Thesis for the degree of Master of Engineering

A Study of Vessel Traffic Risk Management in Mombasa Approach Channel

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A Study of Vessel Traffic Risk Management in Mombasa Approach Channel

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Abstract

Mombasa is the second largest city in Kenya located on the east coast of Kenya. Mombasa is famous for its beautiful natural white sand beach, aquatic life, rich cultural and historical wealth. In this city is the port of Mombasa which is the largest port in East Africa and is the gateway to East and Central Africa and plays a very important role in facilitating trade and development of the region. The port has strategic importance far beyond the borders of Kenya. As the largest port in East Africa, it is the main gateway for the import and export of goods not only for Kenya but also to landlocked countries of the East African Community, the Democratic Republic of Congo, southern Sudan, and southern Ethiopia.

However being among the top five largest ports in Africa, navigating in Mombasa approach channel is a challenge due to its oceanographic structure. Vessel heading into or out of Mombasa port has to maneuver through two major bends and change the heading three times. Local ferries operating at Likoni channel also pose as potential navigation risk on transit vessels with an average of 196 daily crossings. Navigation risk of the ferries is compounded by narrow, 500m wide, waterway at Likoni channel and shallow coral reefs and sand banks at the entrance to the inner channel.

In this thesis paper, the main aim is to improve marine traffic safety by carrying out a risk assessment and proposing countermeasure in Mombasa approach channel using vessel traffic risk management technique; and to investigate navigation risk of local ferry traffic on transit traffic on Mombasa approach channel. The target research area is the fairway area stretching from fairway buoy number 1 to buoy number 10.

The main aim is achieved by carrying out marine traffic survey to determine marine traffic characteristics such as traffic volume and traffic flow of vessel traffic after which, risk assessment on Mombasa approach channel is carried out using three marine traffic risk assessment models namely; Environmental Stress Model, PARK model and IWRAP model and thereafter risk mitigation countermeasures are proposed in this study. Quantitative risk assessment by ES model, PARK model and IWRAP model showed that there is a high risk of crossing collision between local traffic and transit traffic at crossing region where ferry operate; total groundings in Mombasa and Ulsan waterway are equal; powered grounding frequency in Mombasa is almost twice that of Ulsan.

Risk assessment results showed that there is a need to come up with traffic management measures/policies that will mitigate the risk of collision and running aground of vessels thereby improving marine traffic safety. Traffic control of ferries, setting up a Local Traffic Service (LTS), VTS report line due to crossing ferry and proper layout of AtoN were proposed as countermeasures.

A study of the countermeasures showed that; traffic control of the local traffic is effective in reducing collision risk at Likoni channel; Local Traffic Service will improve marine traffic safety by reducing workload on the Mombasa VTS; The reporting line will providing the reference point on when to instruct the ferries to stop crossing thereby increasing marine traffic efficiency and safety; Re-organization of lateral buoys will increase relative position and navigation accuracy when the vessel is navigating in Mombasa approach channel so as to avert the danger of vessel running aground.

From the above observations and results from analysis, this thesis recommends the proposed countermeasures to be applied on the Mombasa approach channel so at to improve marine traffic safety.

Key words: Mombasa approach channel, Local ferries, risk assessment, countermeasures, vessel traffic risk management

몸바사 접근수로의 선박교통 위험관리에 관한 연구

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해양경찰학과

요약문

몸바사는 케냐 동부 해안에 위치한 케냐에서 두 번째로 큰 도시이며,아름다운 자연 백사장, 수중 생물, 풍부한 문화 및 역사적 자산으로 유명하다.동아프리카와 중부아프리카로의 관문이고,지역의 무역과 개발을 촉진하는데 매우 중요한 역할을 하고있으며, 케냐의 국경을 훨씬 넘어서 전략적 중요성을 가지고 있다. 몸바사는동아프리카에서 가장 큰 항구로서, 케냐뿐만 아니라 동아프리카 공동체, 콩고 민주 공화국, 남부 수단, 남부 에티오피아 등 내륙 국가들에 대한 물품의 수입과 수출을 위한 주요 관문의 역할을 하고 있기 때문이다.

그러나 아프리카의 상위 5 대 항구 중 하나인 몸바사의 접근 수로를 항해하는 것은 지정학적 구조로 인해 어려움이 있다.몸바사 항구로 출입항하는 선박은 두 개의 큰 만곡부를 지나야 하며,침로를 세번이나 바꿔야 한다. 또한, 리코니(Likoni) 수로에서 운영되는 페리들은 하루 평균 196 회 항로를 횡단하여 운항하고 있기 때문에 항로를 따라 통항하는 선박에게는 잠재적인 항행위험이 되고 있다. 폭 500m 의 협소한 리코니 수로와 수로 입구의 얕은 산호초 등이 페리의 항행위험을 야기한다.

이 논문의 목적은 선박교통 위험관리 기술을 이용하여, 몸바사 접근수로의 교통량을 조사하고이 수로의 위험성을 평가하여 문제점을 식별하고, 그에 대한개선안을 제안하는 것이다. 대상 연구 영역은 1 번부표에서 10 번 부표까지 해당하는 항로이다.

선박 통행량 및 선박교통 흐름 등의 해상 교통 특성을 결정하기 위하여, 해상 교통량 조사를 실시한 후, 세 가지 해상교통 위험평가 모델 (환경 스트레스 모델, PARK 모델 및 IWRAP 모델)을 이용하여 몸바사 접근 수로에 대한 위험평가를 실시하였으며, 그 이후

위험 경감 대책을 제안하였다. ES 모델, PARK 모델 및 IWRAP 모델에 의한 정량적 위험 평가 결과,페리가 운행하는 교차 지역에서 충돌의 위험이 매우 높았으며, 몸바사와 울산 수로의 총 면적은 동일하나,몸바사의좌초 확률은 울산의 거의 두 배였다.

위험평가 결과 선박의 충돌위험과 좌초위험을 줄이기 위하여 해상교통 안전을 향상시키는 교통 관리 조치 / 정책을 찾아낼 필요성을 보여주었으며, 페리의 교통 통제, LTS (Local Traffic Service) 설정, 페리의 횡단으로 인한 VTS report line 설정 및 항로표지(AtoN)의 적절한 배치가 대책으로 제안되었다.

- 지역 교통량의 관제는 리코니 채널의 충돌 위험을 줄이는 데 효과적이다;
- 지역 교통 서비스(LTS)는 몸바사 VTS 의 작업 부하를 줄여 해상 교통 안전을 개선할 것이다;
- Reporting line 은 페리의통항을 멈추도록 지시하는 기준점을 제공하므로, 해상 교통 효율 및 안전성을 높일 것이다;
- 측방표지의 재구성은 선박 좌초의 위험을 피할 수 있도록 상대 위치와 항법 정확도를 높일 것이다.

위의 관찰 및 분석 결과를 통하여, 본 논문은 제안된 대책을 몸바사 접근 수로에 적용하여 해상 교통 안전을 개선할 것을 권고한다.

핵심용어:몸바사접근수로,해상교통위험평가모델, 지역페리, 위험평가, LTS, 선박교통위험

Chapter 1 Introduction

1.1 Scope of Research

This study investigates the navigation risk imposed on transit traffic by local ferry traffic at Mombasa approach channel in order to improve marine traffic safety. Moreover, this study utilizes vessel traffic management technique to investigate the level of marine traffic safety in Mombasa approach channel. Vessel traffic risk management is managerial technical measures adopted and implemented with an aim of improving marine traffic safety in general terms (Park, 2002). It involves an iteration of activities from traffic survey, quantitative risk assessment, policy alternative to the prediction of the measures implemented so as to improve traffic safety.

In this study, local and transit marine traffic parameters such as traffic volume and traffic flow are defined in traffic survey using various statistics. Quantitative risk assessment is done on Mombasa approach channel using three marine traffic risk assessment models namely ES model, PARK model, and IWRAP Mk2 model. ES model is a quantitative model used to evaluate the difficulty of ship handling caused by a restricted maneuvering area or by traffic congestion (Inoue, 2000) in ports and harbors. In the model, stress values are introduced as ship handling difficulty-indices. The ES model was chosen as a practical model for accessing the navigation risk of local traffic on transit traffic, where numerical stress values due to ship handling difficulty were calculated from ES model.

PARK model is a quantitative assessment model that calculates the risk through internal elements such as characteristics of the vessel (i.e. type, size and tonnage of ships) and external elements such as approaching position of each ship, speed and distance between/among ships (Nguyen et al., 2015).

The numerical risk values are calculated from PARK model formulae obtained from regression analysis of internal and external elements of a vessel. Risk assessment by PARK model was done to emphasize on the level of marine traffic safety on Mombasa channel.

IWRAP model is a quantitative assessment model used in the evaluation of collision and grounding probabilities of vessels in a channel/waterway. IWRAP model uses causation probabilities modeled by MacDuff (1974), Fujii et al, (1974) and Pedersen (1995) to calculate the frequency of collision and grounding in a waterway. IWRAP model is limited to only using vessel statistical data in its calculations.

In this study, the main objectives of the study are approached through traffic survey at Mombasa approach channel, carrying out a quantitative risk assessment to ascertain the level of navigation safety and finally assess effective countermeasures so as to improve marine traffic safety in Mombasa approach channel using vessel traffic risk management technique.

1.2 Literature review

Quy and Vrijling (2008) used a risk-based method for design of Mombasa entrance channel depths using 6,000 TEU post Panamax container vessel as design ship. The probabilistic approach consists of two developed models: (1) a parametric model of the wave-induced ship motions; (2) a Poisson probability model of ship grounding induced by waves for a single ship passage. The result indicated that Mombasa approach channel needs to be dredged to 17.5m for outer channel and 16.0m for inner channel.

Park (2002) used vessel traffic safety management technique to rate the safety of ports and waterway using ES model. After which, Park applied traffic control during rush hour as a traffic management countermeasure. He went ahead to establish the correlation between traffic control rate and reduction in ship handling difficulty. The result showed that when traffic control is at 50%, the ship handling difficulty reduces to a safe level.

1.3 Research Review and Flow-chart

Chapter 1 of this thesis describes its scope, gives a review of the literature and presents a research layout. The first part of Chapter 2 is a general introduction to the Mombasa approach channel; investigation of Mombasa approach channel dimensions by PIANC rules. The next section presents the results of the marine traffic survey where flow, traffic volume traffic and marine traffic characteristics of transit and local traffic are identified. In the last part of the Chapter 2, the marine traffic management and the organization and operation of the Mombasa VTS System are presented. Thereafter results and conclusion are discussed. The beginning of Chapter 3 reviews features of some popular waterway risk assessment models and presents the ES (Environment Stress) model, the PARK (Potential Assessment of Risk) model and IALA Waterway Risk Assessment Program (IWRAP) in detail. In the next section, quantitative risk assessment is done using ES, PARK and IWRAP model on Mombasa approach channel. Chapter 3 finishes by describing results obtained from quantitative risk assessment and compares results with studies done on other fairways. Chapter 4 presents a study of effective vessel traffic risk mitigation measures. The four proposed risk mitigation measures; traffic control of Likoni Ferries, the establishment of Local Traffic Service, VTS reporting line due to crossing ferry Layout of AtoN are discussed to exhaustion. The last part of the chapter discusses the results from a study of the proposed countermeasures. Chapter 5 presents conclusion and recommendation for this study.

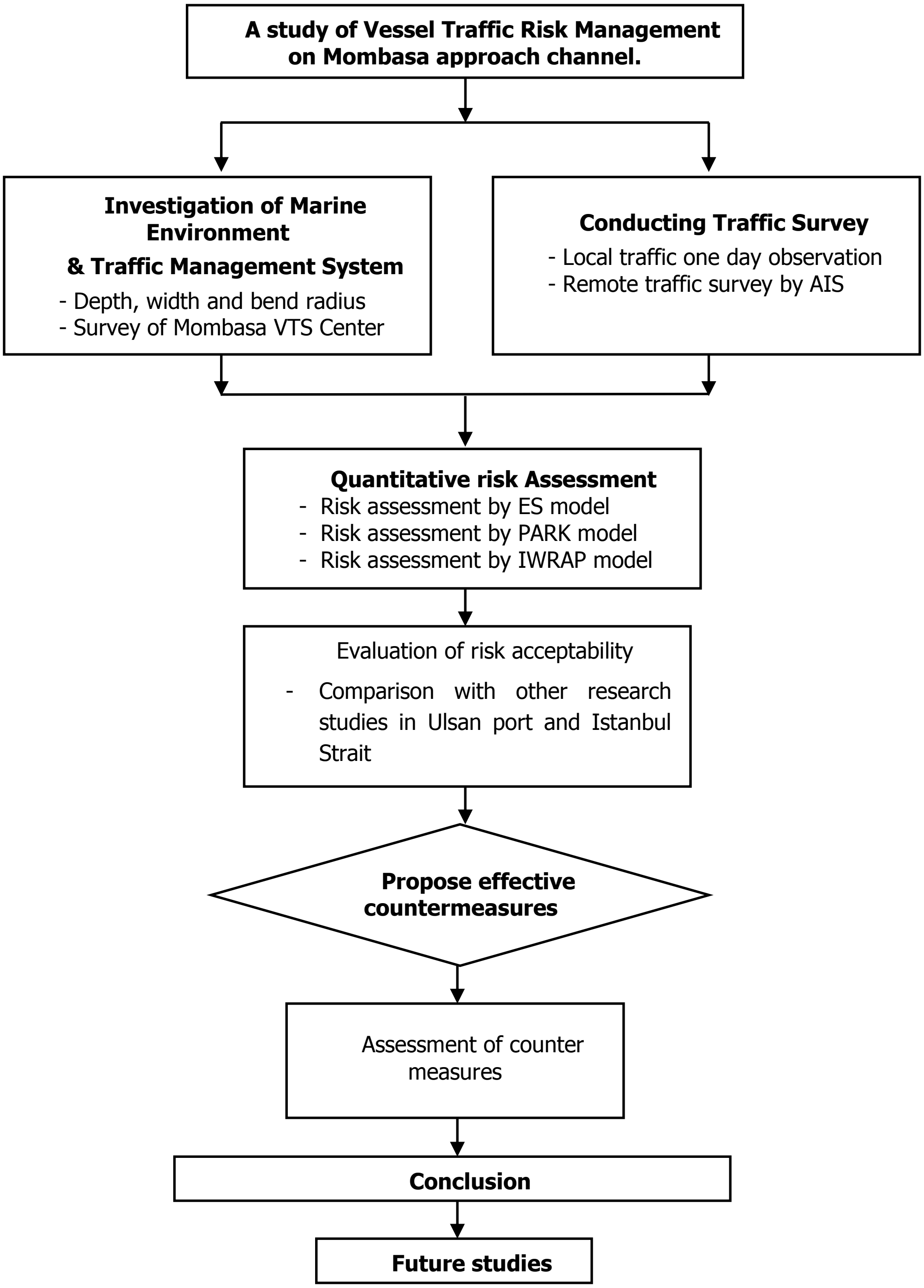


Figure 1.1 Research flow-chart

Chapter 2 Marine Environment, Traffic and Traffic Management in Mombasa Approach Channel

2.1 Introduction to Mombasa Approach Channel

Mombasa is located at $4^{\circ}\ 2'.5S$ and $39^{\circ}\ 3'.83$E (KPA Headquarters) on the East coast of Kenya. Mombasa approach channel is 7nm long divided into the outer channel and the inner channel. The approach channel is marked by 10 buoys (IALA region A) as shown in figure 2.1. Outer channel is exposed to the sea and it is 300m wide, 17.5m deep, marked from buoy 1 to buoy 8. The inner channel is sheltered waters 400m wide, 15m deep (KPA, 2014). The dotted arrow represents general direction of vessels heading to old port which is no longer in use due to its shallow waters, 11.2m deep. The blue bold arrow represents general direction of ocean-going vessels making headway into/out of the port. The bold-purple arrow represents general movement of local ferries at Likoni channel. Pilotage in Mombasa channel is compulsory for all vessels. Mombasa approach channel is monitored by Mombasa VTS which started to operate in 2008.

2.2 Investigation of Mombasa channel dimensions by PIANC rules

2.2.1 Depth, Width and bend radius of Mombasa Approach Channel.

Table 2.1 shows basic dimensions of design vessels selected to verify current Mombasa fairway dimensions using PIANC rules and more so, identify vessel limit that is allowed to navigate in Mombasa approach channel.

