INTELLIGENT GEOSPATIAL DECISION SUPPORT SYSTEM FOR MALAYSIAN MARINE GEOSPATIAL DATA INFRASTRUCTURE

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UNIVERSITI TEKNOLOGI MALAYSIA

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"..My prayer, my…."

To the Pen and what is written, taught, and disseminated by it!
To teachers, who teach without boundaries!
To inquisitive, inspiring, innovative, and creative minds who see beyond their fuzziness!
To those who have answered the call of eventual return
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ABSTRACT

Marine resources for different uses and activities are characterised by multi-dimensional concepts, criteria, multi-participants, and multiple-use conflicts. In addition, the fuzzy nature in the marine environment has attendant features that increase the complexity of the environment, thus, necessitating the quest for multiple alternative solutions and adequate evaluation, particularly within the context of Marine Geospatial Data Infrastructure (MGDI). However, in the literature of MGDI, there has yet to be a concerted research effort and framework towards holistic consideration of decision making prospects using multi-criteria evaluation (MCE) and intelligent algorithms for effective and informed decision beyond the classical methods. This research, therefore, aims to develop and validate an intelligent decision support system for Malaysian MGDI. An integrated framework built on mixed method research design serves as the mode of inquiry. Initially, the quantitative methodology, comprising of Dynamic Analytic Network Process (DANP) model, comprehensive evaluation index system (CEIS), MCE extensions, geographic information system's spatial interaction modelling (SIM), and hydrographic data acquisition sub-system was implemented. Within this framework, a case study validation was employed for the qualitative aspect to predict the most viable geospatial extents within Malaysian waters for exploitation of deep sea marine fishery. Quantitative findings showed that the model has an elucidated CEIS with a DANP network model of 7 criteria, 28 sub-criteria, and 145 performance indicators, with 5 alternatives. In the MCE, computed priority values for Analytic Hierarchy Process (AHP) and Fuzzy AHP are different though their rankings are the same. In addition, the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and Fuzzy TOPSIS results from the MCE extensions showed that they were similarly ranked for the Exclusive Economic Zone (EEZ) (200 nm) area as predicted by the DANP model. Furthermore, re-arrangement of the priorities in sensitivity analysis enhanced the final judgment for the criteria being evaluated; and for the SIM. Qualitatively, the validation of the DANP through the prediction has cumulated a computed value of 76.39 nm (141.47 Km) where this would be the most viable and economical deep sea fishery exploitation location in Malaysian waters and within the EEZ. In this study, MGDI decision and MgdiEureka are newly formulated terminologies to depict decisions in the realms of MGDI initiatives and the developed applications. The framework would serve as an improved marine geospatial planning for various stakeholders prior to decision making.

ABSTRAK

Sumber marin bagi pelbagai aktiviti dan kegunaan bercirikan konsep dimensi pelbagai, kriteria, pelbagai peserta dan konflik pelbagai kegunaan. Sebagai tambahan, sifat samar pada persekitaran marin mempunyai ciri pengiring menjadikan persekitaran lebih kompleks, seterusnya perlunya mencari penyelesaian alternatif pelbagai dan penilaian yang cukup, khususnya dalam konteks Infrastruktur Data Geospatial Marin (MGDI). Bagaimanapun, merujuk kepada literatur berkaitan MGDI, ia masih perlu kepada kerangka dan usaha penyelidikan terarah kearah prospek perkiraan holistik dalam membuat keputusan menggunakan penilaian kriteria pelbagai (MCE) dan algoritma pintar bertujuan mencapai keputusan efektif lagi termaklum melebihi pendekatan klasik. Penyelidikan ini bertujuan membangun dan mengesah sistem sokongan membuat keputusan pintar untuk MGDI Malaysia. Kerangka bersepadu dibina atas rekabentuk kaedah penyelidikan tergabung disedia sebagai mod pertanyaan. Kaedah kuantitatif terdiri daripada model Proses Rangkaian Analitik Dinamik (DANP), sistem indeks penilaian komprehensif (CEIS), tambahan MCE, pemodalan interaksi sistem spatial maklumat geografi (SIM), dan pelaksanaan sub-sistem pengambilan data hidrografi. Dalam kerangka ini, pengesahan satu kes kajian dibuat bagi aspek kualitatif dalam merancang tambahan geospatial paling terdaya dalam perairan Malaysia bagi mengeksploitasi perikanan marin laut dalam. Dapatan kuantitatif menunjukkan model ini mempunyai CEIS jelas dengan model rangkaian DANP berasas 7 kriteria, 28 sub kriteria dan 145 penunjuk prestasi dengan 5 alternatif. Dalam MCE, nilai utama diperolehi bagi Proses Hierarki Analitik (AHP) dan AHP samar adalah berbeza walaupun kedudukan adalah sama. Tambahan, hasil Teknik bagi Susunan Utama mengikut Kesamaan ke Penyelesaian Unggul (TOPSIS) dan TOPSIS samar dari tambahan MCE menunjukkan keduanya diletak pada kedudukan sama untuk kawasan Zon Ekskusif Ekonomi (EEZ) (200 nm) sebagaimana dijangka oleh model ANP. Selanjutnya, susunan analisis sensitiviti ikut keutamaan menambahbaik keputusan akhir yang dinilai; dan juga bagi SIM. Secara kualitatif, pengesahan DANP melalui jangkaan telah mengumpul nilai diperolehi 76.39 nm (141.47 km) dimana kawasan ini berupaya dan paling ekonomi untuk eksploitasi perikanan laut dalam bagi perairan Malaysia dan dalam EEZ. Dalam kajian ini, Keputusan MGDI dan MgdiEureka merupakan istilah ciptaan baru menggambarkan keputusan dalam susunan inisiatif MGDI dan aplikasi yang dibangunkan. Kerangka ini merupakan pembaikan pada perancangan geospatial marin untuk pelbagai pengguna membuat keputusan.

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LIST OF ABBREVIATIONS

AHP	-	Analytic Hierarchy Process
ANP	-	Analytic Network Process
ARC	-	Australia Research Council
ASCII	-	American Standard Code for Information Interchange
CD	-	Chart Datum
CRS		Coordinate Reference System
DANP	-	Dynamic Analytic Network Process
DGPS	-	Differential Global Positioning System
DM	-	Decision Matrix
DMs	-	Decision Makers
DSS	-	Decision Support System
DTM	-	Digital Terrain Model
ESRI	-	Environmental Systems Research Institute
ENC	-	Electronic Nautical Chartsd
FAHP	-	Fuzzy Analytic Hierarchy Process
FER	-	Functional Engineering Requirements
FL	-	Fuzzy Logic
FN	-	Fuzzy Number
FNIS	-	Fuzzy Negative Ideal Solution
FPNIS	-	Fuzzy Positive Ideal Solution
FTN	-	Fuzzy Triangular Number
FTrN	-	Fuzzy Trapezoidal Number
FTOPSIS	-	Fuzzy Technique for Order Preference by Similarity to Ideal Solution
GDSS	-	Geospatial Decision Support System
GIS	-	Geographic Information System

HAT	-	Highest Astronomical Tide
HO	-	Hydrographic Office
HRTO	-	Hydrographic Research and Training Office
IHO	-	International Hydrographic Organisation
i-MGDI	-	Intelligent Marine Geospatial Data Infrastructure
ISLW	-	Indian Spring Low Water (I.S.L.W)
JUPEM	-	Department of Survey and Mapping Malaysia (Portal Rasmi Jabatan Ukur Dan Pemetaan Malaysia)
LAT	-	Lowest Astronomical Tide
LPLW	-	Lowest Possible Low Water
MaGDI	-	Malaysia National Oceanographic Data Centre
MAL	-	Malaysia (caption used for Malaysia on the Nautical Charts)
MAOU	-	Marine Activities Ocean Uses
MBES	-	Multibeam Echosounder
MCE	-	Multi-Criteria Evaluation
MgdiEureka	-	Name of i-GDSS MGDI developed in this research
MHWN	-	Mean High Water Neap
MHWS	-	Mean Low Water Spring
MHHW	-	Mean Higher High Water
MLWN	-	Mean Low Water Neap
MLWS	-	Mean Low Water Spring
MLW	-	Mean Low Water
MLLW	-	Mean Lower Low Water
MNRE	-	Ministry of Natural Resources and Environment
MOSTI	-	Ministry of Science, Technology and Innovation
MS1759	-	Malaysian Geospatial Standard
MSL	-	Mean Sea Level
MTL	-	Mean Tide Level
MyNODC	-	Malaysia National Oceanographic Data Centre
MyGDI	-	Malaysia Geospatial Data Infrastructure
NIS	-	Negative Ideal Solution
NOAA	-	National Oceanic and Atmospheric Administration

