Pacific Region Infrastructure Facility

Establishing Baseline Data to Support Sustainable Maritime Transport Services

Focused on the Republic of the Marshall Islands (RMI)

FINAL REPORT

September 2018

The Pacific Region Infrastructure Facility (PRIF) is a multi-development partner coordination, research and technical assistance facility which supports infrastructure development in the Pacific. PRIF Members include: Asian Development Bank (ADB), Australian Department of Foreign Affairs and Trade (DFAT), European Investment Bank (EIB), European Union (EU), Japan International Cooperation Agency (JICA), New Zealand Ministry of Foreign Affairs and Trade (NZMFAT), United States Department of State and the World Bank Group.

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Note: This project to establish the baseline data to support sustainable maritime transport services has been carried out in collaboration with GIZ, and in particular, with Mr Raffael Held, Marine Engineer Intern on the German Government funded project, Transitioning to Low Carbon Sea Transport in the Marshall Islands, managed by GIZ. This project has been initiated by PRIF in order to support GIZ's work and all other subsequent initiatives by development agencies.

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Glossary of Acronyms

Acronym		Description
ADB	-	Asian Development Bank
AtoN	-	Aid to Navigation
FY2017		Financial Year 2017 (Oct 1, 2016 to Sept 30, 2017)
GHG	-	Green House Gas
GIZ	-	Deutsche Gesellschaft für Internationale Zusammenarbeit
IMO		International Maritime Organisation
LOA		Length overall
MIMRA		Marshall Islands Marine Resources Authority
MISC		Marshall Islands Shipping Corporation
MTCC-Pacific		Maritime Technology Cooperation Centre for the Pacific
NOAA		US National Oceanic and Atmospheric Administration
PII		Pacific International Inc
PRIF	-	Pacific Region Infrastructure Facility
RMI	-	Republic of the Marshall Islands
RRE		Robert Reimers Enterprises Inc
TA	-	Technical Assistance
t CO_2		Emissions of CO_2 in tonnes (ie, excluding other GHG emissions)
t CO_2-e		Emissions of CO_2 equivalent in tonnes (ie, all GHG emissions)
TOR	-	Terms of Reference
US$		United States Dollars

1 Introduction

1.1 Background

1.1.1 Establishing Baseline Data to Support Sustainable Maritime Transport Services

This project, Establishing Baseline Data to Support Sustainable Maritime Transport Services in the Republic of the Marshall Islands (RMI), is an initiative of the Pacific Region Infrastructure Facility (PRIF). It supports an ongoing German Government funded project managed by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), Transitioning to Low Carbon Sea Transport, and all other subsequent initiatives by development agencies.[a]

The GIZ Transitioning to Low Carbon Sea Transport project aims to reduce the emissions from domestic sea transport. It is divided into two parts that build on each other. The first part, of which this PRIF research is a component, will evaluate emissions and economic conditions of the national fleet. Options for low-carbon engine technology for ships will be developed and assessed. In the second part, a ship to be selected jointly with the Marshall Islands Shipping Corporation will be equipped with the technology identified and tested.

1.1.2 Context of Study

The Republic of the Marshall Islands is amongst the lowest lying countries in the world and is particularly vulnerable to the effects of climate change. The country is located in the Pacific Ocean, just north of the equator, and in a similar longitude to Kiribati, Tuvalu, Fiji and New Zealand. It is spread over an EEZ of 2 million square kilometres and consists of a widely scattered group of 29 atolls and 5 islands. Geographically, it is characterized by two chains, the Ratak, or Sunrise, to the east, and the Ralik, or Sunset, to the west. The chains lie about 125 miles (200 kilometres) apart and extend some 800 miles northwest to southeast.

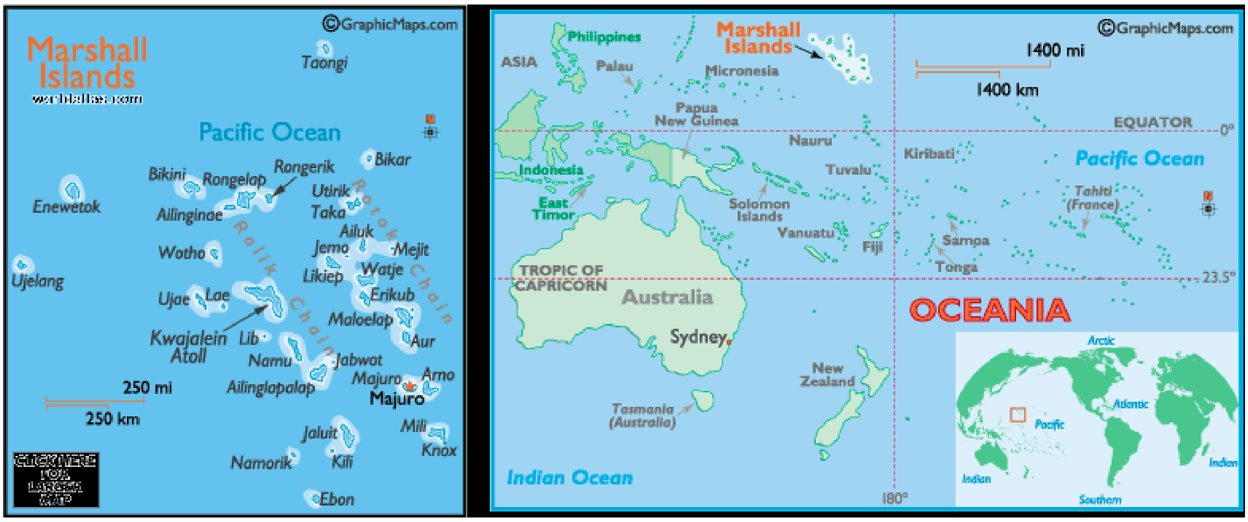


Figure 1: Map of the Marshall Islands

[a] The overall project is a joint initiative of a consortium of partners (German and RMI Governments, University of the South Pacific, Hochschule Emden/Leer, Waan Aelõñ in Majel) and is being coordinated under the Micronesian Center for Sustainable Transport (MCST) framework.