Table 2.1 Dimensions of design ship from Spanish ROM.

Vessel Type	**DWT**	**LoA**	**L_{BP}**	**Beam**	**Draught**
Container (Post Panamax)	100,000	326	310	42.8	14.5
Cruise Liner (Post Panamax)	80,000	272	231	35.0	8.0
Tanker	70,000	225	213	38.0	13.5
Bulk Carrier	60,000	220	210	33.5	12.8
Freight RO-RO ship	50,000	287	273	32.2	12.4

Source: PIANC (2014)

Selection of design ship was guided by the guidelines set in PIANC (2014). In our calculation, design ships will be of moderate maneuverability. A typical one-way channel such as Mombasa approach channel is marked as shown in figure 2.2.

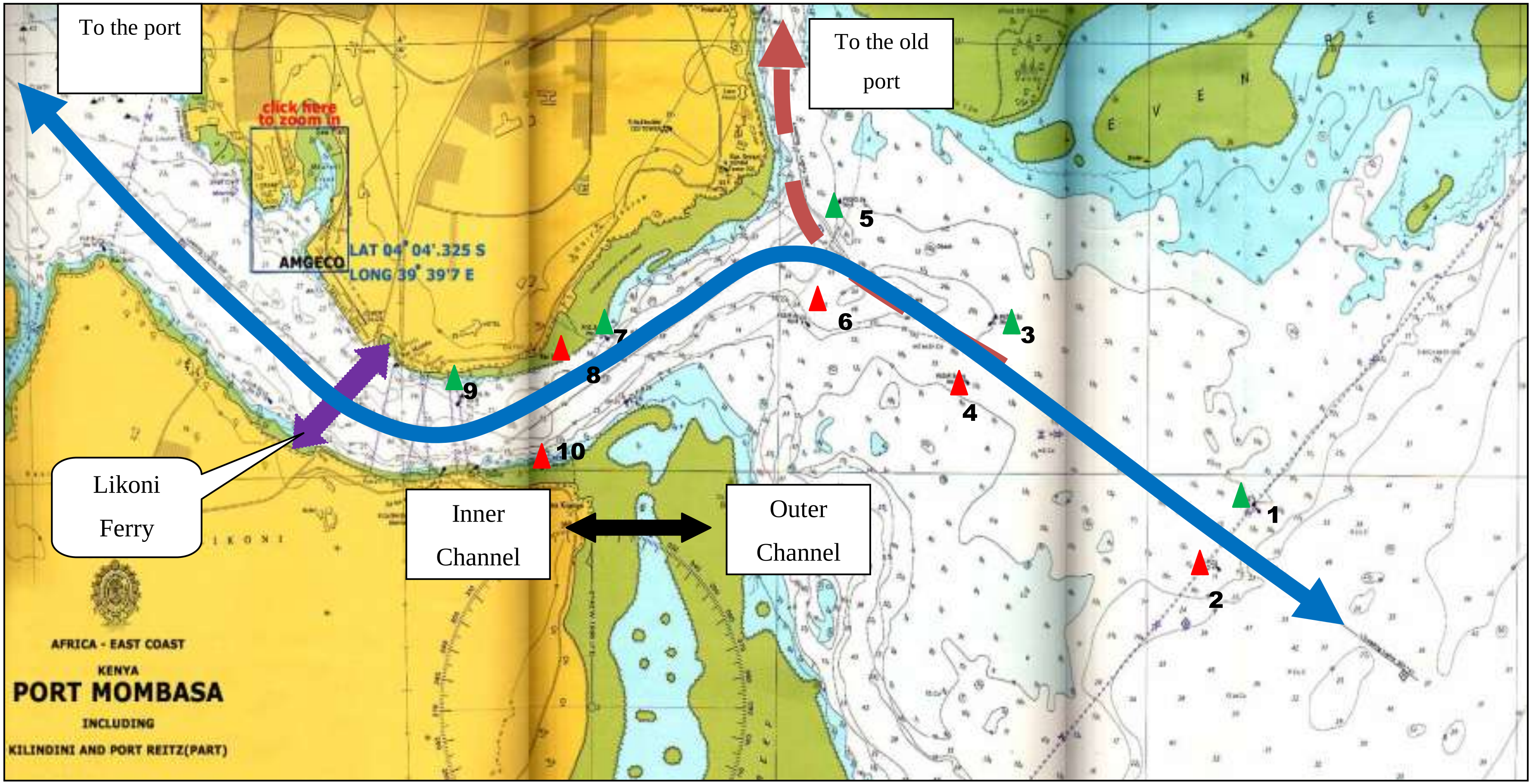


Figure 2.1 Mombasa approach channel research are

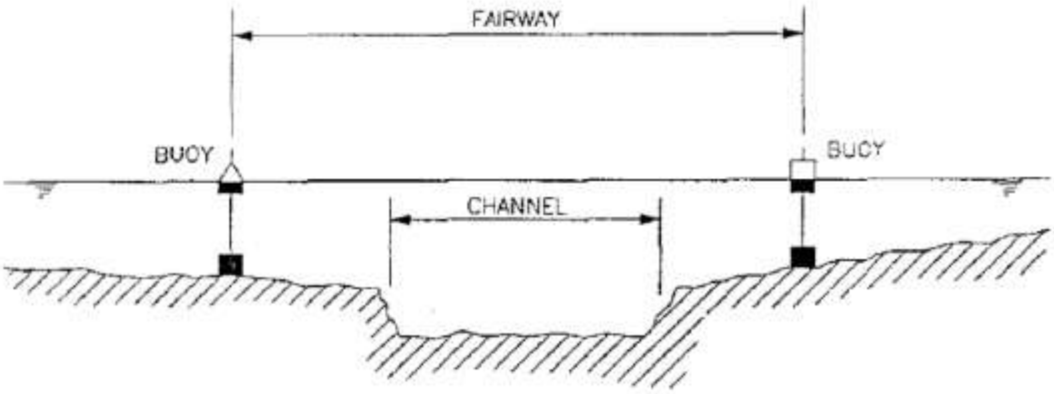


Figure 2.2 One way channel

Width (Straight Section)

The bottom width W of the waterway is given by;

$One\ way\ channel\ \ W = W_{BM} + \sum_{i=1}^{n} W_i + W_{Br} + W_{Bg}$ .... (PIANC, 2014)

Where; W_{Bg} *and* W_{Bg} are bank clearances on the 'red' and 'green' sides of the channel

W_{BM} is basic maneuvering width

W_i is summation of width factors such as wind, current, wave etc.

Table 2.2 shows summation of bank clearance on 'red' and 'green' side, basic maneuvering width and width factors which depend on vessel speed, channel depth, cross wind, current, wave, aids to navigation, bottom surface and cargo hazard level. All the channel width dimensions were estimated based on an operational limit and prevailing conditions in the research target area.

Table 2.2 Detailed calculated dimensions of minimum channel width according to PIANC (2014)

One Way Channel	Outer Channel	Inner Channel
Basic Maneuvering Lane (W_{BM})	1.5 B	1.5 B
Addition for speed (W_{i1})	0.0 B	0.0 B
Addition for channel depth (W_{i2})	0.4 B	0.2 B
Addition for cross wind (W_{i3})	0.2 B	0.2 B
Addition for current (W_{i4})	1.2 B	0.2 B
Addition for waves (W_{i5})	0.0 B	0.0 B
Addition for aids to navigation (W_{i6})	0.2 B	0.2 B
Addition to bottom surface (W_{i7})	0.1 B	0.1 B
Bank clearance on port side (W_{Br})	0.1 B	0.5 B
Bank clearance on starboard (W_{Bg})	0.1 B	0.5 B
Total	**3.8 B**	**3.4 B**

Turning Radius for a curved channel is given by table 2.3. All formulae were derived from PIANC (2014) recommendations.

Curved channel radius is given by the summation of turning radius, swept track when turning, swept path due to drift angle and response time delay in altering course.

Table 2.3 Minimum dimensions of curved channel width according to different sizes of design ship sizes

Ship Type	Loa	Beam (B)	Turning radius (x) (R_C)		Swept track (y) $1.3B$	Drift angle addition (z), a=8 $\left(\frac{L_{oa}^2}{aR_c}\right)$	Response time addition (w) $(0.4B)$	Sum (x+y+z+w) (m)
Container (Post Panamax)	326	42.8	7 Loa	2282	56	6	17	2361
Cruise Liner (Post Panamax)	272	35.0	4 Loa	1088	46	9	14	1157
Tanker	225	38.0	5 Loa	1125	49	6	15	1195
Bulk Carrier	220	33.5	6 Loa	1320	44	5	13	1382
Freight RO-RO ship	287	32.2	5 Loa	1435	42	7	13	1497

Table 2.4 Minimum dimensions of channel width according to different sizes of design ship

Vessel Type	DWT	Beam B (m)	Width of Fairway	
			Outer Channel (m)	Inner Channel(m)
Container (Post Panamax)	100,000	42.8	162.6	145.5
Cruise Liner (Post Panamax)	80,000	35.0	133.0	119.0
Tanker	70,000	38.0	144.4	129.2
Bulk Carrier	60,000	33.5	127.3	113.9
Freight RO-RO ship	50,000	32.2	122.4	109.5

For shallow waters a depth to draught ratio (h/T) of 1.2 or lower is recommended in calculations on vertical channel dimensions (PIANC, 2014).

Table 2.5 Minimum dimensions of channel depth according to different sizes of design ship sizes using h/T ratio of 1.2

Vessel Type	**DWT**	**Draught, T(m)**	**Minimum Depth of Fairway (m)**
Container (Post Panamax)	100,000	14.5	17.4
Cruise Liner (Post Panamax)	80,000	8.0	9.6
Tanker	70,000	13.5	16.2
Bulk Carrier	60,000	12.8	15.4
Freight RO-RO ship	50,000	12.4	14.9

From table 2.4 it is observed that a vessel up to 100,000 DWT, maneuverability is not restricted by the width of the fairway. Therefore 100,000 DWT vessels can be able to maneuver through the outer channel and inner channel fairway without much difficulty. The depth of fairway is influenced by astronomical tides and meteorological effects, current and wind. Mombasa port experiences a semi-diurnal tide, with a tidal range from 4.1m (HAT) to -0.1m (LAT) with MHWS at 3.5m (KPA, 2015). Astronomical effects, wind, and currents are not large enough to affect ship maneuverability hence they have been omitted in this study. Table 2.5 and table 2.6 shows that vessels with draft greater than 14.6m have to consider tide when navigating on the outer channel. Vessel with draft up to 12.5m also has to consider tide when navigating in the inner channel.

Table 2.5 and table 2.6 shows that the ship draft and channel depth plays a huge role in passage planning in Mombasa approach channel. With the current depth, vessels with a draft greater than 14.6m have to navigate with the tide when on load. Vessels with the draft less than 12m are allowed to navigate through the channel but with caution.

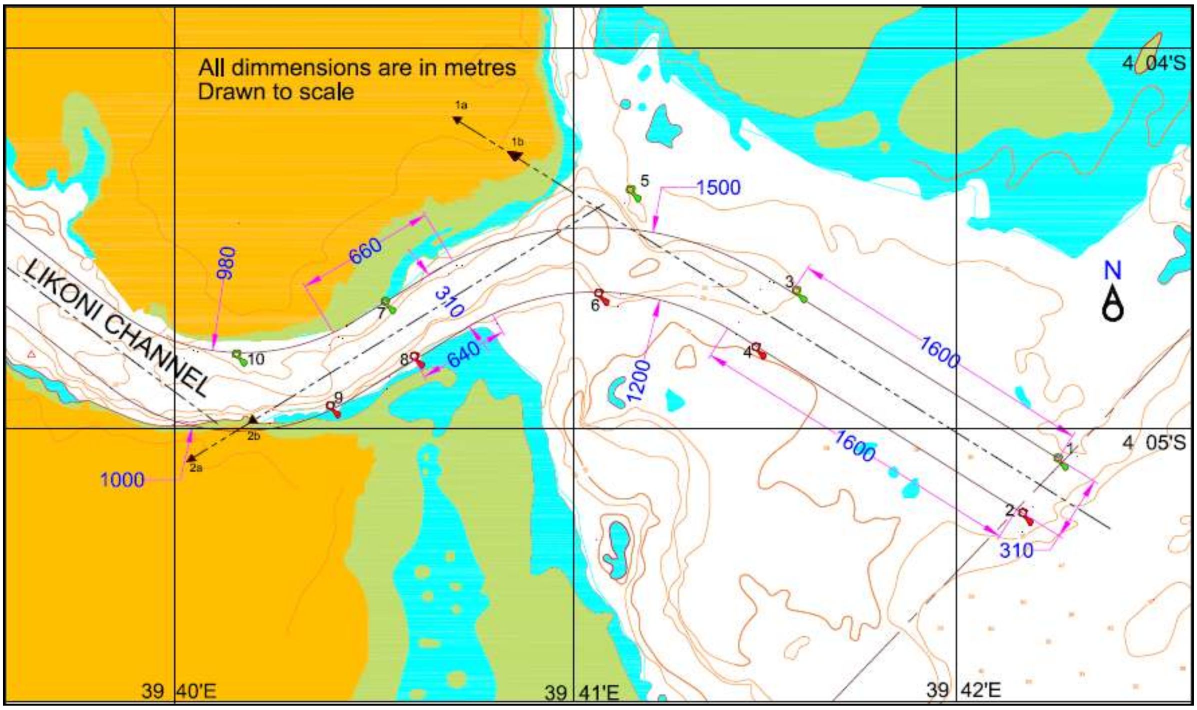


Figure 2.3 Dimensions of Mombasa approach fairway as traced from Mombasa Raster chart using AutoCAD

Regarding shallow water effects, ship course stability generally increases as the water depth decreases from deep water conditions. However, fully laden ships sometimes show more course-unstable features in medium water depths of $h/T \approx 1.5$ (where h is water depth and T is ship draught) than in deep water.

In shallow water of $h/T = 1.2$ or lower, as in many harbor areas, the course-keeping ability of ships is largely improved, but the turning ability is decreased. Therefore it is vital to check whether the two curved channels in figure 2.1 fully conform to minimum dimensions as required by PIANC (2014).

Table 2.3 shows the minimum required curved channel dimension under PIANC (2014) standards. When comparing table 2.3 results with figure 2.3, it is observed that 100,000DWT container (post Panamax) is restricted by channel bend radius to maneuver safely at the channel bends in outer channel and at the entrance to the inner channel.

Table 2.6 Minimum dimensions of channel depth and width according to different sizes of design ship sizes using h/T ratio of 1.2

Area	Current Channel dimensions (m)			PIANC Requirement		Remarks
	Minimum Width of channel (m)	Minimum depth of channel(m)	Maximum allowed DWT	Minimum width of channel (m)	Minimum depth of channel (m)	
Buoy 1-2 to Buoy 5-6	300	17.5	100,000	162.6	17.4	Generally, ships' maneuverability is not restricted by width. But vessels with draft greater than 14.6m have to consider tide when navigating
Buoy 5-6 to buoy 7-8	300	17.5	100,000	162.6	17.4	Generally, ships' maneuverability is not restricted by width. But vessels with draft greater than 14.6m have to consider tide when navigating
Buoy 7-8 to buoy 9-10	300	15	100,000	145.5	17.4	Generally, ships' maneuverability is not restricted by width. But vessels with draft greater than 12.5m have to consider tide when navigating
Bend at buoy 5	1070	17.5	80,000	2361	17.5	Generally, ships' maneuverability is restricted by width of the channel bend.
Bend at buoy 10	1050	15	80,000	2361	17.4	Generally, ships' maneuverability is restricted by width of the channel bend.

2.3 Marine Traffic in the research area

Mombasa approach channel is mainly characterized by two major vessel traffic, that is, transit traffic/ocean going vessels and local traffic. Transit traffic is the ocean going vessels that enter or leave the port of Mombasa while the local traffic are the ferries, tugboats and pilot vessels that navigate at Mombasa approach channel. In this study tugboats and pilot vessels are omitted in classification as local traffic since they have little or no risk on the transit traffic.

2.3.1 Ocean going vessels/Transit Traffic

A five day Traffic survey was carried out at Mombasa approach channel in the period of 10TH to 14TH August 2015 where vessel data was collected from AIS using Marine traffic survey equipment which consists of a laptop with Mombasa ENC map, AIS transponder, and an antenna. Regulation 19 of SOLAS Chapter V requires AIS to be fitted aboard: all ships of 300 gross tonnage and upwards engaged on international voyages, all cargo ships of 500 gross tonnage and upwards not engaged on international voyages and all passenger ships irrespective of size.