NHC	-	National Hygrographic Centre
NFER	-	Non-Functional Engineering Requirements
OGP	-	International Association of Oil and Gas Producers
OO	-	Object Oriented
OOSAD	-	Object Oriented System Analysis and Design
PIS	-	Positive Ideal Solution
QINSy	-	Quality Integrated Navigation System
RAD	-	Rapid Application Development
RMN	-	Royal Malaysian Navy
RDC	-	Research, Development, and Commercialisation
S-57	-	IHO Standard for marine applications
S-100	-	IHO Standard for marine applications, with GIS and UML capabilities
SADD	-	System Analyses, Design and Development
SDSS	-	Spatial Decision Support System
SDM	-	System Development Methodology
SDLC	-	System development life cycle
SIRIM	-	Standards and Industrial Research Institute of Malaysia
TIN	-	Triangulated irregular Network
TOPSIS	-	Technique for Order Preference by Similarity to Ideal Solution
UTM	-	Universiti Teknologi Malaysia
WSADD	-	Web-Based System Analyses Design and Development

LIST OF SYMBOLS

α cut	-	alpha cut
α	-	State transition function
β	-	Output function
C.R.	-	Consistency Ratio
C.I.(μ)	-	Confidence Index
D	-	Data and Information criteria
E	-	Economic criteria
N	-	Environmental criteria
P	-	People criteria
R	-	Resources and Management criteria
S	-	Social criteria
T	-	Technological criteria
δ	-	Alternatives, based on maritime zones
R.I.	-	Random Index
Λ_{max}	-	Eigenvalue

LIST OF TERMINOLOGY

Activity Diagrams	-	For modelling behaviours of a system
ASCII	-	American Standard Code for Information Interchange
Class Diagram	-	UML Class Diagrams and modelling
Sequence Diagrams	-	UML Sequence Diagrams and modelling
Use Case	-	UML Use Case Diagrams and modelling

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CHAPTER 1

INTRODUCTION

1.1 Introduction to the Research

Over the years, there have been different means of exploitations and explorations of environment through varied geospatial human activities that are both heterogeneous and complex in nature from different sources (Chechile and Carlisle, 1991; Checkland and Poulter, 2007; Chung *et al.*, 2010; Hamid-Mosaku, 2002; Nwilo and Onuoha, 1993; Nwilo, 1995; Nwilo *et al.*, 2000; Perry and Sumaila, 2007). This environment, according to Ndukwe (1997) comprises of everything that is contained within the surface of the earth and its surroundings. It is made up of four categories, in which the aquatic environment (oceans, sea bodies, lakes and rivers and their inhabitants) is one of them. This aquatic environment is characterised with different marine activities that are ocean use based. One of such activities is the exploitation of the marine fisheries resources that is used for the case study consideration in this research.

Other components of the environment are: urban environment (human activities and construction), vegetal environment and the atmospheric environment (air or gas layer, close to the earth). The quantitative composition of the earth revealed the abundance of water; covering nearly 71% of the earth surface and between 70% and 90% of the weight of living organisms (Ibanez *et al.*, 2007; NOAA, 2010; Rosenne, 1996). Naeve and Garcia (1995) reiterated the recognition of the need for sustainable marine environment, which is also in line with UNCED (1992) declaration as follows:

> … the marine environment - including the oceans and all seas and adjacent coastal areas-forms an integrated whole that is an essential component of the global life-support system and a positive asset that presents opportunities for sustainable development.
>
> (UNCED, 1992:1; Naeve and Garcia, 1995:23)

The exploitations and exploration of environmental resources have both negative and positive consequences on the environment. Some of the notable environmental problems (Chechile and Carlisle, 1991; Chung *et al.*, 2010; Lenntech, 2009; Nwilo and Onuoha, 1993; Nwilo, 1997; Perry and Sumaila, 2007; Sekiguchi and Aksornkoae, 2008; ThinkQuest Team, 2012) are global warming, climate extremes, depletion of natural resources, tsunamis, hurricane, El-Nino, Upwelling, California Current, and pollution among others. On the other hand, the positive consequences are the advent of information and technological communication (ICT) (Gouveia *et al.*, 2004) and advancement in areas of spacecraft explorations, (Olaleye, 1992; Olaleye *et al.*, 2002) that facilitate development of new tools and approaches (Miller and Small, 2003), and increase in digital technologies – including digital Photogrammetry, digital Remote Sensing and satellite imageries (Olaleye, 1992; SDI Cookbook, 2004; SDICookbook, 2009); and the acquisition, storage, processing, retrieval, manipulation and analysis of these geospatial data.

These new technological revolutions have greatly impacted the aquatic environment, particularly towards the deep seas investigations in areas of deployments and implementation of deep seas observatories. Subsequently, there has been a number of research on the conservation, monitoring (Chechile and Carlisle, 1991; Gouveia *et al.*, 2004) and management (Miller and Small, 2003) of the environment for sustainability, (Hamid-Mosaku *et al.*, 2011a; Hamid-Mosaku *et al.*, 2011b, 2011c, 2011d; UN, 2009; UNCED, 1992; United Nations, 1987), particularly in relation to the aquatic environment. Thus, huge and voluminous amount of information from multiple and diverse sources (Lintern, 2006) cannot only be accessed; their representations, organisations, usage and management are still more complex when compared to other kinds of data (Di *et al.*, 2008). Despite, Ting (2003) argued that spatial data facilitates decision-making and conflict resolutions.

The dynamic aspect of aquatic environment (Abbort, 2005) constitutes varied geospatial inventories (in terms of acquisition, retrieval, analysis, disseminations and presentations) for different applications and location domains. The challenges therefore relate to the collection and maintaining the tremendous volume of geospatial marine data for resipository archiving and the dearth of their easy availability coupled with cost for hardware, software experts and the implementation factors. Philpott (2007) observed that various aspects of these complexities for the marine / maritime environment are within the Marine Geospatial Data Infrastructure (MGDI). Thus, MGDI is a framework that involves geospatial data as well as the means of collecting, managing and disseminating them (Spatial Vision, 2012). It is a comprehensive initiative wherein, according to Pepper (2009), there is no short term issue.

1.2 Background of the Study

Part of the emerging trends in research in recent time within the hydrographic, marine / aquatic environment has been the concept of Marine Geospatial Data Infrastructure (MGDI) or the Marine Spatial Data Infrastructure (MSDI) which is a subset of the Geospatial Data Infrastructure (GDI) of any country (Akıncı *et al.*, 2012; Binns, 2004; Nwilo *et al.*, 2010; Pepper, 2009; Philpott, 2007; Rajabifard *et al.*, 2005; Strain *et al.*, 2004, 2006; Vaez, 2007; Vaez, 2010). For instance, Canada MGDI (GeoConnections, 2002), is part of the Canadian Geospatial Data Infrastructure (CGDI) and the goal of her MGDI is to satisfy the geographic data needs of water-oriented stakeholders. Maratos (2007) observed that the establishment of MSDI must be considered an ‘obligation’; Hydrographic Offices (HOs) and International Hydrographic Organization (IHO) must study and be prepared to respond to its achievement.

Moreover, Rajabifard (2002a, 2002b); observed that as the importance of geographic information in addressing complex social, environmental and economic issues facing communities around the globe is growing, the establishment of spatial data infrastructures to support the sharing and use of this data locally, nationally and internationally is increasingly more important. The underpinning technology for SDI is Geographic Information Systems (GIS). Thus, Fabbri (1998) opined to the justification for geospatial technologies in particular for coastaln/ marine environment, as follows:

> Given the complexities of coastal systems and the multidisciplinarity required for sustainable coastal development, computerized systems are necessary for the integration and distribution of vast amounts of data and expert knowledge. They are also vital for performing analyses to aid decision makers in their difficult task of proving optimal and compromise coastal management solutions.
>
> Fabbri (1998:54).

