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Cost Impact Analysis on the DPWH Guideline and Implementing Rules on Earthquake Recording Instrumentation for Private Buildings using Multi-Criteria Decision Analysis-Analytical Hierarchy Process (MCDA-AHP) in the City of Manila

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Abstract. Philippines lie in the Pacific Ring of Fire, a region where earthquakes and other seismic activities are frequent. Through the NBCDO Memorandum Circular No. 01 Series of 2015, The DPWH Guidelines and Implementing Rules on Earthquake Recording Instrumentation for buildings was implemented with the objectives of: (1) ensuring the safety of building occupants by determining the condition of buildings, and (2) collecting earthquake related data during major seismic activities. Despite being signed on March 12, 2015, the compliance rate of the buildings here in the City of Manila was low. The purpose of this study is to determine the cost impact of the said guidelines to building owners using MCDA- AHP; as well as to identify the amount needed to equip the City of Manila. The research was carried out having SHM experts (for AHP) and building owners (for MCDA) as the respondents for the corresponding parts of the study. The results show that the equipment price has the biggest impact to the building owners and their willingness to pay for ERIs is lower compared to the market.

1. Introduction
Earthquakes in the Philippines are inevitable since the country is located in the Pacific Ring of Fire. Based on the 2004 MMEIRS study, “the Big One”, a 7.2 Magnitude earthquake, is expected in this lifetime to hit Metro Manila and other nearby provinces which will damage up to 1.3 Million residential structures and leave an approximate of 34,000 deaths and more than 100,000 injuries.[1]

Due to unexpected events like earthquake or typhoons the structure may suffer from damages that can lead to the failure or reduction of its structural integrity. A process called Structural Health

Monitoring (SHM) was introduced to monitor and detect the damages of a structure. Local Government Units (LGUs) and DPWH have no other way aside from visual inspection to know the extent of the damages done. A device called Earthquake Recording Instrument (ERI) was introduced as the possible solution in monitoring the structural health of the building.[2,3]

In 2015, the DPWH implemented its Guidelines, Implementing Rules, and Regulations on Earthquake Recording Instrument for buildings (DPWH IRR ERI). This guideline requires all buildings included in the categories listed to install a number of accelerographs as an additional mitigation measure and in order to safeguard lives. [4]

Department of Public Works and Highways (DPWH) adapted the DPWH IRR ERI for buildings last March 12, 2015 with the objectives of: (1) ensuring the safety of building occupants by determining the condition of buildings, and (2) collecting earthquake related data during major seismic activities. Four years after the implementation, the number of buildings that have complied with the DPWH IRR ERI in the City of Manila is still low.

The main objective of this study is to analyze the cost impact of the acquisition of ERIs to building owners. The researchers conducted this study to achieve the following specific objectives: (1) collate and assess data that represent the cost impact of the ERI installation, including the projection of the total cost needed to equip the affected buildings in the City of Manila, (2) utilize the MCDA-AHP to identify the optimum ranking of multiple criteria.

2. Methodology

The researchers gathered data and information needed to support the aim of the study. These information and data were the established facts from journals and the DPWH guidelines and implementing rules on earthquake recording instrumentation for buildings. The researchers gathered data of the buildings required by the guidelines from the office of the building official. The data gathered is a list of all buildings required and list of buildings that have not complied with the guidelines. This can be well summarized using figure 1.

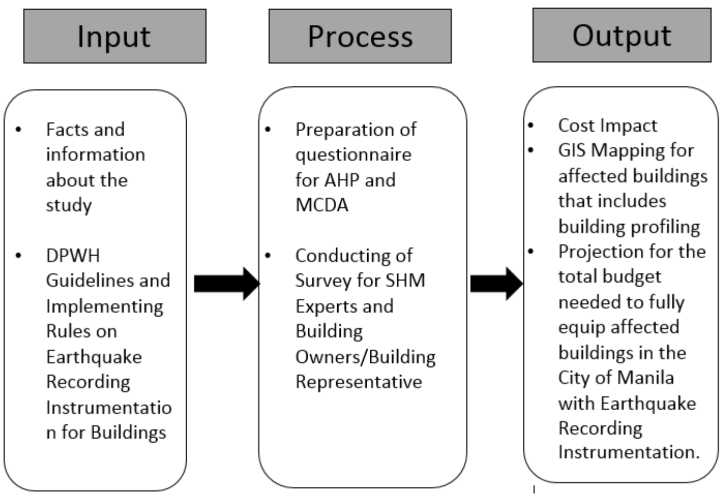

Figure 1. Research paradigm.

