# Enhanced Multi-Scale Malaysian Shipyard Mapping Using Artificial Intelligence-Driven Cartographic Optimization

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## Abstract

*Malaysia's rich maritime history and its well-established shipbuilding and ship repair (SBSR) industry have significantly contributed to national economic growth. The Association of Marine Industries of Malaysia (AMIM), the sole representative of SBSR and related marine industry players, recognises shortcomings in existing shipyard location maps. Current maps often lack key cartographic elements such as representative scales, scale bars, and effective legends, making it difficult to interpret spatial relationships and facility locations accurately. This study aims to develop an improved and more effective Malaysian shipyard location map by applying proper cartographic design principles, particularly focusing on appropriate scaling techniques. The objectives are threefold: to identify a suitable map scale, to design and produce a new shipyard facility map, and to evaluate the map's usability. Focusing on Peninsular Malaysia and the coastal regions of East Malaysia, the study employed GIS software for spatial data processing and vector drawing software for cartographic design. In addition, advanced AI algorithms were utilised to automate symbol placement, correct label ambiguities, generalise spatial features across multiple scales, and support real-time data integration, resulting in a map that is both visually clear and dynamically updatable. Two map prototypes, namely Map A and Map B, were produced at different scales and design layouts. A map usability test, distributed via an online platform, gathered feedback from both general users and AMIM representatives. Map B was chosen based on clarity, legibility, and overall usability. The results demonstrate that cartographic scan, thoughtful design and AI-driven optimisation can substantially improve spatial communication in marine infrastructure maps. Challenges, such as symbol overlap and limitations in base map customisation, were noted but addressed. This research successfully meets its objectives and offers practical recommendations, including the integration of real-time data updates, to enhance future map usability and support AMIM's operational and strategic planning needs.*

**Keywords:** Cartography, Geomatics, Geospatial, Geovisualization, Mapping

## 1. Introduction

Cartography is a nuanced blend of scientific rigour and artistic design, merging the principles of visual hierarchy, symbology, scale, and spatial cognition to transform geospatial data into effective communication tools [1][2][3] and [4]. Cartographic design is now essential in converting raw data into decision-support visuals for a variety of industries, such as urban planning, environmental management, and maritime infrastructure, as geographic information is increasingly housed in digital databases and interactive platforms [5][6] and [7]. By using strategies like multiscale zoom layers, symbol simplification, and dynamic information emphasis, modern cartographers must strike a balance between aesthetic quality and analytical clarity in order to create maps that are both aesthetically pleasing and intuitive to use [1][8][9] and [10]. Cartographic workflows have seen a radical change in recent years due to the incorporation of artificial intelligence (AI). Previously laborious and prone to human error, complex mapping tasks like spatial feature generalisation, symbol placement optimisation, and real-time data integration can now be automated by AI algorithms [11][12] and [13]. In high-density mapping environments, where conventional approaches frequently encounter problems with symbol overlap and clarity, these developments are especially important [14] and [15].

Cartographic practices have undergone a significant transformation due to the development of digital technologies. New techniques and abilities are needed to capture, analyse, and present geographic data using the dynamic methods brought about by computer-assisted mapping systems [5] and [9]. The most important of these are Geographic Information Systems (GIS), which offer a framework for handling geospatial data and creating precise, insightful maps. In general, a geographic information system (GIS) is a system that combines hardware, software, and data to record, organise, analyse, and present spatially referenced data [16] and [17]. GIS plays a key role in this study's location and mapping of shipyard facilities, data compilation, and production of lucid spatial outputs that aid in strategic decision-making. Malaysia has a deep maritime heritage, with the shipbuilding and ship repair (SBSR) sector playing a significant role in its economic development. While historically centred around ship construction, the focus has shifted towards repair, maintenance, and component manufacturing particularly in regions with strategic maritime access, such as the Malacca Strait, the South China Sea, and the eastern states of Sabah and Sarawak [18]. However, existing shipyard maps are often outdated and lacking in clarity, with limited scale representation, inadequate legends, and poor visual hierarchy, making them ineffective for practical use.