1.1.3 RMI Maritime Transport & its Linkage to Climate Change

Inter and Intra island connectivity in RMI (via aviation and/or maritime transport) is essential to provide basic access to services and socioeconomic opportunities for communities on outer islands and atolls, although the cost to provide transport services to these destinations is high.

RMI is almost entirely dependent on imported fossil fuels, which places a heavy burden on national and household budgets. Shifting from the use of fossil fuel propulsion and to renewable energy sources could help in reducing the cost of providing regular and reliable transport services to outer island/atoll communities, thereby supporting more inclusive economic growth for the country.

RMI is severely exposed to the implications of rising sea levels. All its atolls are low-lying; flooding already occurs when adverse climatic conditions coincide with spring tides in the tidal cycle. These rising sea levels are the result of global warming, caused by excessive CO_2 emissions and other Greenhouse Gases (GHGs).

The domestic fleet of the Marshall Islands emits a significant amount of greenhouse gases. The reduction in the use of fossil fuels can thus nominally support climate change mitigation due to the reduction of carbon dioxide emissions.

In recognition of this, RMI has been at the forefront of international efforts to reduce GHGs. In December 2017, Hilda Heine, President of RMI, presented the Tony de Brum Declaration[1] at the One Planet Summit in Paris. Among other matters, the Declaration called for a peak on emissions from ships in the short-term and then reducing them to neutrality towards the second half of this century. This was endorsed by 38 countries and was submitted to the International Maritime Organization's (IMO) Marine Environment Protection Committee (MEPC) meeting in April 2018. The IMO adopted a strategy for a reduction in total GHG emissions from international shipping which should peak as soon as possible and reduce the total annual GHG emissions by at least 50% by 2050 compared with 2008 levels, while, at the same time, pursuing efforts towards phasing them out entirely. That is to say, putting a defined framework around the Tony de Brum declaration.

1.2 The Baseline Study

1.2.1 Objectives

RMI carried out an inventory of its GHG emissions in 2015[2]. This inventory did not differentiate between land, aviation and shipping emissions in its assessment of transport related emissions. The focus of this TA therefore endeavours to identify the shipping related emissions. It is also to provide a set of baseline data that can be used to compare the energy and operational efficiency of the new technologies to be gradually introduced in maritime transport in the RMI. The outcome is to be an RMI endorsed baseline study that will assist in determining the cost effectiveness of future investments in renewable energy and energy saving (low carbon) technologies for maritime transport services.

1.2.2 Context of Limits

IMO differentiates between emissions from domestic and international shipping. It also differentiates between emissions for transport purposes and fishing. RMI has a very large international register of ships, the 2nd or 3rd largest in the world. In contrast, its domestic shipping activities are very small. This TA is limited to assessment of the domestic shipping activities for ships involved in transport tasks, defined as domestic commercial shipping in this report.

Many of the very small craft activities are fishing based. It has not been possible to differentiate the activities of small craft, so they are treated as a whole.

1.2.3 **Scope**

Tasks and Activities of the TA are:

1. Preparation of TORs for local data collection, to identify and manage local resources to gather the baseline data;
2. A baseline of vessels, maritime infrastructure, operating costs, fleet and infrastructure condition, and operating schedules and routes;
3. Investigation and proposal of alternative shipping routes and operation methods to increase the overall efficiency of the fleet and reduce GHG emissions;
4. Development of excel-based templates that will allow updating of the operation and efficiency parameters in order to derive the operational costs and GHG emissions of the new technologies to be proposed; and
5. Preparation of a detailed methodology to replicate the data collection and analysis process in other Pacific countries.

1.2.4 **Outline of Report**

The report is set out in Chapters and Appendices that reflect the scope outlined.

This Introduction is Chapter 1.

Chapter 2 sets out the Baseline Data that has been collected. Appendix 1 describes the domestic commercial fleet. Appendix 2 describes cargo operations using ships' boats at atolls. Appendix 5 is a report on a speed trial that was conducted for mv Kwajalein as part of the data collection process.

Chapter 3 details the baseline year fuel consumption and GHG emissions.

Chapter 4 and Appendix 3 describe the excel template model that has been developed. Chapter 4 also contains the results of the analysis of the Baseline Year, for the MISC fleet.

Chapter 5 looks at Alternative Operating routes and Practices, with suggestions for implementation of the most promising. Appendix 6 contains the details of this analysis.

A set of recommendations are set out in Chapter 6.

Appendix 4 describes the process for replicating data collection and analysis in other locations.

2 Baseline Data

2.1 Definition of Baseline

2.1.1 Period

The baseline year selected for this analysis is the Republic of the Marshall Islands (RMI) Government's Financial Year 2017 (FY2017), from Oct 1, 2016 to Sept 30, 2017. The Marshall Islands Shipping Corporation (MISC) has the same financial year, and FY2017 is the most recent completed year.

2.1.2 Scope

All domestic commercial shipping in the Marshall Islands covering:

- Marshall Islands Shipping Corporation (MISC) services
- Other Domestic Shipping Services
- Intra-atoll small craft operating within lagoons of atolls

2.2 Approach to analysis

2.2.1 Marshall Islands Shipping Corporation

A detailed analysis has been carried out for the MISC shipping services. The fuel consumption of the individual ships has been modelled from 'the bottom up', and compared with and calibrated by the actual fuel consumption derived from MISC's financial records, a 'top down' approach.

This baseline study is in support of a GIZ project looking at reduction in GHG emissions of the MISC ship's so the model developed has the additional purpose of being a tool for the GIZ project to look at the effects of proposed alternative propulsion for the MISC ships.

