INCORPORATING SPATIAL SELECTION CRITERIA WITH DECISION PREFERENCES IN MCE-GIS-BASED SITE SELECTION OF A PRECAST MANUFACTURING PLANT

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Abstract
The Construction Industry Development Board of Malaysia has been actively promoting the use of precast manufacturing in the local construction industry over the last decade. In an era of rapid technological changes, precast manufacturing significantly contributes to improving construction activities and ensuring sustainable economic growth. Current studies on the location decision of precast manufacturing plants aimed to enhanced local economic development are scarce. To address this gap, the present research establishes a new set of spatial criteria, such as attribute maps and preference weights, derived from a survey of local industry decision makers. These data represent the input parameters for the MCE-GIS site selection model, for which the weighted linear combination method is used. Verification tests on the model were conducted to determine the potential precast manufacturing sites in the state of Penang, Malaysia. The tests yield a predicted area of 12.87 acres located within a designated industrial zone. Although, the model is developed specifically for precast manufacturing plant but nevertheless it can be employed to other types of industries by following the methodology and guidelines proposed in the present research. The findings of this study can be recommended as a guideline or decision support module to the precast manufacturers. Consequently, the model is applicable to be suitable to other states as well using the same decision makers' weight and criteria but essentially replacing the attribute maps according to the selected state.

Keywords: *Spatial criteria, multi criteria, Industrialised Building System, precast manufacturing plant*

INTRODUCTION

The expansion of precast manufacturing plants is decided on the basis of demand and contract value-based projects. However, some factories in the United Kingdom (BBC 2010) and Malaysia (BBC, 2010; Kamar, 2011) have discontinued production or were closed. High-tech precast manufacturing plants operate in accordance with project demands and may fail if they incur high operational costs and maintenance under low production demand. Therefore, a feasible location study is critical to understanding the setup of precast manufacturing to warrant continuous production and demand. High and repetitive production implies low production costs. The volume of production is important because precast construction requires repetitive and continuous projects to be profitable.

The review of current literature does not reveal identical findings on precast manufacturing plants plagued by site selection issues. Nevertheless, certain studies provide insight into this problem. For example, Shen (2005) investigated manufactured housing (MH), which is similar to the precast manufacturing system. He evaluated the accessibility of MH to community services by GIS analysis and provided justification for why MH projects are not constructed near large facilities. The majority is located outside cities or suburban locations, and some are located in rural areas. The author recommended the inclusion of more MH zoning concepts in policy and accessibility practice. Policy is a key driver of the development of precast manufacturing.

The decision process entailed by location selection is also crucial in defining the determinants of a good location because most of the important location criteria emerge from the initial stages of site selection. Understanding the location decision process may improve the development of local economic activities and generate sustainable business environments (Badri, 2007). Multi-criteria evaluation (MCE) is frequently used to assess allocation issues, facilitating conceptualization and decision making; these processes include a full range of social, environmental, technical, economic, and financial criteria (AbuSada and Thawaba, 2011; Carver, 1991; Jelokhani-Niaraki and Malczewski, 2015).

Jankowski and Nyerges (2001) agreed that experimentation on decision making tools with GIS technology is feasible through the use of the “classic” site selection reference problem. GIS-based solutions highlight the voice of decision makers and enable the recognition that differential access to GIS data, hardware, software, and “human ware” are significant components of spatial decision making (Harris and Weiner, 1998). MCE-GIS models for site selection are therefore dynamic, and their integration becomes a powerful tool that can provide better cartographic display and infinite database systems (Malczewski and Rinner, 2015).

The current research establishes a site selection model for new precast manufacturing plants within the Northern Corridor Eastern Region (NCER) of Malaysia to fulfill the demand of precast components where supply remains low. The model was tested in Penang, Malaysia, which has only one precast manufacturing plant despite the fact that the state has the highest GDP growth of the manufacturing and construction sectors among the other states (NCER) of Malaysia (Statistics, 2010).

LITERATURE REVIEW

This study provides a useful method for examining an alternative approach to evaluating the criteria that reduce uncertainties in decisions. Each criterion is represented as a map layer in a GIS database. Thus, each layer that represents the evaluation criterion is referred to as an attribute map (Malczewski, 1999). Two types of attribute maps are available: factor and constraint maps (Eastman, 2003). A factor is a criterion that enhances or detracts from the suitability of a specific alternative for the activity under consideration; it is measured on a continuous scale. A constraint serves to limit alternatives under consideration and is expressed in the form of a Boolean map [i.e., 1 (true) or 0 (false)] (Azman et al., 2012a).

