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Analyzing Domestic Ferry Navigation Accidents in Mombasa Channel Using AcciMap

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Abstract *: The AcciMap technique has been a fundamental tool for examining accidents and their causal factors across complex socio-technical systems. This study utilized the AcciMap framework to evaluate ferry navigation accidents in the Mombasa Channel from 2011 to 2020. It categorized the identified causal factors into four primary levels of AcciMap: government, regulatory bodies, ferry operating companies, and ferry operators, including environmental and equipment conditions. The aim is to assess these factors to address systemic deficiencies in ferry operations within the channel. The findings highlight significant gaps in the ferry operation system by using a cause-and-effect analysis. Based on this assessment, the paper offers recommendations to rectify these deficiencies and improve safety in ferry operations. This research underscores the utility of system theory-based tools in uncovering complex, multifaceted causes of ferry accidents and providing a robust framework for enhancing maritime transportation safety.*

Key words *: ferry, mombasa channel, acciMap, systems-theory, marine accident*

1. Introduction

Mombasa Channel is a strategic coastal waterway located in Mombasa County in the Republic of Kenya(Ogara et al., 2023) and is the key link to the Port of Mombasa-the busiest maritime hub in Kenya(Ngangaji, 2019). Given its unique geographical layout, ferry services are an integral part of the county's transport network, with the Mombasa channel serving as the ferry waterway at Likoni and Mtongwe crossings. The Kenya Ports Authority(National Council for Law Reporting, 2022b), operates the Ferry Operation department and is tasked with transporting motorists, passengers, and cargo across Likoni and Mtongwe ferry channels through its fleet of seven ferries namely MV Kwale, MV Nyayo, MV Harambee, MV Jambo, MV Kilindini, and MV Safari(Kenya Ports Authority, 2024a). A daily average of 150,000 pedestrians and 5800 vehicles access the Likoni crossing ferries whereas one ferry operates in the Mtongwe channel from Monday to Saturday.

The defunct Kenya Ferry Services Limited(KFSL) was a state corporation that was founded in November 1989 when the Government of Kenya took administration of the ferry operations from Kenya Bus Services Limited. In 1998, the government, through the National Assembly Sessional Paper No.3, formalized the ownership of the company(Ministry for Transport and Communications, 1998). On 16th June 2021, an executive vesting order(National Council for Law Reporting, 2023b) was issued to transfer the functions and rights of the KFSL to the Kenya Ports Authority(KPA), a State Corporation established through an Act of Parliament in January 1978(Kenya Ports Authority, 2024b) that is responsible for managing and operating all designated seaports along Kenya's coast and inland waterways. The Kenya Maritime Authority(National Council for Law Reporting, 2022a) is tasked with enforcing safety standards for Kenyan ferries, as outlined in the Merchant Shipping (Training and Certification; Survey and Certification) Regulations, 2016(National Council for Law Reporting, 2023a). This includes regular inspections of the ferries, ferry crew training and certification, and maintenance of safety standards onboard the ferries.

Over the years, various ferry navigation accidents have occurred in Mombasa Channel prompting concerns over the safety and efficiency of ferry operations. These incidents have highlighted the complex interactions of contributory factors encompassing governmental, regulatory, managerial, and operational aspects of ferry procedures in the Mombasa channel. Traditional accident investigation methodologies such as sequential and epidemiological accident models often focus on the immediate causes of accidents neglecting the broader systemic issues that affect the decision-making processes contributing to these events(Lehto and Salvendy,

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1991; Katsakiori et al, 2009; Wienen et al, 2017).

To bridge this gap, this paper utilized the AcciMap analysis framework, a systems-thinking technique that projects the multiple layers of causality involved in accidents(Delikhoon et al, 2022; Ahmadi Rad et al, 2023; Underwood and Waterson, 2014). AcciMap offers a comprehensive profile for interpreting how failures at various levels of ferry operation led to accidents. By adopting this analysis tool for ferry navigation accidents in the channel, this research aims to uncover the deeper, systemic issues that influenced the decision-making processes that resulted in these incidents. Finally, the paper provides actionable recommendations to enhance ferry operations in the channel.