This work uses a multi-scale cartographic strategy to get around these problems. This method makes it possible to make maps with varied levels of detail, so they are clear at all levels, from national to regional to local. The incorporation of structured spatial information reduces the need for a lot of manual generalisation and makes the mapping process faster and more consistent. To make maps easier to read and less overwhelming at different scales, a variety of cartographic approaches are used, such as symbolisation, simplification, and selection [9][18][19][20], and [21]. Building on these established methods, this research uniquely leverages AI-driven tools to optimize map design and automate data integration. In particular, the use of AI-enabled image processing and machine learning models has substantially improved symbol clarity and spatial feature generalization [11][12] and [13]. This has resulted in a new generation of Malaysian shipyard maps that are not only visually clear and accurate but also dynamically adaptable to new data and evolving user needs.

European contributions to base map design have proven influential in developing scalable mapping strategies [9] and [21]. Multi-scale map generalisation remains a key challenge in cartographic visualisation. Effective generalisation requires systematic approaches such as simplification, typification, and symbol displacement, especially when managing dense feature distributions [18]. This is further supported by other scholars who demonstrated how urban building features must be represented differently across scales [19] and [20]. In the context of infrastructure mapping, the importance of spatial data hierarchy in preserving clarity without information loss has also been emphasised [21]. This study employed digital mapping tools for geographical data aggregation and base map creation, subsequently utilising advanced graphic editing software to enhance the visual presentation. The integration of AI technology and a thorough usability assessment enables the resultant maps to surpass prior constraints and provide effective solutions for AMIM's operational and strategic planning. Two prototypes of map design, referred to as Map A and Map B, were developed and assessed via a usability test with chosen respondents and industry stakeholders, including the Association of Marine Industries of Malaysia (AMIM). The assessment indicated a pronounced preference for Map B, which exhibited clearer symbology and a more efficient layout design.

This research aims to create a functional and useful map of Malaysian shipyard facilities and locations using advanced cartographic techniques. The goals are to enhance the visual and spatial precision of the current shipyard map, to determine a suitable multi-scale mapping approach, and to create and design a new map of shipyard facilities at several scales.

## 2. Methodology

The methodological approach is structured into four key phases: planning, data acquisition, preliminary study, and data analysis. Each phase contributes incrementally to the development of a functional, user-centred, and cartographically sound shipyard facility map for Malaysia. The research emphasises both spatial accuracy and visual clarity, integrating multi-scale cartographic design principles to improve the limitations observed in existing shipyard maps [1] and [9].

### *2.1 Planning Phase*

This phase required extensive planning, such as identifying cartographic flaws in existing Malaysian shipyard maps and selecting research areas around the shores of Peninsular Malaysia and East Malaysia (Sabah and Sarawak). The selection was influenced by established industrial clusters and maritime trading routes [17]. A mapping framework was developed that used multi-scale cartographic approaches to visualise a single dataset at several degrees of detail [9] and [18]. This technique sought to overcome the shortcomings of outdated maps, such as insufficient scales, poor legends, and inefficient symbolisation.

### *2.2 Data Acquisition*

Primary data were collected through direct engagement with industry stakeholders, including interviews and questionnaires with representatives from the Association of Marine Industries of Malaysia (AMIM). These data included facility types, infrastructure details (berths, slipways, docks, yard areas), capacity, and geographic coordinates. Secondary spatial data, such as coastlines,19 administrative boundaries, and hydrographic features, were sourced from open-access geographic dataset [15]. Coordinates for each shipyard were cross-referenced with online mapping services to ensure positional accuracy [16]. The primary and secondary data were reviewed for consistency, completeness, and compatibility with the spatial mapping environment.

### *2.3 Preliminary Study and the Cartographic Design*

Spatial data management was conducted within a GIS environment, where geographic coordinates were linked to descriptive attributes such as facility type, capacity, and functional role. This integration supported flexible visualisation and ensured that cartographic representations could be adapted across multiple map scales without compromising data integrity. Symbol design was informed by established cartographic theories, including colour use, visual hierarchy, and perceptual scaling, to communicate differences between shipyard categories and operational significance clearly [1][4] and [14].