Once the attribute maps are developed, the evaluation stage combines the information presented by the maps and defines the parameter limits of various factors and constraints (Eastman, 2003). Subsequently, the aggregated information from the attribute maps are used as input parameters for the MCE-GIS module that evaluates multiple criteria by Boolean overlay and weighted linear combination (WLC) techniques. The subsequent section discusses the additional implementation stage of these procedures.

Despite the limitation of a statistical approach to determining new potential sites for precast manufacturing plants, it can be alternatively implemented using the MCE-GIS method. Most statistics are based on probability concepts. An observation in which statistics is impossible is very unlikely. When drawing conclusions in statistical analysis, the line at a certain level of probability should be drawn. Many common statistical calculations and tests have an important assumption on populations studied; that is, that populations are characterized by normal distribution. This assumption indicates that the characteristics of interest in a population are evenly distributed. Traditional statistics is inherently non-spatial because it seeks to represent a data set by its typical response regardless of spatial patterns. The mean, standard deviation, and other statistical values are computed to describe the central tendency of the data in abstract numerical space without consideration for the relative positioning of the data in real world geographic space. Given the size limitation of population samples for precast manufacturers (25 respondents) a value smaller than the number of independent variables (49 variables) additional statistical analyses, such as binary logistic regression or multiple linear regression, are unsuitable (Azman et al., 2013). The literature review indicates that no specific rule is applied in determining the adequacy of sample size for logistic regression, but multivariate statistics scholars have recommended a minimum ratio of 10 to 1, with a minimum sample size of 100 or 50, plus a variable number that is a function of the number of predictors (Peng et al., 2002).

From statistical data on multiple decision makers, the weight of each criterion can be determined using the aggregation of individual priorities (AIP). These weights multiplied by the spatial data layers that represent each criterion are the input parameters for the WLC or simple additive weighting model to determine new potential sites for precast manufacturing. Aside from generating the weights of multiple decision makers, preparing attribute maps is important in spatial data analysis. GIS analysis and databases are employed in a variety of decision making contexts in the main preference of decision sensitivity to the prediction technique in GIS-based models (AbuSada and Thawaba, 2011). GIS technology is unique because the criteria for decision makers can be measured, evaluated, and stored in GIS databases for analysis (Figure 1). Thus, decisions are based on criteria (Effat and Hegazy, 2010).

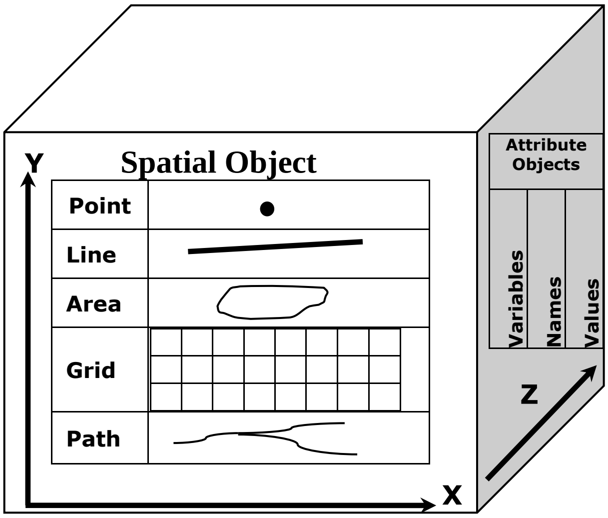

Figure 1. Geomorphic Applications Needed for a Three Dimensional GIS

Studying MCE-GIS using the WLC model necessitates appropriate parameters for the attribute maps determined through literature reviews. In addition, these maps are classified as factor and constraint maps. The decision makers' weights are multiplied by the factor maps, whereas the constraint maps require only a buffer or re-class spatial analytical process that restricts the site screening process. Thus, the areas restricted by rules and physical constraints are excluded from the selection area and assigned a value of 0 during the data preparation stage. These constraint maps are regarded as Boolean images and simply act as masks in the last step of WLC. The WLC process overlays all factor maps and the final mask determines the results for new potential sites.

METHODOLOGY

The total number of precast manufacturers currently registered with the Construction Industry Development Board (CIDB) of Malaysia is 36 (IBSCentre, 2011). Only 25 manufacturers have permanent factories and the rest are temporary in nature, dependent on the terms of a project. The site selection criteria were determined by a multi-criteria decision-making technique. We conducted a survey on decision makers, who are manufacturers, contractors, academicians, and policy makers. The decision maker preferences are used as preference weight parameters in the GIS model to locate new potential precast manufacturing plants.