2.2.2 Other Domestic Commercial Ships

The approach for the other domestic commercial ships has been a 'top down' approach, based on overall annual consumption data and transport tasks undertaken obtained from ship operators. This enables the baseline GHG emissions for these ships to be estimated.

2.2.3 Small Intra-Lagoon Boats

The large number of small intra-lagoon boats that are motorized are mostly powered by outboard engines and fuelled by gasoline (petrol). Very little data is available on individual boats, but the total number of motorized and non-motorized boats at each atoll was recorded in the 2011 census. An operating profile using reasonable assumptions has been analysed in order to obtain a rough order-of-magnitude estimate of the fuel consumption and emissions of this fleet of small craft.

2.3 The Domestic Commercial Fleet

2.3.1 Ship Types

Domestic commercial ships in the Marshall Islands (RMI) fall into 7 groups:

• MISC fleet	4 ships
• Other large commercial trading ships	9 ships
• Smaller inter-atoll ships	7 ships
• Fishing support ships	4 ships
• Tourism ships	2 ships
• Service craft/ tugs	3 ships
• Not accounted for (but on Register)	5 ships
• Total	34 ships

In addition, there are:

- Small intra-lagoon boats over 500 powered & over 600 non-motorized

Intra-lagoon small boats are not required to be registered, but were counted in the 2011 census and are non-motorized (canoes) or in general powered by outboard motors. All other ships should be registered, but not all are. Not all are active. Principal particulars of those that have been identified, registered or not, are shown in Table 1.

Further details of the fleet are set out in Appendix 1.

2.3.2 Age Profile of Fleet

Of the fleet, 6 (18%) are less than 10 years old, 10 (29%) are between 10 and 25 years old, and 14 (41%) are more than 25 years old. The age of the remaining 4 (12%) is unknown.

2.4 Domestic Shipping Services in RMI

Domestic shipping services in the Marshall Islands (RMI) can be sub-divided into four groups:

- Marshall Islands Shipping Corporation (MISC) services;
- Other Domestic Shipping Services;
- Copra Collection;
- Small intra-atoll craft operating within the lagoons of atolls.

2.4.1 Marshall Islands Shipping Corporation

MISC is an RMI State Owned Enterprise mandated by the Marshall Islands Shipping Corporation Act 2004 to provide domestic shipping services within RMI. It operates with financial assistance from the Government of the Marshall Islands. MISC's operations include:

- Field trip services to outer islands, carrying cargo and passengers;
- Charter voyages and special purpose voyages, both commercial and for government, NGO entities and cultural organisations such as churches, as well as disaster and famine relief.

Other voyages may take place such as:

- Diversions
- Dry Dock voyages

It operates four ships that are owned by RMI Government and provided to MISC to operate but without any financial charge:

- Kwajalein: 50m long conventional cargo passenger ship
- Majuro: 44m long landing craft type cargo/passenger ship
- Aemman: 49m long conventional cargo passenger ship
- Ribuuk Ae: 33m long conventional cargo passenger ship

Voyages undertaken in FY2017

The four MISC ships undertook **70 voyages** in total. Two of these were dry dock voyages to Fiji, for Ribuuk Ae at the beginning of the year and for Kwajalein at the end. Of the remaining 68 voyages, 34 were classified as Field Trips, 27 as Charters and 7 as Special Purpose Voyages:

Voyage type	Aemman	Ribuuk Ae	Majuro	Kwajalein	Total
Field trip	11	12	3	8	34
Charter	2	1	19	5	27
Special	1	-	6	-	7
Dry dock	-	1	-	1	2
Total	**14**	**14**	**28**	**14**	**70**

Table 1: Domestic Commercial Ships in the Marshall Islands

Name	Owner/ Operator	Vessel Type	Year Build	Gross Tonnage	LOA (m)
MISC Ships					
mv Kwajalein	MISC	Landing Craft	2013	583	45.6
mv Majuro	MISC	Cargo/ Pax	2013	416	40.4
mv Aemman	MISC	Cargo/ Pax	2004	409	45.0
mv Ribuuk Ae	MISC	Cargo/ Pax	1996	175	33.5
Other Commercial Trading Ships					
LCT Resslynn	Ms. Resslynn Latak	Landing Craft	2007	450	36.5
mv Lady E	E.U.L.G.	Cargo/ Pax	1966	698	50.3
mv Tobolar	TCPA		1980	315	32.4
mv Mata	Kaitol Reimers	Cargo/ Pax	1976	60	19.5
Melissa K	PII	Cargo/ Pax	1992	36	16.2
LC Jerbal	PII	Landing Craft	1969	108	22.6
LC Michelle K	PII		1994		61.6
mv Jejnica	Takao Domnick	Fishing/ Cargo	1980	34	17.1
LCM Chase D	Takao Domnick	Landing Craft	2012	240	28.0
Small Inter-Atoll Ships					
mv Kuban	PII	Cargo/ Ferry	2000	5	12.2
mv Lele	PII	Cargo/ Pax	1999	7	15.2
Four X	RRE		1972		11.8
Iju in Rak	Mayor Joel Jitiam				14.6
LC Christina	Robert Pinho	Mini landing craft			9.8
Miko	Mayor Bernard ChongGum				9.8
Tobwe Mili	Kilang Jitiam	LGC boat; cargo & pax			10.7
Fishing Support					
FV Timur	MIMRA	Fishing/ Cargo	2010	12	13.9
FV Jebro	MIMRA	Fishing/ Cargo	2010	12	13.9
FV Laintok	MIMRA	Fishing/ Cargo	1999	14	16.0
FV Lentanur	MIMRA	Fishing/ Cargo	1999	14	16.6
Tourism					
mv Indies Traders	RRE	Diving/ Survey	1978	95	21.3
mv Windward	RRE	Diving/ Survey	1992	202	23.0
Service craft/ Tugs					
Tarlan 04	KALGOV'T	Search & Rescu	2015	9	16.6
MT Ratak II	PII	TugBoat	1971	282	33.2
MT Ralik II	PII	TugBoat	1970	334	33.2
Not accounted for (but on Register)					
mv. Koba Maron	Anjua Loeak	Non-Commercial	1988	41	23.5
mv Lae	Lae Local Gov,t	Cargo/ Fishing	1980	64	23.0
LCM 82	MOPW	Landing Craft	1967	900	38.4
DeepBlueSea	Heinkey Lomwe	Smal lFish Carrie	1996	4	7.7
mv Barijet	Langmos Hermios	Fishing	1997	12	13.7

MISC voyage **durations** varied between 1 week and 3 weeks, averaging **2 weeks for field trips**, and **1 week for charters**.

