Fuzzy Evaluation of Marine Geospatial Data Infrastructure (MGDI) and MGDI Decisions' Criteria

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Abstract

Marine environment is characterised to be complex due to its dynamic nature, participation of multiple stakeholders with diversified worldviews. It exhibits fuzziness and therefore, possesses Multi-Criteria Decision-Making (MCDM) problems. In this context, Marine Geospatial Data Infrastructure (MGDI) and MGDI decisions are also subjected to these characteristics; thus, making the quest of an MCDM evaluation inevitable. In this paper, MGDI criteria adjudged by domain experts through Delphi process, and reviewed from available policy documents were evaluated and ranked in fuzzy environment. The evaluation was achieved through scoring, Analytic Hierarchy Process (AHP), and Fuzzy Analytic Hierarchy Process (FAHP) approaches. Initial findings from the Delphi process revealed a critically extreme seven point criteria for MGDI and MGDI decisions; their rankings were achieved through AHP and FAHP. The uniqueness in the methods demonstrated in the paper is quite apparent since no previous studies had evaluated such MGDI criteria in a fuzzy environment, as portrayed in the result obtained; which showed that the FAHP model out-performed the Scoring and AHP methods. There were also four equally important criteria that have the same order of ranking. Moreover, these rankings were not readily observed in the other methods; thus showing the inherent decision makers' subjectivities. Data and Information criterion was ranked to be the most outstanding, while social criterion was ranked as the least. This would therefore, help in the holistic consideration of MGDI decisions by policy makers and other stakeholders for marine spatial planning and activities.

Keywords: Delphi, Fuzziness, model, multi-criteria, priority

1.0 INTRODUCTION

The marine environment is life supporting (NOAA, 2010) with endowed and abundant natural and man-made resources, hence necessitating sustainable management and access to geospatial data for decision-making (Feeney, 2003; Mansourian *et al.*, 2006; Scott, 2010). Marine Geospatial Data Infrastructure (MGDI) is a sub-set of the Spatial Data Infrastructure (SDIs) initiatives. Both concepts exist at different levels of governance, participations, and interactions: from the corporate, local, state/provincial, national and regional (multi-national), to global level. MGDIs promote marine economic activities and development for better ocean governance and its environmental sustainability, better management of ocean resources, risk avoidance and management of marine disasters. All these benefits aim to satisfy the geospatial data requirements for marine community within marine environment and Marine Delineation Zones (MDZs).

Examples of global MGDIs are: Oceans 21 (Celliers *et al.*, 2006; Green *et al.*, 2004) projects, and UN Global Oceans Observing System (GOOS) for marine environment; while those at the regions include: Europe's INSPIRE (INfrastructure for SPatial InfoRmation) (Longhorn, 2006; Pepper, 2009); and EMODNet (European Marine Observation and Data Network) projects; as well as TRANSMAP (Transboundary

Networks of Marine Protected Areas) for East Africa; Coastal SDI for Canada (Ng'ang'a *et al.*, 2004; Pepper, 2009), and USA Coastal SDI initiative. Australia marine Cadastre (Rajabifard, Binns, and Williamson, 2005; Vaez, 2007); and Germany (MDI-DE) (Rüh and Bill, 2012; Rüh, Korduan, and Bill, 2012) are examples at the national level.

MGDI therefore, is concerned about seamless geospatial solutions revolving around diversified marine activities involving stakeholders of varied world views in the face of complex and dynamic marine environment (Lamacchia and Bartlett, 2003). Moreover, these complexities are also characterised with Multi-Conceptual Dynamics (MCD) resulting from multi-participant, multi-agency, multi-attribute, multi-objective, and multi-criteria concepts. In addition, most available publications are on SDI with dearth of MGDI for marine Geospatial Decision Supports (GDS) capabilities, MGDI decisions and assessment procedures. For complex system like the marine environment, coupled with MCDs, posits this environment to exhibit multiple criteria decision-making (MCDM) problems that warrant careful evaluation of MGDI criteria at all levels, with attendant marine activities for efficient and improved MGDI decisions.