Statistical Approach for Decision Maker Weight

A quantitative survey is the most suitable survey instrument for data gathering, analysis, and subsequent action planning. This type of survey also provides details on the types of data used in a quantitative survey. The first section of the survey in this study aims to obtain background information, which includes the name, designation, affiliation, number of years working in the construction and IBS industries, and contact details of the respondents. The respondents' survey was the result of the various stages of the quantitative survey, as proposed from the outcomes of previous surveys, preliminary surveys, and focus group discussions. Respondent decision should focus on the 25 precast manufacturers in Peninsular Malaysia through the use of a population survey. The overall rate of return of the survey was 80%. Higher response rates ensure more accurate survey results and show signal legitimacy achievement (Hager et al., 2003). The response rate improved because of consistent follow-up through phone calls. The survey has 49 questions for which the respondents are required to tick preferences on the basis of a seven-point Likert scale. Surveys of varying pages and questions, distributed to companies, enable higher returns than questionnaires with few pages and questions (Greer et al., 2000).

The second section of our survey requires the respondents to choose their preferences in accordance with a seven-point Likert scale for the site selection criteria on precast manufacturing. Likert scales are ordinal scales used to transform the opinions of respondents into a scale, thereby facilitating statistical analysis (Osgood et al., 1957). The seven-point Likert scale is described in Table 1. Flynn et al. (1990) indicated that interval measures may be added or subtracted at points compatible with various statistics. Selecting criteria through the design stage and on the basis of literature reviews is crucial. Therefore, all criteria are important but differences between the criteria are ranked on the basis of the intensity of importance, as introduced by Saaty (1980).

An important aspect in determining the type of statistical test (e.g., parametric or nonparametric tests) is the scale of measurement for the data generated during a survey. Fellows and Liu (2008) described four types of measurement scales that can be used for statistical analysis: nominal, interval, ordinal, and ratio scales. The current work uses ordinal and interval scales. Ordinal scales are used to rank responses with no indication of distance between scaled points or commonality of scale perceptions by respondents. In essence, the scale provides a hierarchical sequence and indicates that the value of one observation is greater or more important than others. An ordinal scale measures each variable when each respondent is asked to assign a level of importance (Table 1).

Table 1. Definition of Seven-Point Likert Scale (Voogd, 1983)

Intensity of Importance Seven-Point Likert Scale	Definition
1	Not Important
2	Less Important
3	Moderate Important
4	Important
5	Strongly Important
6	Very Strongly Important
7	Absolute Important

Conversely, an interval scale is a cardinal scale that employs units of measurement for the scale; the zero point is arbitrary. Interval scales indicate the order of responses and distances between them. Using an interval scale permits statements about the distance between respondents but not about the relationships in ratio terms between scores. Table 2 identifies the various types of scales used in this study.

Table 2. Scale of Measurement of Variables

Section	Variable	Measurement	Scale
Background of Respondents	Working Experience in Construction Working Experience in IBS	1-5 years 6-10 years 11-15 years > 15 years	Interval
Site Selection Criteria	Transportation and Optimum Distance Environment Risk Costs Market Access Resources and Utilisation Land Sites Population Political and Regulation Capacity Labour Competition Work Suitability Inter-Industry Linkage Safety	1= Not Important 2= Less Important 3= Moderate Important 4= Important 5= Strongly Important 6= Very Strongly Important 7= Absolute Important	Ordinal

The dependent and independent variables of this research were formulated on the basis of the site selection criteria for precast manufacturing plants. The dependent variable defines the suitability of precast manufacturing plants. The circumstances for developing the model of site selection criteria for precast manufacturing plants can be determined by MCE-GIS, which has 11 criteria. The criteria are separated into two groups of maps, namely, seven factor maps and four constraint maps. Then, the maps are ready to be applied together with the input from multiple decision makers' preferences in the MCE-GIS model.

Production of Attribute Maps

Table 3 shows the parameters of attribute maps in the form of factors and constraints, which represent the 11 criteria. The 26 attribute maps involved in the study are stored in two types of data: geographic definitions of earth surface features and the attributes that these features possess. These data are presented in IDRISI® GIS software in the form of fundamental map representation techniques; that is, vector and raster techniques (Eastman, 2003).

