Designing innovative AtoNs for inland navigation based on IALA guidelines – Kenyir lake as a case study

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Abstract. Currently, there is no standardized framework for navigation in inland waters. This means that navigation is not bound to comply with international and national standards and requirements. One key element to ensure safety of navigation is Aids to Navigation (AtoNs). However, the non-standard AtoNs currently used on inland waters may lead to confusion and increased navigation risks. The safety of inland navigation is critically important in transporting people and goods. Consequently, appraisal of existing inland navigation practices is needed towards measuring the performance and availability of AtoNs in inland waters. This study is primarily to assess the use of AtoNs on Kenyir Lake in Malaysia to enhance safety and operational efficiency for navigation. Kenyir Lake is chosen as the subject of this study due to its multi-use functions where inland navigation is widely practiced. The study has practical importance in mitigating risks to human life, environment and economic potential as more users engages in navigation. Statistically, in 2015, Kenyir Lake records more than 700,000 users including tourists and local. There is an annual increase by 100,000 tourists each year which provides significant economic contributions. This study comprising of mixed method including observatory analysis, comparative analysis, Adaptable Design Method and Rapid Iterative Testing and Evaluation (RITE). The outcome of this study will be to provide the recommended design for AtoNs to be use for inland navigation that comply with IALA guidelines. The design is set to be more practical, cost effective and standardized.

1. Introduction
Kenyir Lake was built in 1985. It was created through the dam construction of Sungai Terengganu across Sungai Jenagor [1]. It is situated on latitudes 04° 41’ N to 05° 15’ N and longitudes 102° 32’ E to 102° 55’ E in the state of Terengganu. Numerically, the lake is interconnected to 340 islands with over 14 waterfalls and numerous of rivers combined. The lake has the maximum depth of 145 meters and retains the average depth of 37 meters [2]. All the features have set the lake as a core function for purpose of dam for power generation. Due to its unique and attractiveness of natures products has set aside as the main eco-tourism destination for Terengganu state [3]. These can be based on nature itself such as waterfalls, caves, and sanctuaries. Man-made attractions such as Kenyir Bird park, Tropical Park and Water Park. Also, water-based activities such as fishing, excursions and island hopping [4].

Kenyir Lake is locally managed by District Council of Terengganu established as of 1 January 1981. They ensure all regulatory matters regarding the quality of life, under its mandate social and
leisure facilities are managed by the Majlis Daerah Hulu Terengganu (MDHT) [6]. In empowering the development aspects, Lembaga Kemajuan Terengganu Tengah (KETENGAH) was founded on April 12, 1973 to improve and expand the economic and social status of Kenyir Lake areas [5].

Kenyir Lake is subject to tidal conditions especially during the monsoon season generally between October to March. Heavy rain causes swelling of the rivers that feeds into the lake which in turn will cause water level to rise. This phenomenon will cause certain areas and tree stumps to be submerged and may become underwater obstruction. The occurrence of huge water surge reaching up to 9-meter-high is also common if there are heavy rainfall upriver [7]. These phenomena may be a hazard to those not familiar with Kenyir Lake.

The Kenyir Lake has documented population of 16,119 natives and 334 aborigines of the Semaq Beri and Batek Tribe from 49 Villages [8]. Both locals and aboriginals mainly engage with navigation as for daily essential means of transportation for fishing, hunting, and gathering forest products. However, according to KETENGAH, tourism is the prominent user of the lake and these consist primarily of local visitors with about 10% of foreign tourists [3]. These tourism activities done in Kenyir with two main types of vessel which is speed boats and houseboats. Due to the condition of the lake it allows the largest watercraft, houseboat is constructed between 60 to 85 feet long and up to 30 feet wide [10].

KETENGAH has been proactive in the development of Kenyir Lake. One of the efforts with respect to navigation was the placement of signage’s like road signs which provide directional guidance and distances to points of interest within the lake. However, buoys, beacons and navigation lights are more necessary to ensure navigational safety [11]. Current inland navigation is based on sight and hearing only. Users need to plan their voyage effective to avoid restrictions of poor visibility during the nighttime. The latest time to depart from the Tanjung Mentung to the entry point of Pengkalan Gawi is by 1700hrs or they may encounter problems and force to stay overnight as there is no aids to navigation available to assist them to navigate safely.

Local knowledge is crucial due to the geography of the lake. Surrounding areas will appear to be the same all around observed from water level because of the lush greenery of the tropical forest that surrounds the lake [9].

This research is expected to enhance inland navigation through adaptation of standard IALA AtoNs. By innovating the AtoNs for inland use it would be a prominent step to improve the safety and operational aspect of inland navigation.