In total, the ships steamed **49,535 nautical miles** (nm) in FY2017.

Calls at Atolls
Calls at individual atolls are shown in Table 2. A total of 216 calls were made at atolls and islands. Aemman and Kwajalein averaged 5.5 and 3.8 calls per voyage respectively. Ribuuk Ae averaged 2.3 calls, while Majuro, which was mostly on charter voyages, averaged only 1.8 calls per voyage.

Most of the 34 atolls and islands had 4 or more visits in FY2017.

Six atolls had more 12 or more visits in the year, Ailinglaplap, Ailuk, Jaluit, Kili, Namu and Wotje.

Atolls with fewer than 4 MISC ship calls were; Ebadon/ Santo (3 calls), Mili (2), Bikini (1), Enewetak (3 calls plus 1 call made by Enewetak's own ship). Mili is also serviced by private sector ships.

Transport Task Achieved
Cargo
General Cargo: The actual cargo quantities transported has not been recorded. However, outbound general cargo data for about 56% of field trips was available in hard copy form on bills of lading, and this has been analysed as a sample to allow an estimate of the total picture. The total cargo quantity carried by MISC ships in FY2017 is estimated to be:

4,318 revenue tons.

Copra: Copra quantities loaded at each atoll were obtained from Tobolar. The total quantity brought to Majuro by each ship, including MISC's ships was also obtained from Tobolar. Out of a total of 5,482 tons produced, the total copra carried by MISC ships in FY2017 was:

4,089 tons

Passengers
MISC's financial records show the number of passengers carried and a list of atolls visited on each voyage. The number of inbound and outbound passengers in FY2017 was:

Outbound: 1,849
Inbound: 2,262

Earlier Years
No records of general cargo or passengers carried was available for earlier years. However, the 1995 Transport Infrastructure Development Project (ADB TA-2096)[3] reports cargo volumes based on 1994 services of the Field Trip Services (the predecessor of MISC), some 23 years ago. The general cargo volume was estimated to be 5,309 revenue tons, copra 3,936 revenue tons, outbound passengers 1,992 and inbound passengers 1,715. The present numbers represent little change from over 20 years ago.

There is some copra production data available. In the 2005 report on the Conduct of the Copra Trade and Outer Island Shipping Services in the Marshall Islands[4], it is reported that between 1950 and 2004 the annual copra production volume fluctuated between about 3,300 tons and 7,000 tons, averaging 4,918 tons between 1986 and 2004, and 4,244 tons between 2000 and 2004, a small downward trend. The 2004 volume was about 4,900 tons. Most of this copra was transported to Majuro on the Field Trip Service ships. The present levels of 5,056, 7,240 and 5,482 tons in 2015, 2016 and 2017 respectively fit into this profile[11]; there has not been much change for over 65 years, the last three years averaging just 20% more than the 20 year average of 15 years ago.

Table 2: MISC ship calls at Atolls, FY2017

Atoll	Aemman	Ribuuk Ae	Majuro	Kwajalein	Total
Ailinglaplap	7	2	2	2	**13**
Ailuk	1	1	3	7	**12**
Arno		4		1	**5**
Aur	1	4	2	3	**10**
Bikini			1		**1**
Ebon	6	2	2		**10**
Enewetak			1	2	**3**
Jabat	6	1		2	**9**
Jaluit	9	3	3	1	**16**
Kili	5	1	7		**13**
Kwajelein/Ebadon/Santo	3				**3**
Kwajelein/Mejjatto	2	1	5	1	**9**
Lae	5	2	2	2	**11**
Lib	5		1		**6**
Likiep	1	1	1	5	**8**
Maloelap	1	5			**6**
Mejit	1	1		8	**10**
Mili		2			**2**
Namdrik	4	1	2		**7**
Namu	9		5	2	**16**
Rongelap			4		**4**
Ujae	5		2	2	**9**
Utirik	1		2	6	**9**
Wotho	5		2	2	**9**
Wotje	1	2	4	8	**15**
Total	**78**	**33**	**51**	**54**	**216**

2.4.2 Other Domestic Shipping Services

Several private sector and local government ships operate commercially within the Marshall Islands:

- Local government services
- Commercial trips to nearer atolls for copra collection
- Tourism activities
- Fishing support

Voyages Undertaken

These private sector and local government operators provided over **300 voyages** during the year, nearly 200 of which were to Arno or Mili.

Duration of voyages varies; for larger ships such as LCT Resslynn, a voyage may be 1 to 2 weeks. For smaller ships operating to atolls near to Majuro, the duration is typically 1 or 2 days to Arno or Mili, and 3 to 4 days to places like Maleolap, Wotje or Jaluit.

The total distance steamed by other domestic commercial ships is estimated to be **55,500 nm.**

The number of calls at each atoll by type of shipping activity is shown in Table 3. The two atolls closest to Majuro, Arno and Mili, have the most calls, Arno averaging 3 a week and Mili 1, mostly by small inter-atoll ships. The next most frequent services by private sector operators are those to Ebeye, 28 calls pa, and to Jaluit, 26 calls pa.

