

## Research Article

## Integration of ARPA with Bridge Resource Management (BRM) to Enhance the Effectiveness of Collision Prevention in Merchant Vessels

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### Abstract

Collision accidents at sea remain a serious threat to commercial shipping, particularly in high-traffic waters. Although navigation technologies such as ARPA (Automatic Radar Plotting Aid) can provide predictions on vessel positions, speed, and safe distances between ships, human error, miscommunication, and suboptimal use of the system still frequently occur in practice. This article examines the integration of ARPA with Bridge Resource Management (BRM) in the context of merchant vessels, as a strategy to strengthen collision prevention. The method employed is a comprehensive literature review, case study analysis, and the proposal of an integrative model. The findings indicate that the ARPA-BRM integration enhances situational awareness, bridge team coordination, collective decision-making, and proactive risk mitigation capabilities. It is recommended that vessel training (including ARPA & BRM simulators) and operational policies strengthen this synergy to ensure safer navigation.

**Keywords:** ARPA, BRM, maritime collisions, navigation safety, merchant vessels, situational awareness

## INTRODUCTION

Maritime transportation is a key pillar in the global trade system, transporting more than 80% of the world's goods (Sirimanne et al., 2020). Given its significant role in the global economy, the safety of vessel navigation becomes a crucial aspect to address. However, despite rapid advancements in navigation technology, collisions between ships remain one of the most detrimental accidents in the maritime world. The consequences are not only material, such as damage to vessels and cargo, but can also result in serious environmental harm and loss of life (Sari et al., 2024). In this context, human factors often serve as the primary trigger for these accidents, especially due to a lack of coordination between bridge teams, excessive workload, and misinterpretation of data provided by radar systems, such as ARPA (Automatic Radar Plotting Aid) (Hickethier & Yang, 2023). Human factors pose a significant challenge in vessel operations, as, despite technological advancements, human negligence cannot be disregarded.

ARPA itself is a tool designed to assist in vessel traffic control by detecting the paths of other vessels and providing early warnings in the event of potential collisions, measured by parameters such as CPA (Closest Point of Approach) and TCPA (Time to Closest Point of Approach) (Karizi & Lontaki, 2018). ARPA can automatically calculate and display the detected vessel's trajectory, raise alarms for potential collision warnings, and facilitate faster decision-making by the bridge team. However, although ARPA offers ease in detection and warning, its effectiveness heavily depends on the implementation of effective Bridge Resource Management (BRM). Without proper BRM, the potential of technologies like ARPA can be underutilized and, in some cases, could even increase the risk of human error (Lista, 2023). BRM focuses on team collaboration, clear communication, task delegation, and well-coordinated decision-making in critical situations. Without proper BRM implementation, a bridge team may not be able to maximize ARPA's capabilities, which could, in turn, lower overall navigation safety.

Given this, it is essential to explore how the integration of ARPA technology and BRM principles can enhance the effectiveness of collision prevention in merchant vessels. By combining advanced technologies such as ARPA with sound managerial skills and practices in bridge team management, it is expected that a more effective maritime safety system can be created. This research aims to propose an integrative ARPA and BRM model that can be used to improve the operation of merchant vessels, as well as contribute to global maritime safety.

## LITERATURE REVIEW

### ARPA Technology and Its Functionality

ARPA (Automatic Radar Plotting Aid) is a radar system with the ability to automatically track and analyze the position and speed of a target vessel, as well as predict the potential closest point of approach (CPA) or time to the closest point of approach (TCPA). The main functions of ARPA include identifying potential hazards from other vessels, providing early warnings about potential collisions, recommending maneuvers when necessary, and supporting quick and accurate decision-making in critical situations (Hayrulnizam et al., n.d.). Despite its advanced

technology, ARPA has some limitations. Measurement errors due to radar interference or noise, data misinterpretation by operators, and target overload in congested waters are issues that can reduce its accuracy and effectiveness (Zohuri, 2020). Additionally, adverse weather conditions or radar clutter may hinder ARPA's functionality, limiting its ability to provide clear information. Some studies have shown that despite ARPA offering advanced technical solutions, human error, such as incorrect decision-making or data interpretation, remains a major factor in maritime accident incidents (Dominguez-Péry et al., 2021).

