A Fuzzy AHP Approach to Evaluate Contributing Factors in the Occurrence of Adverse Events in Philippine Hospitals

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Abstract

The occurrence of adverse events (AEs) is one of the most prevailing issues in the healthcare industry. Adverse events in hospitals are unintentional errors from clinical procedures or clinical decisions that can lead to serious complications or even death of a patient. There are several contributing factors to AEs which may include patient safety culture among medical practitioners, work environment, and technology, among others. The study aims to develop a framework that evaluates and prioritizes the factors contributing to adverse events in the Philippine hospitals. The Fuzzy Analytic Hierarchy Process (FAHP) is used to establish the contributory factors and sub-factors in the occurrence of adverse events. The results show that technology, with a rating of 19.32%, is the main factor that should be prioritized by hospitals in the Philippines followed by institutional context and workforce condition with ratings of 15.95% and 15.11%, respectively. Experts from both private and public hospitals are considered in the study. Findings show that there is only minimal differences on the responses from both set of experts. For instance, institutional context ranks second on the first set of experts whereas on the second set of experts, it ranks last.

Keywords
Fuzzy AHP, Adverse Events, Decision Framework, Philippine Hospital Sector

1. Introduction

The severity of adverse events has long been recognized as early as the 1950s and 1960s, but the degree to which they are managed and overseen has not been significantly studied not until a number of evidences have surfaced in the mid 1990's in which Harvard Medical Practice Study published results regarding the occurrence of these events in 1991 (World Health Organization, 2002). More researches were done regarding the prevalence of adverse events in the healthcare system such as in Northern Ireland, Australia, United Kingdom of Great Britain and the United States of America. In these studies, the earliest method used to detect adverse events was medical records review according to Thomas, Studdert and Brennan (2002). However, this method was deemed costly and time-consuming because physicians and hospital staff are required to constantly update and review records. Specifically, in the year 1999 the Institute of Medicine (IOM) in the United States started to give light to the adverse events and published the report entitled "To Err is Human - Building a Safer Health Care System".

This report first showed the real score of adverse events in the healthcare setting in which it highlighted that deaths occurring from such adverse events (98,000) outnumbered the deaths from accidents (43,000), cancer (32,000) and AIDS (16,000). IOM, in their report, referred to two medical records reviews in which they identified adverse events and analyze whether these events are preventable. This report then sparked worldwide debates and call for more attention in taking a serious look in reducing the occurrence of adverse events in the hospitals worldwide through more researches.

WHO (2002) indicated that adverse events occur in various settings, but most cases happen in hospitals since incidence associated with health care are high, procedures for development are better reported, and the significance of patient trust is foremost. Identification and reduction of adverse events is a complex and difficult task because it requires broad clinical learning, satisfactory documentation, and subjectivity with respect to the researcher (Thomas & Peterson, 2003). The impacts of the reduction of adverse events are improved patient safety and quality care (Kohn, Corrigan, & Donaldson, 2000). Many factors contribute to the occurrence of adverse events and studying these factors is an effective reduction of adverse events (WHO, 2002). These adverse events could have been avoided through renewed focus on design of work systems and processes (Carayon and Wood, 2010), leading to the development of number of multi-criteria decision-making methods to evaluate the contributing factors to the occurrence of adverse events in hospital sector (Dolan, 2008).

Studies aimed at reducing adverse events started to emerge as early as 1991, one of which was the study of Vincent, Taylor-Adams, and Stanhope in 1997 that developed a framework for analyzing risk and safety in clinical medicine. They incorporated Reason's (1990) study which emphasized the systemic part of human error-related accident along with Hurst and Radcliffe's (1994) socio-technical pyramid model that identified potential human factor part to organizational accidents. The framework developed by Vincent et. al (1997) identified seven major contributory factors which has been numerously cited by many researchers whose interest is in the development of evaluation tools and frameworks using Multi-Criteria Decision methods.