Consequently, the fuzziness of marine environment based on these complexities are in tandem with previous and related researches on ocean policies and governance. For instance, multi-agency involvements were evident at national ocean policies (Othman, Bruce, and Hamid, 2011; Saharuddin, 2001), ocean governance (Ng'ang'a *et al.*, 2004), fragmented and uncoordinated multiplicity of agencies (Bruton, 2007; De Kleijn *et al.*, 2014; Othman, Bruce, and Hamid, 2011; Saharuddin, 2001; Wescott, 2000), attendant conflicts of interest and lack of political support (Bruton, 2007). Furthermore, MCDM problems and analyses due to these complexities and MCDs are evaluated in various forms in literature. One of these ways is the multi-criteria evaluation (MCE) and could be assessed by different MCE models. These include: Analytic Hierarchy Process (AHP) (Feizizadeh, Jankowski, and Blaschke, 2014; Saaty, 2006; Sabri and Yakuup, 2008), Analytic Network Process (ANP) (Blair *et al.*, 2010; Chang, Cheng, and Chen, 2007) and technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) (Tian *et al.*, 2013) method. Despite these models having their peculiar features, they are usually embedded with fuzzy extensions of AHP, ANP, TOPSIS or integration of one model with another for the evaluation, and ranking of their findings.

AHP is used to address complexities in Multi-Criteria Decision Analysis (MCDA) problems wherein the criteria, sub-criteria and the parameters of such decision problems are determined and structured into hierarchies as depicted in **Figure 1**.

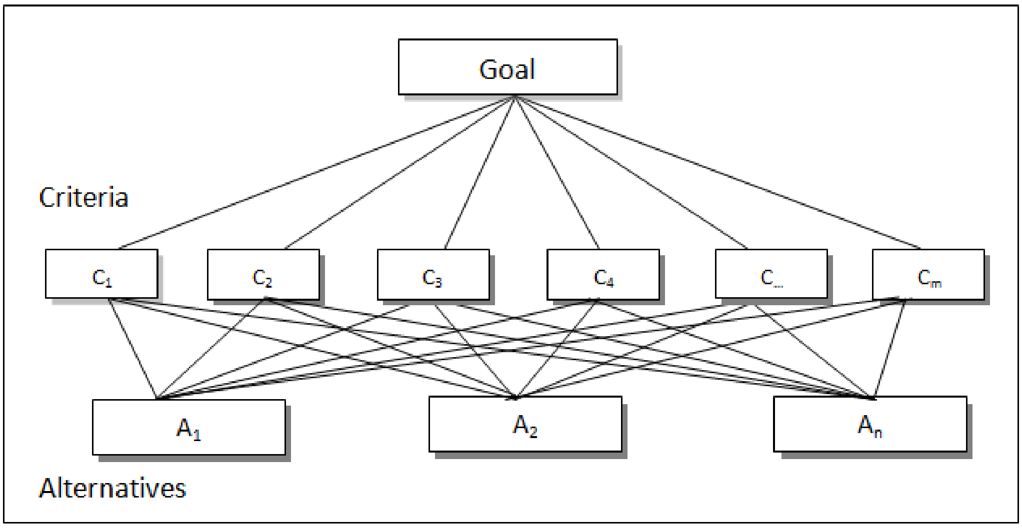

Figure 1: A three level hierarchy in detail (Saaty and Vargas, 2006)

The goal is represented in the first layer, next by the main criteria in second layer. This is followed by the layers for the sub-criteria, sub-sub-criteria (depending on the nature of the problem being addressed) and the parameters (or alternatives) representing the last layer. This structure is based on the AHP founded by Thomas L. Saaty, anchored on a fundamental 1–9 scale (Saaty, 1990a). It is a simple, flexible and quantitative method to overcome difficulties in complex decision domains particularly with respect to systems of conflicting world views. It involves calculations on the priorities of factors by forming their pairwise comparison matrices in order to select the best alternatives among them (Saaty and Vargas, 2006; Vahidnia, Alesheikh, and Alimohammadi, 2009).

On the other hand, FAHP method is formulated to address decision problems that are embedded with fuzziness and complexities (Mikhailov and Tsvenetinove, 2004). These are also peculiar to the marine environment, and in relation to decision makers' uncertainties, subjectivity, and imprecisions as well as in translating their crisp judgment numbers to exact values (Amiri, 2010; Feizizadeh, Jankowski, and Blaschke, 2014; Tian *et al.*, 2013; Torfi, Farahani, and Rezapour, 2010).

Based on the foregoing, this paper aims at evaluating and ranking of performance criteria for MGDI and MGDI decision using AHP model to evaluate their weights in a fuzzy environment due to stakeholders' subjectivity.

2.0 METHODOLOGY

2.1 Model Formulation

The mathematical formulation for both AHP and FAHP models are presented below.