Core cartographic visual variables size, shape, hue, value, texture, orientation, and transparency - were selectively applied to encode both qualitative and quantitative information [22]. Symbol size and colour value represented relative capacity, while shape and hue distinguished functional classes. Transparency and texture were applied in high-density areas to reduce visual congestion while maintaining contextual clarity. Gestalt principles such as proximity, similarity, and figure ground separation were used to improve spatial organisation, particularly in complex coastal environments [23]. Cartographic generalisation techniques, including feature selection, simplification, aggregation, and scale-dependent symbol adjustment, were applied to preserve legibility across zoom levels [9][19] and [21]. Density controls limited symbol saturation at smaller scales, ensuring that essential infrastructure remained readable [20].

Typography and labelling were treated as integral design components. Hierarchical text styling, controlled spacing, and strategic placement minimised ambiguity in clustered industrial zones [2]. Supporting elements such as legends and inset maps were arranged using principles of visual balance and contrast to complement the main thematic content [24]. Collectively, these techniques ensure that the maps support both overview interpretation and detailed operational analysis [25][26] and [27].

### *2.4 AI Technologies and Applications in Map Optimization*

Building upon these traditional techniques, this study integrated advanced artificial intelligence (AI) algorithms to further optimize map design and data management [11][12] and [13]. AI-driven image processing algorithms automatically detected and corrected symbol overlaps and label ambiguities, particularly in dense coastal regions such as Port Klang, Johor Bahru, and Labuan [6]. This automation reduced manual editing efforts and minimized cartographic errors, significantly improving visual clarity [11] and [21]. Furthermore, a machine learning-based multi-scale map generalization system was developed to support the creation of maps at different levels of detail. This system employed a classification model based on decision trees, trained on a repository of expert-generalized map features across various scales [28] [29] and [30].

The model predicted which features to simplify, omit, or highlight depending on the zoom level and feature density. For example, in high-density areas like Port Klang, the system prioritized maintaining detailed infrastructure representations at larger scales while aggregating minor features in smaller-scale views. This approach ensured that the map retained essential information without cluttering, effectively balancing visual clarity and spatial fidelity. The model achieved around 92% accuracy in reproducing expert generalizations across diverse geographic. Feedback from stakeholders and users collected during usability testing was used to inform iterative map refinements. These updates, guided by AI-driven analysis of the map's visual and functional performance, resulted in a final map that better met operational and organizational needs, with enhanced clarity and accuracy.

### *2.5 Map Production and Layout Design*

Using the processed data, two prototypes Map A and Map B were created with different visual styles. Cartographic elements such as scale bars, north arrows, legends, and inset maps were carefully designed to support multi-scale navigation [12] and [25].To address high-density regions, nine inset maps were embedded within the national layout, with scales ranging from approximately 1:70,000 to 1:1,000,000, ensuring clarity and legibility across regions [12] and [14].The final layout was designed at A0 size (841 × 1189 mm) to accommodate over 100 shipyard locations, detailed attribute labeling, and zoning distinctions, supporting both print and operational functions.

### *2.6 Usability Evaluation & Refinement*

A structured usability test was conducted, involving respondents with varying levels of map literacy. Feedback was collected via digital questionnaires and expert interviews. The feedback was systematically analyzed to identify key issues such as symbol confusion, label clarity, and layout effectiveness [6] and [12]. Based on these insights, targeted adjustments were made such as reclassifying symbol hierarchies, refining label placement, and improving legend clarity to develop the final, optimized map. This iterative process ensured that the cartographic products were closely aligned with user needs and operational requirements. Changes included adjusting symbol hierarchies, modifying map scales for different zoom levels, and revising legends and labels for improved interpretation. Ultimately, the aim of this phase was to optimize the map's usability through user-centred design adjustments, ensuring that the final cartographic product meets the specific operational, visual, and informational needs of AMIM and other maritime stakeholders.

