The Decision Model of Internet of Things (IoT) Solutions for Healthcare based on Risk and Challenge Factors

M Dachyar and Nabila Alya Zahra
Industrial Engineering Dept, Universitas Indonesia
Depok, Indonesia
mdachyar@yahoo.com, zahra.nabila.alya@gmail.com

Abstract

Internet of Things (IoT) have a tremendous support to healthcare in the aspect of information capture and processing, which could much improve the healthcare service quality. Hospital needs to consider several factors in implementing IoT. This study aims to select and determine the appropriate IoT solutions in the hospital with the most of minimum risks and challenges. Analytical Hierarchy Process (AHP) method is used to calculate the priority weight of IoT implementation in hospitals based on challenge factors, meanwhile The IoT implementation is assessed with probability and severity scale to get the risk score. Then after obtaining the risk score and weight of challenges, the priority weight and risk score of IoT implementation in the hospital are used for the development of models using AHP-ZOGP. And finally, Zero One Goal Programming (ZOGP) Method is used to create a selection model for IoT implementation in the hospital. The final results from the model showed that Hospital Patient Queue Management System is chosen in every available scenario, with remarkable result that could decrease 38.5% Technical risk, 46.2% Personnel risk and 69.3% challenge in healthcare.

Keywords
Internet of Things (IoT), Healthcare, Risk Management, Analytical Hierarchy Process (AHP).

1. INTRODUCTION

Internet of Things (IoT) brings convenience to Hospital in terms of gathering & managing the information which could improve the healthcare service quality. Service quality in hospital has become the most significant factor to retain patient's loyalty (Dachyar and Minar 2018). Since IoT has ubiquitous computing nature, all of the healthcare sevice components (people, equipments, medicine) can be monitored and supervised continuously (Rahmani et al. 2018). By collecting patients' real time health data, IoT implementation in hospital enable the treatment before the condition become critical (Anurag et al. 2015). IoT implementation in healthcare keeps increasing, where 4 times increment on the number of its device is expected in these past 5 years (Statista 2019). Numeruous implementation of IoT have been made in healthcare services, such as patient monitoring (Dhevi et al. 2018; Li, Hu, and Zhang 2017), object or equipment tracking (Stoller et al. 2013), Patient queue management system (Ghazal, Hamouda, and Ali 2015), Smart ambulance (Fong, Fong, and Li 2018), medical drug storage (Gupta et al. 2018) etc.

Despite the vast development of IoT in the hospital, the implementation of IoT has some challenges such as managing heterogeneity, design, trust, privacy, security, etc [10], [11]. The heterogeneity of various devices, environment, and applications needs to be managed for enabling IoT. In designing IoT, the challenges are how to design efficient architecture, mechanism and protocols, and how to manage large amounts of information to provide useful services. The trust, privacy and security challenges are how to secure the architecture of IoT, and to protect the user's personal information [10]. In 2017 A survey held by Cisco to 1800 stakeholders of IoT initiatives showed that only 26% IoT project has succeeded.

In IoT implementation, all devices have to be connected to local network and internet otherwise it will not work as intended. Many attackers on the internet steal confidential information. The attacker can abuse the data and information obtained which could harm the victim (Lu et al. 2014). From various surveys and previous cases, it can be concluded that the risks and challenges of IoT implementation need to be addressed. This paper aims to determine and select IoT implementation in the hospital with minimum risks and challenges. The combination of

AHP-ZOGP method has been used to a selection model of IoT implementation in hospitals based on risk & challenge factors.

2. LITERATURE REVIEW

2.1 Internet of Things

In 2003, the concept of IoT became popular since the RFID was used on a large scale by the US Department of Defense and Wal-Mart (Madakam, Ramaswamy, and Tripathi 2015). IoT technology enables objects around us such as television, refrigerators, cars, clothing, etc. To collect some useful data using various existing technologies, which will autonomously stream the data to the related device and automatically take action in response (Farooq et al. 2015) (Dachyar, Zagloel, and Saragih 2019). The Internet of Things can also be taken into consideration a global network that enables human-to-human, human-to-object, and object-to-object communication by giving a unique identifier to each object (Aggarwal and Lal Das 2012).