2.1.1 Analytical Hierarchy Process (AHP) Model

Previous researches (Kaya and Kahraman, 2014; Lee, Chen, and Chang, 2008; Vahidnia, Alesheikh, and Alimohammadi, 2009) highlighted the steps involved in AHP model, but in this study, the following steps (Hamid-Mosaku, Mahmud, and Mohd, 2016; Saaty, 1990b; Torfi, Farahani, and Rezapour, 2010) are adopted:

Step 1: Unstructured complex problem is structured into hierarchies centered on the identified criteria, sub-criteria, sub-sub-criteria, and alternatives, based **Figure 1.**

Step 2: Formulate the pairwise comparisons matrices (D) of decision attributes; it consists of elements $\{x_{ij}\}$ of the criteria using Eq. 1; wherein, the degrees of preference of the ith criterion over the jth criterion or vice versa are being compared, so that the relative priorities of all the elements are obtained.

$$D = \begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \\ \vdots \\ C_n \end{array} \overset{Comparison\ matrix}{\begin{array}{c} \begin{array}{ccccc} C_1 & C_2 & C_3 & \cdots & C_n \end{array} \\ \begin{bmatrix} x_{11} & x_{12} & x_{13} & \cdots & x_{1n} \\ x_{21} & x_{22} & x_{23} & \cdots & x_{2n} \\ x_{31} & x_{32} & x_{33} & \cdots & x_{3n} \\ \vdots & \vdots & \cdots & \cdots & \vdots \\ x_{n1} & x_{n2} & x_{n3} & \cdots & x_{nn} \end{bmatrix} \end{array}} \quad (1)$$

These priorities are obtained from experts' judgment based on the Saaty Fundamental scale that ranged between 1 and 9, (see **Table 1)**. Such judgment could be from a single decision maker/expert and/or group of experts. Consequently, preferences for group decision makers' judgment ($\breve{x_{ij}}$) are calculated by averaging their respective judgment. According to Saaty and Vargas (2006), there are two ways of computing this average: Arithmetic Mean (AM) (see Eq. 2) or Geometric Mean (see Eq. 3), (Saaty, 1990b)

$$\breve{x_{ij}} = \frac{\sum_{i=1}^{n} x_{ij}}{n} \quad (2)$$

$$\breve{x}_i = \left(\prod_j^n \breve{x_{ij}}\right)^{1/n}, \ i = 1, 2, \ldots, n, \quad (3)$$

Therefore, the average pairwise comparison matric ($\breve{D}$) is given by Eq. 4.

$$\breve{D} = \begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \\ \vdots \\ C_n \end{array} \overset{Comparison\ matrix}{\begin{array}{c} \begin{array}{ccccc} C_1 & C_2 & C_3 & \cdots & C_n \end{array} \\ \begin{bmatrix} \breve{x_{11}} & \breve{x_{12}} & \breve{x_{13}} & \cdots & \breve{x_{1n}} \\ \breve{x_{21}} & \breve{x_{22}} & \breve{x_{23}} & \cdots & \breve{x_{2n}} \\ \breve{x_{31}} & \breve{x_{32}} & \breve{x_{33}} & \cdots & \breve{x_{3n}} \\ \vdots & \vdots & \cdots & \cdots & \vdots \\ \breve{x_{n1}} & \breve{x_{n2}} & \breve{x_{n3}} & \cdots & \breve{x_{nn}} \end{bmatrix} \end{array}} \quad (4)$$

Table 1: Fundamental Scale of Absolute Numbers (Saaty and Vargas, 2006)

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgment slightly favor one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgment strongly favor one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation

Step 3: The Normalised Comparison matrix (R) is computed based on Eqs. 5 and 6.

$$r_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}} \tag{5}$$

and

$$\text{Comparison matrix}$$

$$R = \begin{matrix} & C_1 & C_2 & C_3 & \cdots & C_n \\ C_1 & r_{11} & r_{12} & r_{13} & \cdots & r_{1n} \\ C_2 & r_{21} & r_{22} & r_{23} & \cdots & r_{2n} \\ C_3 & r_{31} & r_{32} & r_{33} & \cdots & r_{3n} \\ \vdots & \vdots & \vdots & \cdots & \cdots & \vdots \\ C_n & r_{n1} & r_{n2} & r_{n3} & \cdots & r_{nn} \end{matrix} \tag{6}$$

Steps 4 and 5: Compute the Consistency Index (CI) represented as (μ) using Eq. 7.

$$\mu = \frac{\lambda_{\max} - n}{n-1} \tag{7}$$

where λmax represents the principal eigenvalue of the matrix D having an order of n. The consistency is achieved if this equality $(a_{ij}a_{jk} = a_{ik}, \forall i, j, k)$ conditions are true. The validity of the survey is established by computing the Consistency Ratio (CR), which must not be more than 0.10 (Saaty and Kearns, 1985; Torfi, Farahani, and Rezapour, 2010). This is related to CI according to Eq. 8, the random index (RI) denotes the consistency index (**Table 2**) of a randomly generated reciprocal matrix (Önüt and Soner, 2008).

$$\text{CR} = \frac{\text{CI}}{RI} \tag{8}$$

Table 2: Example of generated RI values (Saaty and Kearns, 1985)

n	*1-2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
R.I.	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

The cumulative weights are thereafter used to compute the final ranking of all the criteria and alternatives.