2. Literature Review

2.1. Navigation Safety

IMO has been improving the navigational aspect ever since 1959 and has taken a whole series of relevant conferences, guidelines, and other instruments. This is to ensure that navigation safety is at the top notch which simply means all vessel can navigate, operate, and avoid collision as well as minimize navigational errors, preserves life, property, and environments [12]. Another key supporter is the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) of which Malaysia is also a member [13].

IALA provides standards and recommendations containing information on how member states should manage their AtoNs, e-Navigation and vessel traffic services. IALA endeavors to ensure safe and effective passage of vessels by facilitating the synchronization of marine aids to the global navigation system [14]. This is done by exchanging and comparing between the manufacturers, consultants, authorities, and training institutes from all parts of the world which offers to establish a systematic way to achieve the harmonization of Aids to Navigation [15].

Geographical features are parts of vital role, for example, the lay of the terrain, entry and docking points, depth of water, visibility, background clutter, local traffic etc. To ensure safety, aids to navigation, routeing system and vessel monitoring are used [11]. To counter these hazards,
navigational safety tools would include radio directional devices like radar, radio beacons, aids to navigation (AtoNs) including light houses, modern communication facilities including satellite communications and regulatory measures including traffic monitoring [16].

2.2. Regulatory Requirements for Navigation
Safety in navigation simply means that vessels are safely navigating and operating, avoiding collisions and reduce navigational errors in order to protect human life, the natural environment, and properties. The International Maritime Organization (IMO) has established various measures in the form of conventions since 1959 to achieve this. With the present regulatory requirement, it boosts the effort to provide a secure method to the safety of navigation issues.

2.2.1. International.
Regulatory framework is a set of legislation by which they are applied to advocate safety and effectiveness. It is the presence of the necessary infrastructure that supports the regulation, course or execution of an action, rule, principle, or law proposed or adopted [17]. The international regulatory framework for navigation is governed by the IMO. Its main objective is to promote and assist the widespread acceptance of the utmost practical standards in maritime health, navigational performance, and marine pollution control matters [18]. IMO instruments generally only affect ships involved in international journeys and exclude ships with a gross tonnage of less than 500 tonnes, yachts, fishing vessels, non-mechanically propelled ships, and primitive-built wooden ships [19].

2.2.2. Malaysia.
There is not currently a unified regulatory framework for inland navigation. It is as much subject to the country’s total sovereignty as if they were an actual part of its land territory [20]. The Economic and Social Commission for Asia and the Pacific in its recommendations for the harmonisation of navigation laws and regulations states that a critical regulatory framework and technical standards have not yet been established at the sub-regional level and no harmonized navigation aid framework has been established. As a result, this could threaten the lives of passengers and the environment to the risk. The aids to navigation in each country are different depending on their navigation system. Any conflicts of the unharmonized system in navigation are in total dispute, which also triggers traffic accidents on inland waterways and endangers people’s lives and property [21]. As for Malaysia’s water excluding inland waters, the international instruments and standards are implemented by the Malaysian Marine Department (MARDEP) whose role is to ensure navigational protection and the effectiveness of navigational aids, including their availability and reliability, which comply with IMO and IALA standards [22]. Malaysia is a contributing member of IMO that has also been elected as Council Member Category C for member states which have superior interests with maritime transport or navigation [23]. Malaysia is also a member of IALA, implementing the buoyage system for Malaysian waters and provides a guideline for the construction of a navigation buoy to standardize the type, size, and design of navigational buoys in accordance with the IALA buoyage system [24].

2.3. Aids to Navigation
Aids to Navigation is a type of markers use by the navigator to safely travel from one point to another. This is commonly used by the nautical mariners and by the aviators. The term sea mark is generally referring to the form of aid to navigation which indicates the hazards and the safe passage to the boats, ships, and seaplanes [25]. Generally, there are three types of AtoNs, which are beacons, buoys and cairn built. All having different features. The beacon is a type a floating object anchored to a specific location. Whilst the cairn built submerged to rock or object in a calmer water. Mainly AtoNs serves wide navigational purpose. This include to indicate
channels, dangerous objects, mooring positions, traffic separation schemes, submerged shipwrecks, and others. It can be used during either daylight or nighttime depending on their characteristic and features. Some are only intended to be visible during the daytime and some features might use during the nighttime by having lights and reflectors [13].

3. Methodology

3.1. Introduction

To obtain the information and the required data, the research is divided into 3 main stages which is the appraisal from the literature review, the general study and the specific assessment required. The first stage is the appraisal from the literature review to obtain information on the inland navigation on Kenyir Lake. For the second stage, the general study on the areas of interest is developed. As it is conducted in the Kenyir Lake, sets of the information is obtained regarding the user of the Kenyir lake, type of boats that are present in the vicinity and the availability of the AtoNs. The third stage focused on the assessment of the AtoNs.

