Priority Design of the Telehealth-based Internet of Things Implementation for Hospital Pulmonology Unit

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Abstract

Indonesia is currently facing the COVID-19 virus and tuberculosis outbreaks, affecting the healthcare staff's shortages, especially in the pulmonology unit. To reduce the healthcare staff's workload, it is considered necessary to research Telehealth's implementation based on the Internet of Things. This paper aims to design priority of the Telehealth-based Internet of Things implementation in hospital pulmonology unit with the IoT application criteria consideration using Multi-Criteria Decision-Making approach. This paper uses the combination of the Fuzzy AHP method (Analytical Hierarchy Process) and the COPRAS (Complex Proportional Assessment) method. Fuzzy AHP method is used to assess the importance level of the criteria and sub-criteria for IoT implementation in one of Jakarta's private hospitals. COPRAS method is applied as an alternative priority ranking method for applying the Internet of Things to improve healthcare services. This paper obtains four IoT alternatives priority order that is appropriate in one of Jakarta's private hospitals.

Keywords
Hospital Pulmonology Unit, Internet of Things, Multi-Criteria Decision Making, Fuzzy AHP Method, COPRAS Method

1. Introduction

In 2020, Indonesia was ranked fourth with a population of 273 million, with an average population growth around 1.07%. The United Nation projects that the world's population will increase more than 10 times within 250 years (United Nation 2019). However, according to BAPPENAS, Indonesia is projected to show that the mortality rate will continue to increase to reach 3% until 2045. (BAPPENAS 2018)

Talking about the current situation, the world recently has been shocked by the new Covid-19 virus's presence, which causes infections of the human respiratory tract and has plagued 188 countries. In Indonesia, the Covid-19 virus was recorded up to 700 thousand in the end of October 2020 with 21 thousand deaths. As early September 2020, at least 100 doctors died due to the exposure to Covid-19 in Indonesia (CNN Indonesia 2020). Besides, Indonesia also needs to be alert in dealing with Tuberculosis. Indonesian Tuberculosis statistics recorded that as of March 20, 2020, the estimated tuberculosis cases had jumped to 845,000 cases, where the highest cases were in DKI Jakarta and its surroundings (TBIndonesia 2020). This is quite worrying if it is correlated with Indonesia's government plan to be free of tuberculosis by 2030.

With the increasing number of deadly diseases in Indonesia and supported by the pandemic that is currently endemic, the need for health services will also increase dramatically. In terms of quantity, hospitals tend to experience an average increase of 15.6% throughout 2015-2019 (Ministry of Health 2019). One of the US Institute of Medicine findings stated that medical errors continue as the number 3 killer that kills about 400,000 people each year (CNBC 2018). The current condition in Indonesia is also overwhelmed due to the spike in Covid-19 cases. Due to the possibility of error and the limits of human capabilities, healthcare requires automation where devices can collect their data, reducing the risk of errors and assisting operational services.

IoT-based Telehealth is the delivery of remote health care services that use information and communication technology as a valid information exchange medium to improve quality, cost-effective health services, wherever they are (WHO 2016). During the COVID-19 pandemic, Telehealth technology has become an important defense against the virus. Telehealth use connects remote specialists for emergency assistance, enables healthcare workers to avoid exposure to pathogens, and provides ongoing care for patients with chronic diseases. However, not all hospitals can immediately implement IoT technology. Non-technical barriers such as organizational problems, financing, and user experience need to be considered before implementing IoT.

The rapid increase in cases of human respiratory tract diseases in Indonesia causes high mortality rates, also decreasing in medical personnel services quality. This encourages the urgency of developing automation by implementing Telehealth based on the Internet of Things to help medical personnel handle lung unit patients to improve service quality, wherein its implementation is necessary to consider the factors of applying IoT wisely.

1.1 Objectives

This study aims to design priority options for implementing Internet of Things (IoT)-based Telehealth for remote patient monitoring in hospital pulmonology unit to improve service quality.