2. Methodology

The AcciMap technique was created by Rasmussen in 1997 as a complementary procedure for proactive risk management for complex sociotechnical systems (Rasmussen, 1997). According to AcciMap analysis theory, a graphical map is employed to determine systematic failures at multiple levels within a socio-technical system and reveal the potential root causes and their interdependencies both within and across these hierarchical layers(Diaz De Oleo et al, 2022). The AcciMap technique has found its niche in accident analysis in various transportation domains such as the aviation industry(Debrincat et al, 2013; Tabibzadeh et al, 2019), the maritime industry(Lee et al, 2017; Kee et al, 2017; Akyuz, 2015), and the road and railway industry(Salmon et al, 2013; Stanton et al, 2019).

Conducting the AcciMap analysis involved four steps as outlined by the following steps as demonstrated by Branford(2011):

I. Identification of the controllers: key components whose decisions could have led to the negative outcomes.

II. Identification of the negative outcomes: ship navigation accidents in the Mombasa channel from accident data.

III. Identification of the causal factors and coding them into their appropriate AcciMap levels then inserting the links showing the interrelationships between these factors.

IV. Formulation of safety recommendations.

2.1 Identification of Controllers

This first step involved identifying and outlining all the key controllers involved in the propagation of the ferry accidents. These controllers included individuals, institutions, and regulatory bodies mandated to monitor, operate, and make crucial decisions that affected the safety and efficiency of the ferries in the Mombasa Channel as illustrated in Fig. 1. Comprehending their roles and responsibilities was important in evaluating how their actions and decisions led to the accidents occurring.

At the Government Policy and Budgeting Level, the controller was the Government of Kenya, which was responsible for financial support for ferry maintenance. This support influenced the operational capabilities of the ferries. At the Regulatory Bodies and Associations level, the component was the Kenya Maritime Authority tasked with enforcing safety regulations from the local Merchant Shipping Act(National Council for Law Reporting, 2023a), and international regulations from the International Maritime Organization(2024) to ensure domestic ferry safety. At the organizational level, the defunct KFSL was the controller mandated for managing and operating the ferries. KFSL's duties comprised proper maintenance of the ferries, ferry crew recruitment, and ensuring the operational availability of the ships. The company's management procedures, decisions concerning ferry maintenance, training and recruitment of ferry operators, other technical and operational processes, and adherence to safety protocols played a direct role in ferry operations and safety. The Physical/ Actor events, processes, and conditions level were represented by controllers such as the ferry operators' and engineers' actions and decisions, the environmental conditions in the Mombasa channel, and the conditions of the equipment and machinery. The Outcome Level comprised the culmination of the above levels and the interactions of the factors, and this determined the result which was ferry navigation accidents in the channel.

2.2 Identification of the Negative Outcomes from Accident Data

This section provides a synopsis of ferry accidents officially recorded in the Channel between the years 2011 and 2020 as illustrated in Fig. 2 and Fig. 3.

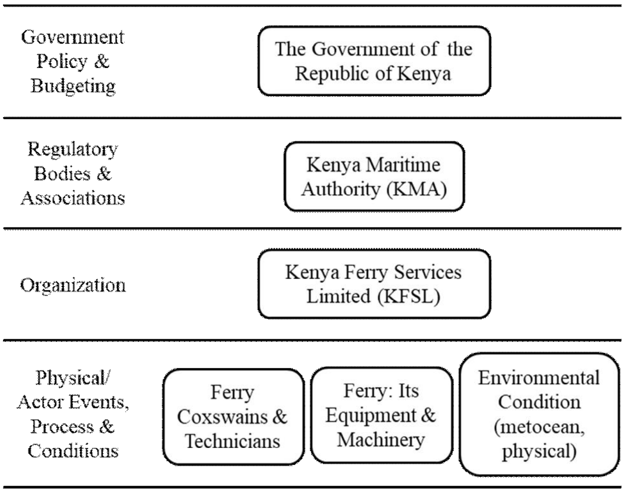

Fig. 1 AcciMap controllers involved in ferry operations in mombasa channel

2.2.1 Collisions Accident

On 15 September 2011, a ferry ship, MV Kwale, collided with a docked cargo vessel, MV Sea Wind at Mbaraki Wharf resulting in damage to both vessels(Mwajefa, 2011). The direct contributory factor was due to the ferry coxswain losing control of the ship due to steering failure as well as not considering the incoming tide. On 21 July 2020, two ferries namely, MV Safari and MV Kwale collided at the Likoni mainland ramp leading to injuries to the passengers onboard as well as a hull breach and subsequent ingress of water to the engine room on MV Safari due to the impact(Ahmed, 2020).