3.2. Research Design

![Figure 1. Research design.](image-url)
There are three main steps, first to determine the type of vessels, their numbers and navigating routes on Kenyir Lake. Second, to study the AtoNs that are currently used in Kenyir lake and comparing their functionality and characteristic. Third to study IALA methods and IMO requirements in order to propose innovated AtoNs that are practical and cost effective for the use in inland navigation for optimum navigation on Kenyir Lake, Figure 1.

3.3. Sampling and Data Collection
First, the structured observation provides information on the types of vessel and their pattern of navigation on the lake. Non-Probability Sampling Methods was used on boaters, vessel owner and authorities to gather the basic navigation data on the departure and destination points, navigation practices and the number of boats navigating on the lake. This data is collected and analyzed with the excel frequency distribution. The navigational routines on Kenyir Lake is gathered from the local authorities to establish the number of vessels navigating during the daytime and night.

Second, direct observation is used to obtain the information the availability of AtoNs on the lake. The data is gathered by listing the type of AtoNs and merge with the official records from the local authority to obtain the number of the AtoNs available and to determine their characteristic and function. The AtoNs is further analyzed for their compliancy to the IALA buoyage system using comparison analysis.

Third, the IALA buoyage system act as the reference and the secondary data in innovating the new AtoNs for inland navigation. This is where all the rule and requirement are considered to achieve the new design of the inland navigation AtoNs.

4. Analysis and Findings

4.1. Navigation on Kenyir Lake
Since Kenyir Lake is a multi-purpose lake that is also a major tourist destination, it is essential to ensure navigational efficiency and user safety. Due to the major contribution towards the navigation is from the tourist, where all of them use the boat as their main transportation to move to the destinated areas.

4.2. The type and number of vessels used for navigation.
For this study, participatory observations include interaction with those on the vessels and joining their activities while non-participatory simply observes and record data i.e. number of vessel or available aids to navigation along the route.

| Date       | Activity                          | Area                                      |
|------------|-----------------------------------|-------------------------------------------|
| July 2019  | Participant observer and non-participant observer. | Pengkalan Gawi and surrounding area.     |
| August 2019| Non-Participant observer.          | Sungai Chomo and Pengkalan Gawi.         |

Table 1 shows the observation from two entry point of Kenyir Lake where most of the navigation is practiced. The type and number of vessel and the pattern is primarily based on these two areas due to it contributes to the major navigation practiced. There are two major types of vessels, houseboats and speedboats which used for navigation on Kenyir Lake. Based on frequency analysis, the highest value is speed boat at 56.30% and followed by the houseboat at 40.74%. This value shows the vessel traffic at Kenyir Lake. Based on a sampling of 135, it was established that 79% operate during the day only, while 21% operates both during the day and night hours. This is due to restriction from the local authorities and for the safety reasons. The helmsman is not allowed to navigate during the nighttime due to limitation of low Aids to Navigation to assist them for navigation.
4.3. The practices of navigation by the helmsman’s on Kenyir Lake.

### Table 2. Navigation practices.

| Element       | Current Navigation Practices                                                                 |
|---------------|-----------------------------------------------------------------------------------------------|
| Vessel movement | 1. By sight and hearing & 2. Depends on local knowledge;                                       |
| Infrastructure | 1. Signboards & 2. Buoys                                                                     |

The navigation practiced by the helmsman on the lakes depends on local knowledge and use sight and hearing only. Moreover, the infrastructure available at the lake only buoys and signboards. The buoy does not comply to current international and national standards which may lead to confusion, Table 2.

4.4. Establishing the type of AtoNs that are currently used on Kenyir Lake

To measure the effectiveness, primary observation is conducted to determine the types of the AtoNs that available on the Kenyir lake. Each type of AtoNs available on Kenyir Lake is recorded with respect to their characteristic and function, Table 3.

### Table 3. The type of AtoNs currently available at the Kenyir Lake.

| AtoNs | Type      | Numbers | Function                        | Colour      | Topmark | Shape |
|-------|-----------|---------|---------------------------------|-------------|---------|-------|
| 1     | Buoy (1)  | 12      | Mark danger                     | Yellow      | ‘X’ mark | Conical |
| 2     | Buoy (2)  | 118     | Mark popular route              | Red         | Square   | Conical |
| 3     | Buoy (3)  | 23      | Mark entrance or mid-point      | Blue        | Triangle | Conical |
| 4     | Warning Sign | 18     | To indicate danger area         | White       | N.A.     | Square |

| Total no. of AtoNs: 117 |

4.5. Compliancy of currently used AtoNs to IALA Standards.

Each of the AtoNs are analyzed for their characteristic and commonality with reference to IALA buoyage system. This is to determine whether each of the AtoNs complies with the IALA requirements.