Table 3: Other Commercial Shipping, Voyages by Atoll, FY2017

Shipping Activity	Atoll	Voyages pa
Commercial Trading Ships	Ebeye	28
	Enewetak	2
	Jaluit	26
	Kili	1
	Likiep	1
	Mejit	1
	Mili	8
	Namdrik	1
	Wotje	2
	General	8
Commercial Trading Ships Total		**78**
Small Inter-Atoll Ships	Arno	143
	Jaluit	8
	Maleolap	1
	Mili	48
	Wotje	1
Small Inter-Atoll Ships Total		**201**
Fishing Support	Aur	5
	Ebeye	2
	Likiep	1
	Maleolap	8
	Mili	1
	Wotje	8
Fishing Support Total		**25**
Tourism	Ailinglaplap	
Tourism Total		
Grand Total		**304**

The significant services are:

- *Melissa K:* PII's most frequent services, mostly to the Southern sector
- *LCT Resslynn*: Fuel deliveries, predominantly to Ebeye
- *Lady E*: Enewetak Local Government's quarterly service to Enewetak
- *Four X, Iju in Rak, Christina, Miko, Kuban, Lele:* Small ships that operate frequently from Majuro to the nearby atolls of Arno and Mili
- *Timur & Jebro*: MIMRA fishing support ships that also undertake commercial activities
- *Indies Trader & Windward*: RRE's tourism vessels used for surfing and diving tourism within Ailinglaplap.
- *M.V. Tobolar*: owned by Tobolar, and collects copra from outer islands. In FY2017 undertook 3 voyages early on, then was out of service for mechanical reasons.
- *LCM Chase D* Transporting of construction materials to and from Majuro to Ebeye, Jaluit and Mili, and between Kwajalein and Ebeye

Other ships that operate, but not significantly in FY2017, (or for which no data was available) include:

- *MS. Mata*
- *LC Jerbal*
- *LC Michelle K*
- *MS. Jejnica*

Transport task
No data was able to be discovered covering the quantity of general cargo or the number of passengers carried on other domestic commercial ships.

2.4.3 **Copra Collection**

Copra collection is undertaken by MISC's ships on field trips, and other commercial ships, especially from nearer atolls such as Mili and Ailinglaplap. Copra from Arno is collected routinely and regularly by smaller ships/ boats operating from Majuro.

The Tobolar Copra Processing Authority (Tobolar) has its own ship, mv Tobolar, but it was out of service for all except 3 trips in FY2017.

Tobolar provided data on the quantity of copra collected by ships from outer islands. In FY2017, 5,492 tons were collected, 4,089 tons by MISC ships, 366 tons by Tobolar's own ship, and 1,021 tons by other ships.

See the comments in the 'Earlier Years' paragraph of section 2.4.1 above for information on historic copra volumes. The present level of just over 5,400 tons fits into the historic profile; there has not been much change for over 65 years

2.4.4 **Intra-atoll small Craft**

A large number of small craft are owned privately on outer islands. The 2011 census reports that motorized boats totalled 582, of which 269 were located in Majuro, and 313 on outer islands. The census number of non-motorized boats was 680, of which 130 were in Majuro, and 550 were located in outer islands.

The TA Data Collection Team obtained responses from 60 residents of outer islands (20% of motorized boat owners) regarding their use of the boats. They more often use their canoes (non-motorized) to go fishing and other daily activities, averaging around 5 - 6 hours per day, while motorized boats are used about 3 to 4 hours daily.

2.5 Infrastructure

2.5.1 **Wharves & Jetties**

There are very few wharves or jetties in the Marshall Islands. At Majuro there are two wharves used for domestic shipping

- Uliga: loading outbound cargo and embarking and landing passengers
- Delap: discharging inbound copra.

Uliga has a nearby shed where MISC aggregates cargo prior to loading. Delap wharf is adjacent to Tobolar's copra mill. Copra is discharged to trucks and carried the short distance to the mill for weighing and moisture testing. These two facilities are in working condition, but are showing signs of lack of maintenance.

Ebeye has a wharf which is used for general cargo and passenger operations.

Jaluit has a wharf at Jabwor which is used for general cargo and passenger operations.

There are MIMRA jetties at various sites around the outer islands, but the MISC captains report that they are not suitable and therefore not often used for cargo operations

It has not been possible to ascertain the condition of the wharves at Ebeye and Jabwor.

2.5.2 Aids to Navigation (AtoNs)

There are very few aids to navigation (AtoNs) in the Marshall Islands. Of those that have been installed, the status and even existence of some that are listed is incorrect. The RMI Ports Authority has an AIS station but it is not operational. Further detail on RMI's AtoNs is contained in the report on SPC's Safety of Navigation Mission in November 2017[5].

Locations of existing AtoNs are: Majuro lagoon, Ebeye/ Kwajalein lagoon, Jaluit Lagoon.

2.5.3 Other Infrastructure

Other items of infrastructure are:

- Reef channels
- Beaches
- Ramps for landing craft
- Ramps for boats

Very little information was able to be collected on individual items. Locations and restrictions on their use such as tidal restrictions and daylight only operations are set out in 2.7 below.

A floating dock and repair facility was sited in Majuro at some time after 2003, but is not now there. General engineering workshop facilities are available in Majuro, although with limited capabilities. Most major marine engineering repairs require the ship to be taken overseas.

2.6 Cargo Operations

2.6.1 Loading at Uliga

Ships loading at Uliga use ship's gear, either a crane or derricks configured for union purchase. MISC aggregate cargo at their nearby warehouse prior to voyage. The cargo is marshalled to the hook on pallets by small forklift trucks on loading day. The load rate is about 10 tons per hour.

2.6.2 General Cargo Operations in Outer Islands

Cargo is discharged to wharf at Ebeye and Jabwor, and to ship's boats and transferred to shore at all other places. On the three larger MISC ships, the boat load limits inside lagoons are 2 pallets of general cargo of about 1 ton each or 2.5 tons of copra in bags. The maximum safe passenger load is 20 persons. When operating to ocean beaches or in bad weather, the Masters typically restrict the loads to 1 pallet (1 ton) or 1.5t of copra, with passenger limits of about 10 persons.