Ortiz-Barrios et al. (2016) developed an evaluation tool by combining Analytic Hierarchy Process (AHP), decision-making trial and evaluation laboratory (DEMATEL), and VIKOR with reference to the factors used by Vincent et. al (1997). The researchers designed an MCDM model to evaluate the risk of adverse events in Columbian hospital sector, while AHP was used to determine the weights of criteria and sub-criteria and DEMATEL was used to evaluate the interdependencies between factors and sub factors. VIKOR was used to rank hospitals according to the risk of adverse events. The study of Ortiz-Barrios only analyzed which factors are more likely to cause adverse events and not to reduce the occurrence of it. It is noticed that all the sub-factors that corresponds to Institutional Context are part of the top ten most representative sub-factors, a reason why this major contributory factor should be focused upon to reduce the risk of adverse events with the help of the local government and a country's own department of health. Among all the sub-factors, age of patient and background were deduced to be the main external factors by which hospitals must invest on action regarding prevention and promotion.

Another study made use of the decision-making trial and evaluation laboratory (DEMATEL) method in reducing adverse events using patient safety culture strategies (Chih-Ming et al., 2016). The study made use of Safe Attitude Questionnaire (SAQ), a popular patient safety culture survey measurement which made use of a six-factor model. DEMATEL method was used to analyze the factors that could help assist and guide hospital decision-makers in establishing patient safety cultural activities to reduce adverse events. Results showed that among the six key dimensions considered in the study, teamwork climate must be the first priority to improve on. This study mentioned that by putting teamwork climate as the top priority, other dimensions will consequently improve; thus, reducing the occurrence of adverse events. However, all the factors identified may not necessarily apply to Philippine hospital setting.

Moreover, further research into these methods has shown that DEMATEL and VIKOR are not designed for prioritizing and ranking of factors, and thus cannot be used to identify which among the factors contributes the most to the occurrence of adverse events. AHP, on the other hand, has been a widely used decision making methodology in medical and healthcare decision, especially in identifying and giving a hierarchy to different attributes (Liberatore and Nydick, 2008). However, despite being used as a tool to determine the different weights of factors and sub factors of adverse events in the study of Ortiz-Barrios et al. (2016), AHP, along with TOPSIS, have been criticized for using crisp values in its ranking methodology. Service sectors such as hospitals try to deliver services based on their own judgment from a criterion which from their own perspective influences the quality of their rendered service.

Therein lies the gap in AHP and such methods: it does not efficiently resolve the ambiguity frequently arising in available information from the inherent fuzziness in human judgment, and therefore is lacking precision. This study has also given the researchers an insight regarding the gap of the research. Although this has been the most similar study, it did not address the ambiguity that stems from that the real-life decisions being done in the hospital sector, therefore showing lack of precision in terms of incorporating the inherent fuzziness in human judgment of the medical experts. The researchers addressed this gap through the incorporation of fuzzy theory in this research and used interval values instead of the crisp values (i.e. Saaty Rating Scale) that AHP and similar methods have previously offered.

In line with this, the researchers developed a framework that can evaluate and prioritize the different factors contributing to the occurrence of adverse events in the Philippine hospitals as there is underreporting of adverse events in Southeast Asia events due to the reluctance of healthcare professionals to talk about adverse events for fear of embarrassment, punishment and legal actions (WHO, 2012). There are several factors ranked, both tangible and intangible, and numerical representation of its importance is needed to evaluate these contributory factors. There are many available tools, and among the evaluation tools that were reviewed and evaluated, the Fuzzy Analytic Hierarchy Process was found to be the most appropriate tool for this study. In fact, according to the study of Ertugrul and Karakasoglu (2008), Fuzzy AHP is a relevant tool in prioritizing the factors of ambiguous decision-making and inherent fuzziness in the human judgment part of the medical experts that stems from real-life decisions being done inside a hospital and is thereby appropriate for this research.

The objective of this study is to develop a framework that evaluates and prioritizes the factors contributing to adverse events with the application of the Fuzzy Analytic Hierarchy Process. Specifically, this study aims to apply the Fuzzy Analytic Hierarchy Process (FAHP) model, identify and understand which factors and sub-factors that contribute to the occurrence of adverse events in hospital management are applicable in the Philippine hospital sector and can be considered in the policy-making for adverse events reduction.

2. Methodology

The study focuses on the development of a framework for identifying factors affecting adverse events that should be prioritized by Philippine hospitals.