2. Literature Review

2.1 Internet Of Things

Internet of Things is a network of objects connected to the internet and can communicate with each other to achieve a goal without human intervention (Naveen & Hegde 2016). The Internet of Things strives to provide an age in which digital and physical entities will seamlessly communicate to provide new domains of applications and services (Alam et al. 2020). Most IoT systems currently exist for the patient and device monitoring, energy use scanners, and location-based services (Dachyar & Azizia 2019). About 60% of health care organizations have applied the Internet of Things (IoT) to their facilities and recognize the benefits (Dachyar & Nattaya 2020).

Telehealth is defined as a telecommunications technology used to improve health information and health services in areas with geography, access, and social. (Hariyati & Sahar 2012). Homecare services using Telehealth have an indirect impact on nurses, such as improving service quality because there is no patient overload in health services. Some benefits of using the Telehealth application as homecare services (Farrar 2015) such as:
1. Effective in modality therapeutic interventions
2. Increase patient awareness for medication adherence and reduce complications
3. Become a monitoring system services for patients with chronic disease
4. Effectively providing health interventions that occur at the same time
5. Provide time effectiveness and efficiency of intervention, as it is carried out flexibly

2.2 Technology Adoption Theory

The TOE framework suggests that technological, organizational, and environmental factors include constraints that serve as both barriers and opportunities gained from technological innovation, thus collectively influencing how companies realize the need to adopt new technology (Hiran & Henten 2020). The TAM framework proposes perceived usefulness (PU) and perceived ease of use (PEOU) as the fundamental determinants of IT adoption. Perceived usefulness (PU) refers to how technology can help users improve their job performance, and perceived ease of use (PEOU) represents how easy the technology can be used or operated by the user (Okorie Awa et al. 2012).

2.3 Multi Criteria Decision Making

Multi-Criteria Decision Making is a set of methods for dealing with evaluating a series of alternatives that many, often contradictory, and various criteria. The purpose of the Multi-Criteria Decision Making is to provide choices, ratings, descriptions, classification, grouping, and to sort alternatives from the most preferred to the least select option (Mulliner et al. 2016).

Among them are several MCDM methods that have been widely used such as the Analytical Hierarchy Process (AHP), Analytical Network Process (ANP), Preference Ranking Organization Method for Enrichment of Evaluations (PROMETHEE), Vlsekriterijumska Optimizacija I Kompromisno Resenje (VIKOR), Elimination Et Choix Traduisant la Realite (ELECTRE), Best Worst Method (BWM), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Decision Making Trial and Evaluation Laboratory (DEMATEL) (Emovon & Oghenenyerovwho 2020).

The MCDM method classifies into the MADM method (Multi-attribute Decision Making) and the MODM (Multi-purpose Decision Making) method. MADM methods can be classified into different groups according to similar characteristics. (Penadés-plà et al. 2016).

2.4 Fuzzy Analytical Hierarchy Process

Analytic Hierarchy Process (AHP) is a multi-criteria decision-making tool (MCDM) to provide subjective judgments on one criterion over another using an approach to eigenvalues for pairwise comparisons. (Contreras-Nieto et al. 2019). AHP considers a set of evaluation criteria and alternatives between which will make the best decision. AHP generates weights for each evaluation criterion according to the pairwise comparison of criteria decision-makers (Das et al. 2012).

However, the AHP method does not account for uncertainty assessment in decision-making by using crisp variables. Therefore fuzzy AHP technique can be seen as a continuation of the analysis methods development that consider the uncertainty of AHP method (Ahmad & Shahzad Siddiqui 2017). Triangular fuzzy numbers (TFN) is a fuzzy set theory that assist in the measurement associated with human subjective assessment of linguistic numbers (Kabir & Sultana 2014).

2.5 Complex Proportional Assessment

The complex proportional preference ranking method (COPRAS) developed by Zavadskas et al. in 1996 assumed a direct and proportional dependence of the significance and utility level of each alternative on the existence of conflicting criteria, positive and negative (Nguyen et al. 2015). The ideal solution on COPRAS method is minimize the costs and maximize the benefits criteria (Yazdani-Chamzini et al. 2013). One of the advantages that make the COPRAS method superior to the other methods is that it can be used to estimate the usefulness of an alternative, which shows how one alternative is better or worse than another (Yazdani et al. 2017).

3. Methods

The research map into several stages consists of the initial stage of the research, the data collection stage, the data processing stage, and the research's final stage.