Table 3. Parameters of Attribute Maps

Code	**Criteria**	**Attribute Maps**	**Parameter of Factor Maps and Constraint Maps**
F1	Costs (Ngah, 1993)	Land cost	Re-class: - Pastures and Scrub < RM 50/m^2 - Agricultural land RM 50 to 75/m^2 - Manufacturing Zone RM 75 to 125/m^2
F2	Resources and Utilization (Braun et al., 2008)	Cement and Sand Steel	10 km 10 km
F3	Transportation and Optimum Distance (Warszawski, 1999)	Expressway Highway Primary Road Secondary Road Urban Road Local Road	50 km
F4	Safety (Buchmueller, Jacobson, & Wold, 2006; Clymer, 1998; Truls, 1997)	Police IPD Fire Station Hospital	35 km 6 km 8 km
F5	Competition (JPBD, 2005)	IBS Factory Pulau Pinang	3000 m
F6	Infrastructures (Ahamad, Hussin, & Shamshad, 2011; JPBD, 2005)	Water Supply Electricity Airport Railway Sea port	500 m 30 m 10 km 50 m 10 km
F7	Politics and Regulation (Warszawski, 1999)	Government Offices	50 km
C1	Land Sites (JPBD, 2005)	Land Use	Re-class: - Agricultural land - Manufacturing zone - Pastures and scrub
C2	Market Access (JPBD, 2005)	Residential Centre	Re-class: - Primary Residential Centre - Minor Residential Centre - Rural Growth Centre
C3	Environmental Risk (Lin & Kao, 1999; Rachdawong & Apawootichai, 2003)	River Single River Double DEM Forest	Away 100m from stream Away 100m from stream Re-class (10% below) Re-class for selected area of non-forest
C4	Population (Rachdawong & Apawootichai, 2003)	Population map	Active population 800–5000 m (10× for each cell)

The digital map data on Pulau Pinang in different layers of spatial information are at the topographic scale of 1: 25,000. This information was officially obtained from the Department of Surveying and Mapping Malaysia (i.e., Jabatan Ukur dan Pemetaan Malaysia (JUPEM)). These maps are of the latest version available (2006) in the format of Rectified Skew Orthomorphic (RSO) and have been converted to a 25 m x 25 m resolution raster attribute map in IDRISI® GIS software.

Map Preparation

Before the application of WLC, all unsuitable areas were excluded from the study area by assigning 0 in the data preparation stage to form constraint maps. All the factor maps were converted into raster maps and multiplied by the mask map to make them accessible for ranking. The results were overlaid with a land use map that acts as a base map to identify the location of potential sites. Additionally, SA was applied to identify the sensitivity of multiple decision makers in the MCE-GIS model and to determine which criteria are significant to the study.

After the preparation of all input data layers, the MCE-GIS model was selected among other decision rules. The model applied the WLC method in the spatial analysis of suitable sites. The outputs produced the WLC score map from the result of multiplying factor maps, weights, and constraint maps (mask map) (Figure 2). Suitable sites were further analyzed to determine the type of precast manufacturing plants, suitable for either mobile- or permanent-type construction.

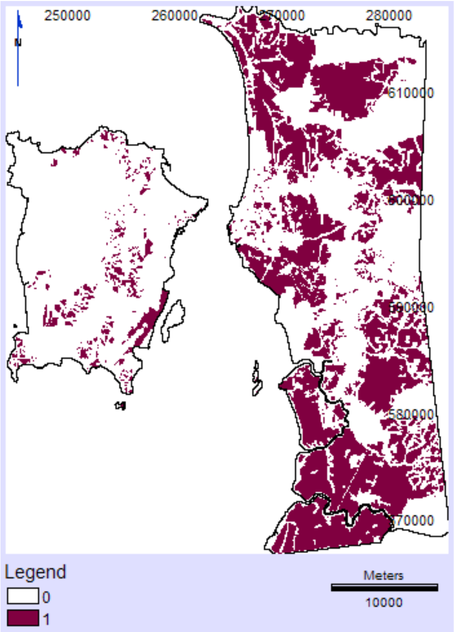

Figure 2. Mask Map (Combines Seven Boolean Maps)

Weight Calculation by WLC

Determining the final set of criteria and attributes before assigning the weights of the factor maps is important. These weights are the input parameters for WLC. The weights of the criteria are obtained from the final statistical analysis of the site selection criteria (Table 5). The criteria are ranked in accordance with the AIP mean. The method of calculating the AIP mean starts with the individual grouping of the attributes by using the geometric mean. Then, the final priorities of each group attribute are aggregated using the arithmetic mean, which represents the final AIP mean of the seven factor maps (Table 4). The detailed coding for each attribute is shown in Table 3.