Ribuuk Ae has smaller ship's boats. These can carry 2 pallets of general cargo (as with the larger boats), but copra is restricted to 2 tons and passenger numbers to 15 persons. On ocean beaches or in bad weather, 1 pallet, 1 ton of copra or 10 passengers.

The time required for boat round trips varies from place to place, from about 50 minutes to 100 minutes depending on distances and the nature of the beach. See Appendix 2 for a discussion on times for boat operations on a location by location basis. .

2.6.3 Copra loading in Outer Islands

Loading copra is the reverse of discharge of general cargo. Copra collection usually occurs on the return trip as it is not desirable to mix general cargo with copra; there is the potential for contamination of general cargo, for example by cockroaches in copra.

Copra is collected from a wide range of places, often the beach adjacent to a grower's home. The cost of intra-lagoon transport mitigates against centralising copra collection. See Appendix 6.1.1 on Centralised Copra Collection for an explanation and analysis, but in summary, the cost of transporting copra to a central place is higher than the cost of taking the ship to the individual beaches.

Copra is carried in bags each with about 100 pounds (45kg) capacity. These are loaded loose into slings laid in the bottom of the ships' boats. The normal load is about 25 bags (2.5 tons) in larger ship's boats, and 20 bags (2 tons) in Ribuuk Ae's smaller boats. In poor weather, or for ocean landings, these limits reduce to about 15 and 10 bags respectively. The copra bags are stowed loose in the ships' holds.

2.6.4 Copra Discharge at Delap

Copra is discharged at Delap in Majuro, adjacent to the Tobolar store and mill. It is stevedored by Tobolar, but the stevedoring is paid for by MISC, ie the terms of carriage include the discharge as part of the freight rate (liner terms). Ship's gear is used in union purchase, discharging to trucks under hook. The copra is transported a short distance, less than 100m, to a weigh bridge where the copra is weighed and moisture tested, then placed in Tobolar's store.

Hours of work are daytime only, not weekends, except when required to finish. The whole process seems very inefficient even taking into account these restricted hours, taking at least 5 days, and often 9 or 10 days for quantities that average only 127 tons per discharge. This is a discharge rate of between 1.5 and 3 tons per hour. Each hook load is about 2 tons, so this means the hook cycle time is only one cycle per hour, more or less. A benchmark for this type of cargo handling is 7 or 8 hook cycles per hour.

The holdup is not on the ship; there is nothing that would suggest the ship cannot discharge at a normal rate. It must be at the unloading of trucks at Tobolar's store. Possibly the weighing and moisture testing process is slow, and as there is no incentive to speed up, the ship is used as temporary transit storage. The 'cost' is the holdup to other ships waiting to berth at Delap, and potentially, causing the need for more ships than would otherwise be needed if the discharge were carried out in a timely fashion.

Potential solutions

- Make the carriage terms 'free out', that is, the cargo interest, Tobolar, becomes responsible for cargo operations. The cost of labour would then been carried by Tobolar.
- Provide a reasonable time for the cargo interest to discharge cargo, say 2 days. Thereafter, demurrage to be charged at a commercial rate to compensate for the lost ship's time.

These two measures would put the cost and risk on Tobolar, who has control over the process, and should concentrate Tobolar's minds to find a solution to the poor productivity.

2.6.5 Shop on Ships

The ships have a shop on board that carries a range of staples and general goods. These are a major source for stores for outer island households. Time is needed at each place for residents to make their purchases.

2.7 Ship Operating Constraints

In an interview with two of MISC's masters, Captain First Lussier (Ribuuk Ae) and Captain Fuisenga (Fui) Sualau (Aemman), operational constraints were discussed, atoll by atoll and place by place:

- Location of access to places
- The ability for ships to enter or leave lagoons through reef passages during darkness,
- The ability to work cargo at night,
- Tidal restrictions at each landing place,
- Probability of weather delays.

Table 4 gives details for each atoll and place.

2.7.1 Lagoon or Ocean Access

All atolls and islands can be accessed by ships of the size operated commercially within RMI. Most places do not have wharves or jetties that are used by commercial ships. Many places, the majority, are accessed on beaches inside the lagoons. Some atoll places and islands without lagoons or with difficult lagoon approaches are accessed from beaches on the ocean side.

2.7.2 Night-time navigation constraints

There are very few Aids to Navigation in the Marshall Islands. Reef entrances to lagoons are narrow with the need to change course to avoid coral heads and other obstacles once inside. The ability to fix the ship's position accurately is therefore critical. The result is that many atolls cannot be entered or navigated during hours of darkness.

Some reef entrances where the ship is heading easterly cannot be entered until the morning sun is sufficiently high so that light reflection is reduced and vision of obstacles through the water is possible, about 1000 hrs.

2.7.3 Night-time cargo operational constraints

Some beaches and locations are too exposed or prone to weather that makes night time cargo work unsafe, for example at a place that has waves sufficient to make boat-work in the dark too hazardous. At these places cargo work is restricted to daytime only.

2.7.4 Tide constraints

Many beaches are restricted as to state of the tide when boat operations can take place; water depths are too low, or reef shelves too wide for cargo to be loaded or unloaded at low tide. Typically cargo operations are restricted between 2.5 hours before low tide and 2.5 hours after low tide, giving a 7 hour working window at the top of the tide in every 12 hour tide cycle.

2.7.5 Weather constraints

Weather delays are experienced at all sites, especially ocean beaches and lagoon beaches that are on a lee shore, ie at the western end of lagoons. Captain Fui and Captain First advised that typically delays are 12 hours, and occur about 10% of the time.