Mittal (2002) further observed that Hydrographic GIS is an emerging utility, which not only promises effectiveness and speed in providing hydrographic products and services but can also provide much needed services to other emerging users of hydrographic and oceanographic data like administrators, oceanographers and engineers. Thus GIS could be a backbone for ocean related data in the larger National Geospatial Data Infrastructure (NGDI). Furthermore, according to Cham and Mahmud (2005) Hydrographic Information System (HIS) has capability of integrating all activities of hydrographic offices on a single integrated digital platform that are linked with databases from other surveys, such as, oceanographic and topographical surveys.

Consequently, the standard of operation in marine environment for data transfer within GIS was released on 1st January 2010 by IHO. This is called ‘S-100-Universal Hydrographic data Model (UHDM) as the Hydrographic Geospatial Standard for Marine Data and Information’. S-100 extends the scope of the existing S-57 Hydrographic Transfer standard. Unlike S-57, S-100 is inherently more flexible and makes provision for such things as the use of imagery and gridded data types, enhanced metadata and multiple encoding formats. It also provides a more flexible and dynamic maintenance regime. S-100 will provide the framework for the development of the next generation of ENC products, as well as other related digital products required by the hydrographic, maritime and GIS communities (IHO, 2009). On the other hand, at the national level, there are Malaysia Geospatial standard MS1759 (2005) and the Malaysia National Oceanographic Directorate Centre (MyNODC) data model (Mokhtar, 2012; MyNODC, 2012b). These documents provide the standards for modelling marine related activities in Malaysia. In addition, MyNODC data model will serves as the custodian of marine data, that are held by different government and non-government establishments (MyNODC, 2012a). Furthermore, the National Hydrographic Centre (NHC) conducts and provides a wide range of hydrographic activities within Malaysian waters, particularly in promoting and enhancing a timely delivery of hydrographical services (e.g. charts and nautical information) for safe navigation (Kamaruddin, 2011).

Nonetheless, researchers such as Rajabifard et al. (2005); Ng'ang'a et al. (2004) argue that the aspect of the marine data infrastructure had been left undeveloped and un-researched until recently compared to the various applications of the same for land areas. Tremendous achievements have been recorded in earlier studies particularly in Australia (Rajabifard *et al.*, 2005; Strain *et al.*, 2006); Europe for example INSPIRE project, (Longhorn, 2006) MOTIIVE project, (Pepper, 2009); Canada (GeoConnections, 2002, 2009; Mittal, 2002; Ng'ang'a *et al.*, 2004; Pepper, 2009).

Also, Malaysia has not given adequate consideration to MGDI compared with the attention and success recorded on land despite the obvious marine extent of the country (Hamid-Mosaku and Mahmud, 2009; Saharuddin, 2001). Malaysia Geospatial Data Infrastructure (MyGDI) (MyGDI, 2009) is fully developed and operational; Hydrography is one of the twelve identified layers (MyGDI, 2009; Taib, 2009a), and for now, there is no technical committee for Hydrogrphy (Taib, 2009a), it is also part of the contents of the Malaysia Geospatial Standard (MS1759) (Matindas, 2008).

From the perspective of the exploitation and exploration of the complex marine environment by stakeholders with different worldviews make the quest for the identification of different marine activities and criteria for their selection generally inevitable, and particularly for MGDI. In line with this, IHO MSDI wWorking Group (MSDIWG) identified ten (10) different types of stakeholders for SDI and MGDI. Consequently, MGDI is also characterised by such complexity; exhibiting multi-criteria, multi-agencies with multi-participant stakeholders at the different levels of MGDI hierarchy, governance, and administration. As such, most SDIs are at the National level, without consideration for MGDI; more interestingly, is the case of Malaysia without a national MGDI and non at the states / local government level of the MGDI hierarchy (see chapter 2). Furthermore, marine and coastal issues at the lower parts of the hierarchies are usually complex in nature, due to more data, information, extensive workforces and drivers. The Malaysian waters and maritime extent are also characterised with the above features. Twenty two (22) marine activities were identified that span through many agencies at different levels of the MGDI hierarchy.

Malaysian waters is one the global feet of 600 marine fish stocks monitored by the Food and Agriculture Organization (FAO) of The United Nations' Fisheries and Aquaculture Department FAO (FAO, 2010). However, Malaysia is yet to take her proper positions among the regional competitors, particularly in respect of her inability, according to FAO (2010) report of being among the recognised most significantly ranked top ten producers of the global fish catches; not among the reported major Asian fishing countries with reported annual regular increased, as well as not reckoned to be among the fourteen countries with significant production of the world inland capture fisheries.

This necessitates the consideration for case study implementation of MGDI and MGDI Decision to one of the identified marine activities, the case of the quantities and values of fishery resources in Malaysia, from Department of Fisheries (DOF) Malaysia (see Chapter 5). Over the years, DOFM (2011) report revealed the progressive increases in both the quantities and values of fishery resources that are being exploited in Malaysia. Thus, Figure 1.1 shows the quantities distributions in tonnes from 2001 to 2011 for Peninsular Malaysia, Sabah, Sarawak and Federal Territory of Labuan. The progression in total production over the years except in 2005 for Peninsular Malaysia are evident; due to a number of measure that were in place for optimum landings of the fisheries resources.

On the other hand, while there were increased progression for the same periods in total production over the years for Sabah and Wilayah Persekutuan Labuan, the case of Sarawak showed progressive decrease for the same periods.

There are two types of these fisheries resources: food fish and non-fish food. While there are three categories for the fish food, which are: marine capture fisheries for both inshore (*laut pantai*) and deep sea (*laut dalam*) resources; aquaculture for both freshwater (*air tawar*) and brackishwater (*air payau*); and public water bodies (*perairan umum*); there are also three categories for non-food fish, these are: seaweed (*rumpai laut*), ornament fish (*ikan hissan*), and aquatic plant (*tumbuhan akuatik*).

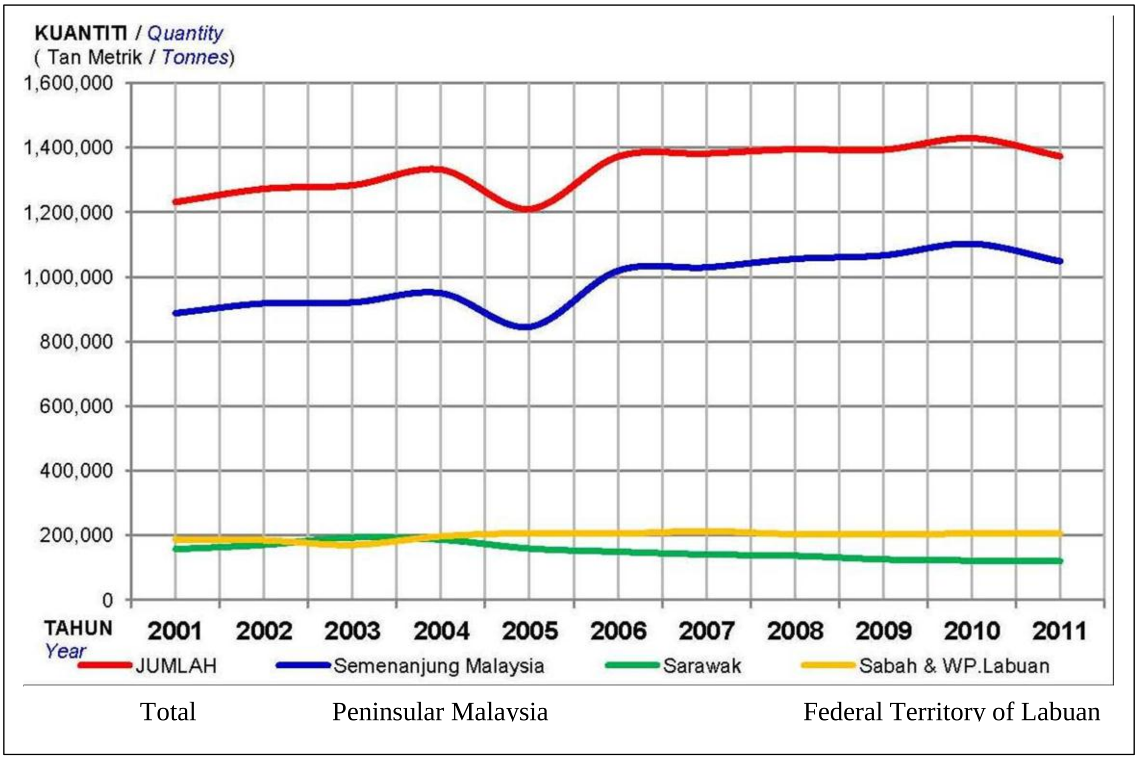

Figure 1.1 Trend of Marine Fish Landings, 2001 – 2011 (DOFM, 2011, p.3, 1.Carta)

The trend of marine landings from 2006 to 2011 in Figure 1.2 shows an unprecedented increase for the inshore resources compared to those from deep sea as well as aquaculture and public water bodies. This trend should have been more for the deep sea resources, moreso, that the Malaysia maritime extend is far more than the inshore area. However, despite these progressions, the deep-sea fisheries resources are evidently less exploited as compared to that of the inshore exploitations.