Table 4. AIP Means of Seven Factor Maps

Criteria	Geometric Mean for Each Attribute	Arithmetic Mean for Each Criterion
Costs (F1)	CS1 = 5.56	6.04
	CS2 = 6.27	
	CS3 = 6.09	
	CS4 = 6.30	
	CS5 = 6.08	
	CS6 = 5.90	
Resources and Utilization (F2)	RS1 = 4.92	5.41
	RS2 = 5.48	
	RS3 = 5.94	
	RS4 = 5.29	
Transportation and Optimum Distance (F3)	TD1 = 4.80	5.27
	TD2 = 5.38	
	TD3 = 5.08	
	TD4 = 5.28	
	TD5 = 5.82	
Safety (F4)	SF1 = 5.59	4.91
	SF2 = 3.39	
	SF3 = 5.62	
Competition (F5)	CP1 = 4.89	4.83
	CP2 = 4.79	
Infrastructures (F6)	IN1 = 2.32	3.70
	IN2 = 3.08	
	IN3 = 2.82	
	IN4 = 3.55	
	IN5 = 5.01	
	IN6 = 5.37	
Politics and Regulation (F7)	PR1 = 3.63	3.63

Figure 3 shows the seven standardized criteria (factor maps) and seven constraint maps used in the WLC method. First, the arithmetic mean was determined and then normalized to represent the multiple decision makers' weights (Table 5). Finally, these normalized weights were assigned to the seven factor maps. The WLC algorithm in IDRISI® GIS software was linearly combined with these maps to produce an output score map of suitability value.

Potential Sites (A) = (Sum (Factor Maps*Weight of Decision Makers))*Mask Map

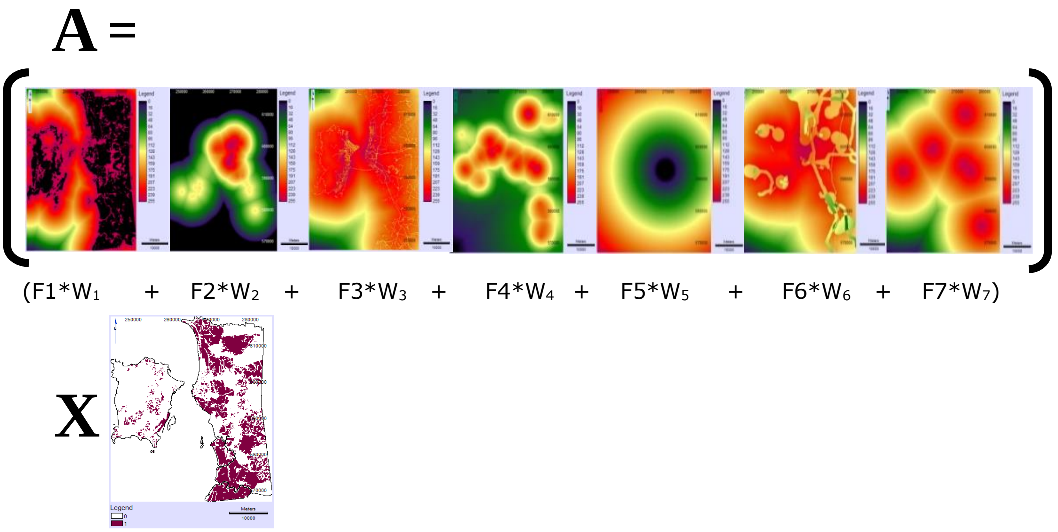

Figure 3. Procedure of WLC

Table 5. Normalized for Seven Weighted Factor Maps

Factor Maps	Arithmetic Mean	Normalized Weight
F1	6.04	0.1788
F2	5.41	0.1601
F3	5.27	0.1560
F4	4.91	0.1453
F5	4.83	0.1429
F6	3.70	0.1095
F7	3.63	0.1074

Results of WLC Method

The resultant potential sites derived by the WLC method are shown in Figure 4. Most of the suitable sites are located in North Seberang Perai, Central Seberang Perai, and North East Pulau Pinang Island. The potential sites fall within the manufacturing zone and potential agricultural land, as indicated by the clustered cells in black (circles in Figure 4). The five potential sites are classified as A1, A2, A3, A4, and A5. The detailed descriptions of the locations are as follows:

- A1 is located in George Town (North East Pulau Pinang Island).
- A2 and A3 are located at Mukim 13 (North Seberang Perai), which is in the manufacturing zone. A3 is located at the Mak Mandin Industrial Estate.
- A4 and A5 are located at Mukim 1 (Central Seberang Perai), which partially falls within the potential agricultural land but most of the areas are in the manufacturing zone. In addition, A5 is located in the Perai Industrial Zone.