2.1.2 Fuzzy Analytical Hierarchy Process (FAHP) Model

There are numerous fuzzy extensions of AHP methods and applications that are all based on the concept of fuzzy logic (Zadeh, 1965) pioneered by Zadeh. Some of the basic fuzzy sets mathematics is presented in the following sub-sections.

2.1.2.1 Interval arithmetic

Given two closed interval sets as: $C = [c_1, c_2, c_3]$ and $D = [d_1, d_2, d_3]$ then some of the fuzzy arithmetic are expressed in Eqs. 9 - 13, as adapted from (Hamid-Mosaku, Mahmud, and Mohd, 2017; Önüt and Soner, 2008; Torfi, Farahani, and Rezapour, 2010; Yang and Hung, 2007).

i. Fuzzy Addition denoted by either, $\oplus$ *or* $C(+)D$:

$$C(+)D = [c_1, c_2, c_3](+)[d_1, d_2, d_3] = [c_1 + c_2,\ c_2 + d_2,\ d_3 + d_3] \tag{9}$$

ii. Subtraction denoted by $\ominus$ or $C(-)D$:

$$C(-)D = [c_1, c_2, c_3](-)[d_1, d_2, d_3] = [c_1 - d_1,\ c_2 - d_2,\ c_3 - d_3] \quad (10)$$

iii. Multiplication denoted by either $\otimes$ or $(\cdot)$):

$$C(\cdot)D = [c_1, c_2, c_3](\cdot)[d_1, d_2, d_3] \cong (c_1 d_1,\ c_2 d_2, c_3 d_3), \quad (11)$$

provided $c_1 \geq 0,\ d_1 \geq 0$

iv. Fuzzy division / : $\frac{A}{B} \cong (c_1/d_3,\ c_2/d_2,\ c_3/d_1), \quad c_1 \geq 0,\ d_1 \geq 0$ (12)

v. Defuzzification of fuzzy numbers $C[c_1, c_2, c_3]$ is given by Singh and Benyoucef (2011) as written in Eq. 13.

$$x = \frac{c_1 + 2c_2 + c_3}{4} \quad (13)$$

2.1.2.2 Triangular fuzzy number (TFN)

The triangular fuzzy number (TFN) is a distinctive fuzzy number (Bector and Chandra, 2005) whose membership function could be expressed by three real numbers (c, m, d) as illustrated in **Figure 2** and expressed by Eq. 14 (Balogun *et al.*, 2017; Bector and Chandra, 2005; Torfi, Farahani, and Rezapour, 2010; Vahidnia, Alesheikh, and Alimohammadi, 2009):

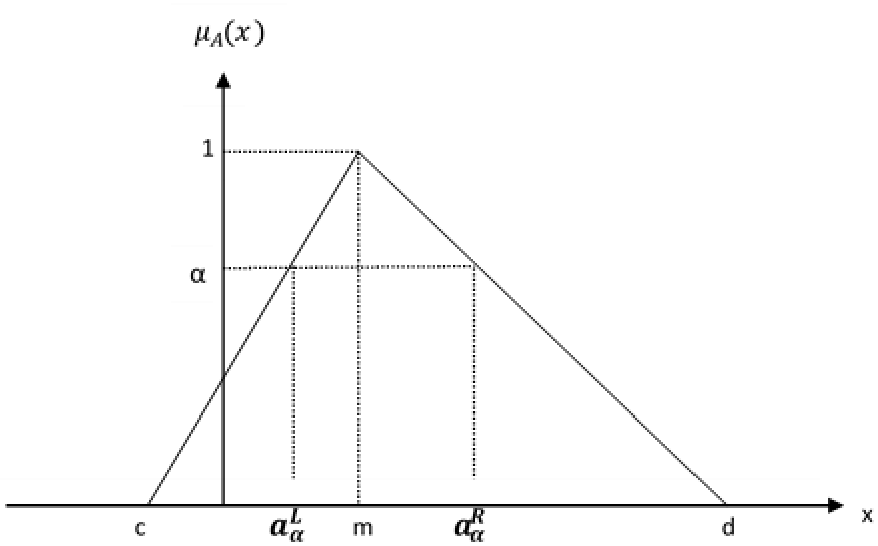

Figure 2: Triangular membership function (Adapted from Bector and Chandra, 2005)

$$\mu_C(x) = \begin{cases} 0, \; if x \leq c, \\ \frac{x-c}{m-c}, \quad if\; x \in [c,m], \quad i.e. \;\; c \leq x \leq m \\ \frac{d-x}{d-m}, \quad if\; x \in [m,d] \quad i.e. \;\; m \leq x \leq d \\ 0, \qquad if\; x \geq d, \end{cases} \tag{14}$$