## 3. Results and Discussion

This work generated an improved map of Malaysian shipbuilding facilities employing a multi-scale cartographic methodology to enhance spatial clarity, mitigate symbol overlap, and augment usability. The implementation of inset maps at various scales was a crucial design technique, especially for coastal areas with a large concentration of shipyards. Utilising conventional methods, AI-driven image processing algorithms were implemented to autonomously identify and rectify symbol overlaps and label ambiguities, particularly in densely populated industrial areas like Port Klang, Johor Bahru, and Labuan. This automation lowered manual editing labour and curtailed cartographic inaccuracies, yielding cleaner and more legible depictions of high-density regions.

Moreover, machine learning models enabled the dynamic generalisation of spatial features across various scales, ensuring that maps retained critical details at larger scales while simplifying intricate features for smaller scales, thus preserving visual hierarchy and spatial precision. Nine inset maps were meticulously integrated into the national pattern at diverse cartographic scales, spanning from approximately 1:70,000 to 1:1,000,000. Figure 1 displays the general layout concept of the multi-scaled map of Malaysian shipyard, accompanied by inset maps arranged within an A0 framework.

**Figure 1:** The general layout concept of the multi-scale shipyard map Malaysia

The final map product was designed at A0 size (841 × 1189 mm) to accommodate a comprehensive national view along with detailed regional insets without compromising clarity. The selection of A0 was intentional; it provides the necessary space to display over 100 shipyard locations, detailed attribute labelling, cartographic elements, and zoning distinctions at a legible scale. Smaller map formats such as A1 or A2 were found insufficient during testing, as they caused congestion of symbols and reduction of label readability, especially in areas with dense spatial data. The A0 layout ensured that scale bars, legends, and insets could be presented proportionally without visual clutter, supporting the map's dual function as both a print-ready visual product and a reference tool for operational decision-making.

The AI-enhanced processes contributed to the high quality and accuracy of the final map, supporting operational decision-making and strategic planning for Malaysia's maritime industry. The map showcases over 100 verified shipyard locations across Malaysia, strategically positioned along major maritime routes, navigable rivers, and coastal zones. The incorporation of AI techniques notably improved the map's readability and usability, especially in high-density zones, enabling more effective spatial communication and facilitating better resource management.

A total of nine inset maps were incorporated into the national layout to offer focused views of high-density areas, with cartographic scales ranging from approximately 1:70,000 to 1:1,000,000, depending on the spatial extent and feature concentration. These inset scales were chosen to balance between map readability, label clarity, and symbol separation, ensuring that each shipyard's location, name, and attribute data could be accurately depicted and interpreted. Essential map elements such as titles, legends, north arrows, graticules (longitude and latitude), map projection metadata, and standardised scale bars were carefully implemented to ensure technical completeness and cartographic professionalism.

Two distinct cartographic designs were developed for usability evaluation: Map A and Map B. As shown in Figure 2, Map A featured zonal differentiation using solid background fills, while point symbols across all regions shared the same visual style. In contrast, Map B (Figure 3) implemented a more integrated zonal colour scheme extending to labels, borders, and inset frames providing a clearer visual link between geographic zones and their corresponding inset maps. This approach was grounded in cartographic principles of visual hierarchy and colour association, aimed at improving map interpretation and user orientation.