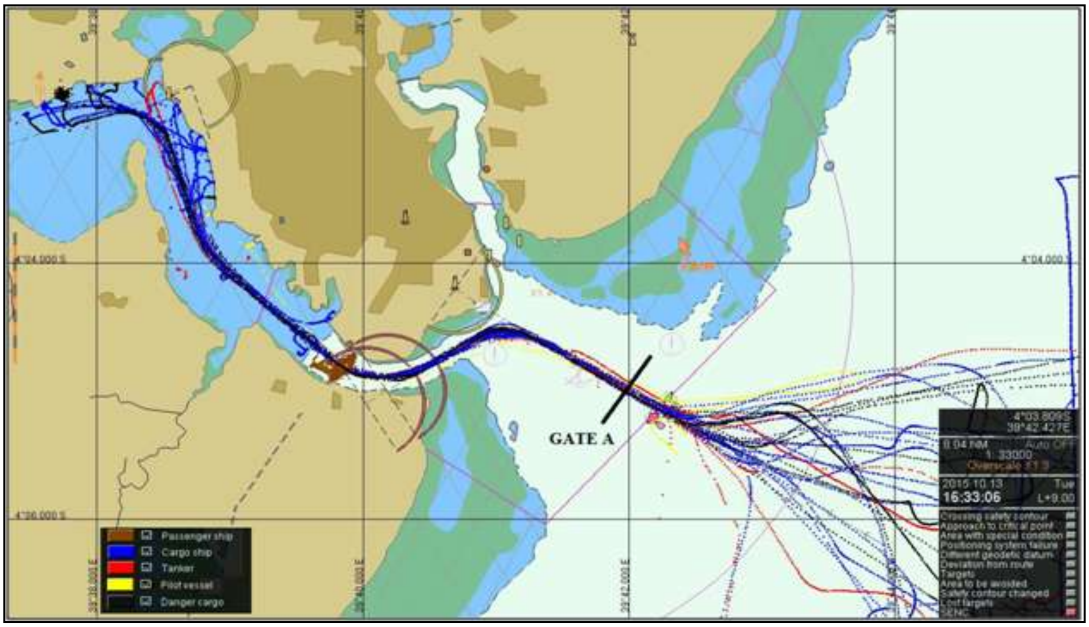
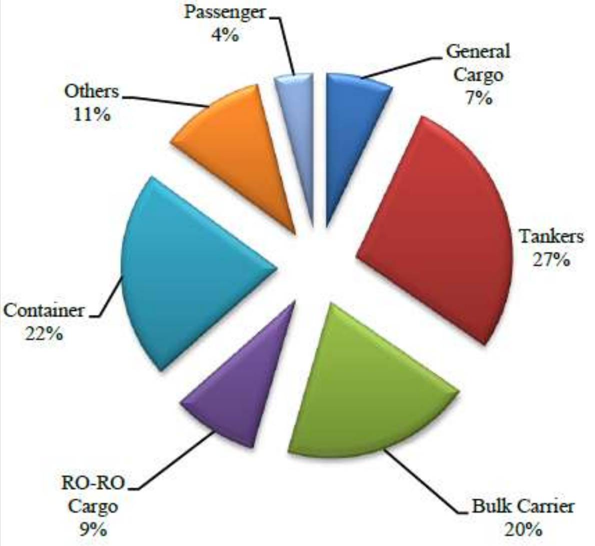


Figure 2.4 Traffic tracks based on vessel type from five day traffic survey

Figure 2.4 shows vessel traffic track plotted from five day AIS data collected from traffic survey. Gate A was created to count the number of vessels entering/leaving the port of Mombasa during the period of traffic survey. Observed traffic of ocean-going vessels is represented by the pie chart as shown in figure 2.5.

The majority of vessels calling at Mombasa port are containers, bulk carriers, and tankers. The 'Others' category consists of pilot vessels, dredger, and off-shore supply vessels.



GROSS TONNAGE	NO. OF SHIPS	(%)
0 - 100	0	0
100 - 500	0	0
500 - 3,000	7	17.5
3,000 – 5,000	1	2.5
5,000 – 7,000	0	0
7,000 – 10,000	0	0
10,000 – 20,000	6	15
20,000 – 50,000	23	57.5
50,000 – 100,000	3	7.5
OVER 100,000	0	0
TOTAL	40	100

Figure 2.5 Types of vessels and gross tonnage navigating in Mombasa channel as observed from gate A in figure 2.4

Figure 2.5 shows classification of vessels by gross tonnage as counted from gate A. It is observed that 57.5 percent of vessels calling at Port of Mombasa fall in the 20,000-50,000 gross tonnage categories. Vessels occupying this category are classified as Panamax vessels. Therefore, it is acceptable to state that majority of vessels calling at Mombasa port are Panamax.

2.3.2 Local Traffic

Figure 2.6 shows local traffic AIS tracks which constitute of ferries that operate at Likoni Channel. The ferries are managed by the Kenya Ferry Services (KFS), a government institution, which owns a total of 7 ferries. The ferry is the only link between Mombasa Island and the mainland, handling 300,000 pedestrians and 6,000 vehicles daily (KFS, 2016). Figure 2.7 shows one-day observation of the ferries that was collected on 21ST August 2015.

Each ferry makes an average of four trips per hour on normal operations which take 5 minutes to cross Likoni channel and 15 minutes to load. On average the ferries makes 196 crossing per day in total. The peak times are from 0500hrs to 0900hrs in the morning when most citizens are heading to work at Mombasa central business district in the island and 1700hrs to 2000hrs in the evening when everyone is rushing back home as shown in figure 2.7

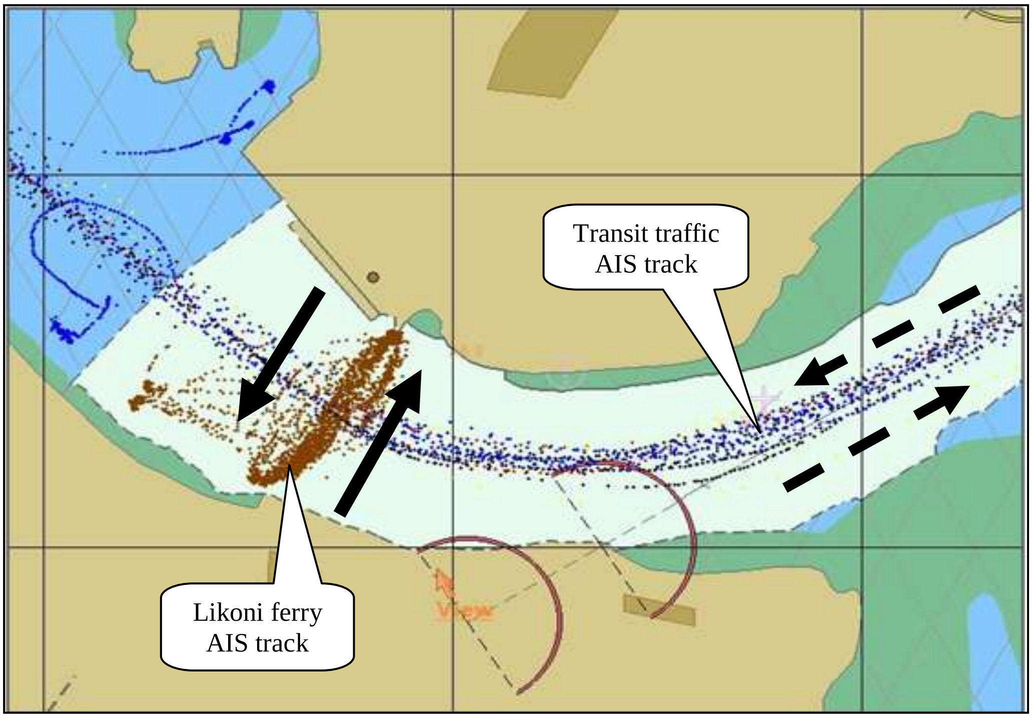


Figure 2.6 Ferry tracks at Likoni channel as observed from five days AIS data

At peak time, four ferries operating at Likoni channel. The ferry in figure 2.8 is 75m LOA, breadth of 16m, maximum speed across Likoni channel at 4 knots with a capacity of 1200 passengers and 25 vehicles.

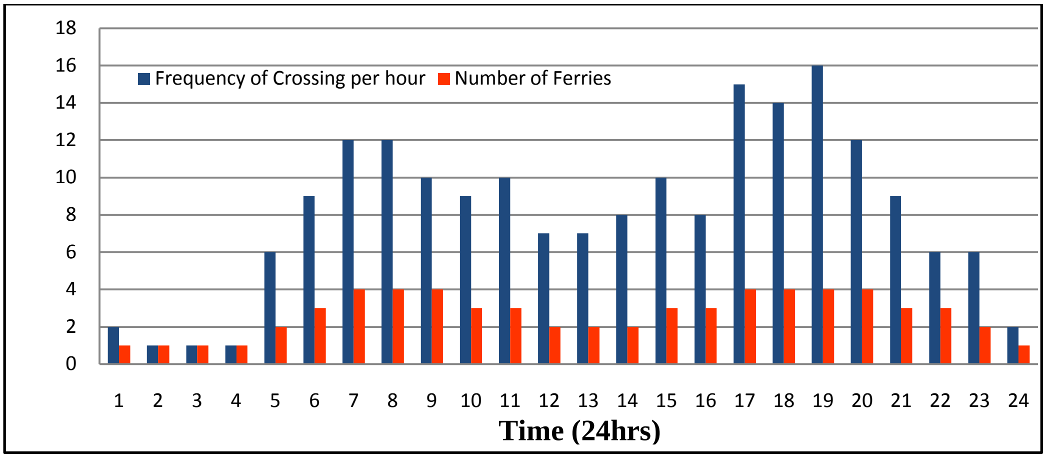


Figure 2.7 The total number of ferries and total number of crossing frequency at Likoni channel per hour

At peak time, four ferries operating at Likoni channel. The ferry in figure 2.8 is 75m LOA, breadth of 16m, maximum speed across Likoni channel at 4 knots with a capacity of 1200 passengers and 25 vehicles.

Figure 2.8 MV Likoni crossing Likoni channel.

From the local traffic survey results, it is evident that ferries pose as potential collision risk with transit vessels especially at peak periods of operation due to heavy local traffic. During the peak period, there is a ferry crossing the channel at any minute of the hour since four ferries operate at that time. Figure 2.9 shows a typical close quarter situation between the ferries and transit traffic. Therefore there is a need to quantify the navigation risk posed by local ferry traffic on transit traffic at Likoni channel.

Figure 2.9 MSC Martina underway to the port as MV Kwale waits to cross Likoni channel

2.4 Marine Traffic management

Marine traffic management is the implementation of managerial technical measures, with the consensus of the relevant people, to improve traffic safety in ports and waterway. Managerial elements of marine traffic management are vessel traffic separation scheme, speed restriction, traffic control by signals, the navigation information service, total traffic volume control, etc. Vessel Traffic Service (VTS) also assists in marine traffic management.

According to IMO definition, “VTS is a service implemented by a Competent Authority, designed to improve safety and efficiency of vessel traffic and to protect the environment”

2.4.1 Examination of Vessel Traffic Service (VTS)

Vessel Traffic Services is a service implemented by a competent authority, designed to improve the safety and efficiency of vessel traffic and to protect the environment. The service should have the capability to interact with the traffic and to respond to traffic situations developing in the VTS area.

The following are the main services that are rendered by a VTS according to IMO Resolution number A-857(20):

a) ***The information service*** is provided by broadcasting information at fixed times and intervals or when deemed necessary by the VTS or at the request of a vessel, and may include for example reports on the position, identity and intentions of other traffic; waterway conditions; weather; hazards; or any other factors that may influence the vessel's transit.

b) ***The navigational assistance service*** is especially important in difficult navigational or meteorological circumstances or in case of defects or deficiencies. This service is normally rendered at the request of a vessel or by the VTS when deemed necessary.

c) ***The traffic organization service*** concerns the operational management of traffic and the forward planning of vessel movements to prevent congestion and dangerous situations, and is particularly relevant in times of high traffic density or when the movement of special transports may effect the flow of other traffic. The service may also include establishing and operating a system of traffic clearances or VTS sailing plans or both in relation to priority of movements, allocation of space, mandatory reporting of movements in the VTS area, routes to be followed, speed limits to be observed or other appropriate measures which are considered necessary by the VTS authority.

The benefit of implementing a VTS is that it allows identification and monitoring of vessels strategic planning of vessel movements and provision of navigational information and assistance.

2.4.2 Mombasa Vessel Traffic Service

Mombasa Vessel Traffic Service (VTS) serves as both port and coastal VTS. The port VTS, is mainly concerned with vessel movement to and from Mombasa port, while the coastal VTS monitors vessels sailing in a delineated rectangular region in the coastal sea marked as Maritime Security Region. This region is under constant watch by Kenya navy against piracy on the vessels waiting to navigate into the port. The Vessel Traffic Centers (VTC) are stationed at 70m high port control tower located at $4^0\ 3.6'S$ and $39^0\ 38.9'E$ and Ras-Serani signal station. Transportation of dangerous cargo, rising ship calls at Mombasa port, complex oceanographic structure of the channel and complex traffic at Likoni channel due to the presence of ferries resulted to the establishment of VTS as from February 2008. The VTS monitors the entire Mombasa approach channel.

Kenya Ports Authority (KPA) is mandated with operation and maintenance of Mombasa VTS. KPA has made sure that the VTS complies with IMO Resolution A-857 (20), guidelines for VTS, SOLAS Chapter V regulation 12, IMO MSC circular 952, IALA Recommendations and Guidelines (IALA VTS Manual).

Mombasa VTS is equipped with two radar stations, at port control tower and at Ras Serani signal station, CCTV, Automatic Identification System (AIS) Base Stations, VHF & HF Base Stations, and other ancillary equipment. Mombasa VTS is able to receive and transmit information to various sources on vessel movements, hazard to navigation, available navigation assistance and other information of interest to the VTS participant. At the Vessel Traffic Centre, Navi-Harbour ENC software is installed for the sole purpose of monitoring vessel movement, the risk of close quarter situation, near misses, collision, grounding and providing caution/alarm where necessary. All these activities and data are recorded for future references.

The Mombasa VTS is equipped to solely provide information service, traffic organization and navigation assistance to transit traffic. This leaves out the local traffic even though traffic survey results show that local traffic poses a collision risk to transit traffic at the Likoni channel. Therefore there is a need to come up with a traffic management service for the Local Ferries.

2.4.3 Ferry traffic Management at Likoni channel

Kenya Ferry Services is government institution responsible for operation and maintenance of the ferries. The ferries carry across passengers and vehicle between Mombasa Island and Likoni mainland at Likoni channel. The ferries have a VHF radio installed for communication. Radar and AIS equipments are not installed on the Ferries.

When inbound/outbound vessel is making headway in the channel, the Mombasa VTS makes a VHF radio call to the ferries to "watch out" for vessel so as to give way to the passing vessel. There is no defined traffic service that has been setup to monitor local ferry traffic. Therefore, there is need to propose a traffic service for the ferries crossing at Likoni part of Mombasa approach channel.

2.5 Results and discussion

Analysis of the depth, width and bend radius of Mombasa approach channel using PIANC rules presented us with the following results;

a) Vessel up to 100,000 DWT with a breadth of 42.8m, maneuverability is not restricted by the width of the fairway. Therefore 100,000 DWT vessels can be able to maneuver through the outer channel and inner channel fairway without much difficulty.
b) A 100,000DWT container (post-Panamax) is restricted by channel bend radius to maneuver safely at the channel bends in outer channel and at the entrance to the inner channel.

c) Vessels with a draft greater than 14.6m have to consider tide when navigating on the outer channel. Vessel with draft up to 12.5m also has to consider tide when navigating in the inner channel.