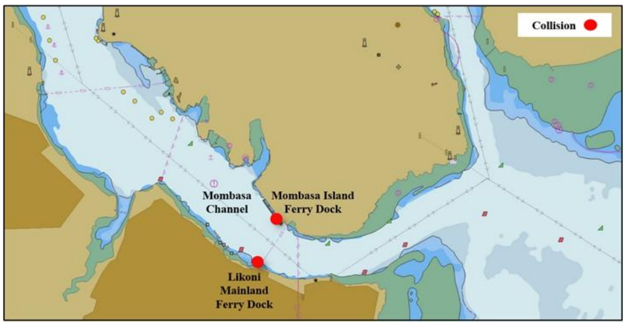

Fig. 2 Ferry collision locations in mombasa channel

2.2.2 Grounding Accidents

On 5 July 2012, the MV Kwale ferry overshot and grounded on the Mombasa Island ferry dock due to high speed coupled with the low tides(Nation, 2012). This led to passengers being stranded on the grounded vessel for more than one hour. Furthermore, on 17 May 2015, the MV Kwale ferry, carrying about 1400 passengers, developed mechanical challenges while underway and was stalled which led to raging waves pushing it off course and towards shallow waters in Mombasa Island side where it hit a coral reef and eventually grounded(Mghenyi, 2015). Moreover, the MV Kwale ferry got stuck on the Mombasa Island's ferry embarkation site on 26 October 2015, leading to a stampede at the busy channel, contributing to injured passengers(Ahmed and Lwanga, 2015). In addition, on 24 November 2015, MV Harambee grounded at the Likoni mainland's ferry landing facility while offloading passengers and motorists due to low tide which exposed its propellers leading to the stalling(Beja, 2015). The ferry was able to sail off the ramp once the high tides resumed. Notably, on 10 April 2017, the MV Kwale ferry was stuck on the ferry berthing facility on Mombasa Island side for about one hour due to the ferry overshooting the ramp in low tide(Atieno, 2017). The weight of the passengers and vehicles also greatly contributed to the grounding accident. The stalled ferry was eventually towed to safe waters by another ferry, MV Harambee, where it was further inspected by the engineers.

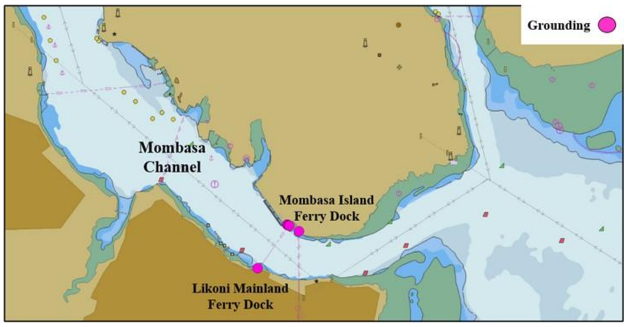

Fig. 3 Ferry grounding locations in mombasa channel

2.2.3 Contact Accident

Two ferries, MV Kwale and MV Kilindini, made contact with the ferry landing platform on Mombasa Island, on 6 October 2014, due to an unforeseen rise in water tide which resulted in the disruption of ferry services. The resulting stampede by the passengers led to several injuries(Nation, 2014).

From the above summary of the accident reports from both the collision, grounding and contact accidents involving ferries in the Mombasa channel, several direct causes of the ferry accidents were identified and compiled in Table 1.

2.3 Ferry Safety Inquiry (2019)

A safety inquiry was conducted in 2019 by the Public Investment Committee(Government of Kenya) to investigate the safety of ferries operated by the KFSL following an incident on one of its ferries, MV Harambee, that resulted in the death of two Kenyans(Public Investments Committee, 2019). A subsequent report detailed the deficiencies of ferry operations within its socio-technical system as consolidated in Table 2.