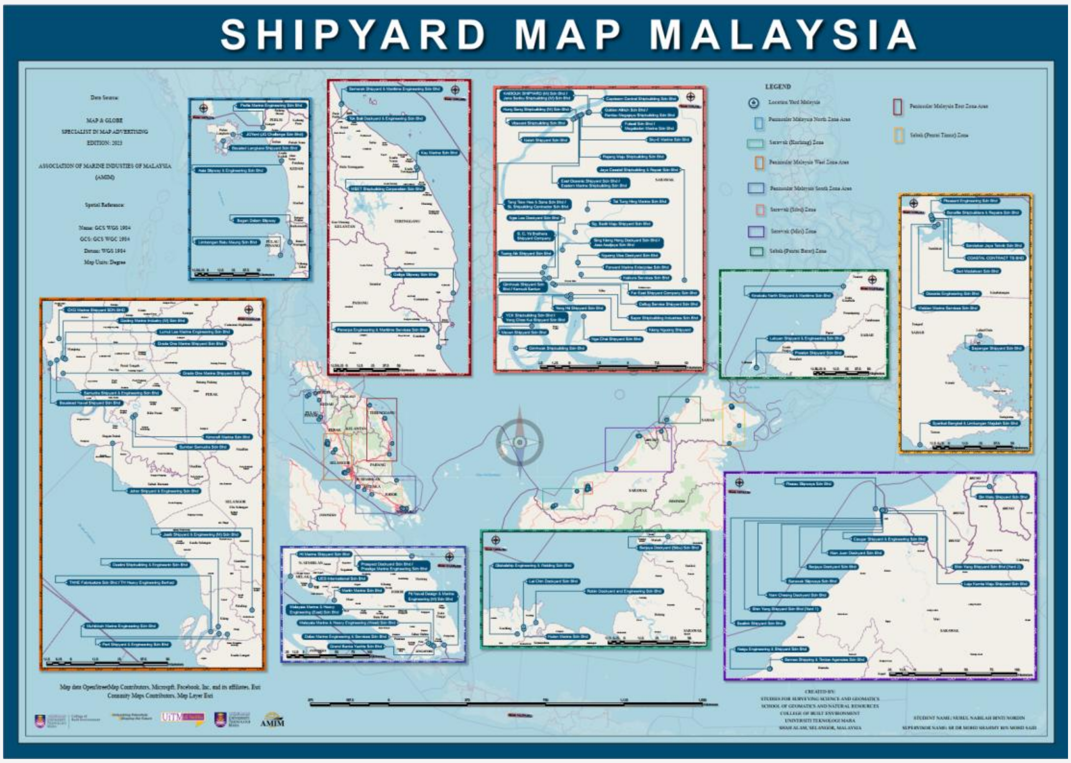

**Figure 2:** The design for prototype map: A (left) and the design for prototype map and B (right)

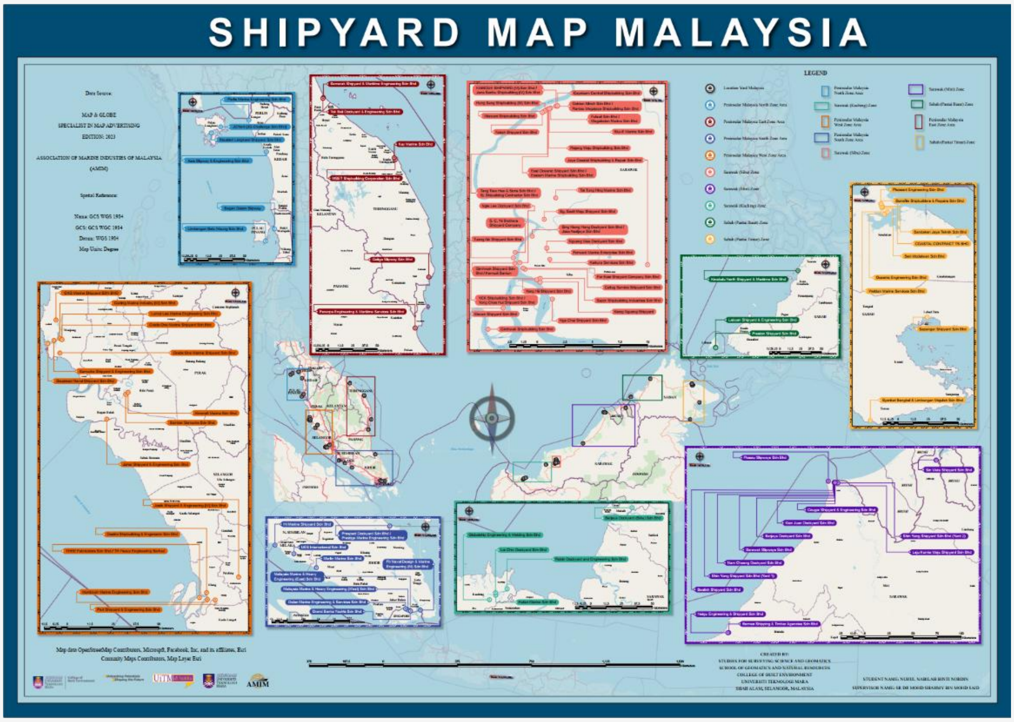

**Figure 3**: The design for prototype map B

To evaluate the effectiveness of these maps, a usability test was conducted using digital questionnaires. In the Map A test, participants were asked to count the number of inset maps displayed. 88% (37 of 42 respondents) correctly identified all 9 inset maps. However, 4% of responses indicated only 0 or 3 insets, suggesting occasional confusion likely due to insufficient separation or inconsistent labelling in the inset layout. The Map B reflects responses to a spatial navigation task, asking which shipyard was nearest to Bagan Datuk. An overwhelming 93% correctly selected Johor Shipyard & Engineering Sdn Bhd, validating the positional accuracy and clarity of the base map. Some respondents, however, misidentified nearby yards such as Sapangar Shipyard or CKG Marine, suggesting possible perceptual issues in symbol placement or inset linkage.

Subsequently, Map B underwent a similar map usability test. Respondents were asked to identify the number of shipyards in the Southern Zone. Seventy-eight percent (33 out of 42) accurately identified 9 shipyards. Slight deviations (e.g., responses of 8 or 7) likely resulted from the spatial clustering of symbols, which can hinder individual symbol distinction at certain scales. When asked about the district location of Neigu Engineering and Shipyard, 92.9% correctly selected Bintulu, reinforcing the effectiveness of administrative boundary labelling in Map B. Minimal inaccuracies, such as referencing “Sarawak” without district-level detail, indicated areas for improvement in label specificity and zone demarcation. Respondents were then asked to select the