### Table 4. Comparison of AtoNs currently used towards the IALA Buoyage System.

| Kenyir AtoNs | IALA AtoNs   | Criteria     | Colour | Shape | Light | Topmark |
|--------------|--------------|--------------|--------|-------|-------|---------|
| Buoy (1)     | Isolated Danger Mark | NO           | YES    | NO    | NO    | Use to mark danger |
| Buoy (2)     | Lateral Mark   | YES          | YES    | NO    | YES   | Preferred channel for the boat to pass by |
| Buoy (3)     | Safe Water Mark | NO           | NO     | NO    | NO    | Mark mid channel or the safe navigable channel |

Table 4 shows that the buoy established in Kenyir Lake does not comply to the guideline from the IALA Buoyage system. For instance, buoy (2) identified in the Table 3 is like the IALA lateral mark but is used to mark popular route in Kenyir Lake.

4.6. Proposal for innovative design of AtoNs for inland navigation.
The findings show that the buoyage system has different distinctive character to the IALA standards for the Lateral Mark, Safe Water Marks and Danger Mark. Therefore, this study proposed to innovate the buoyage system of a new design that is more practical, cost effective and most importantly suitable for use in inland waters.

Adaptable Design Method and Rapid Iterative Testing and Evaluation (RITE) which consist of several steps is used. Critically it is divided into 4 major process. 1) The AtoNs design blueprint; 2) Design adaptation; 3) Design modification; and 4) Verification.

4.6.1. Design Blueprint.

4.6.2. Design Adaptation.

This adaptation process required the AtoNs to be in-line with the requirement obtained through the IALA Guidelines and Recommendation. Lateral Mark, Safe Water Mark, and Isolated Danger Mark are the unstandardized buoy identified at Kenyir Lake. Therefore, in designing the buoy, the requirements are extracted as below, Table 5 and 6;

4.6.2.1 Lateral Mark

Table 5. Characteristic of Lateral Mark.

| Characteristics       | Port                          | Starboard                      |
|-----------------------|-------------------------------|-------------------------------|
| Colour                | Red                           | Green                         |
| Shape                 | Cylindrical, spar or pillar   | Conical, spar or pillar        |
| Top mark              | One red cylinder              | One green cone, pointing upwards |
| Colour of light       | Red                           | Green                         |
| Rhythm of light       | Light flashing with a group of (2 + 1) flashes is allocated exclusively to modified lateral marks indicating preferred channels |

4.6.2.2 Isolated Danger and Safe Water Mark
Table 6. Characteristic of Safe Water and Isolated Danger Mark.

| Characteristics       | Safe Water Mark                                              | Isolated Danger Mark                                      |
|-----------------------|--------------------------------------------------------------|-----------------------------------------------------------|
| Colour                | Red and white vertical stripes                               | Black with one or more broad red horizontal bands         |
| Shape                 | Spherical, or alternatively pillar or spar                    | Optional, pillar or spar preferred                        |
| Top mark              | One red spherical top-mark                                   | Two black spheres, one above the other                     |
| Light Colour          | White isophase, occulting, one long flash                     | White                                                     |
| Light Rhythm          | Morse “A” (●-) rhythms                                       | Group flashing (2)                                         |

4.6.3. Modified Design. The modification of AtoNs in Kenyir Lake is vital in ensuring the safety of navigation and to increases efficiency by standardizing the AtoNs to avoid confusion. The process in modification determined by the major factors are a) Operational Performance b) Lifecycle c) Material Type d) Standards Parts, Insert & Ballast e) Handling & Storage and f) Repair & Maintenance. The factors are respective to the IALA guidelines as established in the blueprint. This is to ensure they are more cost effective, resilience to whether, friendly user, economics, and functionality [14].

Figure 3. Types of Buoyage System as AtoNs at sea. Source (IALA,2018).

Figure 3 shows the standard type of Buoyage system. This research proposes to use conical shape buoys which are more practical and cost effective for use in inland navigation. Considerations for designing the buoys are as follows:

4.6.3.1 Operational Performance. This factor involves taking water, wind and current into account for their operational effectiveness. For instance, if the buoy is a light-built buoy, it will greatly be affected to the rolling and pitching which will reduce their operational efficiency as the aids for navigation [15]. For this purpose of the operational performance the hydrostatic design of a buoy is considered to produce the new design based upon IALA Guideline G1099 on Hydrostatic Buoy Design. The scope include buoyancy, stability, metacentric height, and the position of the buoy [26].

