Potential Crime Areas Analysis Using Integration of Analytical Hierarchy Process (AHP) and Geographical Information System (GIS)

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Abstract

Increasing crime rates in a community can be associated with several factors such as land use, economics activities, building use and demography. A preliminary survey conducted showed that land use and building use are potential cofactors that contribute to a crime. In this research, we attempt to develop a model to predict crime areas by utilizing these two cofactors. To pursue this endeavor, Analytical Hierarchy Proces (AHP) method and Geographical Information System (GIS) were implemented. AHP is used to produce consistent and realistic weight values of crime factors by calculating the consistency ratio (CR) which can thereafter be used for validation. Though, the GIS is applied to visualize the weights obtained from the AHP results in spatial mapping in order to identify potential crime areas, which were classified as either high, medium or low. The data set for this research has been drawn from UGISP Sdn Bhd, which covers the areas of Wilayah Persekutuan Kuala Lumpur (WPKL). From the result, it shows that the potential crime areas are Kuala Lumpur, Bukit Indah, Jinjang and Bandar Tun Razak. As a conclusion, our model would assist the authorities (i.e., Dewan Bandaraya Kuala Lumpur, Malaysia) to identify and rank the potential crime areas, and then they can plan a strategy to monitor this matter properly.

Keywords. Analytical hierarchy process; geographical information system; multi-criteria decision making; spatial analysis

1   Introduction

Monitoring of crimes in Malaysia is necessary to ensure that the statistic of crime rates are still under control [1]. In terms of monitoring, crime analysis is among the chosen approach. The crime analysis is a law enforcement function that involves systematic analysis for identifying and analyzing patterns and trends in crime and disorder. Information on patterns can help law enforcement agencies to deploy resources in a more effective manner, and assist detectives in identifying and apprehending suspects [2]. Generally, crime analysis uses both qualitative and quantitative and also analytical methods [3]. Besides that, crime analysis can assist with these efforts by providing research and analysis of disorder indicators such as trespass warnings that can assist police in addressing these issues before they become more serious problems [1].

Multi Criteria Decision Making (MCDM) provides strong decision making in many domains where selection of best alternative is highly complex [4]. Although MCDM have been applied in many domains. Recently, many decisions are being made from various criterias so the decision can be made by providing the weight for each different criterion [5 – 6]. The problem becomes more complex when many criteria are involved for the alternatives. Thus, MCDM is one of the approaches that helps in making better decisions in complex problem when involved different criteria to select the best solution among a group of alternatives [7]. According to some researches, there are many factors that contribute to crime, but no specific factors are precise in affecting crime [5]. Decision making was used to determine the priority of each multiple factor in crimes by providing the weights [5]. However, in many situations, it is extremely difficult to assign relative weights to the different criteria involved in making a decision on potential crime areas in the mapping unit [6]. The study conducted by [8] mentioned that conventional MCDM method obtained the weight for each criterion from experts groups or surveys. Nevertheless, the weights provided from them has bias in decision making because there are some difficult decisions where experts are not able to provide the exact numerical values to their preference [8].

Therefore, it is compulsory to adopt a method that allows an estimation of the weights. One such method is

the Analytical Hierarchy Process (AHP) that can be used to improve the quality of decision making by reducing the risk of making the wrong decision [9 - 10]. Since the problem is constructed into a hierarchical structure so the importance of each element becomes clear. In addition, AHP incorporates a useful technique for checking the consistency of the decision maker's evaluations, thus reducing the bias in the decision making process [11]. AHP will estimate the reliability of criteria weight by using consistency ratio (CR). The CR value is important as a guidance to check for validation. If the CR value is less than 0.1, the judgments are consistent, so the derived weight can be used [11 – 12]. The old pin maps were useful for showing where the crimes occurred, but unfortunately, it has serious limitations. During updating, the prior crime patterns were lost [13]. Consequently, Geographical Information System (GIS) and data mapping applications for crime mapping has become a necessary tool in law enforcement agencies worldwide, probably one of the most valuable tools available [14]. Meanwhile, crime analysis requires handling both spatial and attribute data in many data layers. Therefore, it is appropriate to use GIS to exploit its strong capability in handling spatial data [15]. Using map can also help to manage, analyse and present the geographic location data [14]. Moreover, an integration of GIS and AHP method for potential crime areas analysis is expected to produce promising results.