3. Results and Discussions

3.1. Demographics

The researchers used Cochran's formula to determine the number of respondents. The researchers used a confidence interval of 90% with a z -score value of 1.65 and a margin of error of 5%. The value of p or the percentage is 50% since it is generally used in determining the level of accuracy. Lastly, the population size was determined to be 157 as given by the Annual Inspection Division of the Office of the Building Official. Applying Cochran's formula, the researchers were able to compute for the sample size as 100.

$$n = \frac{\frac{1.65^2[0.5(1-0.5)]}{0.05^2}}{1+\frac{1.65^2[0.5(1-0.5)]}{0.05^2(157)}} \quad (1)$$

The researchers surveyed a total of 120 respondents in the City of Manila: 100 Building Owner/Representative (only 39 survey questionnaires were returned), and 20 SHM experts. The low rate of return of the questionnaires was attributed to the unwillingness of the building owners/representatives with the reason of confidentiality of their information. Figure 2 shows the composition of the sample population considering their building types. The sample size is composed of: 23 private building A, 10 private building B, and 6 private building C.

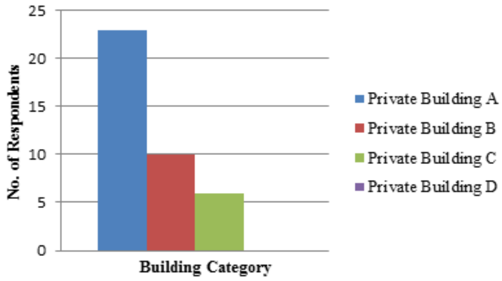

Figure 2. Population demographics regarding Building category.

The researchers also considered whether the respondents have complied with the DPWH IRR ERI or not. Only 33% or 13 respondents have complied with the said guidelines and 67% or 26 respondents have not yet complied based on the sample. This section is divided into two: (1) AHP and (2) MCDA; the two methods that the researchers used in the analysis of cost impact. All of the data presented were findings of the researchers based on the second part of the questionnaire and the AHP questionnaire.

3.2. Analytical Hierarchy Process (AHP)

AHP is used in getting the weights of each cost criterion that affects the decision making of the building owners/representatives based on the perspective of 20 experts related to structural health monitoring and ERI development from: Development of Earthquake Intensity Monitoring System (DEIMS), Universal Structural Health Evaluation and Recording System (USHER) team and the Philippine Structural Integrity Management System (PhilSIMS). The experts consider 30.66% as the weight of the equipment cost, 10.31% for the installation cost, 26.29% for the maintenance cost, and 32.74% for the operation cost.

In the perspective of the experts, the operation cost was identified to be the primary reason that affects the decision of building owners/representatives in the acquisition of ERIs, the equipment cost as the secondary criterion, maintenance cost as the third criterion to be considered, and installation cost as the last criterion to be considered.

The process in obtaining the weights of each criterion was derived using the AHP calculator by K.D. Goepel.[5] The responses of the 20 SHM experts was consolidated; the former participated in the survey. The calculated consistency ratio is 3.7% which is within the acceptable threshold; it means that the results were reliable. The error for each weight presented means that errors may happen even if the consistency ratio is below 10%. The pair-wise comparison matrix and the generated scale and weights considering the 20 SHM experts were consolidated. This shows the importance of each criterion relative to the other criteria.

3.3. Multiple Criteria Decision Analysis (MCDA)

The researchers used Multiple Criteria Decision Analysis approach in the interpretation of the responses of 39 building owners/representatives.[6] In this section, the results of each building types and the aggregate results were presented and analyzed.

There were 23 respondents for building owners/representative of private building A. The results clearly show that Equipment Cost have the biggest impact in the acquisition of ERI since it was identified to have the largest portion in the total cost of the equipment. It is followed by operation cost, maintenance cost, and installation cost consecutively.