4.6.3.2 Life Cycle. The construction of the buoy as well as the material used are greatly contributes to their longevity and long lasting of their life cycle. Some of the example causing the disruption of their functionality such as the degradation of the materials and the fading of the
colour. There is vast type of material that can be used such as metal and plastic. Although, plastic buoy has been subjected for the lower making cost and maintenance cost, but the metal buoy is more resilience and have longer life cycle [14].

4.6.3.3 Material Type. The plastic buoy has been narrowed down the choices of the material for the buoy to be implemented for inland water. The different type of plastic has different properties which providing different performance characteristic. The strength of the material used must be in top consideration as the buoy is exposed to hot tropical climate of Kenyir Lake. The plastic buoy should be sufficiently strong to withstand the maintenance process such as clean up using water jet spraying without losing their colour properties. The plastic buoy options are polyethylene (PE); glass enhanced plastic (GRP); polyurethane / elastomer coated foam; or ionomer foam. For inland navigation on Kenyir Lake, the most suitable material has been identified is Polyethylene.

4.6.3.4 Standards, Parts, Inserts and Ballast. The careful design of the AtoNs must emphasize on the material use and the construction process. This is crucial step to achieve the desired buoy in line with the standards recommended by the IALA.

4.6.3.4.1 Standard parts - It is highly desirable to use common non-corrosive components, such as hot-dipped galvanized steel, marine aluminium, marine grade stainless steel or brass.

4.6.3.4.2 Inserts - Metallic inserts are used to add things like labels, daymarks, etc. to the buoy. In the manufacturing process care should be taken to ensure that threaded inserts are properly fixed and balanced inside the material.

4.6.3.4.3 Ballast - Ballast is used to bring stability to the buoy. The adjustable ballast weight system allows performance optimisation for a range of operating and environmental conditions.

4.6.3.5 Handling and Storage. Handling and Installation. The processing of a plastic buoy does not normally vary from the handling of steel buoys. A plastic boy's weight is usually less than steel people, which makes it easier to navigate. If plastic buoys are stored outdoors for long periods (e.g. on a buoy yard), they should be secured against UV to avoid premature aging and fading.

4.6.3.6 Repair and Maintenance. In accordance to manufacturer guidance, repair and maintenance procedures for synthetic buoys are illustrated in IALA Guideline G1077 on Maintenance of Aids to Navigation.

![Figure 4. Design of conical Safe Water Mark.](image.png)
Figure 4 shows the basic design for Isolated Danger Mark that is in line with the IALA Buoyage system. The modification of the buoy design is almost similar to other type of marks except for their characteristic as mentioned in Table 6. The general construction and materials of all the buoys for inland waters are similar, Table 7.

Table 7. General construction of buoy.

| Parameter                        | PE Buoy                        |
|----------------------------------|--------------------------------|
| Application area                 | Inland water - Kenyir lake     |
| Diameter (m)                     | 0.20 – 0.50                    |
| Height above water/ focal length (m) | 0.50 – 1.00                 |
| Height overall (m)               | 1.00 – 1.50                    |

4.6.4. Verification. The verification process involves independent checking on the design. This includes a) the compliance to international and local standards; b) the compliance of requirement and the technical specification of the product; and c) conformity with the approved design for the cost, function and characteristic. The execution of the verification process involves maritime expert and authority. For the maritime expert, such as COC holders and experienced navigators. Local authority for Kenyir Lake such as KETENGAH, Marine Police and the authority for the safety of navigation in Malaysia, the Marine Department. This is done by providing the overall design of the AtoNs and prototype testing result for review.

5. Conclusion
This paper proposes to innovative AtoNs for inland navigation that are in line with standards and requirements that are currently enforced by IMO, IALA and Malaysia. This new AtoNs will avoid confusion and enhances safety of inland navigation and could be adapted to other areas of inland waters where navigation is practiced. This study proposes lateral mark, safe water mark and isolated danger mark be adapted using the IALA design guidelines for use in inland navigation such as Kenyir Lake. Further study and refinement would be necessary to ensure that the AtoN s are practical, cost effective and standardized.

Acknowledgements
This paper benefited from the research that is supported by the Fundamental Research Grant Scheme (Vot 59528) FRGS/1/2018/TK08/UMT/01/1. The authors would also like to thank the Central Terengganu Development Authority, the Hulu Terengganu District Council, Universiti Malaysia Terengganu, the experts, local community, research assistants and all those who provided cooperation and assistance for this study.

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