### **Bridge Resource Management (BRM)**

BRM (Bridge Resource Management) is an adaptation of the Crew Resource Management (CRM) concept from aviation into the operational context of ship bridge operations. BRM emphasizes the importance of effective team collaboration, clear communication, appropriate task delegation, and collective decision-making in maintaining vessel navigation safety (M. E. Gommosani, 2021). The main goal of BRM is to ensure that all resources, including human, technological, and informational, are used optimally to support the safety of the vessel. The basic principles of BRM include explicit communication and clear feedback (closed-loop communication), shared situational awareness, efficient workload management and task delegation, and team decision-making based on collaboration (Alshehri et al., 2024). Previous research indicates that BRM, which strengthens non-technical skills (NTS) such as communication and leadership, can reduce human errors that are often the cause of accidents in both military and civilian contexts (Cavaleiro et al., 2020). One of the key performance indicators in BRM is situational awareness (SA), which has been shown to have a significant impact on preventing accidents in the maritime world (M. Gommosani et al., 2021). Research on BRM training also shows that visual measurements using technologies such as eye-tracking can be used to evaluate the level of situational awareness in training participants, which, in turn, can enhance the effectiveness of BRM training (Atik, 2020).

### **The Relationship Between ARPA and BRM**

On the ship's bridge, technologies such as ARPA function as support tools for navigation safety. However, the effectiveness of this technology largely depends on how it is integrated into the workflow of the bridge team. In the context of BRM, the bridge team is encouraged to exchange information and cross-check among team members, such as between the Officer of the Watch (OOW), the radar/ARPA officer, and the navigation officer, to ensure that the data provided by ARPA is correctly interpreted and placed within the broader context of navigation, including charts, AIS data, and visibility (Aldén, 2020). Effective communication between the ARPA operator and other team members, such as the captain and bridge officers, is crucial to reduce the risk of misinterpretation and avoid impulsive reactions that could lead to unsafe maneuvers. In this regard, BRM provides a framework for more coordinated decision-making when handling corrective maneuvers, such as course or speed changes, based on the data generated by ARPA. In this way, BRM plays a crucial role

in reducing speculative or unilateral actions that could enhance vessel safety and reduce the potential for collisions (M. E. Gommosani, 2021).

## METHODS

This study employs a combined qualitative approach, integrating a literature review, analysis of ship standard operating procedure (SOP) documents, and case studies of maritime accidents caused by a lack of bridge team coordination or failure to utilize ARPA technology effectively. A qualitative approach was chosen because the focus of this research is to understand the phenomenon and analyze the relationship between various technical and human elements in the context of vessel navigation safety. The study also involves an analysis of international standard documents related to ship navigation systems, as well as case studies to gain a deeper understanding of the application of BRM and ARPA in real-world situations (da Conceicao, 2018).

The data sources used in this research include primary literature, consisting of scientific journals related to ARPA technology, BRM, and navigation safety, as well as official documents from international maritime organizations such as the IMO (International Maritime Organization). STCW (Standards of Training, Certification, and Watchkeeping) training documents related to the BRM and radar/ARPA units were also used as references to understand relevant training guidelines (Tagouzi, 2024). Additionally, operational documents and ship SOPs, particularly those from shipping companies granting access, were analyzed to evaluate the implementation of BRM and ARPA in the operational context of vessels. These documents were anonymized as necessary to maintain confidentiality. Furthermore, the research uses case studies from accident investigation reports, such as the Ever Forward vessel incident, which highlighted that failures in situational awareness and BRM implementation were major contributing factors to collision or grounding incidents (M. Gommosani et al., 2021).