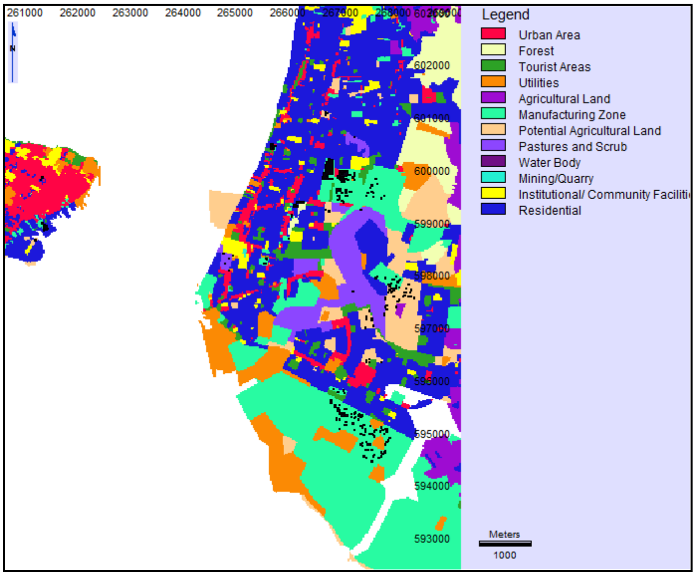

Figure 4. Potential Sites for Precast Manufacturing Plants

In this study, the classes of potential sites are grouped into four levels of suitability, as adapted from Chen et al. (2010). These levels indicate high suitability, moderate suitability, marginal suitability, and unsuitability (Figure 5). The cell size (resolution) of the image map is 25 m, representing an area of 625 m^2 on the ground (Joerin et al., 2001).

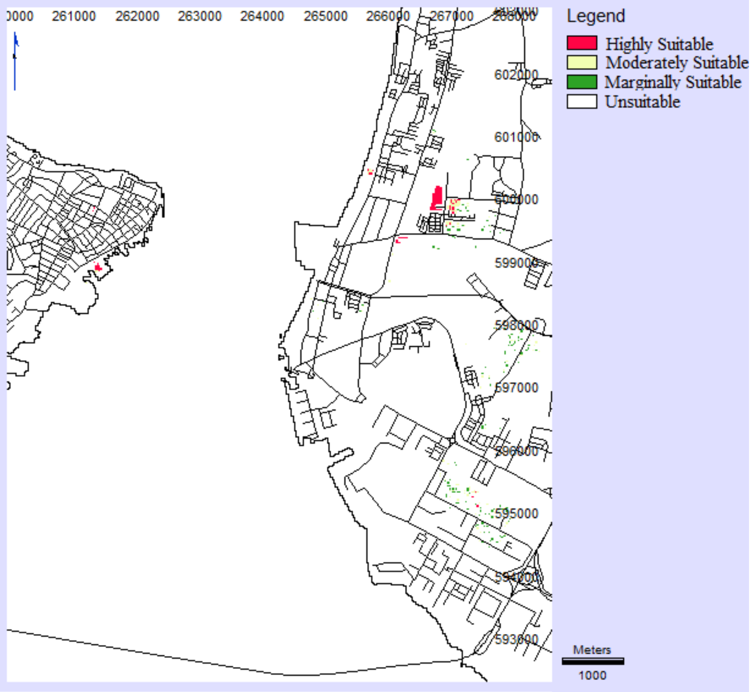

Figure 5. Suitability Classification of Potential Site in Pulau Pinang

Furthermore, the size suitable for precast manufacturing plants is important and is related to the factory productivity and storage space of precast products. The earlier part of the study identified the suitable size for establishing precast manufacturing plants. Five acres are allocated for mobile precast manufacturing plants and a minimum of 15 acres are allotted for permanent precast manufacturing plants as showed in Table 6.

Table 6. Comparison of Permanent and Mobile Precast Manufacturing Plants (Azman et al,. 2012b)

Criteria	Permanent Manufacturing	Mobile Manufacturing
Annual Project	RM100 million above	RM10 million and above
Capital	High	Low
Technology	Prefabricated, semi-auto, automatic	Prefabricated
Maintenance	High bill electricity	Low bill electricity
Land Capacity	Minimum 15 acres	Can start with 5 acres
Mould	Flexible size	Flexible size
Roof of IBS Manufacturing	Permanent Protected from rain	Mobile Develop portable roofing to protect the concrete
Manpower	Maximum 500 workers and average 200 workers Specific task High payment	25 workers Multi tasking Low payment
Product	Hollow Core Slab Half slab Stair case Beam Column Wall panel	Half slab Stair case Beam Column Wall panel
Crane	Permanent At factory: 25-30 tonnes At site: 50-260 tonnes	Permanent or mobile At factory: 25-30 tonnes At site: 50-260 tonnes
Concrete	Required batching plant concrete	Outsource or setup a new batching plant

The results indicate that the site suitable for the minimum size allowed for mobile precast manufacturing plants is class A3. Class A3 also has two potential sites—P1 and P2—where P1 presents a highly suitable site of 12.87 acres and P2 (5.88 acres) is a mixture of highly suitable, moderately suitable, and marginally suitable site, representing the second most important site. On the basis of their sizes, therefore, P1 and P2 are regarded as suitable for mobile precast manufacturing plants. The site satisfies the condition established; that is, an area spanning more than 5 acres but less than 15 acres. Furthermore, the position of the cells in class A3 is contiguous and well clustered. Classes A1, A2, A4, and A5 are not suitable because the cells are not homogenous. They also do not satisfy the criteria on permanent manufacturing or mobile manufacturing.