2.1.2.3 Fuzzy membership function

The Fuzzy Membership Function (FMF) and linguistic variables are used by the experts occasionally in expressing their judgment over the crisp equivalent (Torfi, Farahani, and Rezapour, 2010). They are usually spaced at an equally ranked interval of either 0.25 or 0.30 (Hamid-Mosaku, 2014; Torfi, Farahani, and Rezapour, 2010; Yang and Hung, 2007). In this study, eight level linguistic values were implemented and illustrated in **Figure 3**. These linguistic variables, their sub-criteria grade and the equivalent fuzzy numbers are shown in **Table 3**.

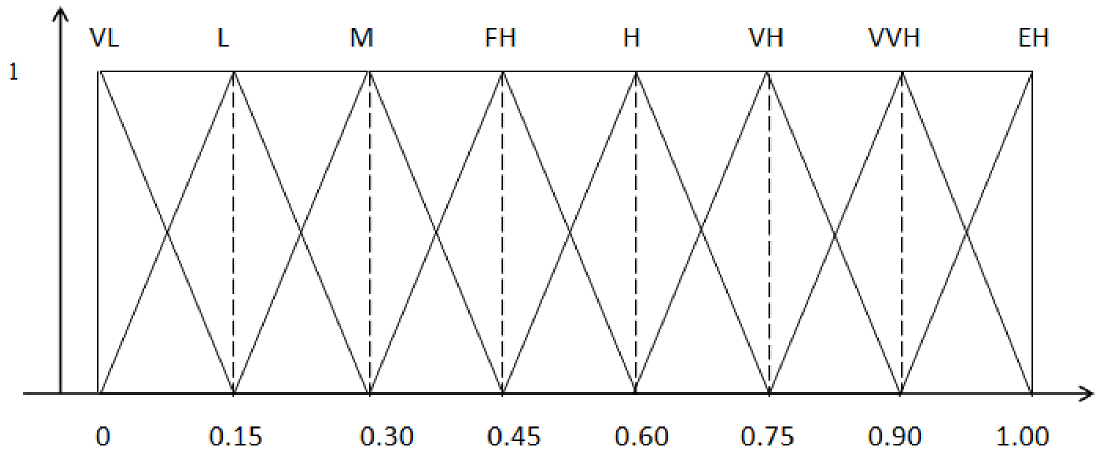

Figure 3: Fuzzy Triangular Membership Function with eight Linguistic values

Table 3: Conversion of eight Triangular FMF to corresponding TFN (Hamid-Mosaku, 2014)

Linguistic Variables	Sub-criteria grade	Triangular Fuzzy Numbers
Very low (VL)	1	(0.00, 0.00, 0.15)
Low (L)	2	(0.00, 0.15, 0.30)
Medium (M)	3	(0.15, 0.30, 0.45)
Fairly High (FH)	4	(0.30, 0.45, 0.60)
High (H)	5	(0.45, 0.60, 0.75)
Very high (VH)	6	(0.60, 0.75, 0.90)
Very very high (VVH)	7	(0.75, 0.90, 1.00)
Extremely High (EH)	8	(0.90, 1.00, 1.00)

2.2 Study Area

Malaysia is situated in Southeast Asia and shares boundary with the Asia Pacific. It has maritime areas ratified based on the UN Convention on the Law of the Sea and separated by over 644 km by the South China Sea. Consequently, Malaysia's continental shelf extent is 373,500 km^2, and her Exclusive Economic Zone (EEZ) is 475,600 km^2 with a Territorial Water of 148,307 km^2. The maritime extent is over 623,907 km^2, total coastline length is 4490 km^2, with an estimated total land area of 332,800 km^2 (Saharuddin, 2001). **Figure 4** shows the location of Malaysia with respect to other neighbouring maritime jurisdictions.