For data analysis, a thematic analysis approach was used to identify key themes in the literature and documents related to communication, task delegation, ARPA data interpretation, and the importance of cross-checking among team members. A comparative analysis was also conducted between the expected SOPs and actual practices implemented on board vessels to examine the gaps between theory and practice in the implementation of BRM and ARPA (Bago & Rcrim, n.d.). Additionally, this study designed an integrative ARPA-BRM model based on existing theories, best practices in the shipping industry, and findings from the case studies reviewed. This model aims to illustrate the bridge team workflow that integrates the use of ARPA within the BRM framework to enhance navigation safety. Validation of the resulting model will be conducted through an expert review involving maritime practitioners, ship instructors, or officers of the watch (OOW) to ensure the accuracy and feasibility of the proposed model (Cavaleiro et al., 2020).

## RESULT AND DISSCUSSION

### Findings from Literature and Case Studies

Based on the literature review and case studies, many navigation accidents are caused by a "chain of small errors" that begin with miscommunication, workload overload, or unilateral decision-making by individuals without adequate coordination with the team. These small errors often develop into major incidents, increasing the risk of maritime accidents (Puisa et al., 2018). For example, in the case of the Ever Forward vessel accident, investigations identified that failure to maintain situational awareness and poor BRM implementation were the key factors contributing to the accident (M. Gommosani et al., 2021). Other research shows that effective BRM practices, including open communication, cross-checking, bridge briefings, and debriefings, have been shown to improve team performance in both simulations and real operations (Cavaleiro et al., 2020; Röttger & Krey, 2019). BRM evaluation through technologies such as eye-tracking also provides additional insights into how participants focus attention and compare the effectiveness of their situational awareness with more experienced participants (Jiang et al., 2021).

### Integrative ARPA + BRM Model

Based on the findings above, this study proposes an integrative model between ARPA and BRM that can be applied to bridge teams. This model combines various functions of ARPA with the roles of BRM within the team's workflow to enhance vessel navigation safety. Below is the proposed integrative model:

**Table 1.** Integrative ARPA and BRM Model for Bridge Teams

| Stage/Element         | ARPA Function                                    | BRM/Bridge Team Role                                                             | Integration Notes                                                             |
|-----------------------|--------------------------------------------------|----------------------------------------------------------------------------------|-------------------------------------------------------------------------------|
| Bridge Briefing       | Input target priority parameters, traffic routes | Team discusses potential risks, task assignments                                 | Pre-sailing ARPA data reviewed together                                       |
| Monitoring & Tracking | Radar/ARPA monitors target, calculates CPA/TCPA  | Duty officer cross-checks data, gives verbal alerts                              | ARPA alarms and interpretations communicated to team                          |
| Conflict Detection    | Displays potential collision alarm               | ARPA operator gives recommendations and informs OOW/captain                      | Quick discussion among members (e.g., "target X CPA in 5 min, can maneuver?") |
| Decision-Making       | Presents maneuver options (heading, speed)       | Bridge team evaluates options based on context (weather, current, other vessels) | Collective decision reduces unilateral actions                                |
| Maneuver Execution    | ARPA continues to monitor the target             | Duty officer synchronizes maneuver, cross-                                       | Ensure close communication during maneuver                                    |

|                       |                     |      |                                                                  |                             |         |  |
|-----------------------|---------------------|------|------------------------------------------------------------------|-----------------------------|---------|--|
|                       |                     |      | checks with team members                                         |                             |         |  |
| Debriefing/Evaluation | ARPA recorded (log) | data | Bridge team reviews decisions, misinterpretations, communication | Learning for the next shift | for the |  |

Some key principles in this integration include:

1. Closed Loop Communication: Every ARPA command or interpretation is confirmed back (read-back) by the receiver to avoid miscommunication.
2. Cross-checking and Redundancy: At least two officers (OOW and radar/ARPA officer) verify ARPA data and compare it with other data (AIS, charts, visual observation).
3. Task Delegation and Focused Workload: Clear task division (monitoring ARPA, visual lookout, communication) to avoid overloading one person.
4. Shared Mental Model: The bridge team should have a common understanding of the situation, priorities, and potential maneuvers.
5. Integrative Simulation Training: Simulation sessions combining ARPA and BRM tasks to train real-world team coordination.