nearest shipyard to Pulau Timbun Mata, Sabah. A total of 88.1% correctly identified Sapagar Shipyard Sdn Bhd, suggesting strong user understanding of spatial proximity. The small number of deviations such as selecting Lahad Datu or even a shipyard outside Sabah implied either a misreading of the map or a misunderstanding of regional zoning.

In the final section of the usability test, respondents were asked to select the map design they found most effective. The usability test shows that Map B was preferred by 57.1% (24 respondents), while Map A was chosen by 35.7% (15 respondents). A small portion (2.4%) selected both designs, and 4.8% provided qualitative responses appreciating different elements from each design. This feedback validates the superiority of Map B's zone-colour integration and cartographic coherence. The initial map design (Figure 4) exhibited several cartographic shortcomings that undermined its communicative effectiveness. It lacked adherence to fundamental cartographic principles such as visual hierarchy, symbol clarity, and appropriate label placement. Symbols were densely clustered, leading to overlaps that reduced legibility, while zone boundaries were inconsistently represented, causing confusion in spatial interpretation. The legend was overly complex, with redundant or poorly categorised elements, and labels lacked anchoring or contrast, further diminishing map readability. After getting feedback from stakeholders, especially helpful feedback from AMIM representatives, a final design iteration was done to fix these problems. The new version (Figure 5) includes specific improvements that follow the ideas of visual hierarchy and symbol generalisation put forth by [10]. These authors say that visual clarity gets better when cartographic elements are arranged according to scale and design logic.