Table 4: Port Entry & Working Restrictions

Atoll	Port	Ability to enter/ depart in dark	Work during darkness	Tide Restriction
Ailinglaplap	Airuk	yes	unrestricted	Restricted
	Buoj	yes	unrestricted	Restricted
	Jabwan	yes	unrestricted	Restricted
	Jah	no	unrestricted	Restricted
	Jeh	yes	unrestricted	OK
	Kattiej	yes	unrestricted	OK
	Mejil	no	unrestricted	Restricted
	Woja	yes	no work	Restricted
	Enewe	no	unrestricted	Restricted
Ailuk	Ailuk	no	no work	Restricted
	Enejelar	no	unrestricted	Restricted
Arno	Arno	no	unrestricted	Restricted
	Bikarej	no	unrestricted	Restricted
	Ine	no	unrestricted	Restricted
	Tinak	no	unrestricted	Restricted
	Tutu	no	unrestricted	Restricted
	Ulien	no	unrestricted	Restricted
Aur	Aur	no	unrestricted	Restricted
	Bikien	yes	unrestricted	Restricted
	Tabal	yes	unrestricted	Restricted
Bikini	Bikini	no	unrestricted	Restricted
Ebon	Ebon	no	unrestricted	Restricted
	Enekion	no	unrestricted	Restricted
	Toka	no	unrestricted	Restricted
Enewetak	Enewetak	no	unrestricted	Restricted
Fiji	Suva	yes	unrestricted	OK
Jabat	Jabat	no	unrestricted	OK
Jaluit	Bokanake	yes	unrestricted	Restricted
	Imiej	yes	unrestricted	OK
	Imroj	yes	no work	Restricted
	Jabwor	yes	unrestricted	OK
	Jaluit	yes	unrestricted	Restricted
	Mejrirok	yes	unrestricted	Restricted
	Narmej	yes	unrestricted	Restricted
Kili	Kili	yes	no work	Restricted
Kwajalein	Carlson	yes	unrestricted	Restricted
	Ebadon	yes	no work	OK
	Ebeye	yes	unrestricted	OK
	MejattoJ	no	no work	Restricted
	Santo	no	unrestricted	Restricted
Lae	Lae	yes	unrestricted	Restricted
Lib	Lib	yes	unrestricted	Restricted
Likiep	Jebal	no	unrestricted	Restricted
	Likiep	no	unrestricted	ok
	Liklal	yes	unrestricted	Restricted
	Melang	no	unrestricted	Restricted
Majuro	Delap	yes	no work	ok
	Majuro	yes	unrestricted	OK
	Uliga	yes	unrestricted	ok
Maloelap	Airok	no	unrestricted	OK
	Jang	no	unrestricted	Restricted
	Kaben	no	unrestricted	OK
	Taroa	yes	unrestricted	OK
	Wolot	no	unrestricted	Restricted
Mejit	Mejit	no	unrestricted	ok
Mili	Enajet	no	no work	Restricted
	Lukonwor	no	no work	Restricted
	Mili	no	unrestricted	Restricted
	Nallu	no	no work	Restricted
	Tokewa	no	no work	Restricted
Namdrik	Namdrik	yes	unrestricted	Restricted
Namu	Loen	no	unrestricted	Restricted
	Mae	yes	unrestricted	Restricted
	Majkin	yes	unrestricted	Restricted
	Namu	no	unrestricted	Restricted
Rongelap	Rongelap	no	unrestricted	Restricted
Ujae	Ujae	no	unrestricted	Restricted
Ujelang	Ujelang	no	unrestricted	Restricted
Utirik	Utirik	no	unrestricted	Restricted
Wotho	Wotho	no	unrestricted	Restricted
Wotje	Nibun	yes	unrestricted	Restricted
	Wormej	ok	unrestricted	Restricted
	Wotje	yes	unrestricted	Restricted

2.8 Financial Information

The Marshall Islands Shipping Corporation provided the project with its preliminary Financial Statements for FY2017, dated February 12, 2018. FY2017 is from October 1, 2016 to September 30, 2017.

2.8.1 MISC Operating Costs

MISC does not have the four ships on its books as assets. The ships are owned by the RMI Government, and appear instead in the Government's own Financial Statements as assets. They are provided to MISC by the Government, without any charge. As a result the profit and loss (P&L) account of MISC does not show any depreciation charge or hire payments for the ships.

The P&L account does cover all other costs of operation, as well as revenues, including RMI subsidies which make up more than 50% of revenue. The operating cost in FY2017 came to US$3.25 million, of which US$40,000 was loss on sale of assets and US$256,000 was a bad debt that is reported to have been since recovered, leaving an operating expense of US$2.95 million. US$0.982 million is administration costs, leaving ship operating expenses of US$1.972 million.

The direct operating costs for each ship are identified in the accounts. Costs that cannot be allocated directly to a ship, but are general ship expenses, such as crew costs for crew not allocated to a particular ship, are also identified. For the purposes of this project, the ship expenses have been divided into unit cost categories as follows:

- *Depreciation:* Estimated from RMI Government' Financial Statements between 2011 and 2016.
- *Daily extended period costs*: an annualised provision for longer term expenditure such as dry docking and fuel for dry docking voyage (actual cost/ 5yrs/ 365 days)
- *Daily Operating Cost*: period costs that are incurred regardless of time on voyages or time between voyages (annual cost / 365 days)
- *Voyage related costs*: mostly foods and other victualling for the voyage (Annual cost / number of voyages undertaken)
- *Cargo costs:* Cost per ton of cargo, mostly stevedoring of copra on discharge at Delap (stevedoring cost / quantity of copra discharged)
- *Fuel Costs*: A cost per volume of fuel and lube oils purchased.

The unit costs that result are shown in Table 5**Error! Reference source not found.**.