Hence, this paper presents the results of integration between AHP and GIS in analyzing the potential crime areas conducted using the data collected for WPKL area. The organizations of this paper are as follows. Methodology of the study is discussed in Section 2. In Section 3, the results and the analysis process were thouroghly discussed. The discussions and conclusions were written in Section 4 and 5 respectively.

2   Methodology

This section discussed the research methodology and conceptual framework that have been applied in this study. The general conceptual framework for potential crime area analysis is shown in **Figure 1**.
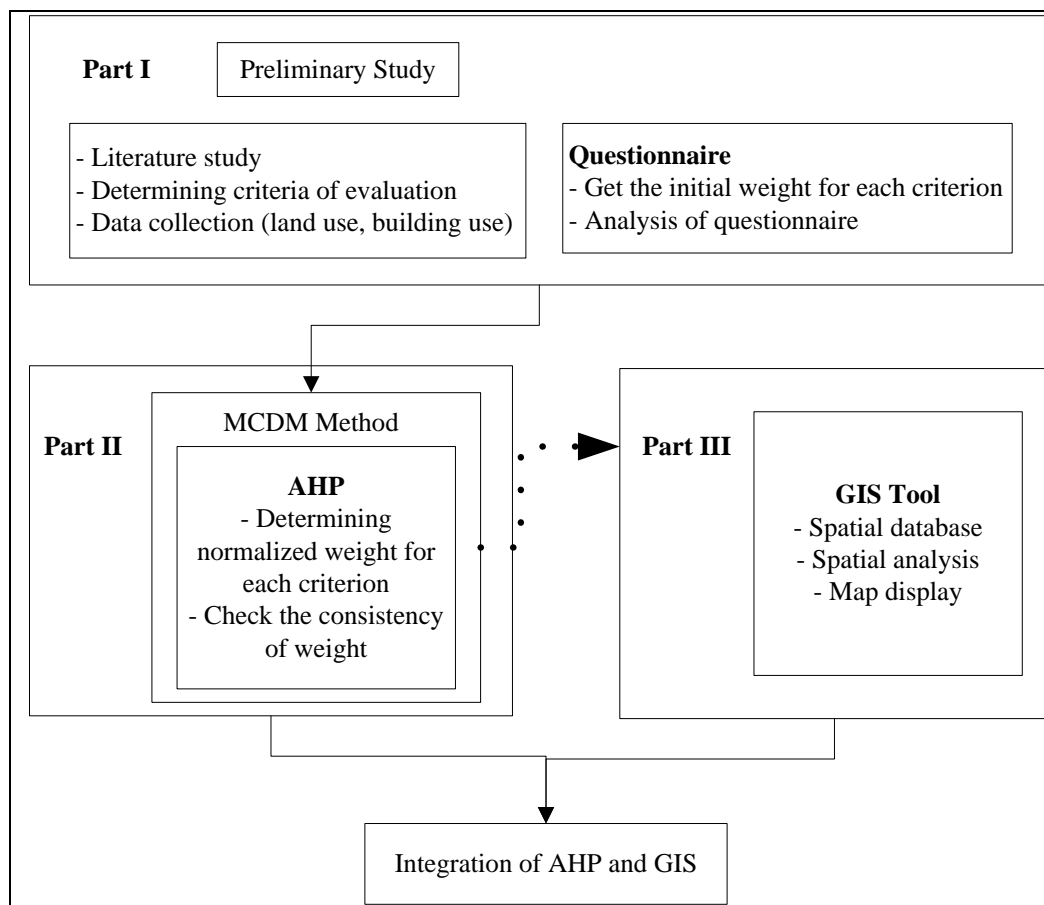

Figure 1. Conceptual Framework of Study

2.1 Research Scope and Area

The data set for this study has been drawn from UGISP Sdn Bhd, which covers the areas of Wilayah Persekutuan Kuala Lumpur (WPKL). Kuala Lumpur is the one of the most developing centre in Malaysia. **Figure 2** shows the location of study area.