From above observations, we can state that Mombasa approach channel width is sufficient for a one-way passage, vessels with draft exceeding 12.5m has to ride on tide when navigating and vessel with Loa above 220m is restricted by fairway bend radius when maneuvering at channel bends

Analysis from traffic survey shows that;

a) The majority of vessels calling at Mombasa port are Panamax in size.
b) Ferries pose as potential collision risk with transit vessels especially at peak periods of operation due to heavy local traffic. During the peak period, there is a ferry crossing the channel at any minute of the hour since four ferries operate at that time.
c) The Mombasa VTS is equipped to solely provide information service, traffic organization, and navigation assistance to transit traffic. This leaves out the local traffic even though traffic survey results show that local traffic poses a collision risk to transit traffic at the Likoni channel.
d) There is no defined traffic service that has been setup to monitor ferry traffic. Therefore, there is need to propose a traffic service for the ferries crossing at Likoni part of Mombasa approach channel.

Observations and results from traffic survey show that; there is a need to come up with a traffic management service for the Local Ferries, there is a need to carry out a quantitative risk assessment of the navigation risk posed by local traffic on transit traffic.

Chapter 3 Marine Traffic Risk Assessment in Mombasa Approach Chanel

3.1 General Overview

Marine traffic risk assessment involves numerical estimation of the safety level of fairway using risk assessment models. Marine traffic risk assessment establishes the current safety level of fairway and level of navigation difficulty in a fairway. The most commonly used Risk Assessment models are IALA Waterway Risk Assessment Program (IWRAP), Ports and Waterways Safety Assessment (PAWSA), Environment Stress (ES), Potential Assessment of Risk (PARK) and Formal Safety Assessment (FSA). In this study ES model, PARK model and IWRAP model were selected as the most appropriate risk assessment models for risk estimation of Mombasa approach channel due to the reasons stated in table 3.1

Table 3.1 Comparison of the Risk assessment models

Assessment Model	Features
IWRAP (IALA Waterway Risk Assessment Program)	– Quantitative model – Recommended by IALA – Calculates collision and grounding probabilities based on traffic volume
ES (Environmental Stress)	– Quantitative model – Calculates ship handling difficulty imposed by surrounding environment (topographical and traffic environment)
PARK (Potential Assessment of Risk)	– Quantitative model – Calculates risk of collision between own ship and target ship considering many factors such as crossing situation, distance, type of vessel, etc.

3.2 The Environmental Stress Model (ES)

ES model was developed by Japanese professors for risk assessment in waterways. ES model quantitatively expresses the relationship ‘ship-human-environment” in which the human factor plays a significant role in triggering an accident. The ES model has three main elements of environmental conditions; Topographical conditions such as land, shoals, shore protection, breakwaters, buoys, fishing net and other fixed obstacles; Traffic conditions such as density of ships and traffic flow; External disturbances such as wind and currents. The ES model structure, which expresses in quantitative terms, the degree of stress imposed by topographical and traffic environment on the mariner, is composed of three parts namely; (Inoue, 2000)

a) Evaluation of ship-handling difficulty arising from restrictions to the water area available for maneuvering. A quantitative index expressing the degree of stress forced on the mariner by topographical restrictions (ESL value) is calculated on the basis of the time to collision (TTC) with any obstacles.
b) Evaluation of ship-handling difficulty arising from restrictions on the freedom to make collision-avoidance maneuvers. A quantitative index expressing the degree of stress forced on the mariner by traffic congestion (ESS value) is calculated on the basis of the time to collision (TTC) with other ships.
c) Aggregate evaluation of ship-handling difficulty forced by both the topographical and traffic environments, in which the stress value (ESA value) is derived by superimposing the value ESL and the value ESS.

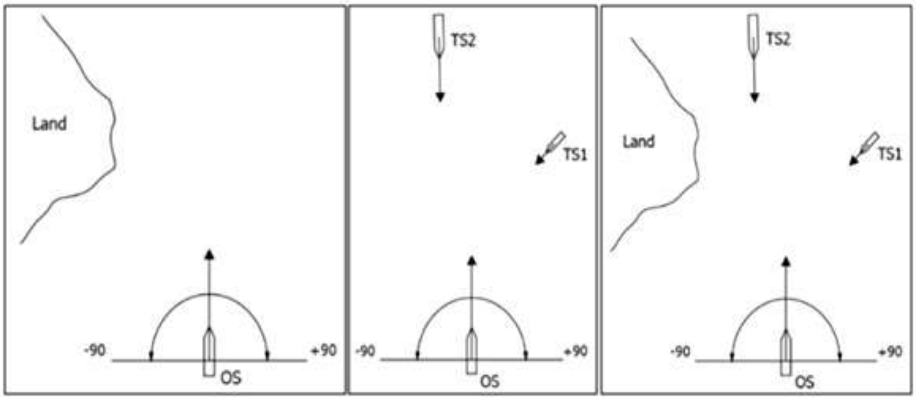


Figure 3.1 Stress to ship-handler caused by land (topography), ships (traffic environments) and an aggregate of the land and ship

The degree of stress is classified according to the extent to which a dangerous situation causes a particular SJ (subjective judgment) value in the range of ±90^0. The conversion formula 1 is given by regression equations found through ship-handling simulator experiments (31-subjects) and a questionnaire, 573-answers (Inoue, 1998).

$$SJ_L, SJ_S = \alpha \times TTC + \beta \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where;

SJ_S, SJ_L is subjective judgment of mariner in relation to time to collision, TTC, with ships

α and β are coefficients determined by combination of size of own ship and target ship

$$ES_L = \sum(ES_L)_i \qquad i = -90 \sim +90$$

$$ES_S = \sum(ES_S)_i \qquad i = -90 \sim +90 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

If there is no danger in any direction, the SJ value of 0 extends over 180°, 0 × 180 = 0 is assigned as the minimum stress value. If there is an immediate danger, regardless of the ship's direction, the SJ value of 6 extends over 180°, so 6 ×180 = 1000 is assigned as the maximum stress value.

The stress ranking is set up by classifying the range of stress values as 0 to 1000 as shown in Table 3.2

Table 3.2 Stress ranking in the ES model

SJ	MARINERS' JUDGMENT	ES value $\Sigma(SJ)_i$	STRESS RANKING	ACCEPTANCE CRITERIA
0	Extremely safe	0		
1	Fairly safe		NEGLIGIBLE	ACCEPTABLE
2	Somewhat safe			
3	Neither safe nor dangerous	500	MARGINAL	
4	Somewhat dangerous	750	CRITICAL	UNACCEPTABLE
5	Fairly dangerous	900	CATASTROPHIC	
6	Extremely dangerous	1000		

Evaluation of ship-handling difficulty arising from restrictions on the freedom to make collision-avoidance maneuvers (ES_S) is used to express the navigational risk imposed on transit traffic by the local traffic in quantitative value.

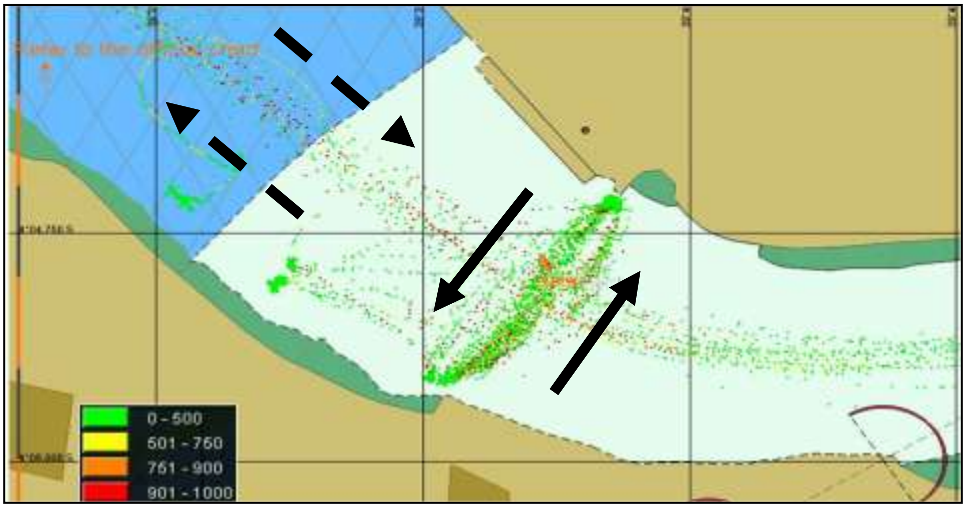


Figure 3.2 Shows ES stress plot of transit and local traffic at Likoni channel

Figure 3.2 is a real-time ES stress plot obtained from traffic survey at Mombasa. The track along the channel represents ESS plot for transit traffic while the ESS plot across the channel is for the ferries. The dotted arrows represent the general movement of transit traffic along the channel while the bold arrows represent the general movement of ferries across the Likoni channel.

Table 3.3 ES stress ranking in the Likoni channel

Stress Value	Transit Traffic		Ferry Traffic		Total	
	Frequency	(%)	Frequency	(%)	Frequency	(%)
900 < ESS ≤ 1000	238	25.2	374	14.6	612	17.5
750 < ESS ≤ 900	27	2.9	85	3.3	112	3.2
500 < ESS ≤ 750	208	22.1	188	7.3	396	11.3
0 ≤ ESS ≤5 00	470	49.8	1910	74.7	2380	68.0

Table 3.3 shows the ESS index compiled for the region $39^0\ 39.5'E,\ 4^0\ 4.5'S$ and $39^0\ 40.0'E,\ 4^0\ 05.0'S$ from real-time traffic survey at Mombasa in the period of 10TH to 14TH August 2015. The ESS index is the stress value calculated on the basis of the time to collision with other ships. From the assessment result, Likoni channel has catastrophic stress at 17.5% in total percentage (transit and local traffic). The total percentage of unacceptable stress ('catastrophic' and 'critical' level) in Likoni channel stands at 20.7%, almost equal to most risky Sector A2 on Istanbul straight which has unacceptable ES stress at 39.8% (Aydogdu et al, 2012). This is quite sizeable to declare Likoni channel as a high collision risk area thereby advising pilots to be cautious always when approaching Likoni channel.

The unacceptable stress level at Likoni channel can be explained by the fact that, there are ferries operating in this area and narrow channel which is 500m wide. These two conditions put stress on the mariner as the vessel approaches Likoni channel.

3.3 The Potential Assessment of Risk Model (PARK)

In 2011, an evaluation index for assessment risk in a waterway was developed through the evaluation of maritime traffic environment (Kim Jong-Sung et al., 2011). The research team conducted surveys on Korean seafarers and then did statistical analysis to find out the relation between evaluation index with ships' LOA, crossing situation (045°, 090°, 135°), overtaking, head-on situation, encountering vessel's side, inside or outside harbor, speed with other vessel (same, fast or slow), speed difference with other vessel and distance with other vessel. Also based on a questionnaire survey, in 2012, a Marine Traffic Risk Model for Mariners was developed (Heo Tae-Yong et al., 2012), in which, the risk of a waterway depends on ship type, gross tonnage, length, width, competency of officer on watch (OOW), etc.

The PARK model is a risk assessment model that has been developed based on the two papers discussed above for the purpose of doing marine traffic safety assessment in Korean waterways. After the study, the research team divided elements that could affect marine traffic safety of a ship into two groups as shown in table 3.4.

Table 3.4 Elements affecting marine traffic safety of a ship

Internal elements		**External elements**	
1.	Type of ship	8.	Crossing situation
2.	Tonnages	9.	Approaching side
3.	Length	10.	Inside/outside harbor
4.	Width	11.	Speed correlation
5	Career	12.	Speed difference
6.	License	13.	Distance
7.	Position		

By regression analysis on the above elements, the impact of each element was found out and shown in table 3.6. The risk of marine traffic safety of own ship in correlation with a target ship is quantified by the "Risk" value that is calculated based on the formula (3) below.

Risk value = 5.081905 + type factor + ton factor + length factor + width factor + career factor + license factor + position factor + 0.002517 * LOA + crossing factor + side factor + in/out harbor factor +speed factor – 0.004930 * speed difference – 0.430710 * distance……………………………………………… (3)

The aggregate risk of marine traffic safety of an own ship is determined by the risk value of it in correlation with the most dangerous target ship.

In other words, it is the maximum value of Risk values of the own ship in correlation with each target ship around. The risk ranking in PARK model when compared with ES stress ranking is as shown in table 3.5.

Table 3.5 Stress ranking in the ES model and the PARK model

ES model (ESA value)		PARK model (Corrected Risk value)
0		0
	NEGLIGIBLE	
500		4
	MARGINAL	
750		5
	CRITICAL	
900		6
	CATASTROPHIC	
1000		7

Table 3.6 Value of factors which indicate the impact of each element to marine traffic safety of a ship in PARK model

Ton factor

not more than 500 ton	0.634656
500-1,000 ton	-0.229980
1,000-3,000 ton	2.180813
3,000-5,000 ton	-0.093240
5,000-7,000 ton	-0.345600
7,000-10,000 ton	-0.765630
10,000-15,000 ton	-0.126220
15,000-20,000 ton	-0.131530
20,000-25,000 ton	0.217815
25,000-30,000 ton	-0.145350
30,000-50,000 ton	-0.656140
50,000-60,000 ton	0.063690
60,000-75,000 ton	-0.381260
75,000-100,000 ton	0.313252
more than 100,000 ton	0.000000

Career factor

not more than 1 year	-0.104830
1-3 years	-0.332360
3-5 years	-0.064230
more than 5 years	-0.136730

Crossing factor

CR45	0.468465
CR90	0.500211
CR135	0.660194
HO	0.626923

Length factor

not more than 70 m	-1.065590
70-90 m	-2.487910
90-108 m	-0.533920
108-123 m	-0.142000
123-140 m	-0.091250
140-160 m	0.754828
160-185 m	-0.499360
185-223 m	-0.927940
223-243 m	0.562870
243-259 m	0.046498
259-277 m	0.709714
more than 277 m	-0.249550

License factor

merchant 1 class	0.177682
merchant 2 class	0.109177
merchant 3 class	0.245199

Position factor

captain	0.184283
chief officer	0.176755
2nd officer	0.296052
3rd officer	-0.075180

Side factor

TS on Starboard side	-0.056600
TS on Port side	0.000000

Width factor

not more than 10 m	0.500588
10-15 m	-0.025510
15-20 m	0.210588
20-25 m	-0.289200
25-30 m	0.360838
30-35 m	0.099504
35-40 m	0.343936
40-45 m	0.046159
more than 45 m	-0.289570

Type factor

fishing vessel	-0.072820
container ship	-0.335320
pure car carrier	-0.031670
tanker	-0.082580
LNG/LPG carrier	0.315854
passenger ship	-1.597980
towing vessel	-0.116540
other cargo ship	0.000000

Speed factor

OS speed # TS speed	0.120578
OS speed < TS speed	-0.056520
OS speed > TS speed	0.000000

In/out harbor factor

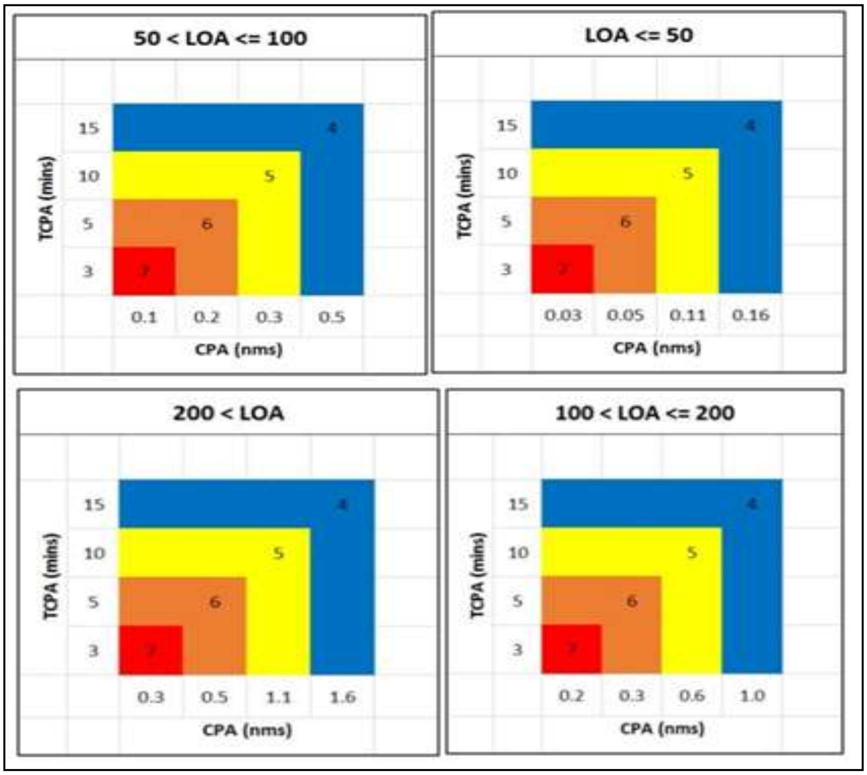
OS inner harbor	0.062305
OS outer harbor	0.000000

The risk values calculated by the PARK model should be calibrated based on the actual distance to collision (CPA: Closet Point of Approach) and time to collision (TCPA: Time to Closest Point of Approach) between own ship and each target ship as shown in table 3.7. The risk value which is calibrated is called the Corrected Risk value.