CONCLUSIONS

A precast manufacturing plant site selection model is applied the State of Penang. The state has the highest CDP growth among the other states in Malaysia. The role of GIS in site selection analysis via the MCE-GIS model has evolved along with the changing perspectives on planning, from scientific approaches to collective design approaches (Malczewski, 2004). The MCE-GIS model was used as a platform to enable the management of criteria data, the production of factor maps and constraint maps, the combination of multiple decision maker preferences with attribute maps by WLC, and the production of potential site maps. This model was verified to ensure its accurate development in accordance with its specifications. The highly suitable site (P1) for precast manufacturing plants was determined using the MCE-GIS model; the site is located in Mak Mandin Industrial Zone, spanning an area of 12.87 acres. Although the potential site falls on a currently industrial activity area, the MCE-GIS model is capable of discovering potential sites on the basis of the specification design of attribute maps. Conversely, spatial statistics extends traditional statistics on two fronts. First, it seeks to map the variations in a data set to show where unusual responses occur, instead of focusing on a single typical response. Second, it can uncover numerical spatial relationships within and among mapped data layers; for example, it generates a prediction map that identifies where likely customers are within a city on the basis of existing sales and demographic information.

REFERENCES

AbuSada, J., & Thawaba, S. (2011). Multi criteria analysis for locating sustainable suburban centers: A case study from Ramallah Governorate, Palestine. *Cities, 28*(5), 381-393.

Ahamad, M. S. S., Hussin, W. M. A. W., & Shamshad, A. (2011). Using GIS Boolean and Fuzzy MCE Approach. *The Malaysian Surveyor, 46*(2), 38-44.

Azman, M.N.A., Ahamad, M.S.S., Hamid, Z.A., Gomez, C.P., Kamar, K.A.M., Hilmi, N.D., Mansor, H., Ismail, Z. (2012a). The Selection of IBS Precast Manufacturing Plant in Malaysia Using GIS. *Malaysian Construction Research Journal.* 10(1), 77-90.

Azman, M.N.A., Ahamad, M. S. S., Majid, T. A., & Hanafi, M. H. (2012b). A qualitative study of precast plants in Malaysia. *Indian Concrete Journal, 86*(10), 47-58.

Azman, M.N.A., Ahamad, M.S.S., Majid, T.A. & Hanafi, M.H. (2013). Statistical Evaluation of Pre-selection Criteria for Industrialised Building System (IBS). *Journal of Civil Engineering and Management*. 19(sup1), S131-S140.

Badri, M.A. (2007). Dimension of Industrial Location Factors: Review and Exploration. *Journal of Business and Public Affairs, 1*(2), 1-26.

Braun, D.R., Plummer, T., Ditchfield, P., Ferraro, J. V., Maina, D., Bishop, L. C., & Potts, R. (2008). Oldowan behavior and raw material transport: perspectives from the Kanjera Formation. *Journal of Archaeological Science, 35*(8), 2329-2345. doi: 10.1016/j.jas.2008.03.004

Buchmueller, T. C., Jacobson, M., & Wold, C. (2006). How far to the hospital?: The effect of hospital closures on access to care. *Journal of Health Economics, 25*(4), 740-761. doi: 10.1016/j.jhealeco.2005.10.006

Carver, S. J. (1991). Integrating multi-criteria evaluation with geographical information systems. *International Journal of Geographical Information Systems, 5*(3), 321-339.

Chen, Y., Yu, J., & Khan, S. (2010). Spatial sensitivity analysis of multi-criteria weights in GIS-based land suitability evaluation. *Environmental Modelling & Software, 25*(12), 1582-1591. doi: 10.1016/j.envsoft.2010.06.001

Clymer, R. E. (1998). Examination of the City of Dover Fire Station Needs. Dover, New Hampshire: City of Dover Fire & Rescue Service Dover.Eastman, J. R. (2003). IDRISI Kilimanjaro Guide to GIS and Image Processing. Worcester, MA: Clark University.

Effat, H. A., & Hegazy, M. N. (2010). Cartographic modeling of land suitability for industrial development in the Egyptian desert. *International Journal of Sustainable Development and Planning, 5*(1), 1-12.

Fellows, R., & Liu, A. (2008). *Research Methods for Construction*. West Sussex, United Kingdom: Blackwell Publishing.