2.1 Participants

Two sets of experts with three members per set were considered in obtaining the data since the study utilizes Fuzzy AHP for developing the framework.

2.2 Use of Fuzzy AHP as a Tool

The conventional AHP has been a widely-used decision making methodology in medical and healthcare decision, but it is inadequate in dealing with vague or imprecise assessments. On the other hand, in fuzzy AHP, it can be viewed as an advanced analytical method developed from the traditional AHP which uses the application of Fuzzy Triangular Numbers (TFN) for calculating the respective weights for the attributes. Fuzzy AHP also uses the hierarchy model of goal, criteria and alternative to evaluate a decision. But for this study, the goal of the researchers was to determine the prioritization weights of the criteria and sub-criteria and not to compare alternative hospitals in the Philippines with cases of adverse events. Below are the steps involved in Fuzzy AHP.

Step 1: Create the hierarchical decision framework. Figure 1 shows a three-level hierarchical decision framework with *n* factor and *m* sub-factors.

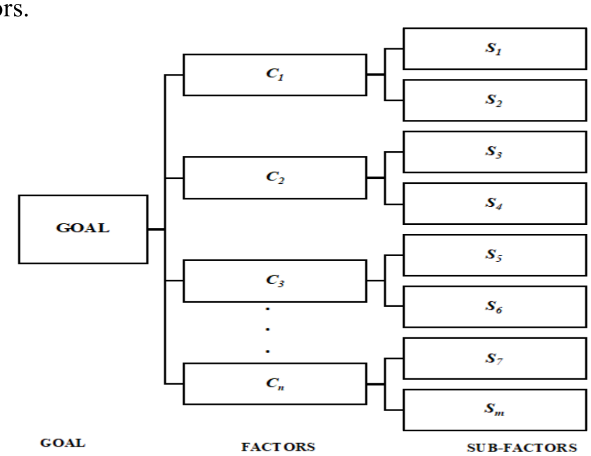

Figure 1. A sample hierarchical decision framework

Step 2: Establish the Triangular Fuzzy Numbers. Table 1 shows the triangular fuzzy conversion scale. Many Fuzzy AHP literature have proposed various TFNs to be used to convert Saaty's priority ratings scale using 0.5, 1 and 2 as degrees of confidence (Bacudio, Esmeria, and Promentilla, 2015), and the one that corresponds better for this study used 2 as the degree of confidence.

Table 1. Linguistic Scale with Triangular Fuzzy Numbers (Bacudio, Esmeria, and Promentilla, 2015)

Value	**Linguistic scale**	**Triangular Fuzzy Numbers (TFNs)**	**Reciprocal Triangular Fuzzy Numbers**
1	Equally important	(1/3, 1, 3)	(1/3, 1, 3)
3	Weakly more important	(1, 3, 5)	(1/5, 1/3, 1)
5	Strongly more important	(3, 5, 7)	(1/7, 1/5, 1/3)
7	Very strongly more important	(5, 7, 9)	(1/9, 1/7, 1/5)
9	Absolutely more important	(7, 9, 11)	(1/11, 1/9, 2/7)

Step 3: Construction of the Fuzzy Pairwise Matrices. The fuzzy judgment matrix was constructed by converting the AHP matrix derived from the experts' answers to the developed survey form, into its corresponding Triangular Fuzzy Number and is depicted in Eq. (1). For this matrix equation, the ãij is a fuzzy triangular number, ãij =(lij, mij, uij), and ãji = 1/ãij and for each TFN, ãij or M = (l, m, u).

$$\tilde{A} = \begin{bmatrix} 1 & \tilde{a}_{12} \dots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 \dots & \tilde{a}_{2n} \\ \tilde{a}_{n1} & \tilde{a}_{n2} \dots & 1 \end{bmatrix} \quad (1)$$

Step 4: Group Decision Aggregation. The matrices from all the experts were aggregated using the fuzzy geometric mean method of Buckley (1985) as shown in Eq. (2), where $\tilde{a}_{ijk}$ is the relative importance in form of TFN of the kth decision maker's view, and n is the total number of decision makers.

$$\tilde{u}_{ij} = \left(\prod_{i=1}^{n} \tilde{a}_{ijk} \right)^{1/n} \quad (2)$$