The aggregate risk of the marine traffic safety of an own ship is determined by its corrected risk value with the most dangerous target ship. In other words, it is the maximum of corrected risk values of the own ship with each target ship..

A five day AIS data was used to carry out risk estimation of the Mombasa approach channel. Risk values were calculated using PARK model, where the transit traffic was assumed as the own ship while the local traffic was target ship. The risk values were used to create a risk profile of Mombasa approach channel as shown in figure 3.3

Table 3.7 Calibration table of the PARK model



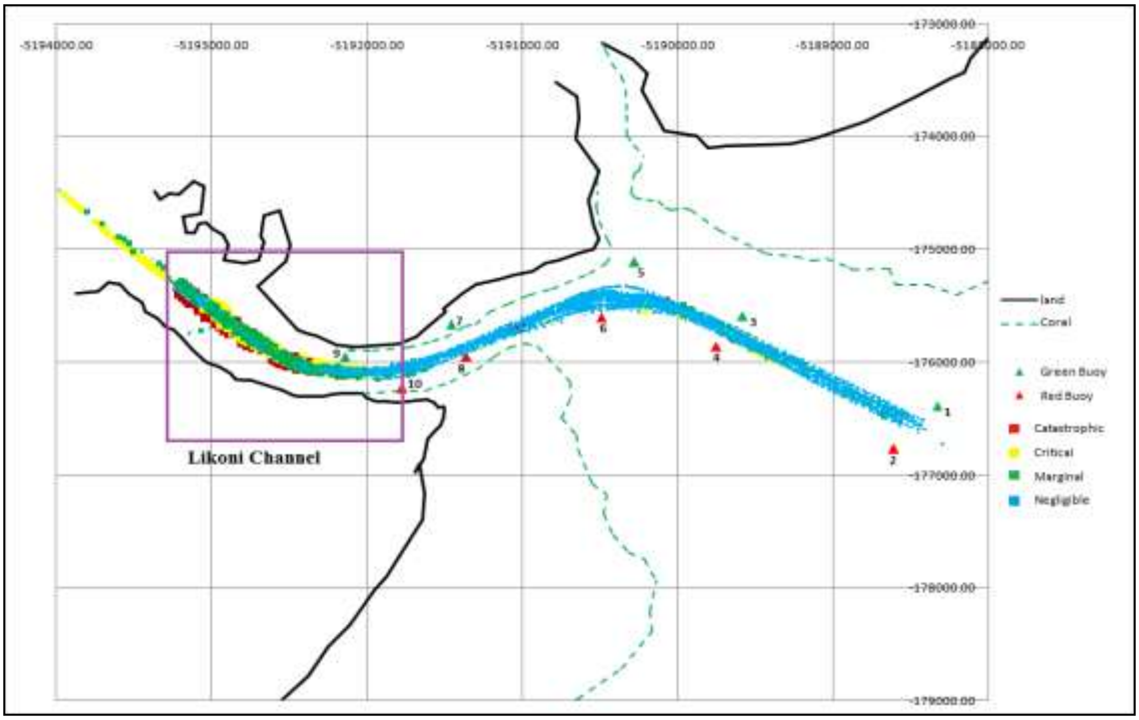


Figure 3.3 PARK risk profile of Mombasa approach channel

Figure 3.3 shows risk plot throughout Mombasa approach channel from buoy 1 to buoy 10. The green dotted line is the boundary of the shallow coral reefs that are always visible during the low tide. The black line is the shoreline. From figure 3.3 it is observed that the region at the entrance into the inner channel (Likoni channel), the risk values are unacceptable. That is, there is a high concentration of catastrophic, critical and marginal risk. Plotting risk values for the Likoni region gives a clear picture of the interaction between local traffic and transit traffic as shown in figure 3.4.

The risk values in the Likoni channel were compiled for the coordinates 39^{o} 40.400’ E, 4^{o} 4.897’ S and 39^{o} 39.504’ E, 4^{o} 4.498’ S after which the risk values were tabulated as shown in table 3.8

From the risk estimation result, table 3.8, it is noted that Likoni channel has a total unacceptable risk (sum of ‘catastrophic’ and ‘critical’ risk) adding up to 35.48% with acceptable risk (sum of ‘marginal’ and ‘negligible’) adding up to 64.52%.

This is attributed to the fact that Likoni channel is a high-density traffic area as a result of ferry operation with a narrow channel of 500m wide.

Table 3.8 PARK Risk level at Likoni channel

LIKONI CHANNEL RISK PROFILE				
RISK PLOT	**RISK RANK**	**FREQUENCY**	**(%)**	**CRITERION**
6 < RISK ≤ 7	Catastrophic	144	11.91	35.48
5< RISK ≤ 6	Critical	285	23.57	
4< RISK ≤ 5	Marginal	375	31.02	64.52
0< RISK ≤ 4	Negligible	405	33.50	
SUM		1209	100.00	

Therefore Likoni channel can be labeled as a high collision risk area for transit traffic with local traffic. Therefore there is a need to come up with risk mitigation measures so as to reduce the unacceptable risk.

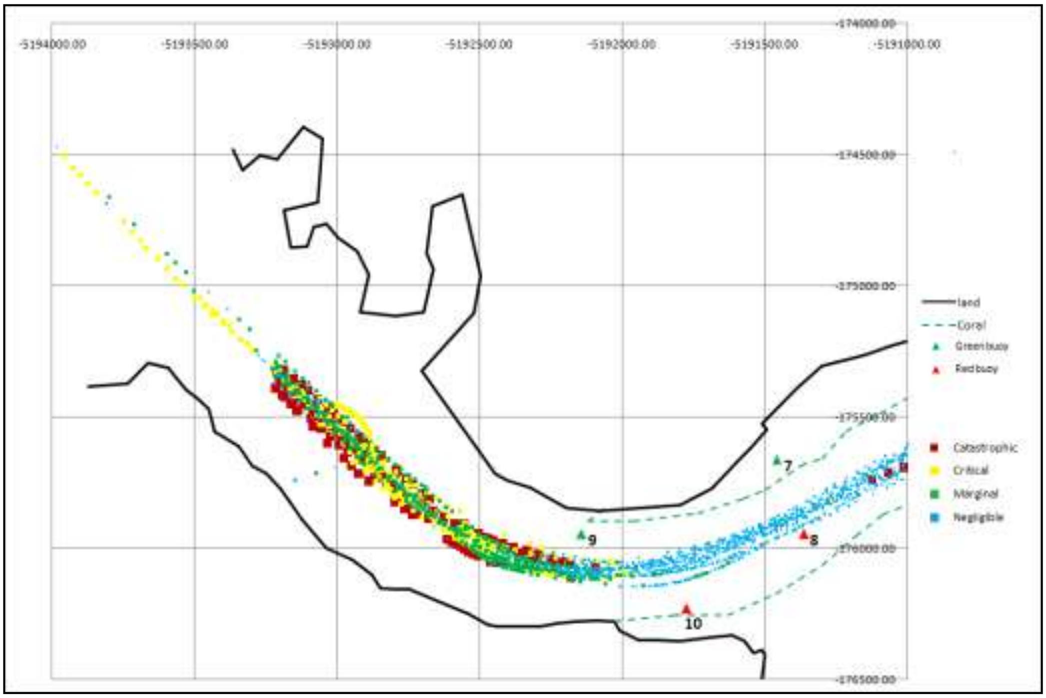


Figure 3.4 PARK risk profile plot of Likoni channel

3.4 IWRAP Mk2 Model

The IALA Waterway Risk Assessment program (IWRAP program) was developed by IALA together with the Canadian Coast Guard, the Technical University of Denmark and the Maritime Simulation Centre Warnemünde in the 1990s and the IWRAP Mk2 program was released in 2009 (IALA, 2009). IWRAP mk2 program is a tool for the evaluation of collision and grounding probabilities by International Association of Lighthouse Authorities (IALA, 2009).

In this study, IWRAP mk2 model is used in assessing collision and grounding probabilities in Mombasa channel. In IWRAP mk2 model the frequency of accidents is modeled by the following basic formula (4);

$$\lambda = NG \times P \ldots\ldots\ldots\ldots\ldots\ldots \text{(4)}$$

Where;

λ Frequency of collision or grounding accidents.

NG Geometric number of collision/grounding candidates.

P Causation factor

Geometric number of collision/grounding candidates and causation factors are modeled from MacDuff (1974), Fujii et al, (1974) and Pedersen (1995) models. IWRAP Mk2 program assumes the following default causation factors which are drawn from Fujii and Mizuki (1974) and McDuff (1974) observations as shown in table 3.9.

Table 3.9 Default causation factors of IWRAP Mk2 program

Incident	Causation factor
Head on collisions	0.5×10^{-4}
Overtaking collisions	1.1×10^{-4}
Crossing collisions	1.3×10^{-4}
Collisions in bend	1.3×10^{-4}
Collision in merging	1.3×10^{-4}
Grounding-forgetting to turn	1.6×10^{-4}

The available IWRAP Mk2 program available had a non-commercial license, basic version. Therefore, traffic distribution was manually uploaded into IWRAP program after sorting AIS data collected during traffic survey by TOAIS (Total AIS) program, a program developed by Nguyen et al (2013) to pre-process AIS data as shown in figure 3.5. The TOAIS program processes the AIS data to produce volume of traffic and lateral distribution of traffic on each route leg drawn by the user.

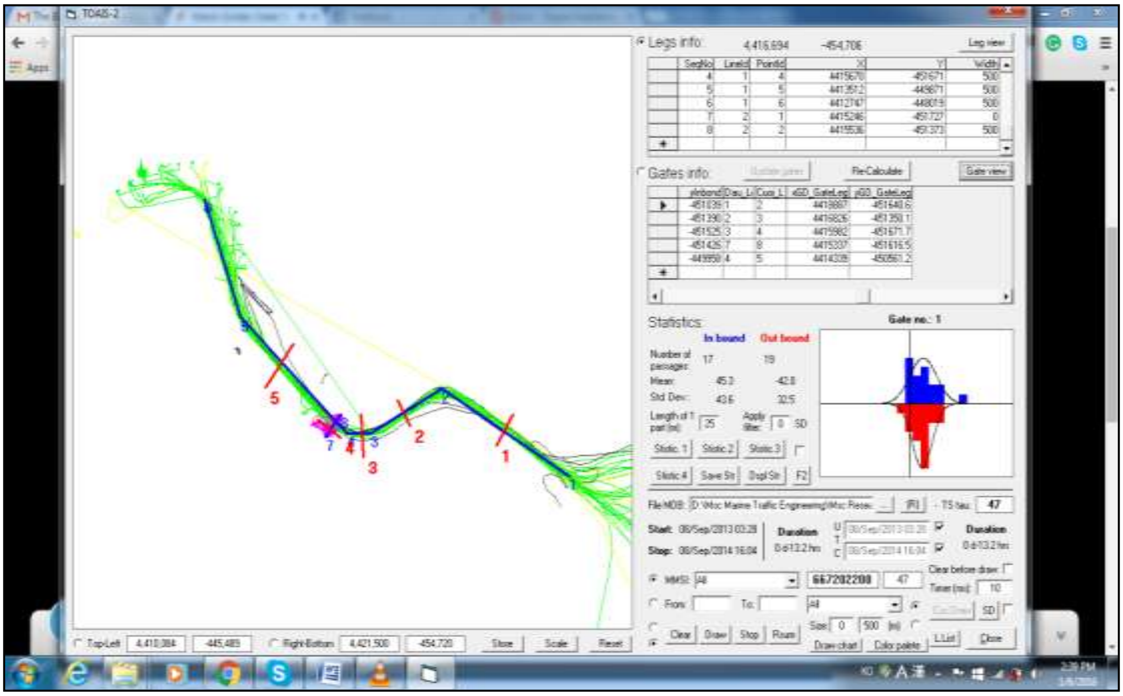


Figure 3.5 Vessel tracks, Legs and traffic distribution from TOAIS program

Table 3.10 Traffic distribution in Mombasa channel as computed from TOAIS program

	Width (m)	**Traffic Volume (vsl/hr)**	**Mean (m)**		**Standard Deviation (m)**	
			East bound	**West bound**	**East bound**	**West bound**
Leg 1	300	0.3	42.0	45.3	32.5	43.6
Leg 2	300	0.3	36.2	30.7	24.1	37.3
Leg 3	300	0.3	18.8	3.5	18.6	46.3
Leg 4	300	0.3	19.5	9.9	56.9	44.6
Leg 5	300	3.7	73.2	88.4	38.9	23.1
Leg 6	300	3.7	36.8	22.9	28.5	41.4
Leg 7	300	0.3	0.9	25.4	29.1	28.3

Each leg and waypoint traffic distribution, traffic direction and default causation factors were defined accordingly as indicated in table 14. Depth curves were traced from an uploaded Mombasa port raster map as shown in figure 3.6.

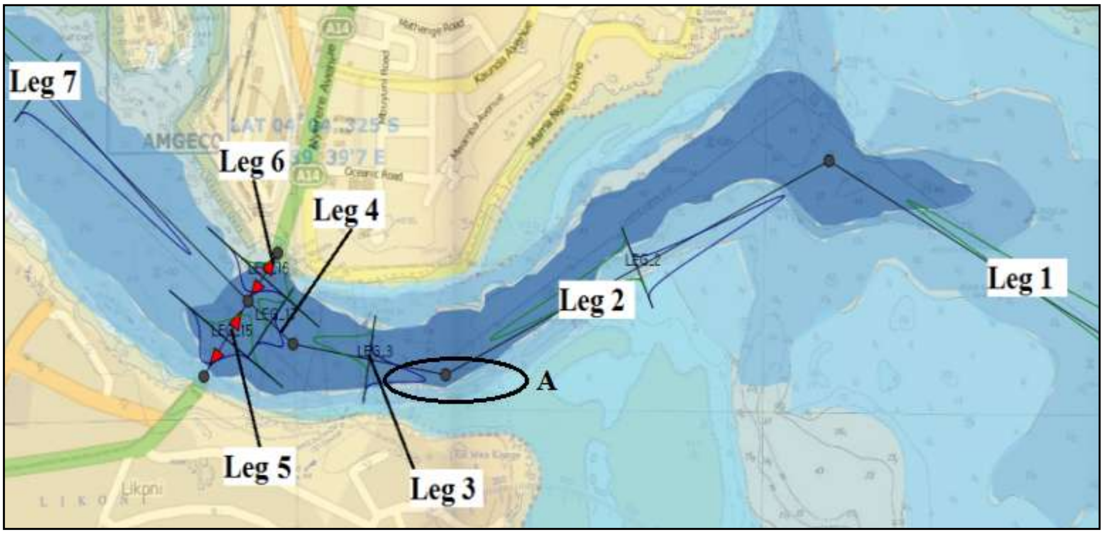


Figure 3.6 Legs, traffic distribution and depth curves on IWRAP Mk2 program

A Leg is the principal and necessary element for the safety assessment in IWRAP. Depth curves from polygon tool are used in grounding frequency calculation (Kim et al., 2011).

It should be noted that probability of a head on collision was not included in our results because Mombasa approach is a one-way channel. From table 3.11 it is observed that total groundings in Mombasa and Ulsan waterway are almost equal but powered grounding frequency in Mombasa is almost twice that of Ulsan. Region A, as shown in figure 3.7, has the highest risk of grounding. The high risk of grounding is due to shallow coral reefs and large sand banks at the entrance of inner channel which is always exposed during low tide.