Table 1 Summary of direct causal factors for ferry accidents in the channel

Date	Ferry Name (Accident type)	Direct Cause
15. Sep. 2011	Kwale&Sea Wind (Collision)	Loss of control of MV Kwale ferry by ferry operator
05. Jul. 2012	Kwale (Grounding)	High speed and low tide led to ferry overshot on the ramp (inadequate docking procedure)
06. Oct. 2014	Kwale&Kilindini (Contact)	High tide
17. May 2015	Kwale (Grounding)	Mechanical failure & Presence of Coral Reef
26. Oct. 2015	Kwale (Grounding)	Mechanical failure & Limited Operational Ferries
24. Nov. 2015	Harambee (Grounding)	Ferry overshot at ramp & Low tide
10. Apr. 2017	Kwale (Grounding)	Ferry overshot on the ramp when docking & Low Tide
21. Jul. 2020	Kwale&Safari (Collision)	Mechanical failure thereby losing steering capability

Table 2 Summary of systemic issues identified in 2019 ferry safety inquiry

Safety Issues	Details
Inadequate maintenance (p.23)	Ferries continued to operate without undergoing scheduled dry-docking for major repair works. The reason for the inadequate maintenance was due to budgetary constraints at KFSL.
Engine overuse/operation using limited ferries (p.23)	Some of the ferry engines operated for long hours beyond recommended service hours without undergoing engine overhauls.
Safety Certificates (p.24)	One of the ferries was allowed to operate with an expired class certificate and was still issued a Kenya Passenger Ship Safety Certificate despite not meeting the class certification requirements.
Regulatory Oversight in Ferry Inspections (p.24)	KMA had only two safety officers with the prerequisite qualifications to inspect the ferries contributing to lapses in ferry inspections. Furthermore, the regulatory body did not have a succession plan to ensure the continuity of ferry inspections.
Budgetary Constraints (p.25)	The amount of funds allocated to KFSL by the Government of Kenya for the maintenance of ferries was lower than the amount required to ensure sufficient repairs were conducted.
Unqualified Ferry Operators (p.26)	17 out of the 25 active ferry coxswains did not have the required certificates of competency under the old and new Merchant Shipping (Training and Certification) Regulations of 1970 and 2016 respectively.

2.4 Coding Causal Factors from Accident Reports

The next phase of AcciMap analysis was to combine the identified contributory factors from Table 1 and Table 2 and systematically code and classify them into their thematic areas by the respective AcciMap Levels: Government Policy & Budgeting, Regulatory Bodies & Associations, Organization, Physical/Actor Events, Processes & Conditions as outlined by Salmon et al.(2020), as categorized in Table 3.

At the government level, the theme of the causal factors reflected the all-encompassing governmental influence on ferry safety through policy and funding. Moreover, coding in the regulatory category exposed the gaps in regulatory frameworks and enforcement. Furthermore, the coded organization level revealed safety issues within ferry operations that heightened the risk of accidents and lastly, coding at the physical/actor events levels highlighted the roles of these conditions as the immediate triggers of the accident.

Table 3 Coding of causal factors in AcciMap classification format

Category	Safety Issues for AcciMap Classification
Government Policy & Budgeting	<u>Inadequate Budget allocation for ferry maintenance</u>
Regulatory Bodies & Associations	<u>Failure to implement safety of shipping and maintenance of safety standards</u>: Lack of enforcement of maritime safety regulations such as ferry operators sailing without prerequisite certification and training & expired class certificates.
	<u>Lack of succession planning to ensure continuity of ferry inspections</u>: This contributed to a shortage of safety inspectors in the regulatory body
	<u>Lapses in ferry inspection procedures</u>
Organization	<u>Employing coxswains without prerequisite training and certification</u>: Not hiring competent ferry operators; no training in competency
	<u>Unsafe operation practices</u>: such as overloading
	<u>Inadequate ferry maintenance</u>
	<u>Overreliance on limited vessels</u>: Ferry engines operating beyond recommended service hours
Physical/Actor Events, Processes & Conditions	<u>Tidal influence</u>: low tides & high tides [Physical Condition]
	<u>Mechanical failure</u> [Physical Condition]
	<u>Inadequate docking procedures</u>: Ferry overshot at high speeds and in overloaded conditions due to navigation errors [Actor Activities]
	<u>Loss of control</u> (in the context of navigational error) [Actor Activities]
	<u>Presence of Coral Reef</u> [Physical Conditions]

3. Results and Discussion

The subsequent phase of the AcciMap analysis was the creation of the cause-and-effect links between these safety issue themes across the entire AcciMap framework as illustrated in Fig. 4. These links highlighted the interrelations among these contributory factors as well as the roles of decision-makers and crucial stakeholders involved at each level. More details are given in the subsections, explaining the identified factors within each AcciMap level.