The initial stage of research is in the form of literature studies in determining topics, problem formulation, objectives, and research methods. The collection stage includes collecting criteria through a literature study on previous research about criteria IoT adoption in healthcare service and distributing research questionnaires. Questionnaires were collected among several experts in the pulmonology unit to obtain criteria validation, calculate the weight of criteria, and rank IoT-based Telehealth alternatives. The data processing stage uses the integration of the Fuzzy AHP method in calculating the importance of the criteria, with the COPRAS method to rank IoT-based Telehealth alternatives. The last stage is the analysis of research results and conclusions.

Fuzzy Analytical Hierarchy Process (Fuzzy AHP) is used to see the level of importance of each criterion and sub-criterion IoT-based Telehealth implementation. The expert will answer the questionnaire about pairwise comparison among criteria and sub-criteria, which then be processed using the Fuzzy AHP method. The results of processing the questionnaire data with Fuzzy AHP are the weighted values for each criterion and sub-criterion, which will be used in IoT-based Telehealth alternatives priority assessments using the COPRAS method.

The COPRAS (Complex Proportional Assessment) method will generate performance scores for each alternative based on a literature study. The experts fill out the questionnaire regarding each alternative point towards each criterion and sub-criterion. This method results in the priority assessment of IoT-based Telehealth alternatives, where the highest relative significance value is deemed the best alternative priority to be implemented in the hospital pulmonology unit with 100% utility rate.

4. Data Collection

4.1 Criteria and Sub-criteria

Conduct literature studies on previous studies to determine the criteria for adopting IoT devices based on integrating the Technology-Organization-Environment framework, Technology Acceptance Model, and Security. The integration of the framework is carried out to obtain a more accurate criteria analysis result. Experts validated the sub-criteria using 5-point Likert scale, where the minimum threshold for sub-criteria acceptance used in the study was 3.5 (Dachyar & Risky 2014). Criteria and sub-criteria validation are listed in Table 1.

Table 1. Selected Criteria and Sub-criteria

Criteria	Sub-criteria
Technology (C1)	Vulnerability (T1)
	Technology Innovation (T2)
	Reliability (T3)
	Interoperability (T4)
Organization (C2)	Top Management Support (O1)
	IT Support (O2)
	Financial Readiness (O3)
	Cost (O4)
	User Innovativeness (O5)
Environment (C3)	Competitive Pressure (E1)
	Government Policy (E2)
	Industry Support (E3)
	Social Persuasion (E4)
Safety (C4)	Trust in Technology (S1)
	Privacy (S2)
	User Safety (S3)
	Data Security (S4)
	System Security (S5)
	Accountability (S6)
Perceived of Usefulness (C5)	Efficiency (PU1)
	Perceived Benefit (PU2)
	Time Saving (PU3)
	Responsive (PU4)
Perceived Ease of Use (C6)	Usability (PE1)
	Accessibility (PE2)
	User Interface (PE3)
	Customization (PE4)
	Effort Expectancy (PE5)

It is found that 28 sub-criteria and 6 criteria will be further processed in this research. Each of the criteria and sub-criteria weights will be calculated based on the experts assessments.

4.2 IoT-based Telehealth Alternatives

The proposed alternatives come from tracing the study literature about telehealth usage for remote patient monitoring in the pulmonology unit and its success rates. Then, the alternatives got validated with the expert involved by conducting a discussion group online regarding its usability potential and Indonesia's technology infrastructure conditions. The IoT-based Telehealth alternatives approved are listed in the Table 2. The alternatives priority assessment conducted with the COPRAS method by considering each criterion's weight and sub-criterion IoT-based Telehealth implementation.

Table 2. IoT-based Telehealth Alternatives

IoT-based Telehealth Alternative	Source
Smart Inhaler	(Devon 2019), (Chrystyn et al. 2019).
Ingestible Capsule	(Hughes 2015), (Proteus 2017).
Wireless Body Area Network	(Datta et al. 2015), (Angelucci et al. 2020)
Home Spirometry	(Kumar et al. 2019), (Kupczyk et al. 2020)