Flynn, B. B., Sakakibara, S., Schroeder, R. G., Bates, K. A., & Flynn, E. J. (1990). Empirical research methods in operations management. *Journal of Operations Management, 9*(2), 250-284. doi: 10.1016/0272-6963(90)90098-x

Greer, T. V., Chuchinprakarn, N., & Seshadri, S. (2000). Likelihood of Participating in Mail Survey Research - Business Respondents' Perspectives. *Industrial Marketing Management, 29*(2), 97-109. doi: 10.1016/s0019-8501(98)00038-8

Hager, M. A., Wilson, S., Pollak, T. H., & Rooney, P. M. (2003). Response Rates for Mail Surveys of Nonprofit Organizations: A Review and Empirical Test. *Nonprofit and Voluntary Sector Quarterly, 32*(2), 252-267. doi: 10.1177/0899764003032002005

Harris, T., & Weiner, D. (1998). Empowerment, Marginalization, and "Community-integrated" GIS. *Cartography and Geographic Information Science, 25*(2), 67-76. doi: 10.1559/152304098782594580

IBSCentre. (2011). List of IBS Precast Concrete System Manufacturers. from Construction Industry Development Board (CIDB) http://ibsnet.econstruct.com.my/ibsnet_public/manufacturers/index/page:4/manufacturer.keyword:Precast%20concrete%20system

Jankowski, P., & Nyerges, T. (2001). GIS-Supported Collaborative Decision Making: Results of an Experiment. *Annals of the Association of American Geographers, 91*(1), 48-70. doi: 10.1111/0004-5608.00233

Jelokhani-Niaraki, M., & Malczewski, J. (2015). Decision complexity and consensus in Web-based spatial decision making: A case study of site selection problem using GIS and multicriteria analysis. *Cities, 45*, 60–70.

Joerin, F., Thériault, M., & Musy, A. (2001). Using GIS and outranking multicriteria analysis for land-use suitability assessment. *International Journal of Geographical Information Science, 15*(2), 153-174. doi: 10.1080/13658810051030487

JPBD. (2005). The Studies Structure Planning of Penang 2005-2020: Jabatan Perancangan Bandar dan Desa.

Lin, H.-Y., & Kao, J.-J. (1999). Enhanced Spatial Model for Landfill Siting Analysis. *Journal of Environmental Engineering, 125*(9), 845-851.

Malczewski, J. (1999). *GIS and Multicriteria Decision Analysis*. New York: Wiley.

Malczewski, J. (2004). GIS-based land-use suitability analysis: A critical overview. *Progress in Planning, 62*(1), 3-65.

Malczewski, J., & Rinner, C. (2015). *Multicriteria Decision Analysis in Geographic Information Science*. *Advances in Geographic Information Science* (p. 331). https://doi.org/10.1007/978-3-540-74757-4

Ngah, K. (1993). *Peraturan dan Kawalan Guna Tanah Bandar*. Kuala Lumpur: Dewan Bahasa dan Pustaka.

Osgood, C. E., Suci, G. J., & Tannenbaum, P. H. (1957). *The Measurement of Meaning*. Urbana, IL: University of Illinois Press.

Peng, C. Y. J., Lee, K. L., & Ingersoll, G. M. (2002). An Introduction to Logistic Regression Analysis and Reporting. *The Journal of Educational Research, 96*(1), 3-14.

Rachdawong, P., & Apawootichai, S. (2003). Development of Criterion Weights for Preliminary Site Selection: A Pilot Project of Supanburi Industrial Estate. *Songklanakarin Journal of Science & Technology, 25*(6), 773-781.

Saaty, T. L. (1980). *The Analytic Hierarchy Process*. New York: McGraw-Hill.

Shen, G. (2005). Location of manufactured housing and its accessibility to community services: a GIS-assisted spatial analysis. *Socio-Economic Planning Sciences, 39*(1), 25-41. doi: 10.1016/j.seps.2003.10.008

Statistics. (2010). Gross Domestic Product (GDP) by State, 2009, from http://www.statistics.gov.my/portal/index.php?option=com_content&view=article&id=340%3Agross-domestic-product-gdp-by-state-2009-updated-25112010&catid=98%3Agross-domestic-product-by-state&lang=en

Truls, V. (1997). Increased police enforcement: Effects on speed. *Accident Analysis & Prevention, 29*(3), 373-385. doi: 10.1016/s0001-4575(97)00003-1

Voogd, H. (1983). *Multicriteria evaluation for urban and regional planning*. London: Pion.

Warszawski, A. (1999). *Industrialised and Automated Building Systems*. London: E & FN Spon.