the risks using COPRAS of the current process eases the IoT selection in order to achieve the research goal.

Scenario 3 results in the greatest time reduction at 37% (IoT-based patient monitoring and intelligent monitoring analytics). On the contrary, the least time reduction is at 11%, which belongs to scenario 2. IoT-based patient monitoring contributes the most time reduction of the ICU patient monitoring process.

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