5. Results and Discussion

5.1 Criteria and Sub-criteria Weighting Calculation

The second questionnaire was distributed to carry out weight assessments on each of the criteria and sub-criteria based on the opinions and experiences of relevant field experts in the form of a 5-point scale questionnaire. The second questionnaire data results will be processed using the Fuzzy AHP method to obtain the importance of 6 criteria and 28 sub-criteria selected based on the membership function with 3 levels, namely the triangular fuzzy number. The 5 scale Triangular Fuzzy Number range shown in Table 3

Table 3. Triangular Fuzzy Number (TFN)

Scale	Description	Triangular Fuzzy	Triangular Fuzzy Reciprocal
1	Equal	1,1,1	1,1,1
3	Moderate	2,3,4	1/4, 1/3, 1/2
5	Strong	4,5,6	1/6, 1/5, 1/4
7	Very Strong	6,7,8	1/8, 1/7, 1/6
9	Extreme	9,9,9	1/9, 1/9, 1/9

Source: (Ayhan 2013)

Data processing results using fuzzy AHP are in the form of criteria and sub-criteria local weights, and global sub-criteria weights. Table 4 shows the final weight criteria, also local and global weighted sub-criteria. The table below indicates that the highest weight value criterion belong to the Perceived Ease of Use criterion with a weight of 0.355, and the smallest weight criterion belong to the Environmental criterion by the value of 0.082. Besides, the results of the global weight value calculations for each sub-criterion are obtained with the User Interface sub-criterion as the highest level of importance, namely 0.115. Meanwhile, the trust in technology sub-criterion became the lowest global weight value of 0.006.

Table 4. Final Weights Criteria and Sub-criteria IoT-based Telehealth Implementation

Criteria	Criteria Weight	Criteria Rank	Sub-criteria	Global Weight	Sub-criteria Rank
Technology	0.112	3	Vulnerability	0.014	26
			Technology Innovation	0.025	16
			Reliability	0.031	11
			Interoperability	0.042	9
Organization	0.107	5	Top Management Support	0.020	20
			IT Support	0.021	19
			Financial Readiness	0.025	15
			Cost	0.018	21
			User Innovativeness	0.023	18
Environment	0.082	6	Competitive Pressure	0.016	23
			Government Policy	0.015	24
			Industry Support	0.024	17
			Social Persuasion	0.027	14
Safety	0.109	4	Trust in Technology	0.006	28
			Privacy	0.011	27
			User Safety	0.015	25
			Data Security	0.030	13
			System Security	0.031	12
			Accountability	0.016	22
Perceived Usefulness	0.235	2	Efficiency	0.033	10
			Perceived Benefit	0.058	5
			Time Saving	0.068	4
			Responsive	0.075	3
Perceived Ease of Use	0.355	1	Usability	0.046	8
			Accesibility	0.096	2
			User Interface	0.115	1
			Customization	0.051	6
			Effort Expectancy	0.047	7

Furthermore, in determining whether the respondents' assessment shows a consistent value, the consistency value calculation is carried out. The Fuzzy AHP calculation is obtained votes consistency ratio of the integrated pairwise comparison matrix. In calculating the consistency ratio, the consistency value must be less than or equal to 0.1 (Gogus & Boucher, 1998). In this study using a fuzzy approach, there are two consistency calculation. The consistency of the mean (CRm) and the consistency of the upper and lower limits (CRg) was calculated in Table 5.

Table 5. Consistency Ratio Calculations

Consistency	**Mean Values**				**Upper & Lower Values**			
	λ max	**CIg**	**RIg**	**CRm**	**λ max**	**CIg**	**RIg**	**CRg**
Criteria	6.174	0.035	1.200	0.029	6.161	0.032	0.382	0.084
Technology Sub-criteria	4.076	0.025	0.794	0.032	4.073	0.024	0.263	0.092
Organization Sub-criteria	5.155	0.039	1.072	0.036	5.141	0.035	0.360	0.098
Environment Sub-criteria	4.076	0.025	0.794	0.032	4.075	0.025	0.263	0.095
Safety Sub-criteria	6.162	0.032	1.200	0.027	6.158	0.032	0.382	0.083
Perceived Usefulness Sub-criteria	4.048	0.016	0.794	0.020	4.046	0.015	0.263	0.059
Perceived Ease of Use Sub-criteria	5.106	0.026	1.072	0.025	5.099	0.025	0.360	0.069

The table shows both the computation of the mean's consistency ratio (CRm) and the upper & lower limit's consistency ratio (CRg) have ratio values are below 0.1 for all of the criteria and sub-criteria. So the results of expert's assessments are stated to be consistent.