2.2 Internet of Things in Healthcare

The dependence of healthcare services on IoT is growing daily to enhance access to healthcare services, improve the quality of healthcare services and, most significantly lessen the costs of healthcare services (Niewolny 2013). Throughout the world, there have been many IoT applications in healthcare services implemented. For example, a smart ambulance can make a diagnosis in the fleet so that medical staff can make preparations before patients' arrival at the hospital (Fong, Fong, and Li 2018). AutoBed is a system equipped by real-time location awareness devices consisting of infrared, radio-frequency identification (RFID) tags, and computer vision that uses the "triage" recommendation from the nurse and the real-time data of which hospital beds are available to determine the best feasible match (Gittleson 2013). Remote health monitoring that can help doctors identify deviations in the patient's vital signs with sensor based technologies (Wagenen 2018). RFID system to monitor hospital equipments (Stoller et al. 2013) and many more. Those implementations proven that IoT implementation in the hospital could improve the service quality.

2.3 Analytic Hierarchy Process Method (AHP)

AHP is a method with a series of pairwise comparisons that rely on the wisdom of experts in evaluating preference among a set of options (typically more than two). Practically, AHP is used to solve preference problems where options are assessed based on numerous criteria (Contreras-Nieto et al. 2019). In this study, AHP was used to calculate the priority weights of IoT implementations based on challenge factors (Farid, Ahmad, and Alam 2015) and to calculate the priority weights of ZOGP objective (Kengpol, Meethom, and Tuominen 2012).

2.4 Zero-One Goal Programming Method (ZOGP)

Goal Programming can be considered as an extension of linear programming to address several objective functions that are generally conflicting. In Linear Programming the objective function is set for only one quantity whether it is "to maximize" or "to minimize", however, GP is capable of carrying several objectives related to each other. Therefore, decision makers can determine priority weights for each goal (Kengpol, Tuamee, and Tuominen 2010). The common ZOGP format is similar to GP with differences in the main variables. ZOGP has zero and one variables where zero represents non-selection while one represents selection. The ZOGP model is a tool to select several alternatives that have a minimum deviation from the target.

ZOGP can also be combined with other methods, for example AHP (Badri 1999; Kengpol, Meethom, and Tuominen 2012) Analytical Network Process (ANP) (Tsai and Chou 2009; Wei and Chang 2008; Wey and Wu 2007), Decision Making Trial and Evaluation Laboratory (DEMATEL) (Tsai and Chou 2009) , etc. A combination of the AHP-ZOGP method is used in this paper.

3 METHODS

The first step is to collect risk and challenge factors from literature and ask for validation to hospitals' IT experts in Indonesia. Factors whose geometric mean values fall below the threshold will be eliminated from this study. Priority weight of IoT implementation based on challenge factors calculated using AHP method and the risk score of each IoT implementation calculated using the Probability and Severity scale method. The priority weight and risk score of IoT implementation in the hospital are used to develop the selection model of the IoT implementation in hospitals using the AHP-ZOGP method.

3.1. Validation of Risk & Challenge Factors and Subfactors

Based on the review of the literature, there are 6 challenge factors (21 subfactors) (Bandyopadhyay and Sen 2011) and 15 risk factors of IoT implementation (Daskala 2017). Validation of these factors will be carried out by 8 hospitals' IT experts through a Likert 1-5 scale questionnaire where 1 represents very unrelated and 5 represents very related.

Table 1. Selected factors and subfactors of challenge

Factors	Subfactors
Network Foundation	Mobility limitations of the current Internet architecture
	Limitations of the current Internet architecture in terms of availability
	Manageability limitations of the current Internet architecture
	Limitations of the current Internet architecture in terms of scalability
Security	Securing the architecture of IoT
	Proactive identification and protection of IoT from arbitrary attacks
Privacy	Personal information control (data privacy)
	Need for privacy enhancement technologies and relevant laws on protection
Trust	Need for easy and natural exchange of critical, protected and sensitive data
	Trust must be a part of the IoT design and must be built into it.
Managing Heterogeneity	Managing heterogeneous applications
	Managing heterogeneous devices
Design	Managing large amount of information and extracting large volume of data to provide useful services
	Desig of an efficient architecture for sensor networking and storage
	Developing sensor data stream processing mechanisms
	Sensor data mining—correlation, aggregation filtering techniques design

The threshold for the challenge factors is 3.7 and 3.3 for risk factors. After this step, the results shows that there will be 6 challenge factors (16 subfactors) (see Table 1) and 9 risk factors (see Table 2) included in this research, These risk factors are classified into two domains based on risk classification by James & Tarala 2015 (Open Threat Taxonomy) (Launius 2019).