Step 5: Fuzzy Synthetic Value Computation. The resulting value of fuzzy synthetic extent S_i with respect to the *i*^th^ factor was computed using Eq. (3).

$$i = \sum_{j=1}^{m} u_{ij} \; x \left[\sum_{i=1}^{n} \sum_{j=1}^{m} u_{ij} \right]^{-1} \quad (3)$$

Where:

$$i = \sum_{j=1}^{m} u_{ij} \; x \left[\sum_{i=1}^{n} \sum_{j=1}^{m} u_{ij} \right]^{-1} \sum_{i=1}^{n} \sum_{j=1}^{m} \tilde{u}_{ij} = \left(\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i \right)$$

Step 6: Fuzzy Priorities Approximation. Using these synthetic extent values, the non-fuzzy values that represent the weight of one factor over others were obtained using Chang's (1996) method to find the degree of possibility that

$S_b \geq S_a$. The method was summarized in Eq. (4.4), where d is the ordinate of the highest intersection between μ_{Sa} and μ_{Sb}.

$$V(S_b \geq S_a) = \begin{cases} 1 & , \quad if\, m_b \geq m_a \\ 0 & , \quad if\, l_a \geq u_b \\ \dfrac{l_a - u_b}{(m_b - u_b) - (m_a - l_a)}, & \quad otherwise \end{cases} \tag{4}$$

Both values of V (Sa ≥ Sa) and V (Sa ≥ Sa) were required to compute for the minimum degree of possibility for a TFN Si to be greater than the number of n TFNs Sk as proposed by Dubois and Prade (1980), where k= 1, 2, …, n and k # i, and n is the number of factors described previously, as shown in Eq. (5).

$$V(S_i \geq S_1, S_2, \ldots, S_k) = \min V(S_i \geq S_k), = w'(S_i) \tag{5}$$

The computed w′(S) value represents the relative preference or weight, a non-fuzzy number, of one factor over others, thus these weights were normalized in order to allow it to be parallel to weights defined from the AHP method. The scores of sub-factors with respect to each factor was also be done by aggregating the weights through hierarchy and followed the Fuzzy AHP steps done for the criteria.

Step 7: Comparison Consistency Tests. The limit set for individual judgment was at 0.10 or less (Saaty, 1980) and 0.05 or less for group (Srichetta and Thurachon, 2012).

The consistency rate (CR) needs to be computed first and it was defined as a ratio between the consistency index (CI) and the random consistency index (RI). The computation for CR of a pair-wise matrix is illustrated in Eq. (6) below.

$$CR = CI / RI \tag{6}$$

The Consistency Index (CI) was based on the eigenvalue λmax and was computed by averaging all eigenvalues of the pair-wise comparison matrix as shown in Eq. (7) while Table 2 shows values of RI in different values of n.

$$CI = (\lambda max - n)/(n - 1) \tag{7}$$

Table 2. Values of Random Index (RI) per Different Number of Factors

n	RI	n	RI
3	0.58	8	1.41
4	0.90	9	1.45
5	1.12	10	1.49
6	1.24	11	1.51
7	1.32	12	1.48

3. Results and Discussion

There are seven criteria considered in this study, namely, Institutional Context, Patient Characteristics, Technology, Work Environment, Workforce Condition, Working Methods and Work Team. Table 3 shows the description of each criterion.

Table 3. Adverse Events Criteria

Criterion	Description
Institutional Context	Refers to the system of bodies, rules, regulation, policies, procedures and processes applied to a certain country that characterize the task environment of hospital sector.
Patient Characteristics	Refers to the background of the patient such as age, culture, personality, etc.
Technology	Refers to the medical equipment used in hospitals.
Work Environment	Refers to the architectural designs, physical environment, and status of the hospital buildings.
Workforce Condition	Refers to the physical condition of the medical professionals.
Working Methods	Refers to the policies, procedures and protocols used in the hospital.
Work Team	Refers to group of medical professional carrying recurring tasks in the hospitals.

Figure 2 shows the decision structure for prioritization of factors affecting the occurrence of adverse events.