**Learning from Mistakes:** After shifts or voyages, the bridge team conducts debriefings regarding difficult decisions or maneuvers, matching ARPA data with team decisions for future learning.

### Practical Implications Discussion

The practical implications of this integrative model include several recommendations that can be applied by the shipping industry and maritime educational institutions. First, training for crew members or maritime educational institutions should align ARPA modules with BRM, where the use of ARPA should be an integral part of the BRM procedures involving the entire bridge team (Cavaleiro et al., 2020). Second, ship bridge SOPs need to emphasize the importance of clear communication procedures, including who reports what, when to call for backup, and when decisions should be made by the team, particularly in situations involving ARPA data (Badokhon, 2018). Shipping companies should also foster a safety culture that ensures every bridge team member feels secure in voicing opinions and is proactive in identifying abnormal situations that require immediate attention (Ghonaim, 2020).

Additionally, shipping companies can conduct routine audits to assess the performance quality of bridge teams, such as through combined ARPA and BRM simulations, and evaluate the non-technical skills of team members, which are a key indicator of maritime safety (Kalaitzi, 2019). Tighter regulations from maritime authorities or flag states can also be an important step to ensure that certain vessels, particularly large ones, implement the integrative ARPA-BRM SOP, accompanied by joint training for the entire bridge crew (Karvouni & Sigeri, 2025).

## CONCLUSION

This study highlights the importance of ARPA (Automatic Radar Plotting Aid) as a navigation technology in detecting potential collisions between vessels. However, the reliability of ARPA heavily depends on how the bridge team interprets and responds to the data provided by the system. Without effective collaboration among bridge team members, the functionality of ARPA can be hindered, which may lead to risky decision-making errors (Mulligan, 2020). In this context, BRM (Bridge Resource Management) plays a crucial role by providing a collaborative framework that involves clear communication, data cross-checking, and collective decision-making in critical situations. The implementation of BRM can enhance the effectiveness of ARPA usage, reduce human error, and improve team situational awareness (Geldbach & Seemann, 2020).

The integrative ARPA-BRM model outlined in this article demonstrates that both elements can complement each other and function effectively if applied in a structured and communicative manner within the bridge team's workflow. By integrating ARPA into a collaborative BRM framework, human errors can be minimized, shared situational awareness can be enhanced, and maneuver decisions can be made more safely and consistently, ultimately improving vessel navigation safety.

## Recommendations

Based on the findings and the proposed model, several recommendations can be made to enhance maritime safety and improve the effectiveness of ARPA and BRM implementation. Maritime educational institutions should consider designing simulation curricula that integrate ARPA usage scenarios with bridge resource management (BRM) working conditions. This approach will ensure that students and prospective seafarers become familiar with the combination of these two elements in real-world situations. Additionally, shipping companies are encouraged to revise their bridge Standard Operating Procedures (SOPs) and policies to clearly define coordinative roles, communication protocols, and ARPA response procedures within the bridge team context. This will help foster a more effective and safer working environment. It is also recommended that BRM training programs explicitly incorporate ARPA practices, utilizing realistic simulators or full mission bridges to provide hands-on training in complex scenarios, thus reinforcing BRM principles. Furthermore, bridge team performance should be periodically evaluated, addressing both technical aspects like ARPA operation and non-technical aspects such as communication and decision-making. This can be achieved through debriefing sessions, test scenarios, and the analysis of ARPA data or maneuver recordings during voyages. Finally, future research should focus on empirical trials, such as simulation experiments that compare the effectiveness of ARPA with and without BRM integration, measuring outcomes like error rates, maneuver reaction times, and situational awareness scores. By implementing these recommendations, maritime safety is expected to improve, and the utilization of both technology and human resources in vessel operations can be optimized.

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