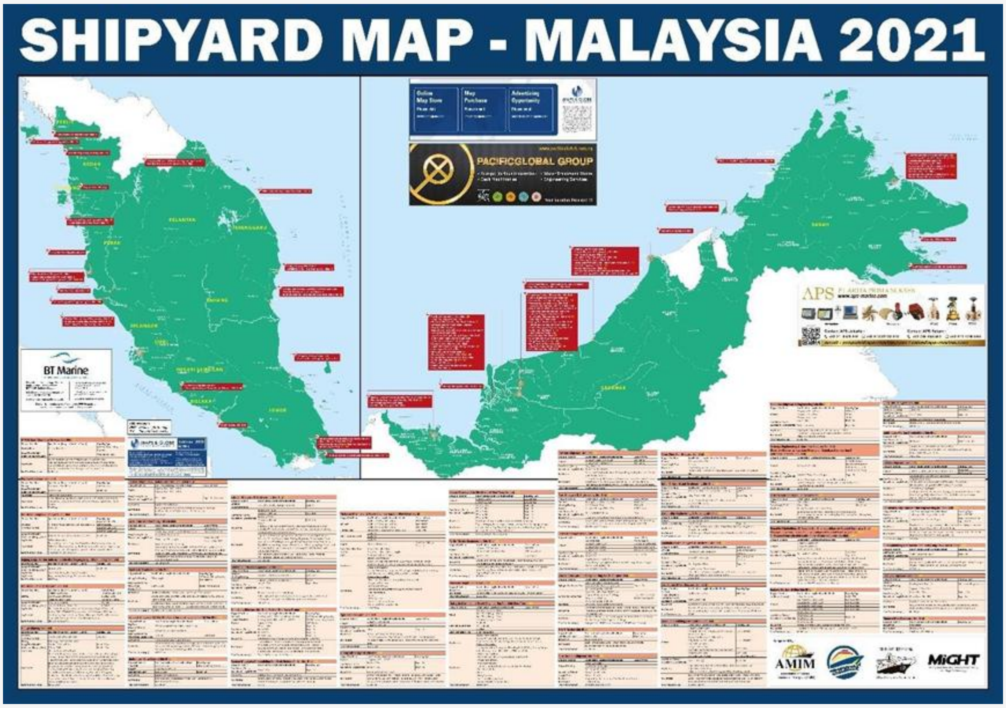

**Figure 4:** Multi-Scale layout with A0 final composition (Current Version)

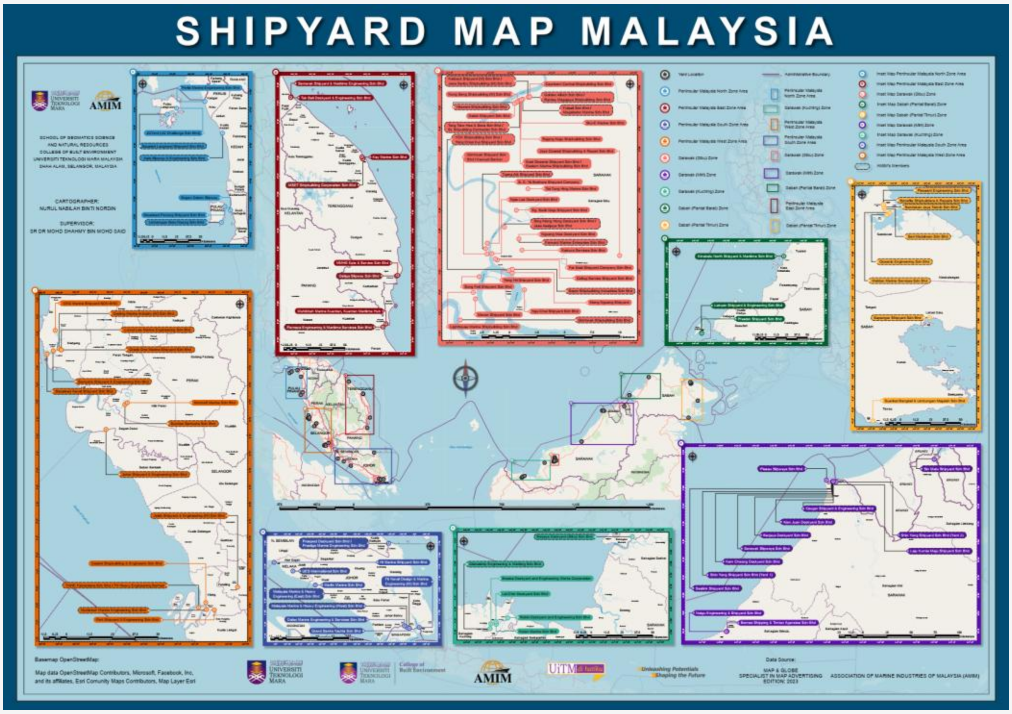

**Figure 5:** Multi-scale layout with final A0-size cartographic composition (revised version)

**Table 1:** Cartographic comparison of Old vs. New Malaysian shipyard maps

| The Old Shipyard Map of Malaysia | The New Shipyard Map of Malaysia |
|---|---|
| a) Absence of representative fraction (RF) and scale bars | a) Accurate integration of spatial references including longitude, latitude, and scaled shipyard layouts |
| b) Oversimplified dot symbols used to represent shipyard locations | b) Multi-scale design with 9 inset maps to reduce symbol overlap and enhance detail |
| c) Incomplete or ineffective legend elements | c) Expanded and clearly structured legend for all cartographic symbols and zones |
| d) Limited and inconsistent color scheme | d) Color-coded zoning with consistent color matching across base map and inset frames |
| e) Poor typographic hierarchy and inconsistent label placement | e) Improved typography with adjusted font size, placement, and labeling frame for clarity and hierarchy |
| f) Omission of standard orientation tools such as the north arrow | f) Inclusion of essential cartographic elements including north arrow, graticules, and title blocks |
| | g) Unique alphanumeric codes assigned to each shipyard, referenced across base and inset maps |
| | h) Enlargement of inset map frames to allow greater spatial focus on high-density locations |
| | i) Visual emphasis on AMIM member yards to support organizational awareness and management |
| | j) Added labels for identifying nearest shipyards by zone or administrative area for improved navigational context |

Figure 5 is reproduced at a reduced scale for journal publication. Improvements include clearer labels thanks to better font choice and placement, aligning zone boundaries for better spatial coherence, consistent and intuitive symbol use, and a simpler legend that makes it easier to read the map quickly. These changes to the map's cartography have made it much easier to use and understand, and they have effectively addressed earlier complaints about too many symbols, unclear zoning, and poorly organised label anchoring.