Figure 2. Study of Area

2.2 Research Data and Sampling

Due to data limitation, this study focus on building use and land use data set as the main criteria. The study by [16] stated that questionnaire forms have been used as instrument to gather primer data from the respondents. In order to determine the weight of each criterion, 100 sets of questionnaire were distributed to police and the experts from the related fields regarding the crime analysis. The results of questionnaires were shown as numerical values to present the ranking of potential crimes.The weight obtained from the questionnaire as shown in **Table 1**.

Table 1. Weight of Criteria and Sub Criteria

Criteria	Weight	Sub-Criteria	Weight
Land Use	8	Residence	9
		Open Space	8
		No Development Area	7
		Industrial	6
		Business and Services	5
		Empty Land	4
		Institutional and Community	3
		Infrastructure and Utility	2
		Transportation	1
Building Use	6	Bank	9
		School	8
		Petrol Station	7
		University	6
		Hotel	5
		House	4
		Transport Terminal	3
		Parking Lot	2
		Market	1

2.3 Analytical Hierarchy Process (AHP)

AHP has been applied for many years. It was introduced and developed by Saaty (1980). In the AHP method, obtaining the priority vector and weights for each criterion are required.The procedures involve few essential steps [17 - 18].

A. Define the unstructured problem. The goal of this study is to identify the potential crime areas in WPKL. The criteria used are land and building use.

B. Developing the AHP Hierarchy. The principle utilized in AHP for problem solving is to construct hierarchy. The hierarchy allows assessment of the contribution criterion, starting from the lower levels to the higher levels of the hierarchy [19]. It begins by decomposing the overall goal into a number of criteria and sub-criteria. The goal is presented at the top level of the hierarchy. Major criteria comprise level two, while sub-criteria in level three [20, 21]. By applying this step in potential crime areas analysis, the decision criteria relevant to our goal can be identified. **Figure 3** shows the potential crime areas hierarchy.
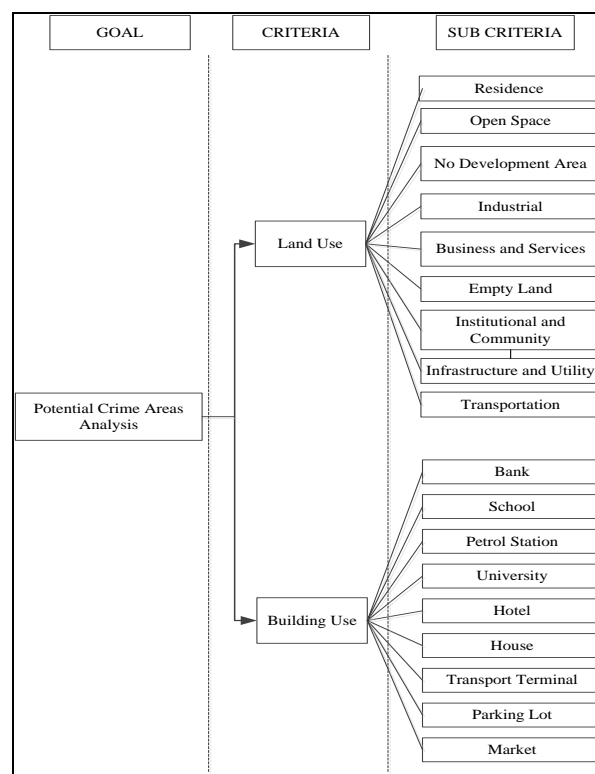
Figure 3. Potential Crime Areas Analysis Hierarchy

C. Criteria of Weighting. Criteria scores were determined according to the scale that represents score value of 9 to 1. The bigger the score value, the higher the rank of the criteria [19]. The importance of each criterion relative to other criteria is shown by criteria weighting. **Table 2** shows the scale of relative importance according to Saaty (1980) [17].