The quest that this research therefore seeks in addressing is to investigate the particular region within Malaysian waters and exclusive economic zone (EEZ) in line with MGDI initiatives where marine fishery resources are mostly and abundantly exploited, with greater quantities of landing and providing viable economy to the country. This will be in terms of increased annual values and contribution to the national economy, as well to Vision 2020 initiatives. This will also be in relation to different stakeholders and participants with different worldviews that are associated with this sector.

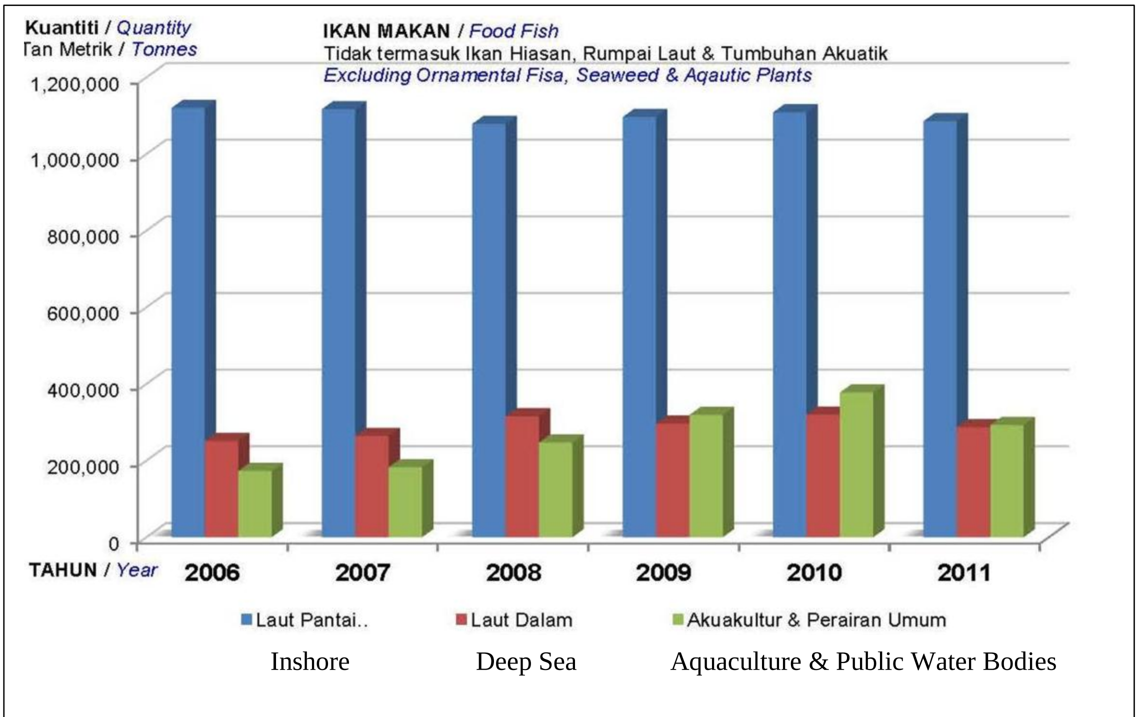

Figure 1.2 Trend of Marine Fish Landings, 2006 – 2011 (DOFM, 2011, p.1, 1.Carta)

This research problem is also supported by the claim of the Malaysia Department of Fisheries (DOFM, 2013):

> The potential of deep-sea fishery needs to be exploited and developed at a faster pace in the direction of harvesting fish stock in the international water for high value fish like tuna geared towards achieving the goals and aspiration of Vision 2020. The exploitation of fishery resources within the Exclusive Economic Zone (EEZ) warrants capable management such as surveillance; and entrepreneurship from also the private sector.
>
> (DOFM, 2013:1)

1.2.1 Research Perceived Gaps in Knowledge

There have not been concerted research efforts in addressing the gaps in knowledge which this research is addressing as evident from reviewed literature; most studies being progressively investigated under MGDI focus on marine cadastre, (Ng'ang'a *et al.*, 2004; Rajabifard *et al.*, 2005; Rüh *et al.*, 2012; Strain *et al.*, 2006) without consideration for the decision support aspects, that is particularly based from the backdrop of multidimensionality evaluation and analysis. Furthermore, many researchers (Adewunmi, 2007; Akıncı *et al.*, 2012; Anderson *et al.*, 2009; Binns *et al.*, 2004; Hossain *et al.*, 2009; Hossain and Das, 2010; Ng'ang'a *et al.*, 2004; Olaleye, 1992; Pourebrahim *et al.*, 2011; Pourebrahim *et al.*, 2010; Rajabifard *et al.*, 2005; Strain *et al.*, 2006) opined to the need to consider the decision making elements, particularly evaluation of relevant performance indicators (Rajabifard *et al.*, 2003); while others, in addition, proffer artificial intelligent (e.g. neural network, fuzzy logic) techniques (Abadi, 2007; Ascough Ii *et al.*, 2008; Bailey, 2005; Kahraman, 2008; Lamacchia and Bartlett, 2006; Pourebrahim *et al.*, 2010) in addition to being intelligent (Bailey, 2005; Feng and Xu, 1999) and innovative (Abadi, 2007; Rajabifard, 2002a) but none of these is yet to be fully achieved in MGDI development and implementations in many countries as well as in Malaysia.

Furthermore, exploitation of marine resources and activities were not holistically investigated in most of these studies. Malaysian waters with abundant resources are yet to be fully explored in the context of MGDI and decisions, particularly with respect to deep sea exploitations. Moreover, her maritime extent with a long stretch of EEZ offers potential economic and viable fisheries resources that are inadequately harnessed and exploited.

In addition, while the Australian SDI and marine cadastre were partly implemented for Port Phillip Bay (Strain, 2006; Strain *et al.*, 2004, 2006; Vaez, 2010) as the case studies, the case of fisheries resources in the context of MGDI are yet to be explored. Though, in terms of the national ocean policies (Saharuddin, 2001; Wescott, 2000) and ocean governance (Cho, 2006; Ng'ang'a *et al.*, 2004; Saharuddin, 2001) observed that the organisational structures governing the ocean for implementing national policies are well in place but in a fragmented and uncoordinated fashion. It is based on these proceeding reviews that necessitated what is termed as "**MGDI Decision**" by the researcher. Thus, the gaps are from the interactions of three distinct entities: SDI and MGDI reviewed literature, highlighting different initiatives and issues relating to MGDI, that are over distributed in line with different ocean use based marine activities. The clouds of gaps showed that there is need for MGDI to support decisions, as shown in Figure 1.3.