3.1 Government Policy & Budgeting

At the Government of Kenya level, the key factor analyzed was the inadequate financial allocation for ferry maintenance. This lack of sufficient budget led to a systemic failure to ensure the availability of resources required for regular upkeep and upgrade of the ferries by KFSL. This financial deficit developed conditions for poor ferry maintenance management and inadequate seaworthiness that led to high navigation risks for the ferries.

The Government of Kenya plays a crucial role in promoting maritime safety. Therefore, it is recommended that the allocation of the budget for ferry maintenance be increased to provide the requisite resources for maintaining ferry infrastructure and enhancing safety standards. Furthermore, domestic ferry safety policies and regulations should be updated and strengthened to address the gaps in enforcement and regulations.

3.2 Regulatory Bodies & Associations

At the regulatory level controlled by the KMA, factors that contributed to the ferry navigation accidents centered on the failure of the regulatory body to enforce safety standards on crew certification and vessel seaworthiness. The shortage of ferry inspection officers exacerbated the deficiencies in ferry inspections without a clear succession plan to ensure the continuity of ferry inspections even after the retirement of the safety officers.

The Kenya Maritime Authority(KMA) as the regulatory body should recruit and train more safety officers to oversee ferry inspection and certification duties. Moreover, regular, and thorough inspections should be done to determine latent safety risks. Finally, stricter adherence to ferry safety standards should be enforced to hold the ferry company and ferry operators accountable for promoting passenger safety.

3.3 Organization

At the KFSL level, various managerial and operational inadequacies were determined. Employing unqualified ferry operators was a critical factor that contributed to navigation errors and poor decision-making during ferry transits. Moreover, inefficient ferry maintenance management led to continuous mechanical failures that impacted the ferries' maneuverability in the channel leading to stalling and eventual drifting which led to various ferry accidents. Furthermore, the overreliance on limited ferries meant that the available ferries were overburdened and frequently subjected to wear and tear in the absence of adequate downtime for maintenance. Lastly, the ferry company encouraged overloading practices to meet the ferry demand, which increased navigation risks by operating ferries exceeding their capacity limits.

Kenya Ports Authority(KPA) as the current organization responsible for ferry operations in the Mombasa channel should hire qualified ferry crew members and implement strict routine preventive maintenance schedules to keep the ferries in optimal condition. As for overloading, the organization can enforce stringent capacity regulations ensuring that the ferries maneuver within safe limits.

3.4 Physical/Actor Events, Processes & Conditions

At this level, the human, environmental, and equipment conditions performed a critical role as the immediate precursors to the ferry accidents. The unqualified ferry operators made significant navigation errors under low water tide conditions and in the presence of coral reefs in the Channel leading to loss of control of the vessel. These navigation errors also contributed to poor docking procedures of the vessels at high speeds and in overloaded conditions. Furthermore, inadequate ferry maintenance led to inadequate seaworthiness which contributed to the prevalent mechanical breakdowns of the ferries.

To mitigate the safety risks at the last level comprising of Physical/Actor Events, Processes, and Conditions, proper docking procedures should be implemented and training of the ferry operators to safely navigate environmental hazards such as low water tides should be enforced.