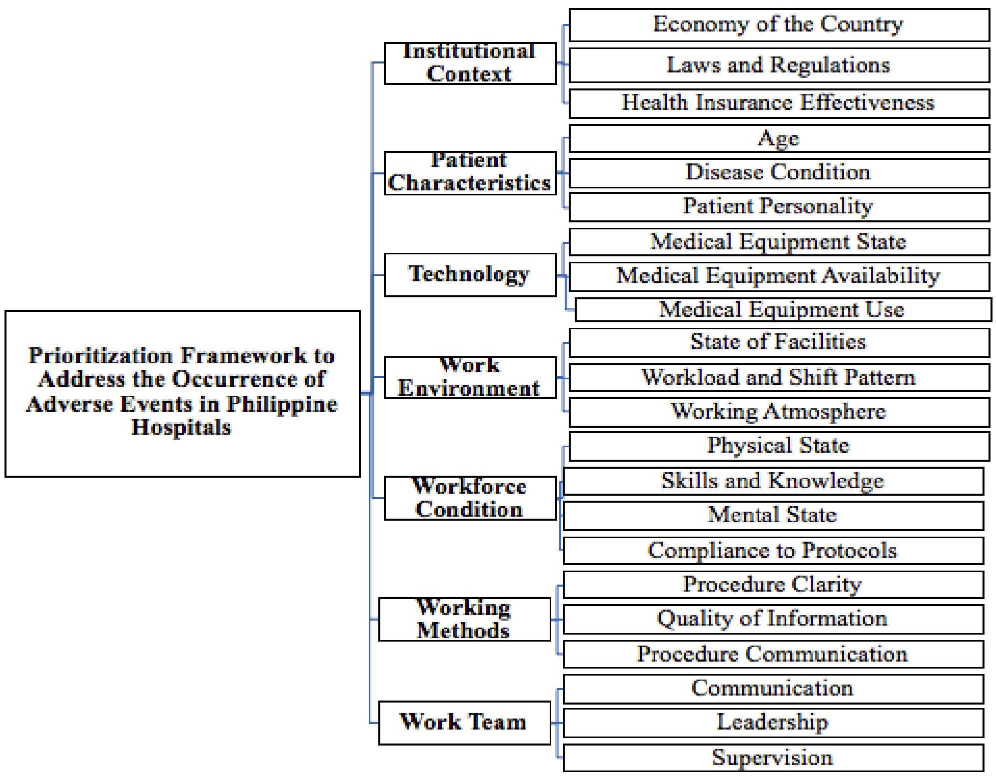

Figure. 2. Decision Structure for Prioritization of Factors

Table 4 shows the summary of rankings of factors from both set of experts. For both sets of experts, Technology is the main factor that should be prioritized by Philippine hospitals. However, there is minor difference in the second priority since Institutional Context ranked second for the first of experts while it ranked last for the second set of experts. This differences in ranking of sub factors might be due to the fact that Set A Experts are from public hospitals that is why Institutional context is on top of their list while Set B of experts came from private hospitals. Technology-related adverse events occur mostly in public hospitals such as Philippine Government Hospital (PGH) because medical equipment is unusable, or only partly usable, at any given time (Crisostomo, 2017).

Table 4. Summary of Factor Ranking

	Global Aggregated Ranking			
Rank	Set A Experts		Set B Experts	
	Criteria	*Weight*	*Criteria*	*Weight*
1	Technology	19.32%	Technology	31.98%
2	Institutional Context	15.95%	Work Environment	22.93%
3	Workforce Condition	15.11%	Workforce Condition	17.61%
4	Work Environment	15.01%	Work Team	12.60%
5	Working Methods	13.17%	Working Methods	7.59%
6	Work Team	10.81%	Patient Characteristics	6.82%
7	Patient Characteristics	10.63%	Institutional Context	0.46%

The value judgments of an expert in hospital management were used to derive the fuzzy pairwise comparison matrix for the criteria shown in Table 5. Two sets of experts were used to validate the results of the developed Fuzzy AHP model. Table 5 indicates that sub-factors from Technology, Medical Equipment State and Availability, were the top two sub-factors that should be prioritized by Philippine hospitals among all sub-factors. In addition, there were minor changes in the ranking in which sub-factors of Institutional Context and Patient Characteristics were ranked last.