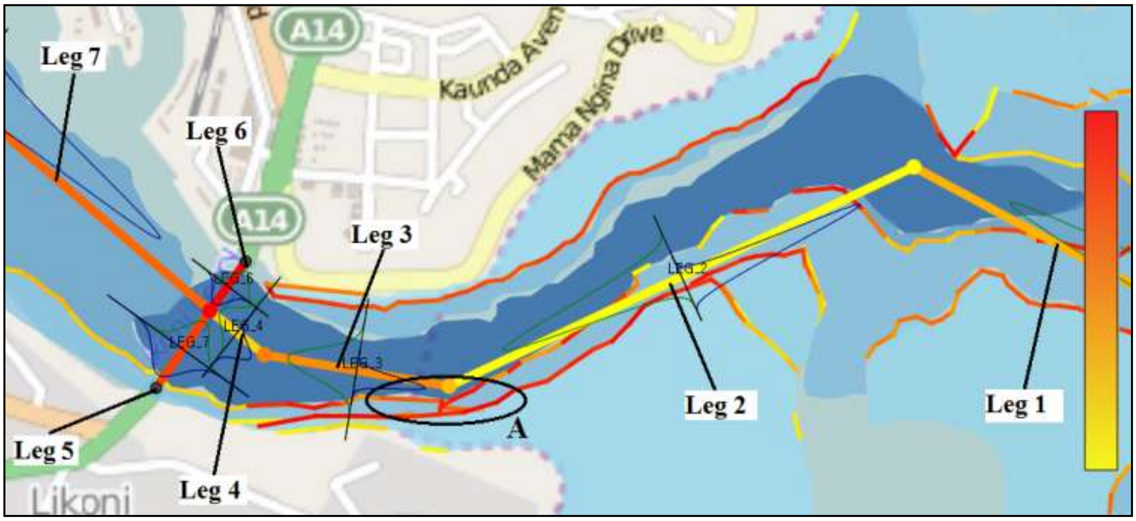


Figure 3.7 Assessment results from IWRAP Mk2 program

There is a high risk of crossing collision at Likoni channel represented by leg 6 and leg 7 from figure 3.7, due to heavy traffic from ferries crossing in this area. Leg 3 has a high risk of bend collision with predicted bend collision frequency at 0.007616 incidents per year. The total crossing collision frequency in Ulsan is three times that of Mombasa waterway.

Table 3.11 Frequency of grounding and collision as calculated by IWRAP Mk2 Program compared to Ulsan

INCIDENT	FREQUENCY (INCIDENTS/YEAR)	
	MOMBASA	ULSAN
Powered grounding	2.183	1.37536
Drifting grounding	0.0802	0.839026
Total groundings	2.264	2.21438
Overtaking	0.00279	0.198466
Crossing	0.01253	0.0440573
Bend	0.001696	0.147784
Total collisions	0.03989	0.682107

3.5 Results and Discussion

A study on the marine traffic risk assessment shows the following observations, recommendations, and conclusion.

a) The ES model and Park Model were the most practical in assessing the navigation risk of the local ferry on the transit traffic. The ES and Park model express the ship to ship interaction in quantitative value.

b) The IWRAP program, recommended by IALA, was most preferred in estimating the risk of collision and grounding on Mombasa fairway.

c) Risk assessment by ES model showed that the total percentage of unacceptable stress ('catastrophic' and 'critical' level) in Likoni channel stands at 20.7%, almost equal to most risky Sector A2 on Istanbul straight which has unacceptable ES stress at 39.8% (Aydogdu et al, 2012).Risk assessment by PARK model shows that Likoni channel has a total unacceptable risk (sum of 'catastrophic' and 'critical' risk) adding up to 35.48%.

d) There is a high risk of crossing collision at the crossing region where ferry operates.

e) Total groundings in Mombasa and Ulsan waterway are almost equal but powered grounding frequency in Mombasa is almost twice that of Ulsan

From the observations above, we can conclude that Likoni channel, the region where ferry crosses, is a high collision risk area for transit traffic with local traffic. Therefore there is a need to come up with a traffic management measures that will mitigate the risk of collision and grounding thereby improving marine traffic safety. The high risk of powered grounding is as a result of the presence of shallow coral reefs and sand banks in the channel. Proposing mitigation measure that improves position fixing when underway in the fairway will reduce the risk of a vessel running aground.

Traffic control of ferries, Local Traffic Service (LTS), VTS report line and proper layout of AtoN were the proposed countermeasures which are discussed in chapter 4.

Chapter 4 A Study of Effective Vessel Traffic Risk Mitigation measures

Vessel traffic management is a crucial element in navigation safety that offers the managerial technique to assess the effect of each marine traffic management measures systematically. It moreover simplifies the ability to explain the logical necessity of implementing the policies to the relevant traffic safety authority (Park, 2002). In this study, mitigation measures are assessed with the sole aim of reducing risk to acceptable level thereby improving navigation safety in Mombasa approach channel. After study of marine traffic risk assessment results, Marine traffic safety experts recommended the following risk mitigation measures for Mombasa approach channel;

a) Traffic control of Likoni Ferries
b) Establishment of Local Traffic Service
c) VTS reporting line
d) Layout of AtoN

Each of the mitigation measures is discussed to exhaustion in this chapter.

4.1 Traffic Control of Likoni Ferries

Traffic control is a risk mitigation policy implemented on local ferry traffic at Likoni channel. Traffic Control of Likoni Ferries involves activities that reduce collision risk between local ferry and transit traffic. Proposed traffic control activities are;

a) Stopping the ferry when transit traffic is making headway into/out of the port
b) Ferry to be stopped at the far end of the fairway so as to reduce close quarter situation.
c) Stop the ferries when transit traffic is 1.5 miles away (buoy number 6).

PARK model was preferred as suitable risk assessment model due to the following reasons;

a) The PARK model is good for applying in waterway which has congested traffic area and land effect does not impose on risk value clearly (Park, 2013)

b) In the coastal waters (2–10 nautical miles far from the coast), the PARK model gives consistent results than the ES model. (Nguyen, 2013)

c) PARK Model equation has more subjective variables (external elements as shown in table 3.4) therefore giving us more options when establishing countermeasures for mitigating risk of marine traffic as opposed to ES model which only has the TTC as a subjective variable.

The above three traffic control activities were simulated by modifying five-day AIS data collected in traffic survey in accordance with traffic control activities mentioned above. The risk values were calculated using PARK model to verify whether unacceptable risk will reduce to an allowable level. Figure 4.1 shows PARK risk plot when traffic control was implemented. It is observed that the marginal risk (green) is dominant on the Likoni channel.

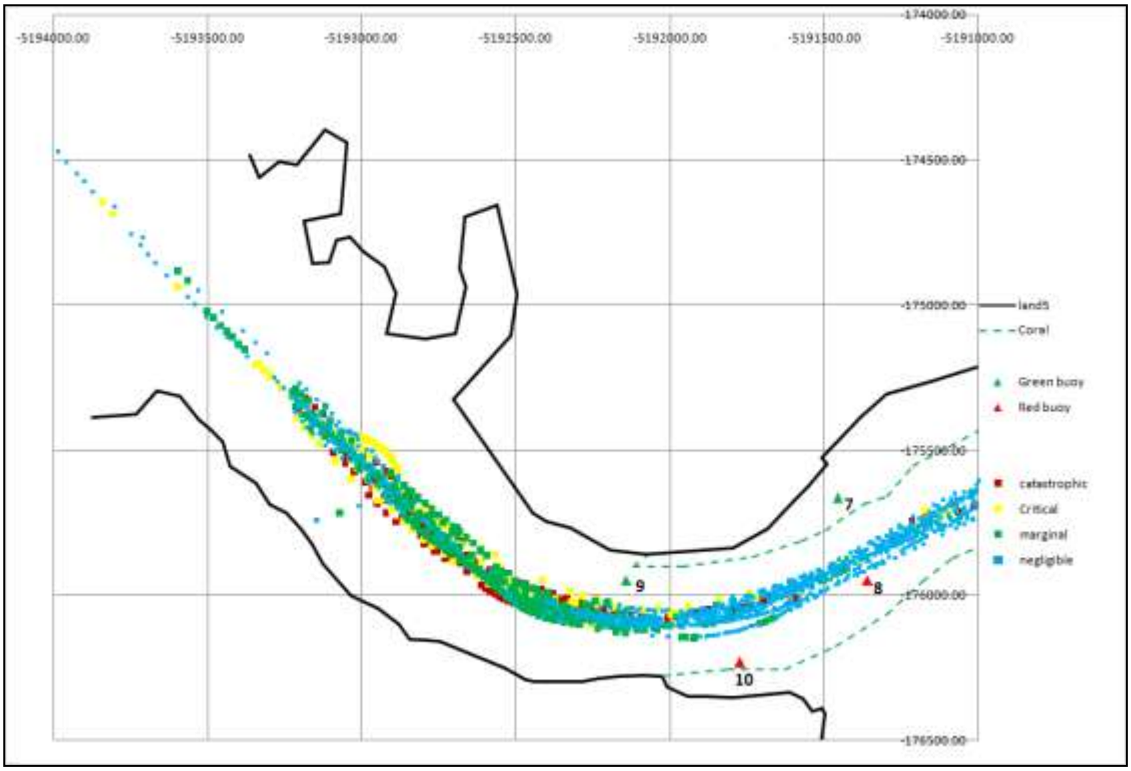


Figure 4.1 PARK risk profile after traffic control of local ferry traffic

From table 4.1 it is observed that traffic control effectively reduces unacceptable risk level (sum of 'catastrophic' and 'critical' risk) from 35.48% to 27.85% which is in the region of allowable risk level.

Therefore it is prudent to conclude that traffic control of the local traffic is effective in reducing collision risk at Likoni channel as demonstrated by PARK model.

Table 4.1 PARK risk level at Likoni channel when traffic control is implemented

TRAFFIC CONTROL				
RISK PLOT	**RISK RANK**	**FREQUENCY**	**(%)**	**CRITERION**
$6 < RISK \leq 7$	Catastrophic	124	10.25	27.85
$5 < RISK \leq 6$	Critical	213	17.60	
$4 < RISK \leq 5$	Marginal	374	30.91	72.15
$0 < RISK \leq 4$	Negligible	499	41.24	
SUM		1210	100.00	

4.2 Local Traffic Service (LTS)

Local Traffic Service functions in a similar fashion as Vessel Traffic Service, only that it is mainly concerned with efficiency and safety of local ferry traffic. LTS was suggested to supplement traffic control as a risk mitigation policy.

The LTS is tasked with implementation of traffic control of Local ferry. Therefore, LTS is to be operated and maintained by the Kenya Ferry Services (KFS). The LTS has similar functions as VTS as shown in table 4.2. However, LTS does not interact with the transit traffic and more-so does not require to be run by a competent authority.

For the LTS center to be effective in its function, VHF equipment has to be installed for information service, navigation assistance and traffic organization. To minimize the cost of running a LTS, the VTS can share Radar images via data link with the LTS so as to monitor traffic in area of coverage. Figure 4.2 shows proposed location of the Local Traffic center and coverage area of LTS.

Table 4.2 Comparison between functions of LTS with VTS

	Local Traffic Service (LTS)	*Vessel Traffic Service (VTS)*
Information service	Collect information of transit traffic so as to advise local traffic.	Broadcast information to transit traffic
Traffic organization	Planning of decongestion of fairway when transit traffic is underway.	operation management of transit traffic and planning of vessel movements so as to prevent congestion and dangerous situations
Navigation assistance	offered when local ferry has difficulty in navigation	rendered when transit traffic has difficulty in navigation

The LTS centre is proposed to be located at Likoni, at the entrance to the inner channel, since this is a high traffic area with a narrow channel, 500m width. The coverage area is a region bounded by a distance of 1.5 nm from ferry crossing region. The details on location of LTS and LTS coverage area were proposed from IMO Resolution A.857 (20); Guidelines for Vessel Traffic Services.

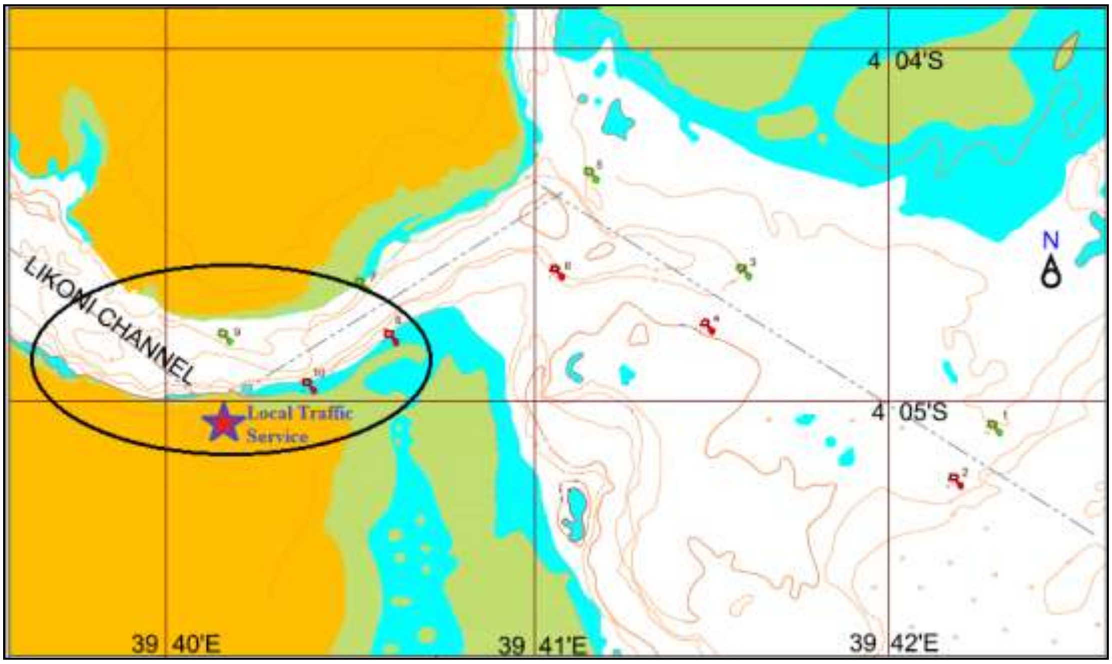


Figure 4.2 Location of LTS centre and coverage area of the LTS

4.2.1 Validation of Local Traffic Service by expert survey.

Questionnaire survey was conducted to the Mombasa VTS officers (VTS-O) who have experience on Mombasa approach channel. The aim of the questionnaire was to collect opinion on effectiveness of setting up a Local Traffic service as shown in the Annex. A total of 7 questionnaires were gathered from the VTS officers with an average experience of 3.71 years as VTS-O.

The survey consisted of two parts as show in the Annex. The first part had four questions on Local Traffic Service. Questions 1, 2 and 4 are evaluated and graded on five Likert scale; 1-minimum/lowest risk to 5-maximum/highest risk. The questions are evaluated from “1-not effective” to “5-very effective” on the questionnaire.

Participant’s evaluation on how effective will the LTS contribute to the reduction of risk of collision between ferry and ocean-going vessels showed an average score of 3.43 on a five Likert scale. Moreover, participants agreed by a score of 3.33 on a five Likert scale that LTS will reduce workload on VTS. 85.7 % of participants agreed that the proposed area coverage is adequate for the LTS. Participants agreed that the position of Local Traffic Centre is favorable with a score of 4.29 on a five Likert scale.

The result generally shows that;

a) The VTS-Os agree, by a slight majority, that the establishment of a Local Traffic Service will reduce the risk of collision between ferry and ocean-going vessels.
b) Majority of the VTS-Os agree that establishment of LTS will reduce workload on the VTS.
c) A high majority of VTS-Os agree that the area coverage of 1.5nm from crossing area is adequate for the LTS.
d) A high majority of VTS-Os agree that the location of LTS traffic centre is favorable.

Therefore we can conclude that the proposals that are made in the Local Traffic Service are valid and agree with the opinion of the traffic experts.

4.3 VTS reporting line

Mandatory ship reporting system means a ship reporting system that requires the participation of specified vessels or classes of vessels, and that is established by a government or governments after adoption of a proposed system by the International Maritime Organization (IMO) as complying with all requirements of regulation V/8–1 of the International Convention for the Safety of Life at Sea, 1974, as amended (SOLAS), except paragraph (e) thereof. Ship reporting systems are established to improve safety of life at sea, safety and efficiency of navigation, and/or increase the protection of the marine environment.

There is no existence of a vessel reporting line in Mombasa approach channel. Vessels of 300 GRT or more which intends to enter the Port of Mombasa have to notify the Harbor Master at least 24-hours before the arrival. In this study, the proposed vessel reporting line is to avoid a case of collision between inbound transit traffic with ferries at Likoni channel thereby improving marine traffic safety.