Table 2. Scale of Relative Importance

Intensity of importance	Definition
1	Equal importance
3	Somewhat more important
5	Much more important
7	Very much important
9	Absolute important
2, 4, 6, 8	Intermediate values

D. Pair-wise Comparison Method. AHP requires evaluation of the pair-wise comparison matrices using measurement theory [20]. For each level in the hierarchy it is necessary to know whether the pair-wise comparison has been consistent in order to accept the results of the weighting [18].Typically, the value of weight will be normalized where the sum of weight of each criterion is equal to 1. If it has 'n' criteria such as $C_1, C_2, ..., C_n$ with the weight $W_1, W_2, ..., W_n$, the equation used according to the following formula [19].

$$\sum_{i=1} Wi = 1 \tag{1}$$

E. Consistency Analysis. Consistency Ratio (CR) has been used to measure on how consistent the judgment relative to large samples of purely random judgments. If the CR is exceed 0.1, the judgments are untrustworthy because they are too close to randomness and the exercise is valueless or must be repeated [21]. The measure of consistency, called Consistency Index (CI) by using the following formula.

$$CI = \frac{\lambda \max}{n-1} \tag{2}$$

Table 3 shows the average random consistency index (RI) of sample size 500 matrices [21].

<div align="center">Table 3. Consistency Ratio of Jugments</div>

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

The measure of consistency, called Consistency Ratio (CR) using the following formula.

$$CR = \frac{CI}{RI} \tag{3}$$

2.4 Geographical Information System

GIS provide a new alternative approach to the conventional statistical methods [22]. A main advantage of GIS is that it can be visualize the spatial patterns of crimes in mapping. Moreover, another function of GIS is to also visualize the relations between crime and its correlates and the differentiation of crime type and its related attributes [23]. ArcGIS Desktop provides a set of analytical and data maintain capabilities for the trained GIS professional. It is also deployed to perform data very well when working with sources of data and services such as Enterprise Geodatabase, ArcGIS Image Server and ArcGIS Map Services [22 - 23]. The main analysis task are used ArcGIS Spatial Analysis to create the mapping for identifying the potential crime areas in WPKL. The mapping was reclassified into three categories: high, medium and low potential.

2.5 Integration of AHP and GIS

MCDM is the tool for analyzing decision problem and evaluating alternatives based on a decision maker's preference. However, it lacks the capability of handling the spatial data that are important to spatial analysis. Thus, the need for combining the strengths of both methods has encouraged researchers to seek integration of AHP and GIS. **Figure 4** shows the flowchart of integration AHP and GIS.
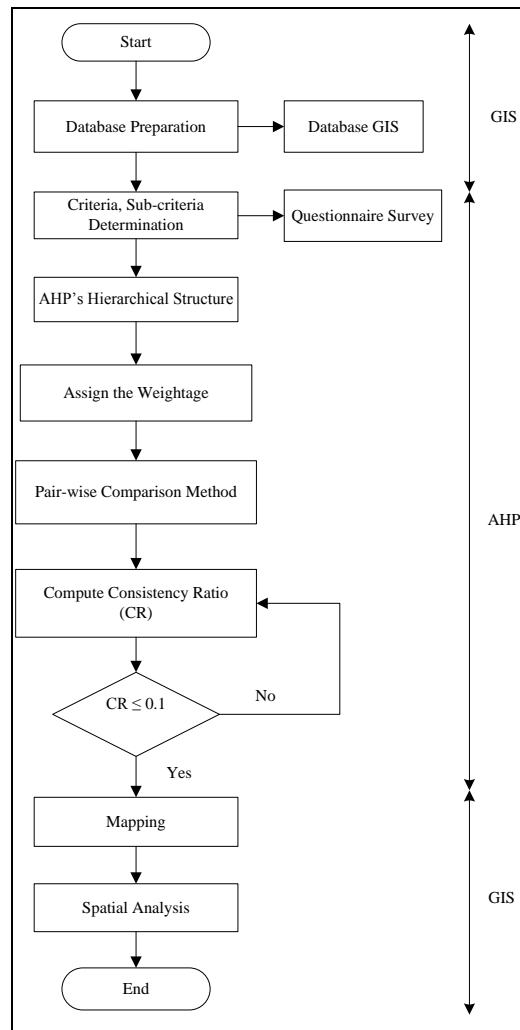
Figure 4. Flowchart of Integration AHP and GIS

3   Results and Analysis

To define the potential crime areas in spatial mapping, we used the following criteria and sub criteria in **Table 4**. As stated previously, weightage for each criterion obtained from the analysis of questionnaire has been used to get the normalized weight using AHP. The matrix algebra (Eigenvector) was used to turn the matrix into ranking of normalized weightage. The final process to get ranking priorities from a pairwise matrix using AHP is as shown in **Table 4**.