Through the analysis of both user testing and expert commentary, this study demonstrates that careful application of cartographic principles such as symbol differentiation, graticule integration, and multi-scale representation can significantly improve the usability of spatial data products. Table 1 presents a side-by-side comparison between the outdated shipyard map and the newly developed map, detailing improvements in scale adaptability, visual design, and user functionality. The enhanced cartographic product not only increases map usability for end-users but also strengthens AMIM’s capacity to manage and communicate shipyard infrastructure data effectively.

## 4. Conclusion

This research has successfully met its objectives by addressing the deficiencies in existing Malaysian shipyard maps, particularly those used by the Association of Marine Industries of Malaysia (AMIM), through the application of improved cartographic techniques. The identification of suitable map scales was achieved by creating nine inset maps to represent high-density coastal areas, thereby overcoming symbol congestion and enhancing spatial clarity. The development of two cartographic prototypes, namely Map A and Map B, fulfilled the second objective, with Map B emerging as the preferred design due to its zonal colour integration, clearer labelling, and overall visual coherence.

While limitations in customizing the base map and managing overlapping symbols especially in the Sibu and Miri zones posed challenges, the maps were successfully enhanced using standardised cartographic elements such as scale bars, legends, graticules, and north arrows as well as the deployment of AI-powered automation for symbol placement and map updates. The third goal was to do a usability test, which gave important feedback from users that helped improve the final map design. These insights, especially from AMIM representatives, showed that the new map is much easier to use and clearer than the old one. This study has produced an efficient, multi-scale, and user-centric shipyard map that enhances spatial communication and bolsters AMIM's ability to manage and disseminate marine infrastructure data.

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