Table 1. MCDA-AHP ranking for private building A.

Criterion	Rank
Equipment Cost	1
Operation Cost	2
Maintenance Cost	4
Installation Cost	3

Only 10 building owners have responded for the buildings in private category B. Equipment Cost also ranked first in the cost impact survey followed by operation cost, maintenance cost, and installation cost. It was identified in the result; equipment cost is the most impactful for building owners of schools and hospital.

Table 2. MCDA-AHP ranking for private building B.

Criterion	Rank
Equipment Cost	1
Operation Cost	2
Maintenance Cost	4
Installation Cost	3

There were six that responded for buildings belonging to category C. The building owners/ representatives ranked the equipment cost as first cost that affects their acquisition of ERI. Second is the operation cost; maintenance cost as third place; and installation cost as the cost that lead to least impact in the acquisition of ERIs.

Table 3. MCDA-AHP ranking for private building C.

Criterion	Rank
Equipment Cost	1
Operation Cost	2
Maintenance Cost	4
Installation Cost	3

The total number of respondents for all of the building categories is 100 however only 39 respondents or 39% of the total respondents were willing to participate in the survey. Based on the result of the cost impact survey for each building, equipment cost was always considered to have the biggest impact in the acquisition of ERI followed by the operation cost, maintenance cost and installation cost ranked consecutively.

Table 4. Aggregate MCDA-AHP ranking.

Criterion	Rank
Equipment Cost	1
Operation Cost	2
Maintenance Cost	4
Installation Cost	3

One significant finding of the research is that the willingness to pay (WTP) allocated budget of the building owners/representatives only differs on the ranking of the installation cost and maintenance cost to the results of the MCDA-AHP study. The WTP obtained were: (1) Equipment Cost- ₱593,590 (2) Operation Cost- ₱400,000; (3) Installation Cost- ₱184,615.38; and (4) Maintenance Cost- ₱120,512.82. The prices were obtained using the mean values of the WTP of the owners as presented in Appendix G. The mean values were subtracted to the preceding package to obtain the WTP of each criterion.

According to Greef & Ghoshal [7], maintenance cost is treated as one of the largest operating expense and is critical since it is needed to maintain the condition of the equipment [8]. Owners and operators see the maintenance cost only as additional cost and as a window to save money. This was proven in the findings since the allotted budget for the maintenance cost is lesser than the installation cost even though they were valued by SHM experts and the owners in reverse.

3.4. Total Cost Projection

This section discusses the cost projection in fully equipping the City of Manila with ERIs. The researchers asked the building owners/representatives about their budget or how much were they willing to pay for the installation of ERI. The researchers presented four packages in order to have a more detailed outcome.

The buildings affected by the guideline were categorized to determine the total number of ERI needed in the City of Manila based on Table 5. The number of buildings without ERI is tallied per building category and the total number of building was computed as 131. According to the Office of the Building Official of the City of Manila particularly the Annual Inspection Division the total number of private buildings required to install ERI were 157. It consists of 90 private building A, 57 private building B, and 10 private building C. Based from the data obtained only 26 private buildings or only about 17% of the total number of buildings have already complied with the DPWH IRR ERI.

To obtain the total number of ERI needed, the number of buildings without ERI is multiplied with the number of ERI needed per building category. For private building A it is required to have 3 units of ERI while for other building category only one unit is required. The total number of ERI units needed was computed as 298.

Table 5. Tally for the total number of ERIs needed for the City of Manila.

Building Category	No. of Bldgs. in Manila w/o ERIs	No. of ERI req'd per bldg..	Total No. of ERI needed
Private Bldg. A	79	3	237
Private Bldg. B	53	1	53
Private Bldg. C	8	1	8
Private Bldg. D	0	1	0
TOTAL	**131**		**298**

3.5. Cost Projection per Package

The researchers considered four packages in projecting the total cost needed for the City of Manila to be 100% compliant. As shown in Table 5, the total number of ERI needed in the City of Manila is 298 units.