The outbound traffic before leaving the port has to report to the Mombasa VTS thereby initiating traffic control of the ferries. The reporting line will add to the Mombasa VTS support systems thereby increasing marine traffic efficiency and safety by constant monitoring of the reporting vessel from reporting area to berth using ARPA/Radar or AIS. The position of reporting line was determined using stopping characteristics of the design ship as shown in table 4.3.

Table 4.3 Dimensions and maneuvering characteristics of design ship

Vessel type	**Container**
Length overall	279m
Breadth	40.4m
Draft	14m
Full speed ahead	27.1 kn
Stopping maneuver head reach (Full ahead to full astern, FAH-FAS)	13.4 cables (1.34nm)
Stopping maneuver head reach (Slow ahead to slow astern, SAH-SAS)	9.88 cables (1 mile)

Source: Transas Ship models (2014)

The position of reporting line was determined using stopping characteristics of the design ship as shown in table 4.3. Mombasa port accommodates vessel with up to 290m length overall (LoA). Therefore a design ship with 279m LoA provides a suitable choice which is within the limit on maximum size of ship. The reporting line is to be located approximately 2 nautical miles from Likoni ferry crossing point at Likoni channel. That is, the position of paired buoy No. 3 and 4 as shown in figure 4.3. The use of head reach, slow ahead to slow astern (SAH-SAS), is the criteria used to identify the position of reporting line. The SAH-SAS stopping maneuver is carried out at 14 knots which is the closest speed, 11knots ±4knots SD, with which vessels navigate through Mombasa approach channel. Therefore SAH-SAS stopping distance is used in calculating position of ship reporting line. A factor of safety, 2, was picked to provide sufficient safe distance for stopping maneuver.

The details below are proposed for the ship reporting system as per IMO Resolution MSC.43 (64) – Guidelines and Criteria for Ships Reporting System;

a) The reporting line is to be named MOMREP (Mombasa Ship Reporting line)

b) Reporting line is to be located at paired buoy No. 3 and 4.

c) Distance from the ferry crossing line to reporting was calculated as

$$2 \times (SAH - SAS) = 2 \times 1 = 2nm$$

d) The reporting system should be mandatory for every vessel of 300GT or more.

e) All west-bound vessels with the exception of pilot and dredging vessels are to take part in ship reporting system

f) The participating vessel must report to Mombasa VTS centre and LTS when passing buoy No. 3 and 4 using VHF voice radio communication giving the following details; ship name, call sign, and speed.

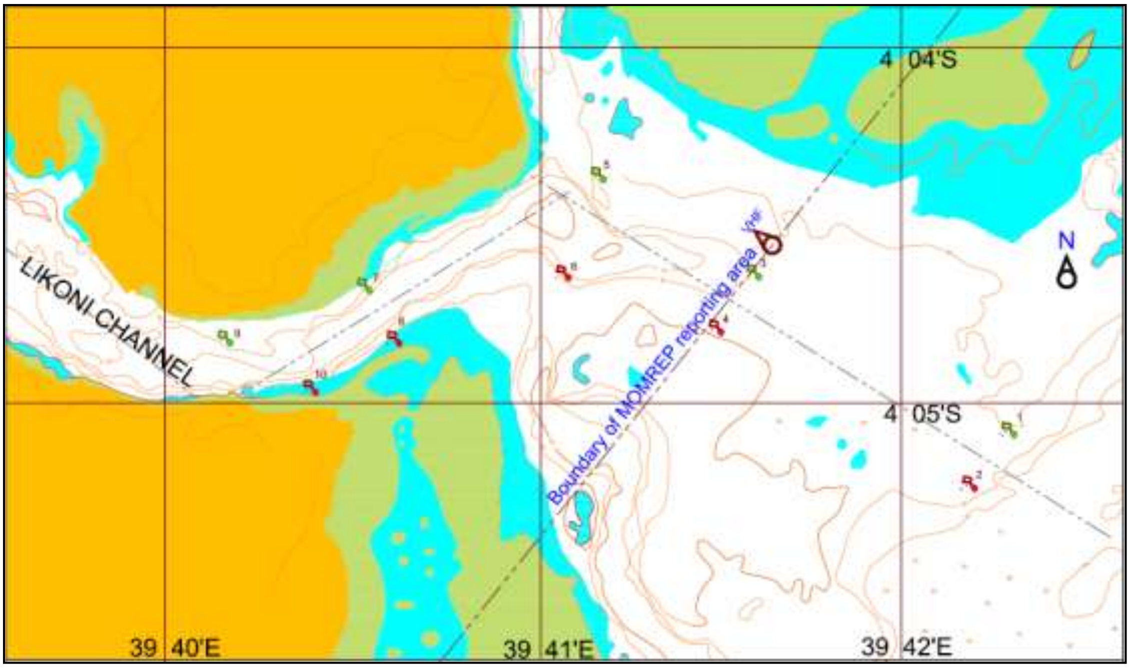


Figure 4.3 Location of Mombasa reporting line (MOMREP) on Mombasa approach channel

4.4 Layout of AtoN

In principle, navigation comprises monitoring or establishing a vessel's position or movement along a planned passage. In general, it is considered that proper marking of waterways/fairways, dredged channels and canals by visual and radar aids remains important to mitigate risk (IALA, 2011). The high accuracy short range visual AtoN are mostly used close to shore and in restricted waterways, where the navigation accuracy cannot be improved further by improving the position accuracy using radio navigation. The mariner needs to be able to determine exactly the distance from the vessel to certain points or lines; for instance, a critical hazard or the limitation of the fairway. This distance can then be calculated as the difference between two absolute positions. The distance can also be found directly, if there is a visual aid, or a radar target, or any other device indicating the relevant point or line. The position of the AtoN should be accurate and in accordance with IHO standards, in order that a vessel can establish its position sufficiently and follow a route in the fairway by visual or radio navigation means.

In narrow, winding or meandering passages, such as Mombasa channel, it may be difficult for mariners to correlate the vessel's position with chart information in a timely manner. In these circumstances, visual AtoN will be the primary means of navigation (IALA 2011).

In this study, a review on whether the current arrangement of visual AtoN complies with recommendations from IALA guideline No. 1078, and IHO is carried out. Moreover, we establish whether there is a need to provide additional visual AtoN so as to increase relative position and navigation accuracy when the vessel is navigating in Mombasa approach channel so as to avert the danger of vessel running aground.

Figure 4.4 Channel orientation and Visual AtoN arrangement as shown by AIS track on Mombasa approach channel

Figure 4.4 shows AIS plot by Vessel type in relation to installed AtoN in Mombasa approach channel. Figure 4.5 shows current lateral buoy arrangement (buoy number 1 to 10) and the two leading lights in Mombasa approach channel (Ras Serani leading lights marked as 1a and 1b and Likoni leading light marked as 2a and 2b on figure 4.5). From figure 4.5, the following observations on the visual AtoN in Mombasa approach channel comply with the recommendations from IHO, the IALA Maritime Buoyage System (MBS) and IALA guideline No. 1078;

a) The fairway is marked by lateral buoys numbered 1 to 10.
b) There shall be AtoN at least at bends and junctions of the fairway. Buoy 6 and buoy 9 are installed at the bends while buoy 5 is installed at the junction leading to the old port.
c) There is two conspicuous pair of buoy 1 and 2 at the beginning of fairway.
d) The buoys are lit and colored (red and green) according to IALA Maritime buoyage region A guidelines so as to increase the useful range.

From the above observations there is need to redesign AtoN layout so as to increase navigational accuracy of Mombasa approach channel which is characterized by unique channel orientation, two bends and two straight channel, and most of all the presence of shallow coral reefs and sand banks at the entrance to inner channel pose as navigation risk for vessels which may run aground in case of any maneuvering error. Therefore the following AtoN re-design is recommended.

a) AtoN's to be placed evenly according to the channel orientation. A pair of buoy at every junction of changing channels orientation.
b) AtoN's to be placed equidistant from the central axis of the fairway.

Figure 4.5 shows the AIS track by vessel type when the proposed buoy arrangement is installed. Figure 4.6 shows the accurate dimensions of the buoys and their spacing when redesigned according to IALA guideline No. 1078. Figure 4.7 shows AIS track plot with the proposed buoy arrangement on the Mombasa approach channel.

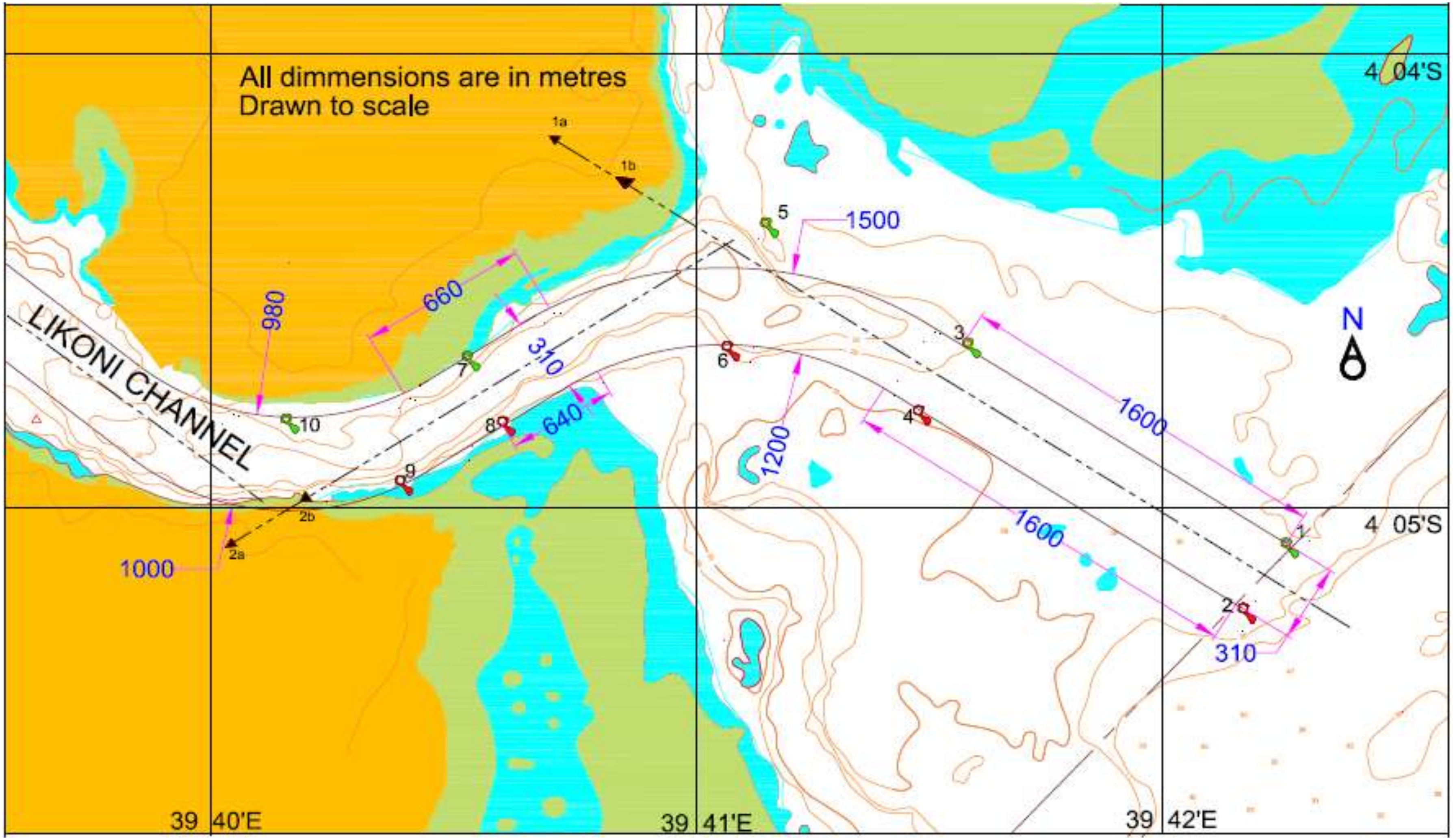


Figure 4.5 Dimensions of channel and current AtoN arrangement in Mombasa approach channel

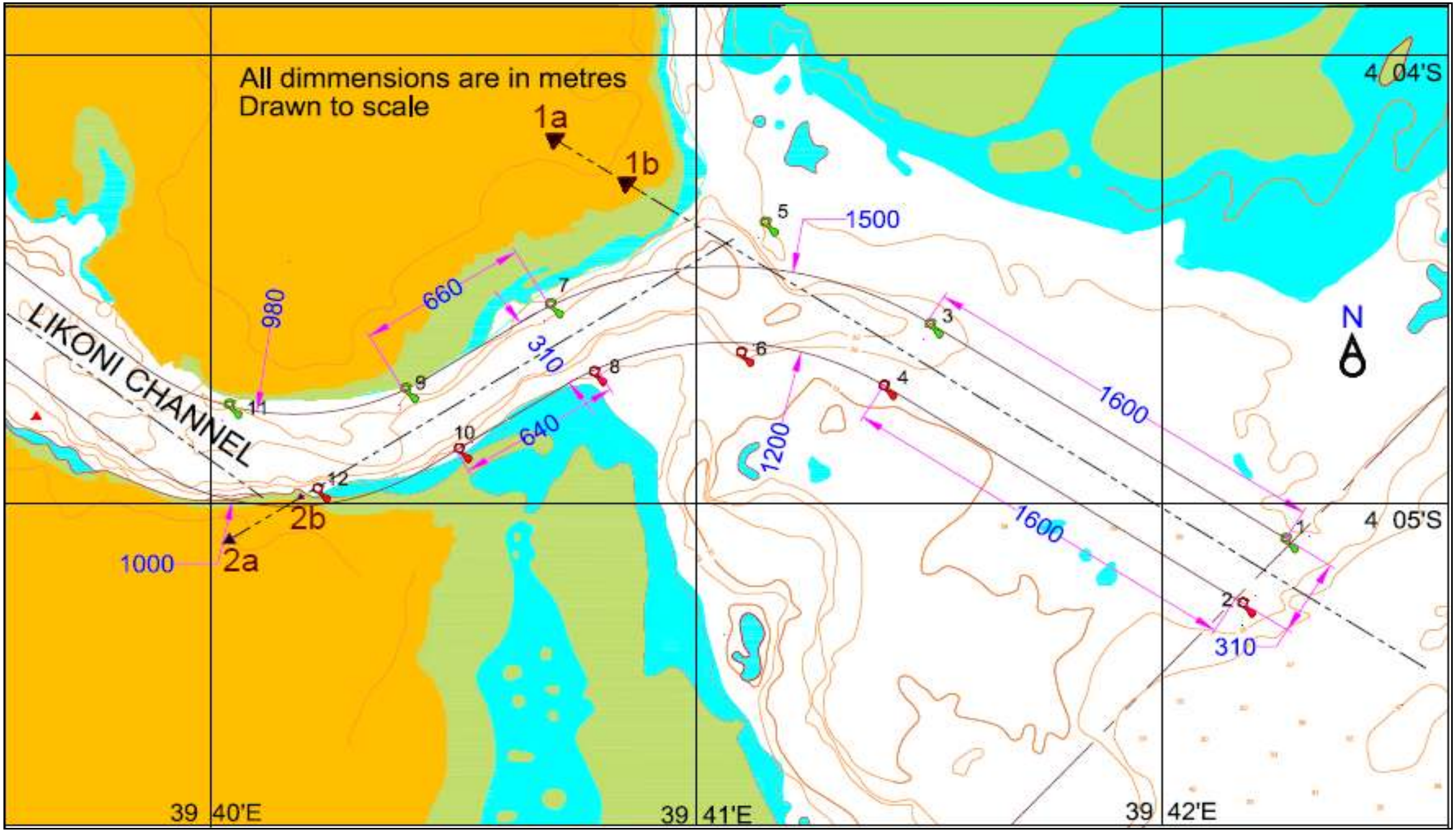


Figure 4.6 Dimensions of channel and re-organized buoy arrangement according to channel orientation in Mombasa approach channel