5.2 IoT-based Telehealth Alternative Ranking

The third questionnaire distribution was carried out to obtain expert's assessments of IoT-based Telehealth devices by considering the criteria and sub-criteria for implementing the Internet of Things adoption in hospitals. Once the questionnaire is completed, the data processing by COPRAS method (Complex Proportional Assessment) for the implementation of priority is based on each alternative utility level. The calculation results show each alternative's utility level compared to other alternatives in Table 6.

Table 6. IoT-based Telehealth Alternative Implementation Ranking Calculation

Value	IoT-based Telehealth Alternatives			
	Smart Inhaler	Ingestible Capsule	Wireless Body Area Network	Home Spirometry
Pi (*Benefit*)	0.001823	0.001913	0.001945	0.001935
Ri (*Cost*)	0.000024	0.000026	0.000024	0.000024
Qi (Significancy)	0.001848	0.001937	0.001970	0.001960
Ni (Utility)	0.937769	0.983044	1.000000	0.994861
Rank	4	3	1	2

It can be seen that data processing using the COPRAS method classifies the criteria into a benefit (Pi) and cost (Ri) criteria. Benefit criteria is a criterion; the greater the value, the better, while the cost criteria is a criterion; the smaller the value, the better. The calculation results indicate that the main priority in implementing IoT-based telehealth for the pulmonology unit is the wireless body area network.

5.3 Sensitivity Analysis

Sensitivity analysis was carried out in this study to analyze the sensitivity that occurs in ranking IoT devices. There are four scenarios to be tested. The first scenario is the possibility of a pandemic covid 19 that continues to plague and the emergence of a new type of corona evolution. Those led to an increased need to adopt IoT-based Telehealth in hospital, so the perceived usefulness weight increased by 50% (Nasajpour et al. 2020). The second scenario is ransomware virus attack can threaten the entire hospital information especially IoT devices tend to be more susceptible from hacking (Selvaraj & Sundaravaradhan 2020), so the organizational and security weights are increased by 50%.

The third scenario is Delloite survey showed 70.2% of people are still questioning the safety of digital health services, also government regulation of the technology is still limited (Hoeng 2019), so that the environmental weight is increased by 50%. The last scenario is that connectivity is the main cause of Indonesia's digital health services being underdeveloped due to the gap in certain patient areas connections (Kompas 2019), thus the weight of technology and perceived ease of use are increased by 50%. The result comparison among the initial condition and scenarios are listed in Table 7.

Table 7. Sensitivity Results

Telehealth Alternative	Initial Condition		1st Scenario		2nd Scenario		3rd Scenario		4th Scenario	
	Ni	Rank	Ni	Rank	Ni	Rank	Ni	Rank	Ni	Rank
Smart Inhaler	93,7%	4	94,3%	4	94,1%	4	93,4%	4	91,6%	4
Ingestible Capsule	98,3%	3	99,4%	2	97,7%	3	98,1%	3	96,6%	3
Wireless Body Area Network	100%	1	99,3%	3	100%	1	99,8%	2	100%	1
Home Spirometry	99,5%	2	100%	1	98,7%	2	100%	1	98,2%	2

The table shows the results of data processing in each scenario. It indicates an alternative ranking in 1st and 3rd scenarios experienced the main priority changes become home spirometry technology. Besides, 2nd and 4th scenarios remain the same technology priority, Wireless Body Area Network.

6. Conclusion

This study aims to design the best priority IoT-based telehealth applications for remote hospital pulmonology unit patient services using a combination of Fuzzy AHP and COPRAS methods. Fuzzy AHP calculation results indicate the Perceived Ease of Use criterion and User Interface sub-criterion as the highest weight of a total of 6 criteria and 28 sub-criteria. The COPRAS calculation shows that the Wireless Body Area Network technology has the highest utility level, which makes it a top priority in considering IoT-based Telehealth implementation in pulmonology units. Based on sensitivity testing through scenario analysis, Home Spirometry also needs to be considered as being a top priority in several scenarios.

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Biography

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