The price per package as presented in Table 6 was computed based on the answers of the building owner/representative on the last part of the survey which is the willing to pay (WTP) part. The total cost per package was computed by multiplying the number of ERI units needed and the price per package. The following were the packages and its inclusions: (1) Package 1 - Equipment Cost, (2) Package 2 - Equipment Cost and Installation Cost, (3) Package 3 - Equipment Cost, Installation Cost and Maintenance Cost, (4) Package 4 - Equipment Cost, Installation Cost, Maintenance Cost, and Operation Cost.

The price range values of each package were computed using the frequency table. The researchers used the formula of Confidence Interval after identifying the average of the WTP of the building owners. Table 6 shows the frequency table for package 1[9].

Table 6. Frequency table for Package 1.

UL	LL	$\tilde{x}$	f
100000	200000	150000	16
200000	500000	350000	10
500000	1000000	750000	7
1000000	3000000	2000000	6

Table 7. Cost Projection for the City of Manila.

Package	Price Range	Total cost
Package 1	₱423,325 - ₱763,855	₱126.1 M - ₱227.6 M
Package 2	₱578,481 - ₱977,929	₱172.4M - ₱291.4M
Package 3	₱693,132-₱1,104,304	₱206.6 M - ₱329.1 M
Package 4	₱1,020,990-₱1,576,446	₱304.3 M - ₱469.8 M

3.6. Budget difference of building owners with and without ERIs.

The researchers divided the results of the budget allotment on the installation of ERI to those who have already installed ERIs and those who have not. On Table 6 the results show that the WTP of those who have installed ERIs was far greater compared to that of those who have not yet complied with a percentage difference ranging from 27.04%-71.04%.

WTP of the building owners/representatives presented in Table 8 is computed in the same way as presented in sample computation presented below Table 4.6 the only difference is that the samples were divided in two groups: (1) with ERI, and (2) without ERI. The percent difference was computed using the formula:

$$Percentage\ Difference = \frac{WTP_{with\ ERI} - WTP_{without\ ERI}}{\frac{WTP_{with\ ERI} + WTP_{without\ ERI}}{2}} \quad (2)$$

Table 8. Willingness to pay of building owners with and without ERIs.

	With ERI	W/o ERI	Percentage Difference
Package 1	₱542,004-₱1,265,888	₱274,716-₱602,207	65.45%-71.04%
Package 2	₱591,461-₱1,377,770	₱450,564-₱899,436	27.04%-42.01%
Package 3	₱929,044-₱1,670,956	₱474,051-₱922,103	57.76%-64.86%
Package 4	₱1,320,471-₱2,225,683	₱732,418-₱1,390,659	46.18%-57.29%

Due to unavailability of data, the researchers have only compared package 1 or the equipment cost with the market price. Maintenance cost and the other costs vary on different occasions according to technical specialists. Only Product A, a locally manufactured ERI, is within the range of WTP of the sample population.

Table 9. Price of different ERIs available in the market [10].

Brand Name	Unit Price
Product A	₱480,000
Product B	₱925,000
Product C	₱1,227,200
Product D	₱1,248,000

4. Conclusion and Recommendation

It was identified that the City of Manila has a rate of compliance of 17% (as of March 2019), a rate that is considerably low for an IRR that is in effect for four years.

Equipment cost was identified to have the most substantial impact to building owners in the compliance to the DPWH IRR ERI. It was also found out that the willingness to pay of building owners with regards to the acquisition of ERIs is lower compared to the value of ERIs available in the current market.

The units needed in order to fully equip the City of Manila with ERI shows that there is a problem in the implementation of the LGU or lack of cooperation from the building owner/representatives.

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Complete compliance of the building owners to the DPWH IRR ERI for the city of Manila has a long way to go. The results show that a lot of money is needed to achieve complete compliance. The researchers have determined that the number of units needed is 298 units that costs around ₱126.1 - ₱227.6 million. [11]

Other than the cost, the researchers have identified some of the other problems relating to the non-compliance of the building owners/representative during their data gathering process. It was known that there are lack of information regarding the importance of the installation of ERIs, and the miscommunication of the Office of the Building Official to the building owners regarding the implementation. They have also pointed out that the punishments on the non-compliance were lighter compared to the cost of the ERI itself.

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