Table 5. Summary of Sub-factor Rankings

	Global Aggregated Ranking			
Rank	Set A Experts		Set B Experts	
	Criteria	*Weight*	*Criteria*	*Weight*
1	Medical Equipment State	7.10%	Medical Equipment Availability	14.57%
2	Medical Equipment Availability	7.10%	Medical Equipment State	13.34%
3	Health Insurance Effectiveness	5.93%	Workload and Shift Pattern	9.76%
4	Economy of the Country	5.49%	Working Atmosphere	8.39%
5	Quality of Information	5.46%	Mental State	7.27%
6	Workload and Shift Pattern	5.43%	Communication	6.53%
7	Skills and Knowledge	5.34%	Skills and Knowledge	5.13%
8	Communication	5.18%	State of Facilities	4.78%
9	Medical Equipment Use	5.12%	Supervision	4.11%
10	State of Facilities	5.11%	Medical Equipment Use	4.07%
11	Age	4.80%	Quality of Information	3.56%
12	Disease Condition	4.64%	Physical State	2.73%
13	Laws and Regulations	4.53%	Disease Condition	2.66%
14	Working Atmosphere	4.47%	Compliance to Protocols	2.48%
15	Mental State	4.12%	Patient Personality	2.36%

The difference in the ranking of the three main sub factors, especially for the third ranks might also be rooted from the fact that the Set A experts are from public hospitals, while Set B experts are from private hospitals. In the Philippines where inequity in health status and access to services is more pronounced in public hospitals, health insurance may have been viewed by Set A experts as a major issue, attributing to the factor of the low level of financial protection offered through its national health insurance agency (Levinson, 2010). The main health insurance provider in the Philippines, Phil Health, covers only the basic hospital bills; thus patients are often liable for substantial co-payments and if there is a need for further treatment, the patient may choose not to proceed with the treatment due to the lack of financial support or the hospital management may refuse to give further treatments unless the patient has the capacity to pay for the treatment expense.

4. Conclusions and Recommendations

The factors and sub-factors contributing the occurrence of adverse events in the Philippine hospitals have shown to be a complex field of study. Given this, the researchers have geared towards the development of a framework that could further help in the continuous improvement of hospitals in the Philippines, specifically on addressing the issues of adverse events. To do this, the researchers used the Fuzzy Analytic Hierarchy Process (FAHP) in the prioritization of factors and sub-factors contributing to the occurrence of adverse events in Philippine hospitals. In this approach, the factors and sub-factors were weighed and ranked which can be used for policy-making in hospitals, project assessment as well as in assessing risks. Technology (19.32%) is the main factor that should be prioritized by hospitals in the Philippines followed by Institutional Context (15.95%) and Workforce Condition (15.11%) as the second and third most influential factor. On the other hand, Working Methods (10.81%) and Patient Characteristics (10.63%) were the least contributing factor to the occurrence of adverse events.

Validation of results was also added in the study to make sure that the framework developed can be used by hospitals in the Philippines which was done by having another set of experts. The implication of the results validation shows that the framework developed in this study is useful for developing policies on how to reduce occurrence of adverse events in Philippine hospitals. In addition, there are only minimal differences between the results of the initial and final validation answered by two different sets of experts. Technology (31.98%) is still the most contributing factor in the occurrence of adverse events in Philippine hospitals. There is a disparity between the second priority of the first and second set of experts wherein Institutional Context ranked last in the second set while it ranked second in the first set of experts. These differences in rankings can be further studied and analyzed by future researchers.

Through validation and sensitivity analysis, the developed framework in this study showed that it is consistent and reliable; however, there are still improvements that can be done in the study. First, future researches can make use of larger sample size of experts in order to obtain better results. In addition, researchers could also explore the possibility of expanding the use of Fuzzy AHP with the application of other tools like Decision-Making Trial and Evaluation Laboratory (DEMATEL) which could further address the issue of dependencies of the factors since the researchers of this study only made the best effort in order to avoid dependencies; therefore, the authors have only assumed criteria independence. Future researches could also explore the use of other multi-criteria decision methods to tests if the same results can be generated.

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