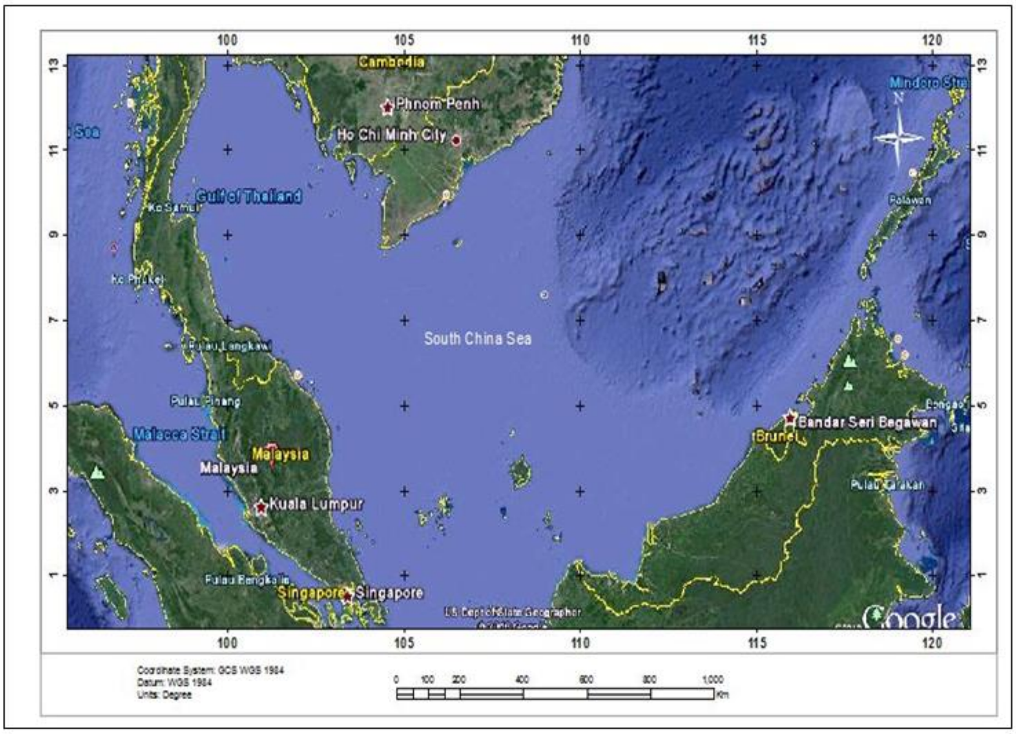

Figure 4: Malaysia amidst neighbouring countries

2.3 Analytical Hierarchy Process (AHP) Procedure

The outcome of the reviewed literature and deductions from policy documentations that were further justified through experts' evaluation using Delphi model resulted in a seven-point criteria as shown in **Table 4**, from an initial eleven factors. Thereafter, instrument (questionnaire) based on both scoring and AHP hierarchical structure was designed, validated, and was later used to formulate the pairwise comparisons matrix $(\breve{D})$for data collection, involving different expert groups for further evaluation.

Table 4: Seven-point criteria for MGDI (Hamid-Mosaku, 2014)

s/n	*Final criteria*
i.	Economic
ii.	Social
iii.	Environmental
iv.	Resources and Management
v.	Data and Information
vi.	Technology
vii.	People

2.4 Fuzzy Analytical Hierarchy Process (FAHP) Procedure

Sequential to the steps for AHP earlier established, the additional steps in FAHP are as follows (Torfi, Farahani, and Rezapour, 2010; Yang and Hung, 2007):

Step 6: By using the concept of triangular fuzzy numbers (FTN), it transforms the real elements of relative matrix (from Eqs. 5 and 6) into an eight level linguistic variables (based on Figure 1, Table 3 and Figure 2 through Eq. 14.

Step 7: Formulate fuzzy positive reciprocal matrices from Step 6.

Step 8: Thereafter, compute fuzzy weights using these reciprocal matrices using Eqs. 9 to 12.

Step 9: Using Eq. 13, the fuzzy weights were defuzzified to their equivalent crisp weights and are later normalized for ranking.

2.5 Empirical Applications of the Models

The models being populated in this study are empirically applied to MGDI implementation.

2.5.1 AHP Empirical Application

Table 5 presents the mean pairwise decision matrix ($\breve{D}$) obtained from three experts judgment by geometric mean method (Eq. 3). This is based on the concept expressed in **Figure 1** and Step 2 of sub-section 2.1.1. The peculiarities of the AHP decision matrix (D) are as presented in Eqs. 15 and 16.