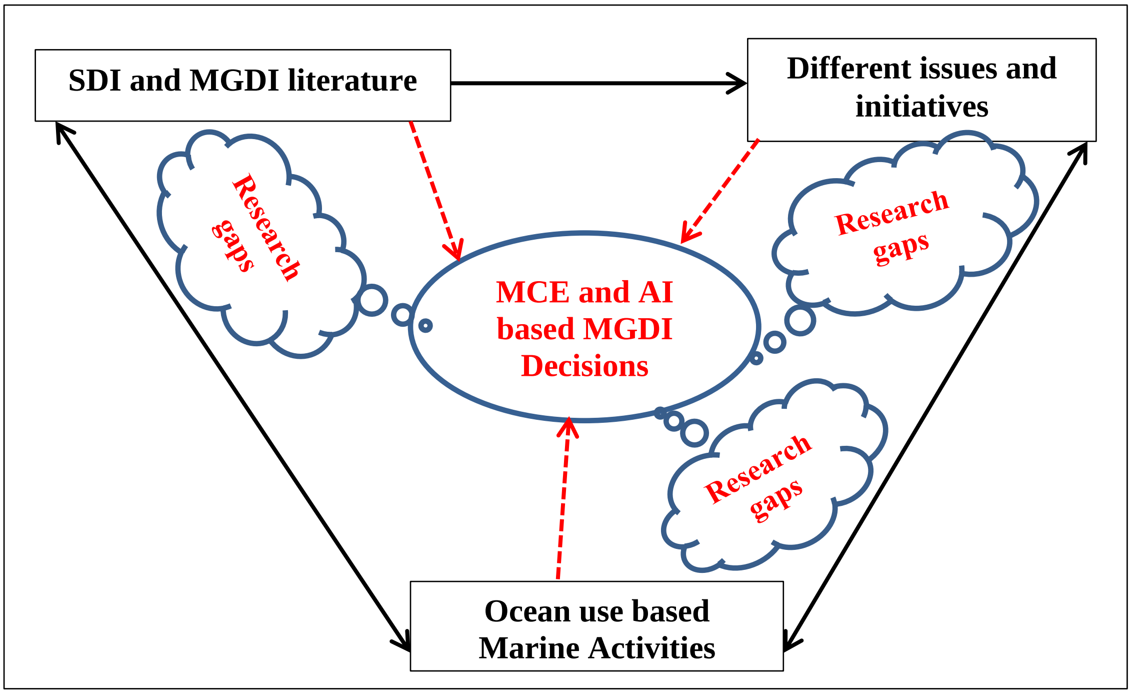

Figure 1.3 Pictorial Research gaps

Hence, the recent and paramount trends about the knowledge gaps that this research is addressing are as follow: (i) how MGDI should support decisions, (ii) 'MGDI Decision' using intelligent algorithms, (iii) application of A.I. techniques in a (iv) complex marine environment, (v) that are characterised by multidimensionality concepts, and (vi) fuzziness, with (vii) stakeholders and decision makers having conflicting worldviews in relation to (viii) exploitation of deep sea resources (e.g. fisheries) among the (ix) identified marine activities that are ocean uses based.

1.3 Statement of the Problem

The statement of the problem for a research is generally viewed from three perspectives, which are: theoretical / conceptual, empirical and practical considerations of the problems being addressed within the research domain. At the conceptual level, previous researches focused on marine cadastre and coastal delimitation; pinpointed the gaps in knowledge which constitute the MGDI Decision problems. Moreover, there is dearth of practical MGDI Decision research applications adequately addressing the issues of decision-making structures and the need for intelligent MGDI support systems. To date, there are no empirical models that specifically treat the multi-criteria, multi-agencies and multi-participant decision problems for MGDI (Checkland and Poulter, 2007; Feeney, 2003); which can effectively model, not only the comprehensiveness of the initiative but also, the complexity nature (Mokhtar, 2012) of marine activities that are ocean use-based.

A peculiar instance for both conceptual and empirical consideration is the Permanent Committee on GIS Infrastructure for Asia and the Pacific (PCGIAP) identification of the following four research areas relating to marine cadastre at the end of the international workshop on "Administering the Marine Environment – The Spatial Dimension" that was held in Malaysia in 2004 (Collier, 2005; Rajabifard *et al.*, 2004; Strain *et al.*, 2006):

i. Resolving issues in the definition of the tidal interface
ii. The use of natural rather than artificial boundaries in a marine cadastre
iii. Extension and application of the ASDI to support a marine cadastre
iv. Marine policy, legal and security issues and the marine cadastre

Furthermore, in term of collaboration and partnerships in support of SDI development, there has been a relatively poor understanding (Warnest, 2005).

The Hydrographic Geospatial Standard for Marine Data and Information (IHO, S-100) capabilities with respect to hydrographic modeling using Unified Modeling Language (UML) consideration in MGDI developments, constitute another source of conceptual research problem.

Additionally, there arise decision problems within stakeholders and decision-makers having different preferences with respect to the relative importance of evaluation criteria and decisions. Consequently, their decisions are often surrounded by uncertainties, impreciseness, biasness, vagueness, and ambiguities. Furthermore, some stakeholders' (from different technical and non-technical backgrounds) even show preferences to linguistic terms, such as: high, medium, low; to crisp values, in expressing their judgments. This is being compounded by the fuzzy dynamic nature of the ocean and shoreline surfaces. This study therefore incorporates the use of artificial intelligence (A.I) algorithms in modeling these anomalies. Thus, one of the artificial intelligent techniques that has been demonstrated to handle these anomalies in respect of multi-criteria evaluation (MCE) is the fuzzy logic (Bailey, 2005; Feng and Xu, 1999; Kahraman, 2008; Lin *et al.*, 2007; Negnetivisky, 2005). Moreso, complex decision problems of these nature are both empirically and practically maneuvered by intelligent systems; since according to Mokhtar (2012); Shin and Xu (2009); Shoureshi and Wormley (1990), such systems represent new approach to addressing complex problems.

Practically, effective decision-making incorporating GIS capabilities have necessitated Spatial Decision Support Systems (SDSS) (Bailey, 2005; Crossland, 1995). However, existing Decision Support Systems are domain specific, they are not directly tailored to the design and development of MGDI; thus, there is dearth of SDSS applications for MGDI in general as well as in Malaysia. This is further justified in Mokhtar (2012), wherein DSS is on the fifth stage out of sixth of MyNODC Roadmap; though MGDI for the agency is on second stage. A SDSS is based on the multi-criteria evaluation (MCE) principles, being geospatial in nature; SDSS shared the peculiar characteristics of spatial decision problems and challenges (Bailey, 2005; Malczewski, 1996; Malczewski, 1999) such as: large number of decision alternatives; the outcomes or consequences of the decision alternatives are spatially variable; each alternative is evaluated on the basis of multiple criteria; some of the criteria may be qualitative while others may be quantitative; typically more than one decision maker (or interest group) is involved in the decision-making process. In addition, existing software are yet to incorporate these concepts.

The foregoing researches dealt majorly on marine cadastre and other underlying issues relating to effective utilization and management of marine resources coupled with jurisdictional ownership of delimitation of the marine boundaries, without practical consideration for decision making capability. In spite of these research trends, the marine activities and resources are generally yet to be fully exploited empirically and practically, particularly with respect to deep seas potentials. Consequently, according to DOFM (2013), attention has just been raised concerning the unharnessed and non-holistic exploitations of Malaysian waters resources, particular the deep sea fisheries resources, and specifically, towards effective exploitations of these resources for actualization of Vision 2020.

Empirically, the stakeholders in this sector are multidimensional: according to DOFM (2010), there are 73 fishery districts in Malaysia: 41 for Peninsular Malaysia, 15 for Sabah, 16 for Sarawak, and one for Federal Territory of Labuan. Likewise, according to DOFM (2011), the workforce of the fisheries sector in 2011 consisted of 134,110 fishermen operating majorly on traditional fishing gears, compared with 129,622 in 2010 with an increment of 3.46%. This represents 98,135 of local fishermen while 35,975 were foreign fishermen (non-Malaysian citizens) from Thailand, Vietnam and Indonesia. There were 53,002 units of licensed fishing vessels in 2011 compared to 49,756 in 2010, and 28,599 fish farmers and culturists involved in various aquaculture systems, representing an increment of 8.78% compared with 26,291 persons in 2010.

Despite Malaysian waters being one of the FAO global feet of 600 marine fish stocks, her fishery resources are yet to harness holistically, without full exploitation that resulted in her inability to be properly placed among the other Asia pacific countries, as conveyed in the FAO (2010) report, and in section 1.2.

Moreover, regardless of this, Malaysian's available resources, infrastructure and participation, the MGDI, and decisions evaluation based on MCE techniques are yet to be given adequate practical research consideration. Thus, the justification and motivation for the design and development of an intelligent Geospatial Decision Support System for Marine Geospatial Data Infrastructure (*i-GDSS MGDI*) is therefore a *sine qua nom* generally for every coastal state and for actualization of environmental component of Malaysia's Vision 2020 economic development plan.