Table 2. Selected risk factors and their domains

Domain	Risk Factors
Technical	Denial of service attack/flood
Technical	Spoofing of credentials/bypass authentication
Technical	Large-scale and inappropriate data extracting / surveillance
Technical	Man-in-the-middle attack (Hackers)
Technical	Unauthorised access to / deletion / modification of devices / data
Technical	Worms, viruses and malicious code
Technical	Function creep

Domain	Risk Factors
Technical	Profiling
Personnel	Procedures / instructions not followed

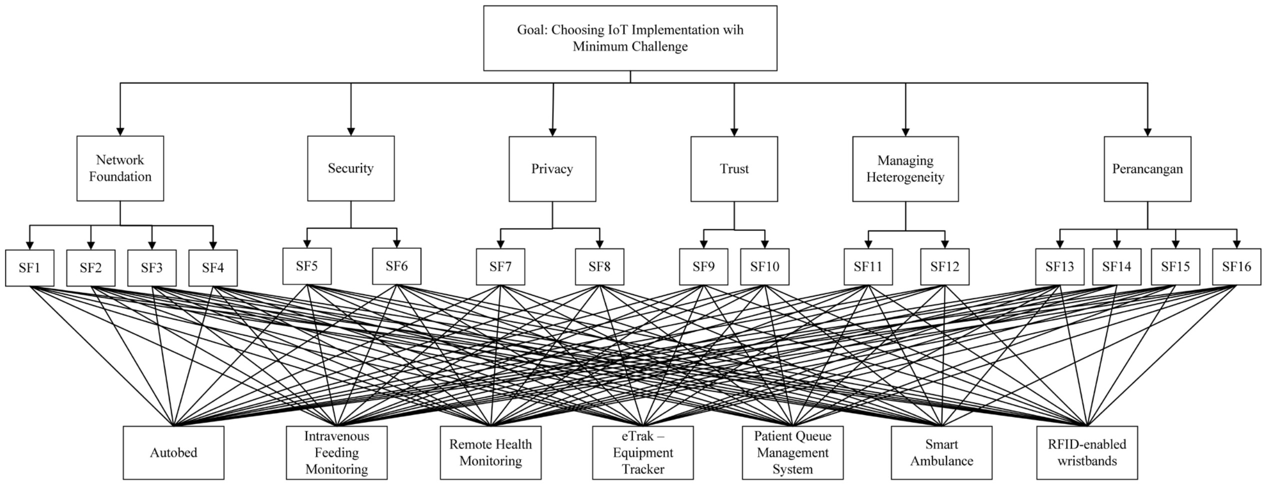

Figure 1. Hierarchy of AHP Model in Selecting the Best IoT Implementation in Hospital

3.2 Weight of The Alternative Based on The Challenge Factors and Subfactors

Hierarchy structure of the AHP model is composed of factors, sub-factors, and alternatives, shown in Fig. 1. Five hospitals' IT experts were asked to fill in the questionnaire to do a pairwise comparison by giving a 1-9 score between two elements. The score represents the preference of one alternative compared to the others. For example, an expert prefers element a two times compared to element b which means the expert prefers element b ½ times compared to element a

In Table 3 the inconsistency ratio of experts' judgment fall below 0,1, this means that the judgments are valid and pairwise comparisons do not need to be re-evaluated. Table 4 shows the final results of the AHP calculation for the priority weights of the IoT implementation alternatives. The priority weight obtained will be an input to construct the ZOGP model.

Table 3. Inconsistency Ratio related to Each Expert

Expert Code	Inconsistency
1	0.0484
2	0.0391
3	0.0537
4	0.0515
5	0.0524

Tabel 4. Final Weight of IoT Apllication in Hospital based on the Challenge Factors

Alternative		Weight
1	Autobed-Automatic Patient Placement	0.109
2	Intravenous Feeding Monitoring	0.125
3	Remote Health Monitoring	0.087
4	eTrak – Equipment Tracker	0.117
5	Patient Queue Management System	0.307
6	Smart Ambulance	0.083
7	RFID-enabled wristbands	0.172

3.3 Risk Assessment of The Alternative

Risk assessment is performed in terms of severity and probability (Kengpol, Meethom, and Tuominen 2012) by asking 5 hospitals' IT experts to fill out questionnaires on a 5 Likert scale. Scale 1 indicates the probability is very unlikely and has no impact while scale 5 indicates a very high probability and very severe impact. To get the final score, the probability and severity scale is multiplied. Risk assessment is carried out on technical risks and personnel risks. The resulting risk value will be an input for the ZOGP model.