$$x_{ii} = x_{jj} = 1 \quad (15)$$

$$x_{ij} = {}^{1}\!/_{x_{ji}} \quad (16)$$

Table 5: Mean experts group AHP pairwise comparison matrix

Intelligent MGDI Criteria	Economic	Social	Environ mental	Resources and Management	Data and Information	Technology	People
Economic	1	3.5569	2.2904	1.0771	0.6409	0.9655	1.5536
Social	0.2811	1	0.5504	0.3017	0.1789	0.2714	0.4371
Environmental	0.4366	1.8169	1	0.63	0.3274	0.4932	0.7937
Resources and Management	0.9284	3.3146	1.5873	1	0.5952	0.8963	1.4425
Data and Information	1.5603	5.5897	3.0544	1.6801	1	1.5081	2.4268
Technology	1.0357	3.6846	2.0276	1.1157	0.6631	1	1.6091
People	0.6437	2.2878	1.2599	0.6932	0.4121	0.6215	1

2.5.2 FAHP Empirical Application

The transformed normalised decision serves as the input values for the FAHP model, the fuzzy weights are thereafter computed using Eqs. 9 to 12, and their corresponding defuzzified values were also computed by using Eq. 13.

3.0 RESULTS AND DISCUSSION

3.1 Analytical Hierarchy Process (AHP)

The AHP result for the AHP application is presented in **Table 6**, with both the Normalised Decision Matrix and Priorities obtained from the above matrix (D). Also, the CR value obtained (0.0007) could be seen to be less than the threshold value of 0.10 for AHP model. Thus, the weights obtained are therefore consistent and accepted for further evaluation.

Table 6: Group Normalised Decision Matrix and Priorities from AHP model

Intelligent MGDI Criteria	Economic	Social	Environ mental	Resources and Management	Data and Information	Technology	People	**Priority**
Economic	0.1699	0.1674	0.1946	0.1658	0.1679	0.1677	0.1677	**0.1716**
Social	0.0478	0.0471	0.0468	0.0464	0.0469	0.0472	0.0472	**0.047**
Environmental	0.0742	0.0855	0.085	0.097	0.0858	0.0857	0.0857	**0.0855**
Resources and Management	0.1577	0.156	0.1349	0.1539	0.1559	0.1557	0.1557	**0.1528**
Data and Info	0.2651	0.263	0.2595	0.2586	0.2619	0.262	0.262	**0.2617**
Technology	0.176	0.1734	0.1723	0.1717	0.1737	0.1737	0.1737	**0.1735**
People	0.1094	0.1077	0.107	0.1067	0.1079	0.108	0.108	**0.1078**
C.R. Test result: **0.00066**								

3.2 Fuzzy Analytical Hierarchy Process (FAHP) Evaluation

The various FAHP results obtained from the empirical applications is presented in **Table 7.** Finally, in **Table 8**, the criteria rankings were compared with their respective methods.

3.3 Discussion

Three datasets were collected based on three methods (scoring, AHP and FAHP models) in order to observe their variability and suitability for MGDI and MGDI decisions. As earlier established, the computed C.R. value of 0.007 being less than 0.1 indicates acceptability of both the survey and the experts' judgment. Moreover, the ranking comparisons indicate a general trend among these methods, but it could be observed that the values for the ~~S~~scoring method are generally lower than those from the AHP except for the 'People criterion' and 'Resources and Management criterion'. The AHP ranking was distinguishable, since there were no tallies in their values; the first four values were higher than same from the FAHP values. However, the last three values from the FAHP were higher than their corresponding values under AHP model.

Likewise, unlike what were obtained in the other two methods (i.e. scoring and AHP), the following criteria: Economic, Technology, Resources and Management, and People were ranked with the same value (14.4 %) under FAHP; next, is the Environmental criterion at (13.4 %), and was followed by the least ranked, that is the Social criterion with a rank value of 6.9 %, while Data and Information, with a value of 21.9 % is the most highly ranked criterion. Hence, these four criteria are equally important for MGDI consideration, and such MGDI decisions would be important to stakeholders. Furthermore, the perceived stakeholders' subjectivities and judgment were manifested through these results, since they were not easily detectable through the other two methods. This assertion reveals the usefulness of this study in supporting cases of stakeholders' subjectivity as reported in literature, which fuzzy integration can be used to resolved the uncertainties (Amiri, 2010; Singh and Benyoucef, 2011; Torfi, Farahani, and Rezapour, 2010).

Consequently, the comparisons also revealed some outstanding results: while Environmental criterion was ranked sixth, the least ranked is the Social criterion, whereas 'Data and Information' criterion is generally the most highly ranked criterion. Parts of the implication of these results are that environmental factor was not significantly ranked, which negate the expectation of such factor in marine environment and other hydrographic studies. In addition, social factor reflects its least significance, as compared to the expectation accorded to issues relating to marine geospatial data and information, with respect to MGDI and MGDI decisions, as revealed in **Table 8**.