Therefore, the following is the problem statement for this research:

Marine resources exploitation in the context of MGDI is fraught with multidimensional stakeholders and MGDI Decision-making problems that are characterised with complexities; multi-criteria in nature with many sectors, and multiple participants, are yet to be given adequate research attentions over the years. Thus, despite the progressive increase in quantities and values of fisheries resources over the years, there is dearth of related applications and knowledge gaps in literature with respect to Malaysian fisheries resources for the deep sea area due to under-exploitation of her EEZ; lacking adequate consideration of these multidimensional nature of the fishery sector that necessitates modeling the resources using MCE analysis by Dynamic Analytic Network Process (DANP), and their fuzzy extensions to further enhance efficient, effective and informed decision for an optimal location within the EEZ where deep sea fishery resources are fully exploited and explored.

1.4 Research Questions (RQs)

This research is centered on intelligent Geospatial Decision Support System (GDSS) for MGDI, addressing the concepts of MGDI and in respect of decisions for exploitations and exploration of marine resources particularly for the deep sea areas; based on the reviewed literature, the research background, the problem statements as well as observed knowledge gaps (Abadi, 2007; Bailey, 2005; Feeney, 2003; Feeney *et al.*, 2001; Pourebrahim *et al.*, 2011; Pourebrahim *et al.*, 2010; Sari, 2006; Sari *et al.*, 2007; Scott, 2010). Thus, Figure 1.4 shows the interlink of the three research questions (Creswell, 2003, 2007; Sari, 2006; Sari *et al.*, 2007; Yin, 2009) used to answer the following questions:

i. How the study is to be incorporated into the present scenarios of MGDI and marine resources exploitation and exploration? Despite the number of researches, there still exists the dearth in knowledge about the multi-criteria decision making capability of MGDI for the evaluation of performance indicators for MGDI developments. This is RQ1, as stated in 1.4.1.

ii. What type of knowledge framework / model is required for intelligent GDSS for MGDI? This is sequel to the dearth of knowledge framework. This is RQ2, as stated in 1.4.2.

iii. How to evaluate the methodologies from RQ2 using deep sea exploitation of Malaysia fishery sector as the case study? This is RQ3, as stated in 1.4.3.

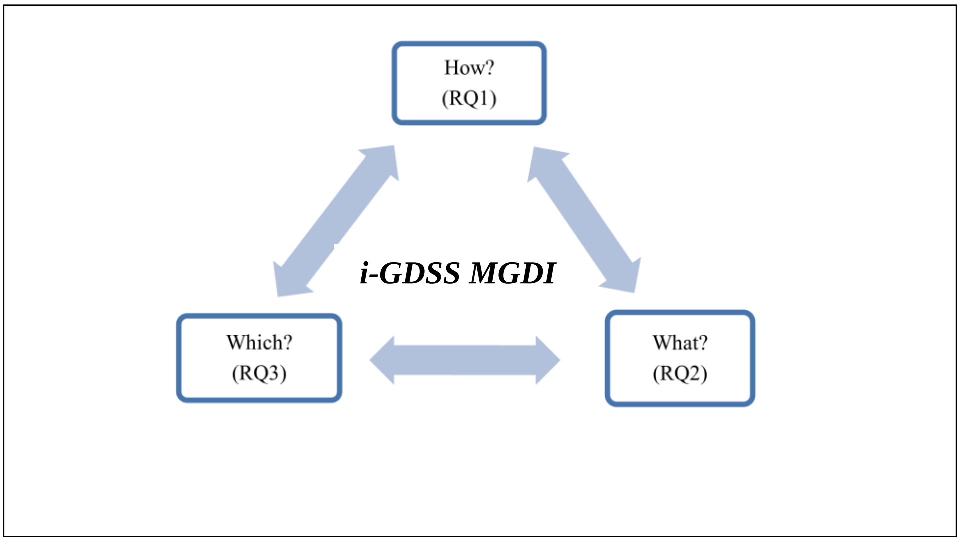

Figure 1.4 The three basic Research Questions (RQs)

The RQs for this research are therefore formulated as follow, providing relevant answers as contribution to knowledge:

1.4.1 Research Question 1

RQ1: How is the incorporation of MGDI implementation within the context of abundant marine resources, and identified complexities with stakeholders having conflicting world views be modelled with respect to ocean use based marine activities that will intelligently aid decision that are apt for MGDI and exploitations of marine resources?

1.4.2 Research Question 2

RQ2: What concept and framework of knowledge based on multi-criteria evaluation (MCE) and artificial intelligent (A.I.) technique effectively achieves the proposed intelligence?

1.4.3 Research Question 3

RQ3: Which part of the Malaysia's exclusive economic zone (EEZ) is apt for viable deep sea exploitation of marine fishery and aquaculture resources?

Thus, RQ1 addresses the nature of the stakeholders, having different conflicting world views and action plans in addition to being multi-criteria, multi-participant and multi-agencies in nature, as well as the perceived gaps in knowledge. RQ2 addresses the quest for a multi-criteria evaluation (MCE), artificial intelligent (A.I.) methodological solutions while RQ3 provides the means for a case study investigation in aiding decision to predict the region within Malaysian EEZ that is apt for an optimal exploitations of the deep sea fisheries resources.

1.5 Goal / Aim

Based on the gaps in knowledge from the backdrops of the statement of the problem and research questions posed for this research, the goal / general objective of this research is therefore stated as follows:

> To develop and validate an intelligent geospatial decision support system for Malaysian Marine Geospatial Data Infrastructure (MGDI) for ocean use based marine activities and specifically for deep sea fishery resources

1.5.1 Objectives of the Study

The specific objectives of this research are as follow:

i. To collate, evaluate and structure the most important criteria, parameters and relevant performance indicators for the development of intelligent Marine Geospatial Data Infrastructure (*i-MGDI*) that are apt for exploitation of marine activities and resources.
ii. To resolve and understand issues revolving around feature data dictionary in existing nautical charts and those in used by other hydrographic communities.
iii. To explore, develop and implement a generic computational model, whose intelligent algorithms are derived from the identified intelligent systems for the exploitation of Malaysian deep sea fishery resources.
iv. To evaluate, investigate and predict, using a case study approach the most viable geospatial extent within Malaysian EEZ for optimal exploitation of deep sea and high value marine fishery resources, like the tuna.

This shows that the first, and second objectives are being addressed through RQ1, while the third objective addresses RQ2; and the fourth objective is being addressed RQ3.

1.6 Research Motivations

There still exist to date, the perceived gaps in knowledge with respect to existing NSDI and / or MGDI initiatives, this is further justified in Mokhtar (2012); Feeney (2003). The motivations for this research therefore seek to fill in these gaps for MGDI Decision problems considerations. This is partly driven by the quests to innovate a scientific tool with integrated methodologies to depict and model marine activities - which is one of the complex environmental phenomena for the exploitation of the resources. As such, it is fraught with multi-criteria factors involving many sectors with a large number of participants; fuzzy circumstances emanating from ocean dynamics, as well as uncertainties, impreciseness and vague decisions by the stakeholders; imposing difficulties in traditional tools and mere ocean delineation that cannot be accurately depicted. Thus, the choice of MCE analysis in fuzzy environment resulted from inherent subjectivity in experts views and judgment.

Furthermore, this approach provides a comprehensive index framework that is directed towards an holistic understanding and structuring of the various criteria for MGDI, ocean activities with marine resources. Therefore, motivation is geared towards providing a geospatial decision support system (Fabbri, 1998; Mokhtar, 2012); that can model these complexities in marine activities through the development of an intelligent geospatial decision support system for MGDI. Accordingly, Shin and Xu (2009); Shoureshi and Wormley (1990), considered intelligent systems to be a new approach to deal with complex problems, particularly, when it has to be characterized by uncertainties, impreciseness, biasness, ambiguities, and vagueness; and when stakeholders' express preferences to linguistic terms instead of crisp values, in expressing their judgments.

There is dearth of such integrated approach in knowledge as a result of the reviewed literature. Furthermore, Feeney (2003) emphasised:

> …little has been done to document how SDIs support decision-making and thus how SDI decision support capacity can be evaluated and improved. As a result, it is believed that the potential role of SDIs for spatial decision support is currently underdeveloped, particularly in the application of data and the incorporation of supporting technologies into the decision process.
>
> (Feeney, 2003:196)

> …the need for evaluation and performance indicators.
>
> (Rajabifard et al., 2003:xxvii).