Table 4. Criteria of Weighting in AHP

Level 1			Level 2			Overall Weight
Criteria	W_1	CR_1	Sub-Criteria	W_2	CR_2	($W_i = W_1$ x W_2)
Land Use	0.571	CR = 0 (≤ 0.1)	Residence	0.200	CR = 0.095 (≤ 0.1)	0.114
			Open Space	0.178		0.102
			No Development Area	0.156		0.089
			Industrial	0.133		0.076
			Business and Services	0.111		0.063
			Empty Land	0.089		0.051
			Institutional and Community	0.067		0.038
			Infrastructure and Utility	0.044		0.025
			Transportation	0.022		0.013
Building Use	0.429		Bank	0.200	CR = 0.095 (≤ 0.1)	0.086
			School	0.178		0.076

			Petrol Station	0.156		0.067
			University	0.133		0.057
			Hotel	0.111		0.048
			House	0.089		0.038
			Transport Terminal	0.067		0.029
			Parking Lot	0.044		0.019
			Market	0.022		0.009

Table 4, shows that 'Land Use' is the most important criteria with a value of 0.571 and 'Building Use' is the least important criteria with a value of 0.429. Moreover, residence and bank are the most important sub-criteria with a value of 0.200 while transportation and market are least important sub-criteria with a value of 0.022. As we can seen from the results, the judgment of normalized weight for each criterion are reliable and consistent because the value obtained are acceptable in validation. As a result, the potential crime areas were mapped as shown in **Figure 5**. Using raster suitability analysis in GIS, intersection of both data; land use and building use will produced the new layers. The resulting layers have all of the attributes of the original layers by using over-lay concept. In addition, the potential crime areas were classified as high potential (red colour), medium potential (orange colour) and low potential (yellow colour). By overlaying the criteria maps, we concluded that Kuala Lumpur, Bukit Indah, Jinjang and Bandar Tun Razak are categorised as the most potential crime areas.
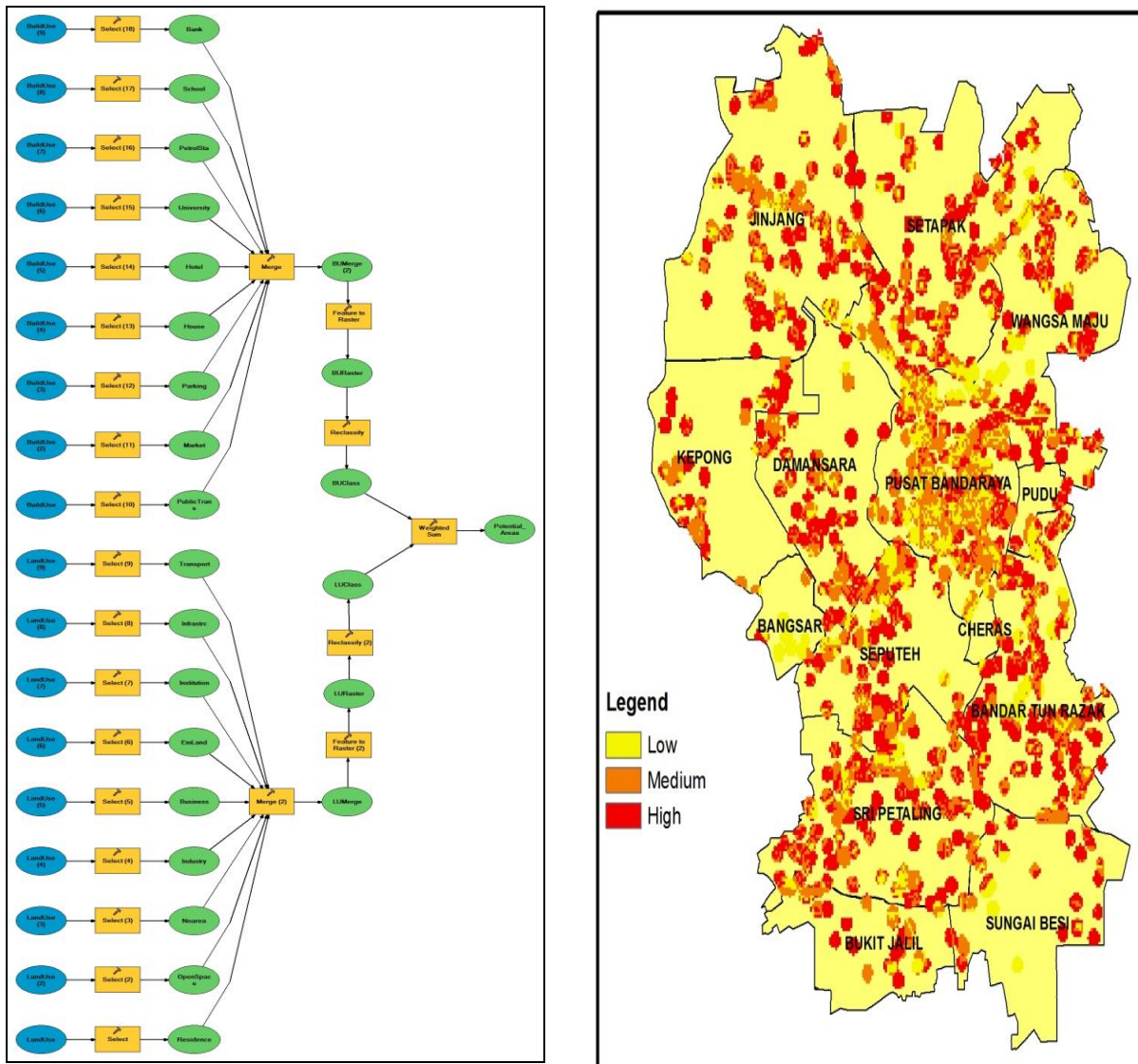