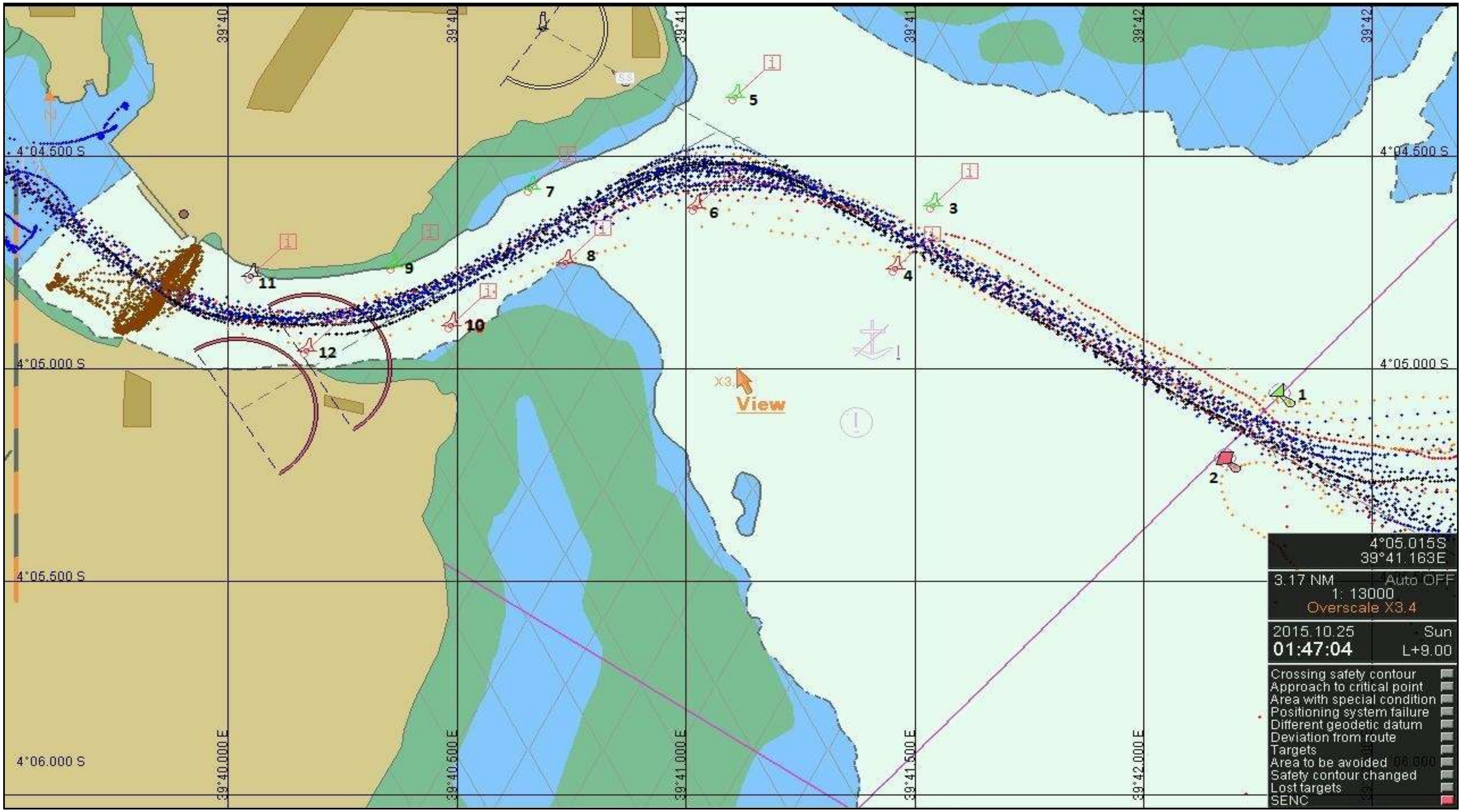


Figure 4.7 Channel orientation and Visual AtoN arrangement in Mombasa approach channel from AIS tract plot

4.4.1 Validation of Layout of AtoN by expert survey

Questionnaire survey was conducted to the Mombasa VTS officers and marine Pilots who have experience on Mombasa approach channel. The aim of the questionnaire was to collect opinion of the experts on effectiveness of re-designed AtoN layout on Mombasa approach channel. A total of 7 questionnaires were gathered from the VTS officers with an average experience of 3.71 years as VTS-O.

The second part of the questionnaire had three questions on layout of AtoN as shown in the annex. Questions 1, and 3 of part two, are evaluated and graded on a five Likert scale; 1-minimum/lowest risk to 5-maximum/highest risk. The questions are evaluated from "1-not effective" to "5-very effective" on the questionnaire.

Participant's evaluation on whether current layout of AtoN is effective in reducing risk of grounding showed an average score of 3.67 on a five Likert scale. Moreover, participants agreed by a score of 3.14 on a five Likert scale that proposed layout of AtoN reduce the risk of grounding. A majority of the participants (57%) left question 2 blank thereby giving a room for discrediting the survey study. Question 2 is most crucial in establishing the valid reasons on whether to re-design the Mombasa approach channel AtoN layout according to marine traffic experts' opinion.

From the above reason, we can conclude that redesign of AtoN layout needs further research where more diverse marine traffic experts from Mombasa such as Pilots, harbor masters, captains and ferry skippers are involved in the survey study. Moreover, the survey study can be validated by carrying out ship handling simulation on the proposed AtoN layout.

Chapter 5 Conclusion

The Mombasa port is the principal port in Kenya and East Africa at large. The Mombasa approach channel plays a very significant role in maintaining a constant trade between East African nations and the world through shipping. Local ferries operating at Likoni channel pose as potential navigation risk on transit vessels with an average of 196 daily crossings. To add on this, the unique oceanographic structure, s- type channel orientation, narrow width at the inner channel, and the presence of shallow coral reefs and sand banks pose as navigation risk to the transit vessels.

This thesis attempts to find a solution for improving marine traffic safety in this area through vessel traffic risk management technique by carrying out marine traffic risk assessment and proposing countermeasures. The research target area is Mombasa approach fairway marked from buoy number 1 to buoy number 10.

The effects of marine environment factors, such as widths, depth and bend radius of fairway were evaluated by comparing actual fairway dimensions with guidelines from the PIANC (2014). This first step demonstrated that; the channel width is sufficient for a one-way passage, vessels with draft exceeding 12.5m has to ride on tide when navigating and vessel with Loa above 220m are restricted by fairway bend radius when maneuvering at the channel bends.

Local and transit marine traffic parameters such as traffic volume, traffic flow were analyzed. It was observed that; majority of vessels calling at Mombasa port are Panamax in size; ferries pose as potential collision risk with transit vessels; Mombasa VTS is not equipped to monitor local traffic; there is no defined traffic service for local ferry traffic. Therefore we concluded that there is a need to come up with a traffic management service for the Local Ferries, and moreover, there is a need to carry out a quantitative risk assessment of the navigation risk posed by local traffic on transit traffic.

A quantitative risk assessment using, ES model, PARK model and IWRAP Mk2 model was carried on Mombasa approach channel. Risk assessment by ES model showed that the total percentage of unacceptable stress in Likoni channel stands at 20.7%, almost equal to most risky Sector A2 on Istanbul straight.

Risk assessment by PARK model showed that total unacceptable risk adds up to 35.48% at Likoni channel. IWRAP model showed that there is a high risk of crossing collision at the crossing region where ferry operate, total groundings in Mombasa and Ulsan waterway are equal but powered grounding frequency in Mombasa is almost twice that of Ulsan.

Risk assessment results showed that there is a need to come up with traffic management measures/policies that will mitigate the risk of collision and grounding thereby improving marine traffic safety. Traffic control of ferries, setting up a Local Traffic Service (LTS), VTS report line due to crossing ferry and proper layout of AtoN were proposed as countermeasures. A study of these countermeasures was carried out and the findings were listed as follows;

a) Traffic control reduces unacceptable risk level from 35.48% to 27.85% which is in the region of allowable risk level of bellow 30%. Therefore we conclude that traffic control of the local traffic is effective in reducing collision risk at Likoni channel as demonstrated by PARK model.
b) Local Traffic Service will improve marine traffic safety by reducing workload on the Mombasa VTS, which will be dedicated to monitoring transit traffic and moreover reduce the risk of collision between ferry and ocean-going vessels. LTS will provide information service, traffic organization of ferries and navigation assistance to the local ferry traffic.
c) The reporting line will add to the Mombasa VTS support systems thereby increasing marine traffic efficiency and safety by constant monitoring of the reporting vessel from reporting area to berth using radar, CCTV, AIS or any other effective means.
d) Re-organization of lateral buoys will increase relative position and navigation accuracy when the vessel is navigating in Mombasa approach channel so as to avert the danger of vessel running aground. However, future research on layout of AtoN in comparison with experts opinion was proposed.

In summary, the aforementioned countermeasures are efficient in promoting marine traffic safety and marine traffic efficiency. They are highly recommended to be adopted at Mombasa approach channel.

However, in future, ship handling simulation needs to be carried out to determine optimum arrangement and number of visual aids to navigation on Mombasa approach channel in accordance to Mombasa marine traffic experts. Moreover, an experimental simulation should be carried out to determine how effective is use of reporting line in improving marine traffic safety.

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Annex

QUESTIONAIRE SURVEY ON A STUDY OF MARINE TRAFFIC RISK COUNTERMEASURES IN MOMBASA APPROACH CHANNEL

Greetings,

This questionnaire is prepared to be used in a study called "A Study of Marine Traffic Risk Countermeasures in Mombasa Approach channel" with the aim of improving marine traffic safety in the Mombasa Approach channel. This questionnaire form is made and given to you with a desire to receive your valuable ideas from your experience and expertise about the following matters:

- Setting up a Local Traffic Service (LTS) at Likoni area so as to monitor local ferry traffic so as to reduce risk of crossing collision between local ferry traffic and ocean-going vessels
- Redesign of Aids to Navigation (AtoN)
- Your valuable ideas for improving navigation safety

In this questionnaire your personal information is not required. Thus your name or any information which could identify you is not requested. Information which is requested about your career experience will promote the quality and reliability of the survey and will be used exclusively for academic purposes. Therefore we assume that the information will not be given to a third party.

We would like to sincerely thank you for your kind interest and participation in our study.

QUESTIONS

Present Position:

☐ Pilot at Mombasa ☐ VTS Officer

☐ Ocean going Master ☐ Skipper on Likoni ferries

☐ Other

Career Experience:

☐ Pilot ……..years

☐ VTS-Officer …… years

☐ Ferry Skipper …….years

☐ Sea work experience …….years

Local Traffic Service (LTS)

Local Traffic Service (LTS) is a traffic management service concerned with safety and efficiency of local ferry traffic at Likoni channel. Local Traffic Service is tasked with implementation of traffic control of ferry traffic so as to reduce risk of crossing collision with the ocean going vessels.

1. In your opinion, how effective will the LTS contribute to the reduction of risk of collision between ferry and ocean-going vessels?

Not effective ◄------				------► Very effective
[1]	[2]	[3]	[4]	[5]

2. How effective will the formation of a LTS reduce workload on VTS?

Not effective ◄------				------► Very effective
[1]	[2]	[3]	[4]	[5]

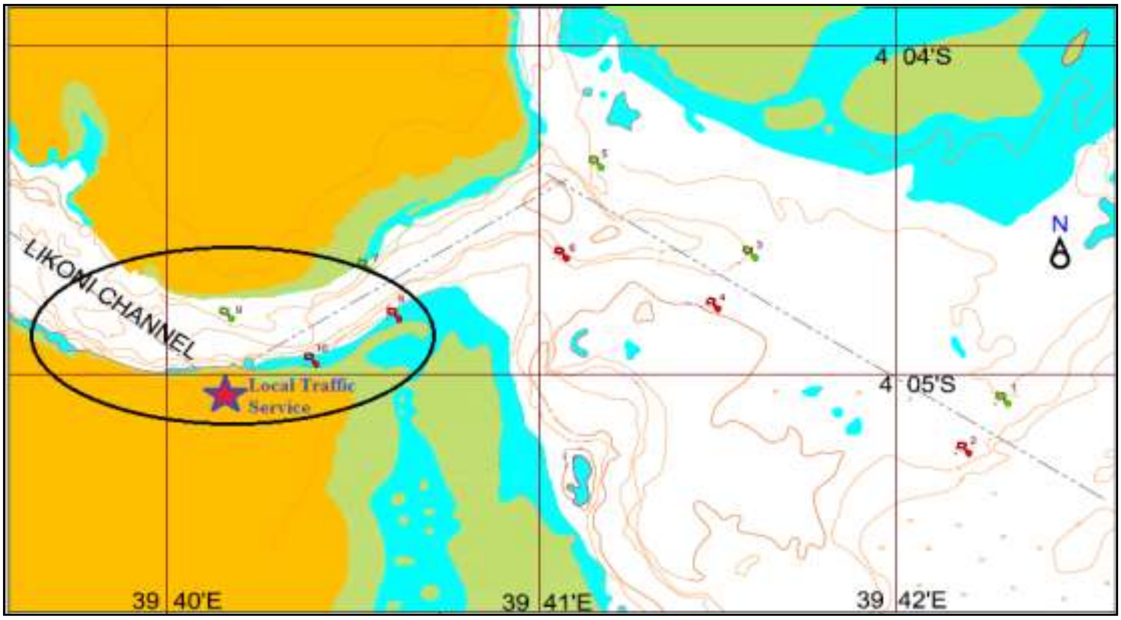
3. Is the proposed area coverage enough for the LTS?

☐ Yes ☐ No

4. The star on the map shows proposed location of the LTS traffic centre. Is this location favorable for a LTS traffic centre? If not, please mark on the figure 1 your preferred location.

Not effective ◄- ► Very effective				
[1]	[2]	[3]	[4]	[5]

Figure 1. Local Traffic Service area coverage and location of LTS traffic centre



Layout of Aids to Navigation (AtoN)

The two maps shows current layout of AtoN, figure 2 and the proposed AtoN arrangement, figure 3. The proposed AtoN arrangement was done according to Mombasa channel orientation. The proposed AtoN has a pair of buoys at every point the channel orientation changes (buoy 3-4, buoy7-8, buoy 9-10) thereby making it unique from current AtoN. The additional number of buoys will increase position accuracy of vessel when navigating.

1. Is the current layout of AtoN effective in reducing risk of grounding? Figure 2

Not effective ◄- - - - - - - - - - - -				- - - - - - - - - - - ► Very effective
[1]	[2]	[3]	[4]	[5]

2. Is there need to redesign the current system of AtoN?

☐ Yes ☐ No

3. Will the proposed layout of AtoN reduce the risk of grounding? Figure 3

Not effective ◄- - - - - - - - - - - -				- - - - - - - - - - - ► Very effective
[1]	[2]	[3]	[4]	[5]

Figure 2. Current layout of AtoN

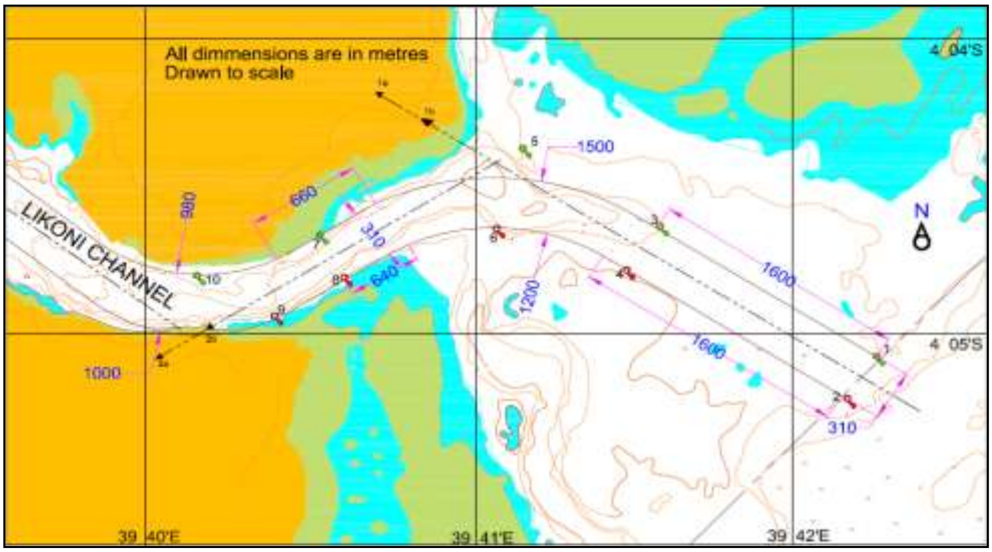


Figure 3. Proposed layout of AtoN