1.7 Significance of the Research and Expected Contributions

The significance of research and contribution to knowledge are generally conceived from the backdrop of three areas (as in the case of problem statement): theoretical / conceptual; empirical; and practical contribution to knowledge. For the theoretical / conceptual consideration, using the IHO, S-100 Hydrographic Geospatial Standard for Marine Data and Information, 2010, it is expected that this research will highlight the effectiveness of MGDI and decision model that enhances the geographic data needs of water-oriented stakeholders and HOs.

Theoretical contribution of this study from the extensive literature reviewed will significantly bring to the fore the state of art of research trend in MGDI; thus filling the gaps in knowledge about MGDI and justification for the decision support capabilities.

Another theoretical significance of this research as parts of the outcome of the review literature offers a rationale for an integrated / hybrid methodology that was initially proposed. This is borne out of the multi-dimensional characterization of the marine environment and stakeholders, making the quest for multi-criteria evaluation (MCE) and analysis inevitable, as previous studies failed at such consideration. In addition, the integrated approach proposed for this research offers practical and better results than when any of the methods is considered alone. Moreso, the drawbacks in any of the method when used singly will be augmented by the integrated approach.

Furthermore, the artificial intelligent consideration offers another theoretical significance of this research providing strong theoretical links through the fuzzy logic extensions with better understanding of the fuzzy nature of this environment, stakeholders, and the decisions to be taken about the marine activities, as well as the exploitation of the resources. On the other hand, the incorporation of stakeholders with marine environment and activities based on the marine resources and their modelling by fuzzy logic consideration offers another practical significance and contribution by providing another links between the research theoretical basis and methodologies, thereby assisting decision-makers towards arriving at better and informed decisions.

In terms of the empirical and practical considerations, adequate elucidations, evaluations and selections of the most important criteria that cover different paradigms in marine environment such as sustainability (environment, economic, social), innovation, technology and externalities were examined that directly and / or indirectly influence *i-MGDI Decision*s for geospatial planning, use of the oceans, and exploitation of marine resources were obtained through a comprehensive index evaluation system (CEIS). Consequently, these evaluated criteria (7), sub-criteria (28), and parameters (145) will aid the development of effective scenarios that enhance the suitability and sensitivity analyses of the various map layers for *i-MGDI Decision*s within different maritime zones delimitations and ocean uses themes.

This comprehensive evaluation index system (CEIS) significantly offers a broad conceptualization of the factors for MGDI from a sustainable and marine activities based ocean resources, as well as providing the evaluation framework for the research. In this way, a number of qualitative and quantitative factors are incorporated for MGDI as well as the 22 marine activities that were reviewed, and structured for effective, efficient and informed decisions. This involves interactions of different exogenous and endogenous variables from these qualitative and quantitative factors.

The expected outcome of this prediction will enhance the newly incorporated MGDI Decision concept for better understating and management of the vast marine resources.

This research is also significant in offering additional empirical evidence about the relationship between these qualitative and quantitative factors that must be apt for MGDI initiatives which were not fully addressed in previous studies as evident from reviewed literature. Thus, the gaps in knowledge that were earlier observed can adequately be addressed. Up to date, this is the first known empirical research direction in the realms of the MGDI initiatives wherein the MCE analysis for decision making is given priority. Thus, providing evidence-based multiple alternative solutions for MGDI and MGDI Decision for exploitations of the marine resources.

The expected findings from this research will provide geospatial regions within Malaysian EEZ where the marine resources are potentially available for viable economic exploitations and explorations. The rigorous prediction of the most viable and economical region of Malaysia's EEZ that this research aims at achieving offers another empirical and practical significance.

As Malaysia is a coastal state, the development of MGDI offers both empirical and practical contribution to knowledge which must attract the attention of stakeholders; particularly in enhancing the drive towards the realization of the Vision 2020 as well as being a catalyst for the nation's Economic Transformation Program (ETP). This will ensure safe environment with viable economic prowess that will contribute to the nation's Gross Domestic Product (GDP) for an egalitarian society; in tandem with the nation visions and in line with global recognition and knowledge discoveries.

1.8 Scope of the Research

Due to the multi-dimensional characterisations of the marine environment, the stakeholders and fuzzy nature of different drivers of MGDI initiatives, this research aims at developing an intelligent decision support system for Malaysian MGDI through the implementation of a predictive scenario for the region where the deep sea marine fishery exploitations are highly predominant within Malaysian EEZ.

The study will focus on the implementation of MGDI initiatives in achieving the exploitations of deep sea marine resources, and in particular for Malaysia fishery sector, by predicting the most viable region within Malaysian EEZ, through the incorporation of diverse qualitative and quantitative factors into the modelling.

The disciplinary scope of this research involves aquatic and hydrography components of the environment through the vast ocean extents, and the various means of data acquisition techniques (but excluding data exchange and interoperability technology capabilities e.g. MarineXML), using integrated hybrid methodology. In addition, this integrated approach is sequential in implementation and application, in which its components are loosely coupled; they are not necessarily meant to be used at once for the identified marine activities ocean uses based and resources exploitations.

Case study research design approach of qualitative research design aspect for mixed method is applicable to this research, involving design, data acquisition techniques, and data analysis (Creswell, 2003; Yin, 2009); thus, providing both empirical and practical justification of the scope of this research. In addition, survey instrument was developed based on both qualitative and quantitative factors of the CEIS, involving interactions between endogenous and exogenous variables for MGDI and MGDI Decision consideration and were later distributed among marine stakeholders. Consequently, Multiple-case studies (Cross-Case Analysis) for Malaysian waters were chosen for the validation of the support system in respects of Malaysian fishery sector for both inshore and deep sea exploitations. An intelligent GIS. implementation for this fishery sector was also achieved through the implementation of spatial interactive models (SIM).

Likewise, the research is being accomplished within the scope of provisions of the international laws (for example, the UN Convention on the Law of the Sea (UNCLOS)) as well as other domestic provisions concerning maritime activities / ocean uses, policies and boundary demarcations.

1.9 Research Justification

Effective ocean use with adequate rights, restrictions and obligations within the different zones of any maritime regime, directly impacts the coastal state and her neighbours with various attendant environmental, economic, social, technological implications towards effective marine resources exploitations and explorations for service deliveries; efficient, effective and informed decisions. The implications are borne of the interactions of different exogenous and endogenous variables from the qualitative and quantitative factors that are parameterised in arriving at the CEIS.

As Malaysia sits astride one of the world's busiest sea routes, the Straits of Malacca, which links Southeast and Northeast Asia, Asia and Western Europe and Asia and North America. Thus, the protection of the freedom of navigation and this important sea-lane trade route is very paramount to Malaysia (Saharuddin, 2001). With abundant and diversified natural ocean resources with extensive maritime areas with a relatively long coastline, Malaysia therefore must harness the full potential of these abundant resources, which is achievable through the developments and implementation of MGDI, and taken cognizance of the need for a MCE analysis in a fuzzy realm. This is even more imperative towards achieving the environmental components of Vision 2020 initiatives.

1.10 Operational Definitions of Terms

Some of the key terms used in the context of this research are defined as in the following sub-sections.