Figure 5. Modeling of GIS and Potential Crime Areas Mapping

4 Discussion

In the proposed model, AHP used to calculate the weights of the criteria, and GIS functionality was used to extract the suitability map with the weights calculated. As a result of the study, we find that the proposed model is practical in identifying potential crime areas with respect to multiple criteria. The finding is extremely pertinent for law enforcement to control the potential crime areas for public safety. We have evaluated the integration of AHP and GIS which has not previously been used for this purpose. Furthermore, we hypothesized that AHP can deals with the complex problems which involved multiple criteria simultaneously compared with Weighted Sum Model (WSM) method [24]. By reducing complex decisions to a series of pairwise comparisons and then synthesizing the results, AHP helps to capture both objective and subjective aspects of a decision. In addition, AHP incorporates a useful technique for checking the consistency of the decision maker's evaluations, thus reducing the bias in the decision making process compared with methods like TOPSIS and ELECTRE, the consistency is not controlled [25].What's new in this paper is application of domain in finding out the potential crime areas in spatial mapping based on land and building use factors and a new model in raster suitability analysis using GIS. However, the result is increasingly flexible if more types of data used. It is anticipated that the current paper will help the decision maker with ability to look in to the future and make the best possible decision. However, the limitation of this study, when the number of the levels in the hierarchy increase, the number of pair comparisons also increase, so that to build the AHP model takes much more time [20]. Due to data limition currently, it is difficult to provide a flexible and consistent analysis. In future research, it is recommend that adding more existing data and using defuzzization methods such as enhance current AHP with Fuzzy method.

5 Conclusion

This paper proposed integration between AHP and GIS to identify the potential crime areas based on the data collected. AHP method, which is commonly used in multi-criteria decision-making exercises, was found to be a useful method to determine the weights. Compared with other methods (i.e., conventional MCDM and weighted sum used for determining weights), the AHP method is superior because it can deal with inconsistent judgements and provides a measure of the inconsistency of the judgement of the respondents. Moreover, GIS was found to be a technique that provides greater flexibility and accuracy for handling digital spatial data. Thus, the combination of AHP method with GIS in our experiment proves that it is useful to be applied in potential crime areas analysis.

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