In Table 5 and Table 6, under the technical risk & personnel risk, P represents the geometric mean of the probability score from the experts, while S represents the geometric mean of the severity score from the experts. The risk score obtained in this section will be used to develop selection model of Internet of Things implementation.

Table 5. Technical Risk Score of Each Alternative

#	IoT Implementation in Hospitals	Technical Risk		Score
		P	S	
1	Autobed-Automatic Patient Placement	3.2	2.9	9
2	Intravenous Feeding Monitoring	3.3	2.2	7
3	Remote Health Monitoring	3.8	2.4	9
4	eTrak – Equipment Tracker	2.6	2.4	6
5	Patient Queue Management System	3.6	2.2	8
6	Smart Ambulance	3.5	2.6	9
7	RFID-enabled wristbands	3.0	2.2	7

Table 6. Personnel Risk Score of Each Alternative

#	IoT Implementation in Hospitals	Personnel Risk		Score
		P	S	
1	Autobed-Automatic Patient Placement	2.9	2.4	7
2	Intravenous Feeding Monitoring	3.3	2.5	8
3	Remote Health Monitoring	3.8	3.1	12
4	eTrak – Equipment Tracker	2.5	1.9	5
5	Patient Queue Management System	3.4	2.0	7
6	Smart Ambulance	3.1	2.7	8
7	RFID-enabled wristbands	2.9	2.5	7

3.4 Construction of ZOGP Model

The construction of objective functions is carried out by calculating the weight of the objectives, namely the challenge factor, technical risk factor, and personnel risk factor to determine the preference level based on stakeholders' goal in making the decision. Questionnaire was distributed to 5 hospitals' IT experts with inconsistency ratios below 0.1. The priority weights of the objectives are shown in Table 7. Next, to construct the constraints, input from previous processes is needed.

Table 7. Weight of Goals

Goal		Weight
1	Challenge	0.435
2	Technical Risks	0.310
3	Personnel Risks	0.254

$$Min = \sum_{i=1}^{n} w_{iAHP}\left(g_i d_i^- + g_i d_i^+\right) = w_1\left(g_1 d_1^- + g_1 d_1^+\right) + w_2\left(g_2 d_2^- + g_2 d_2^+\right) + \cdots + w_n\left(g_i d_i^- + g_i d_i^+\right) \quad (1)$$

Subject to:

$$\sum_{j=1}^{7} w_{jAHP}\, x_j + d_1^- + d_1^+ = 1$$

$$\sum_{j=1}^{7} T_j\ x_j + d_2^- + d_2^+ = T$$

$$\sum_{j=1}^{7} P_j\ x_j + d_3^- + d_3^+ = P$$

$x_j \in \{0,1\}$

$j\ \in (element\ of\ alternative)$

$$d_1^-, d_1^+, d_2^-, d_2^+, d_3^-, d_3^+ \geq 0$$

Where w_{iAHP} is priority weight of goal i to build the objective function, w_{jAHP} is priority weight of IoT implementation alternative j, T_j is technical risk value of IoT implementation alternative j, P_j is personnel risk value of IoT implementation alternative j, T is the technical risk limit and P is personnel risk limit.
Five hospitals' IT experts have decided the limit value of technical and personnel risk are 15. Therefore, based on the data obtained, the mathematical model is as follows:

- Objective function

  $Min.Z = 0.435\ (d_1^- + d_1^+) + 0.310\ d_2^+ + 0.254\ d_3^+$ (2)

- 1st constraint. Priority weight of challenge of IoT implementation alternative is equal to 1

  $0.109X1 + 0.125X2 + 0.087X3 + 0.117X4 + 0.307X5 + 0.083X6 + 0.172X7 + d_1^- - d_1^+ = 1$ (3)

- 2nd constraint. Minimizing technical risk value to 15

  $9X1 + 7X2 + 9X3 + 6X4 + 8X5 + 9X6 + 7X7 + d_2^- - d_2^+ = 15$ (4)

- 3rd constraint. Minimizing personnel risk value to 15.