1.10.1 Decision Support System (DSS)

DSSs are geocomputational systems developed to access and utilise domain (discipline-focused or experiential) knowledge bases to support decision-making by the generation of alternative solution scenarios between multiple criteria, and often spatial representations of these through maps and cartographic tools (Feeney *et al.*, 2001)**.**

1.10.2 MGDI Decision

The decision considerations are those suited to the design and development of MGDI based on the various identified marine related activities that are ocean use based (Table 2.14). Often, there are decisions to be taken by any of the marine stakeholders in relations to these identified activities. The MGDI Decision (as in Purchasing decision (Bayazit *et al.*, 2006)) therefore is an innovative taxonomy used in this research to capture the decision making considerations involved in the developments and use of MGDI concepts. It is an acronym device through this study, involving decisions that must be taken in relations to MGDI concepts and initiatives that centered on the ocean uses marine related activities. Thus, MGDI Decision is a new concept in cognisance with MGDI initiative and development based on the understanding that there exists a multi-conceptual nature of the stakeholders in the realms of decision making in relation to marine environment needs, hydrographic services, marine surveys services, and the various applications that are being explored. For instance, the following are some of the decisions that are suited to MGDI Decisions:

i. Assessment of the criteria for new pipeline routes optimally and sustainably;
ii. Selections of appropriate tools: software and hardware for hydrographical campaigns for new projects;
iii. Assessments of on-going projects, such as: dredging, offshore installations;
iv. Selection of appropriate human capacity building for hydrographic surveying and marine related projects, ports management, and fish landing;
v. Operational assessments for effective hydrography service delivery;
vi. Location of viable and economical marine activities for MGDI within any of the maritime zone delineations;
vii. Assessment of the flow of ships to Malaysian ports as an attractive ports of destinations from any parts of the world, and as applicable to other coastal states;
viii. Assessment of the amounts of fisheries landing and aquaculture from Malaysian waters from near shore to the deep sea fishing, and as applicable to other coastal states;
ix. Marine related decisions by any of the stakeholders in relation to the identified twenty two (22) marine activities that are ocean uses based.

1.10.3 Multicriteria Analysis (MCA) and Multicriteria Decision Analysis (MCDA)

Multicriteria Analysis (MCA) and Multicriteria Decision Analysis (MCDA) refer to a group of formal approaches to the analysis of decision processes and problems, which aim at determining an overall preference among different alternatives. Each alternative under examination is evaluated on the basis of its performance with respect to a body of decision criteria (Coastal Wiki, 2012).

1.10.4 Decision Making

Decision-making, according to Malczewski (1999) may be broadly defined to include any choice or selection of alternative course of action.

1.10.5 i-MGDI

An intelligent Marine Geospatial Data Infrastructure, whose intelligence is built from MultiCriteria Evaluation (MCE), Artificial Intelligent (AI) as well as GIS consideration, as reviewed from literature.

1.10.6 Intelligent Algorithms

These are modeling algorithms that are suited for this study as reviewed from literature from the backdrop of MCE, A.I. (fuzzy logic) and GIS.

1.10.7 MGDI Decisions Problems

These are the highlighted gaps in knowledge that constitute the research problems that are being addressed in this study, as highlighted in sub-section1.10.2.

1.11 Structure of the Research

This research thesis is organised according to the discussion from the previous sections in this chapter into eight chapters. There are four different phases, arranged into chapters as shown in Figure 1.5. In chapter 1, the background to the study, previous related research, observed research gaps, research questions, research goal and objectives, research scope, research design, and operational definitions of key terms, are parts of the discussions. In effect, chapter 1 addresses the general picture of this research, highlighting the various research questions as well as the research specific objectives generally and specifically the first research objective and in parts RQ1.

Literature reviews cover two chapters – chapter 2 and 3. In chapter 2, discussions cover MGDI initiatives, standards issues, ocean administration, and in relation to Malaysia ocean policy, as well as a critical review of Malaysia Maritime environment, existing infrastructure and maritime delineation. In chapter 3, intelligent systems, using intelligent algorithms as they are related to the development of the intelligent MGDI are presented. At the end, this chapter addresses in part the first specific objective as well as RQ1. In Chapter 4, the models for the actualization of the research are presented, that are based on the arguments developed from the previous chapters and linked to the others, so that the contribution to knowledge of the research compared to previous ones can be appreciated.

Chapter 5 addresses the research methodology based on the conceptual and theoretical models serving as the operational lens for the adopted mixed method research design. This involves data acquisitions from related stakeholders' activities pursuant to the marine environments, questionnaire surveys, interviews, analysis, and hydrographic data. Necessary algorithms designed were implemented that aid the development of the intelligent decision for MGDI. Consequently, this chapter addresses the second specific research objective and RQ2.

The case study implementation is achieved in Chapter 6; addressing the third specific research objectives and RQ3. It covers the prediction of the deep sea marine fishery resources exploitations for Malaysian waters; which forms part of the major research problems that are being addressed in this study.

Chapter 7 addresses the general considerations of the results, analyses and discussion sections of this research; particularly with respect to the case study area of Malaysian waters. Chapter 8 addresses the concluding part of the research. It provides an evaluation of this study with respect to the set objectives for the study as well as providing implications of the research findings and areas of usefulness of this research to other areas of applications, limitation to the present efforts, contribution to knowledge, future direction of research areas in MGDI, MGDI Decision and possible recommendations.

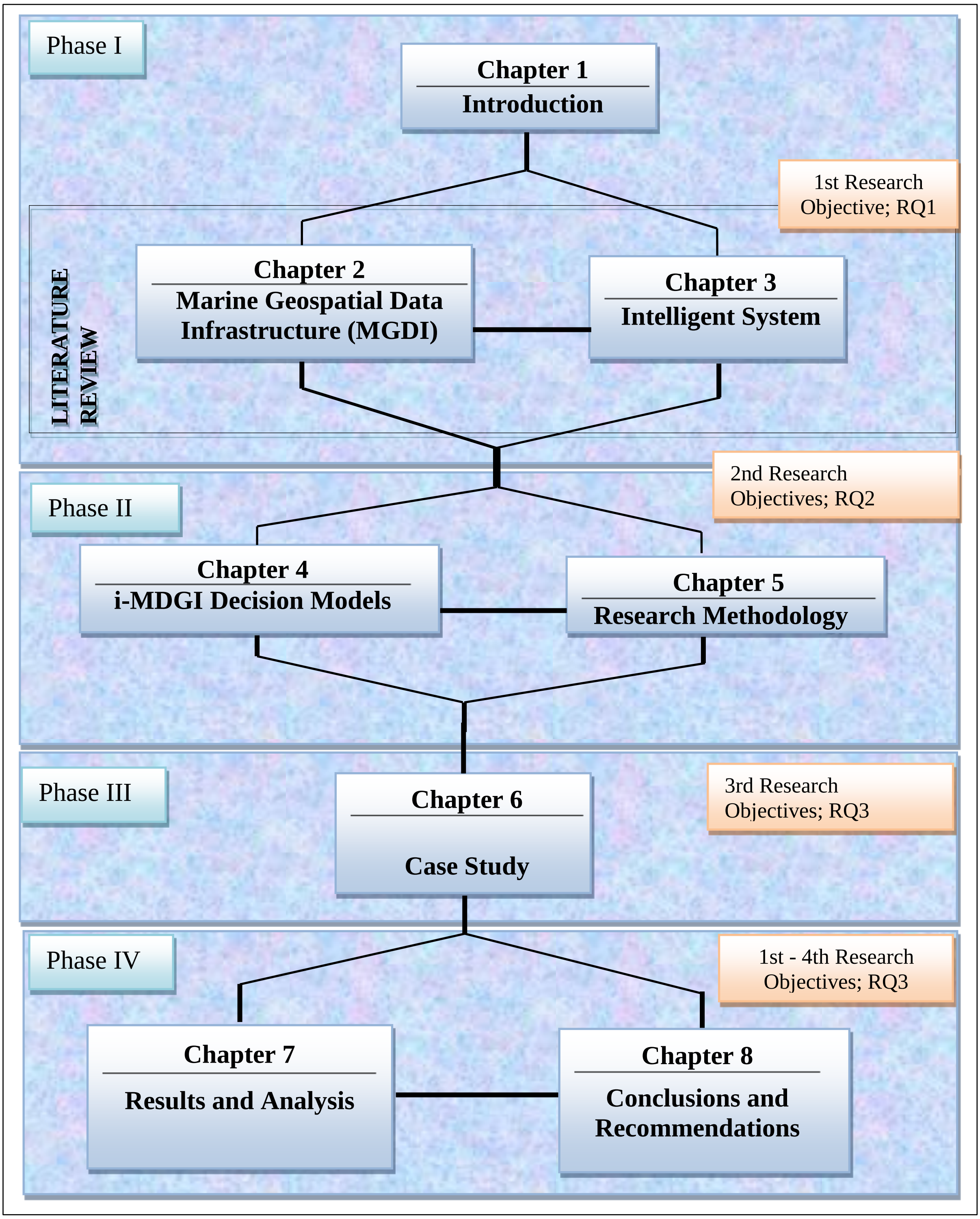

Figure 1.5 Structure of the Thesis - phases and arrangement of the chapters

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