4.0 CONCLUSION

In this paper, the complexities of the marine environment posit it to be subjective in the face of multi-dynamics concepts, thus exhibiting multi-criteria decision problems. Consequently, the marine environment was investigated with respect to MGDI and MGDI decisions based on these perceived subjectivities by the FAHP model. To achieve this, Delphi and AHP methods were used in the design of the questionnaire used for this investigation. The priorities were obtained by three methods: Scoring, AHP, and FAHP models, and were later assessed and compared. This is one of the emerging manuscript wherein this integrated approach is been implemented, particularly with respect to MGDI and MGDI decision. From the results, the weights from these methods were equally ranked. Meanwhile, the least ranked criterion is the 'Social' factor, while 'Environmental' factor was unexpectedly ranked sixth, and the most highly ranked is 'Data and Information' criterion.

Furthermore, the results also revealed the importance of the FAHP model in dealing with stakeholders' subjectivities and uncertainties, predominantly when their judgment were expressed by the crisp values. Though, the values from the other two methods are higher than those from the FAHP, the FAHP values could aid better decisions since the inherent variability were manifested in the FAHP results; four out of the criteria were ranked equally, which were not manifested in the other two methods. Consequently, this study posits the usefulness and practical applications of the evaluated criteria and their suitability for MGDI and MGDI decision with respect to real-world marine geospatial planning by different stakeholders and policy makers.

Table 7: Fuzzy AHP Normalized Decision Matrix, Fuzzified Priority, Defuzzifed Priority and the normalised Priority results

Fuzzy AHP Normalized Decision Matrix (Step 6 and 7)								Priorities (weights)			
Intelligent MGDI Criteria	Economic	Social	Environmental	Resources and Management	Data and Information	Technology	People	Fuzzy Priority (wi) (Step 7)	Defuzzified Priority (Step 8)	Normalised Defuzzified Priority (Step 9)	Ranking
Economic	0, 0.15, 0.3	0, 0.15, 0.3	0, 0.15, 0.3	0, 0.15, 0.3	0, 0.15, 0.3	0, 0.15, 0.3	0, 0.15, 0.3	0, 0.15, 7.74	2.0092	0.144	2
Social	0, 0, 0.15	0, 0, 0.15	0, 0, 0.15	0, 0, 0.15	0, 0, 0.15	0, 0, 0.15	0, 0, 0.15	0, 0, 3.87	0.9679	0.069	7
Environmental	0, 0, 0.15	0, 0.15, 0.3	0, 0.15, 0.3	0, 0.15, 0.3	0, 0.15, 0.3	0, 0.15, 0.3	0, 0.15, 0.3	0, 0.12, 7.24	1.8712	0.134	6
Resources and Management	0, 0.15, 0.3	0, 0.15, 0.3	0, 0.15, 0.3	0, 0.15, 0.3	0, 0.15, 0.3	0, 0.15, 0.3	0, 0.15, 0.3	0, 0.15, 7.74	2.0092	0.144	2
Data and Info	0.15, 0.3, 0.45	0.15, 0.3, 0.45	0.15, 0.3, 0.45	0.15, 0.3, 0.45	0.15, 0.3, 0.45	0.15, 0.3, 0.45	0.15, 0.3, 0.45	0.02, 0.29, 11.62	3.0551	0.219	1
Technology	0, 0.15, 0.3	0, 0.15, 0.3	0, 0.15, 0.3	0, 0.15, 0.3	0, 0.15, 0.3	0, 0.15, 0.3	0, 0.15, 0.3	0, 0.15, 7.74	2.0092	0.144	2
People	0, 0.15, 0.3	0, 0.15, 0.3	0, 0.15, 0.3	0, 0.15, 0.3	0, 0.15, 0.3	0, 0.15, 0.3	0, 0.15, 0.3	0, 0.15, 7.74	2.0092	0.144	2

Table 8: Comparisons of the rankings of main criteria from Scoring, AHP and FAHP

Intelligent MGDI Criteria	Ranking by Scoring	Intelligent MGDI Criteria	Ranking by AHP	Intelligent MGDI Criteria	Ranking by FAHP	Ranking
	% Average Ranking		% Average Ranking		% Average Ranking	
Data and Information	25.6	Data and Information	26.2	Data and Information	21.9	1
Technology	17.0	Technology	17.4	Economic	14.4	2
Economic	16.7	Economic	17.2	Technology	14.4	2
Resources and Management	15.5	Resources and Management	15.3	Resources and Management	14.4	2
People	11.9	People	10.8	People	14.4	2
Environmental	8.5	Environmental	8.6	Environmental	13.4	6
Social	4.7	Social	4.7	Social	6.9	7

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