  $7X1 + 8X2 + 12X3 + 5X4 + 7X5 + 8X6 + 7X7 + d_3^- - d_3^+ = 15$ (5)

The results of selection model of IoT implementation in hospitals are shown in Table 8.

Table 8. Result of ZOGP

Variable	Value
d_1^-	0.521
d_1^+	0
d_2^+	0
d_3^+	0
X_1	0
X_2	0
X_3	0
X_4	0
X_5	1
X_6	0
X_7	1

In Table 8 value 1 indicate selection while 0 indicate non-selection, X5 represents Patient Queue Management System and X7 represents RFID-enabled wristbands.

4 Results and Discussion

4.1 The Results of Selection Model of IoT Application in Hospital

From the previous data processing, the results of the selection of IoT implementation in hospitals are, the Patient Queue Management System and RFID-enabled wristbands. Next, the author wants to find out whether there is a change in the results of the selection of IoT implementation in the hospital, if there are several scenarios.
The first scenario is that there is a massive Denial of service (DoS) attack that also has the potential to attack internet networks in hospitals. In order to face the DoS attacks, hospitals will be more vigilant on technical risks so that the technical risk objective priority weight will be increased while the limit value of technical risk will be decreased. The second scenario is that there is a previous case of an error caused by human resources of the hospital so the hospital decided to further raise awareness of personnel risk. In the second scenario, the personnel risk objective priority weight will be increased while the limit value of personnel risk will be decreased. The comparation between the scenarios are shown in Table 9.

Table 9. Results of ZOGP

Variable	Normal	Scenario 1	Scenario 2
	Value	***Value***	***Value***
Objective	0.227	0.003	0.003
d_1^-	0.521	0.693	0.576
d_1^+	0	0	0
d_2^+	0	5	1
d_3^+	0	8	1
X_1	0	0	0
X_2	0	0	0
X_3	0	0	0
X_4	0	0	1
X_5	1	1	1
X_6	0	0	0
X_7	1	0	0

In Table 9, the selected IoT implementation on the first scenario is only Patient Queue Management System (X5) while the second scenario shows that it also selects e-Trak Equipment Tracker (X4) besides the Patient Queue Management System (X5). From the scenario results we can conclude that the change in objective priority weight and limit value of each risks affected the selected IoT implementation.

4.2 Analysis of ZOGP Scenarios

In Table 10 we can see the differences of the objective functions' weight (stated as W1, W2, and W3) and technical (T) and personnel (P) risk limits of each scenario that is carried out.

Table 10. Value of each variables

	Normal	**Scenario 1**	**Scenario 2**
	Value	Value	Value
W1 (Challenge)	0.435	0.005	0.005
W2 (Technical Risk)	0.210	0.99	0.005
W3 (Personnel Risk)	0.234	0.005	0.99
T	15	13	15
P	15	15	13

In scenario 1 there is a change in the objective function value and the results of the chosen IoT implementation. The normal condition shows that the selected IoT implementation was X5 (Patient queue management system) and X7 (RFID-enabled Wristbands) while in scenario 1 it becomes only X5. It can be concluded that the higher technical risks will make hospitals more selective and careful in selecting the IoT implementation.

In scenario 2, the selected IoT are X4 (eTrak-Equipment Tracker) and X5 (Patient queue management system). It can be concluded that the Personnel risk of eTrak-Equipment Tracker and Patient queue management system are quite low so that they both get selected when there are differences in the priority weight in the selection model.

5 Conclusion

The selection problem of IoT implementation based on risk and challenge factors can be solved using the AHP-ZOGP method. This study found 6 challenge factors (16 subfactors), namely Network Foundation, Security, Privacy, Trust, Managing Heterogeneity and Design and 9 risk factors classified into technical risk and personnel risk, which need to be considered in implementing IoT in hospitals. IoT implementation that can be implemented in all scenarios is the Patient Queue Management System which could decrease 38.5% Technical risk, 46.2% Personnel risk and 69.3% challenge.

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Biographies

M. Dachyar is a Professor, and Head of Management Information System and Decision Support (MISDS) Laboratory, Industrial Engineering Dept., Universitas Indonesia. His research on management information system, decision support system, operations management, and business process reengineering.

Nabila Alya Zahra is a research assistant at Laboratory of Management Information System and Decision Support (MISDS), Industrial Engineering Dept., Universitas Indonesia. Her research focused on information system and decision support system