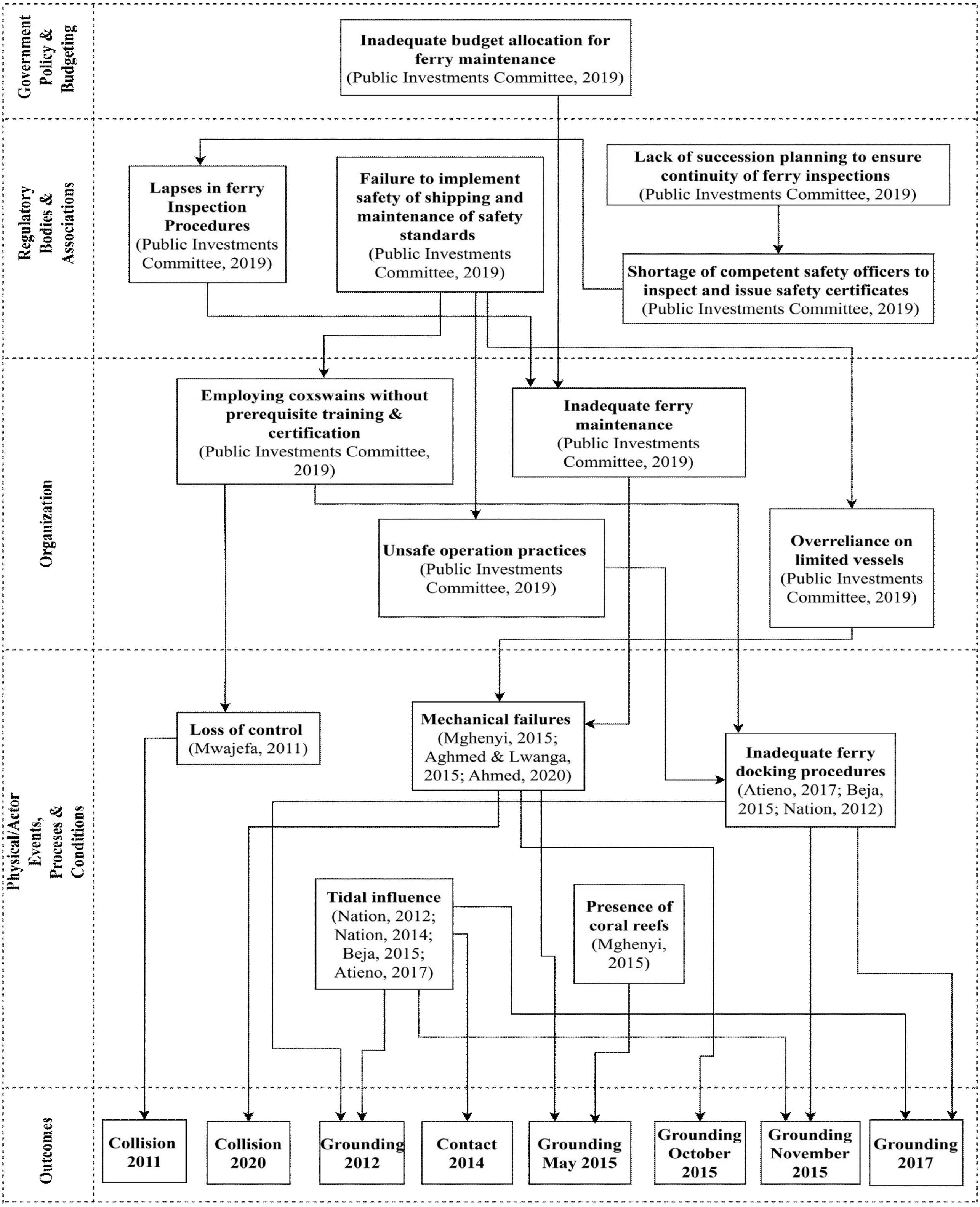

Fig. 4 AcciMap analysis for ferry navigation accidents in mombasa channel

4. Conclusion

This paper has evaluated the systemic factors leading to ferry navigation accidents in the Mombasa Channel through the AcciMap analysis tool. A broad understanding of the underlying causes at four levels has been provided for all accidents individually. Based on this study, a series of recommendations for every AcciMap level has been developed to improve domestic ferry safety and prevent future accidents. Addressing these recommendations in the various AcciMap levels can enhance ferry safety in the Mombasa channel. An integrative and preemptive approach to ferry safety management is integral to deter future accidents and promote the safety of human life and the protection of the environment.

Further studies will focus on quantifying the AcciMap causal factors and their relative contributions to ferry accidents thereby allowing a more data-driven assessment of navigation risk. This will involve the participation of maritime safety professionals and experts in the analysis whose insights will enhance the accuracy of causal factor prioritization. By integrating expert knowledge with quantitative data this methodology will establish a more comprehensive understanding of high-risk ferry navigation safety issues, facilitating the advancement of targeted safety implementations and informing policy decisions to extenuate risk of navigation and enhance ferry safety in Mombasa Channel.

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