Table 5: Unit Costs- MISC Ship Operations

Unit costs		Kwajalein	Aemman	Majuro	Ribuuk Ae
Annual depreciation	US$ pa	228,000	185,000	228,000	92,000
Annualised extended period costs	US$/ day	153	153	153	153
Period Operating costs (excl depreciation)	US$/ day	550	564	409	422
Cost per Voyage (foods etc)	US$/ voyage	2,544	1,855	1,243	1,624
Cargo costs (copra stevedoring)	US$/ cargo ton	7.25	7.25	7.25	7.25
Fuel costs					
Diesel	US$/litre	0.77	0.77	0.77	0.77
Gasoline	US$/litre	1.24	1.24	1.24	1.24
Lube oils	US$/litre	1.72	1.72	1.72	1.72

2.8.2 Other Domestic Ship Operating Costs

No accounts were available from other operators, but in interviews, several indicated the level of costs incurred.

Large ships such as Lady E and LC Resslynn budget for about the same expenditure as the MISC ships, with fixed period costs (including dry dock provisions) in the range $500 to $600 per day.

Medium sized ships, Mata and Ijn In Rak are examples, have a fixed period cost of about $300 to $350 per day.

The small ships have fixed period costs ranging from $150 to $250 per day.

Fuel costs can be estimated from the annual fuel consumption data advised by the operators of other domestic commercial ships, and set out in Table 7.

2.8.3 Cost of Fuel

MISC's average fuel prices for FY2017 are shown in Table 6. Other operators are likely to purchase their fuel at similar or slightly higher cost.

Table 6: Fuel Prices, FY2017

Fuel Type	*US$ per US gallon*	*US$ per litre*
Diesel	$2.93	$0.77
Gasoline	$4.68	$1.24
Lube Oils	$6.50	$1.72

2.9 Sources of Data

Data sources are referenced directly in the text or in Endnotes. Accurate recent data has been difficult to obtain. In many cases, data has either been derived from records for which the primary purpose was not recording the data required, or the data source was old.

2.9.1 Derived Data

An example of derived data is the records of fuel consumption on MISC's ships. All that was available was the financial record of fuel *purchased*. This was converted to quantity purchased through the invoiced prices, but still did not result in the amount of fuel *consumed*. The quantity remaining on board each ship at the beginning and end of each voyage and for the financial year beginning and end was not recorded, and so leads to inaccuracies in the estimate.

Another is the consumption of gasoline by intra-atoll small craft. No records could be found, not even of the total quantity of gasoline transported to each atoll. An estimate was made by conducting an anecdotal survey of boat users[b] but no indication of the representation of this sample was possible, leaving estimates extremely vague.

2.9.2 Old Data

Examples of old data are estimates of the number of intra-atoll small craft, and of the quantity of passengers and cargo carried. Intra-atoll craft were counted in the 2011 census, but no census has been conducted since then. On the basis that the population of atolls has not changed much in the intervening 6 years, the 2017 number of boats has been assumed to be unchanged.

The quantity of MISC's passengers and cargo is captured voyage by voyage on tickets and bills of lading, but the recording of this was not transferred to manifests, and many of the hard copy tickets and bills of lading were missing from the records. Estimates have had to be made for example, by

[b] See Section 3.2.4- Fuel Consumption & Emissions- Intra-atoll small Craft

proportioning the total cargo quantity according to the number of voyages for which records were available out of the total number of voyages. These estimates have been compared with more accurate data recorded in 1995, 23 years ago, and have been shown to be more or less accurate. This is however a less than satisfactory method of obtaining and validating data.

2.9.3 Improvements to Data Recording

Very small enterprises such as single-ship shipping companies do not generally wish to have complex data recording. It is time consuming and non-productive on a day-to-day basis. But medium and large sized enterprises should seek to record data as these provide the inputs to efficiency analysis.

A company such as MISC should have a reliable data collection system. Financial data is well recorded at MISC. MISC's predecessor, the Field Trip Service of the Ministry of Transportation and Communications, did set up a manifest and ship operating efficiency system developed for it by an ADB Technical Assistance in 2005[6]. It is understood that this system was in use until at least 2012. Reinstating this system, or an improvement of it should be a priority. Such a system would record not only passenger and cargo quantities, but also fuel consumption, distances steamed, time handling cargo etc; the vital data needed to carry out voyage analysis and thus monitor the efficiency of the ship operations.

Similarly, local government has a need to record data. Fuel consumed on atolls is one data item that is useful for economic analysis. This could be captured through Household Expenditure Surveys, or perhaps through transportation records such as cargo manifests. It would be very useful if local governments were tasked with the collection of such data.

It is desirable that the next census continues to record that data on motorized and non-motorized boats that the 2011 census captured.

3 Baseline Fuel Consumption & GHG Emissions

3.1 Methodology for Baseline Emissions

3.1.1 Calculation of Fuel Consumption

As set out earlier, the fuel consumption of the MISC ships has been modelled from 'the bottom up', and compared with and calibrated by the actual fuel consumption derived from MISC's financial records, a 'top down' approach.

The approach for the other domestic commercial ships has been a 'top down' approach, based on overall annual consumption data and transport tasks undertaken obtained from ship operators.

The challenge has been in the collection of data. A 'bottom up' calculation requires detailed data on the ship's fuel consumption at the range of speeds of interest, the pattern of voyages undertaken, the weather conditions encountered on passage, and the amount of time spent under way at sea, at anchor or drifting and alongside, both working cargo and idle. However, in order to consider changes to operational patterns there is no reliable way, other than to collect these data.

A 'top down' approach can serve as a benchmark, and changes to consumption levels can be looked at, both in terms of overall consumption, and transport effort (distance x cargo and passenger quantities carried). The data required is total consumption for a period, and the transport task carried out. This does not however allow for investigation of changes to operational patterns.

The type of data that needs to be collected and the manner in which it can be used in analysis is set out in Appendix 3 and Appendix 4.

Very little data is available for the large number of small intra-lagoon boats. The motorized boats are mostly powered by outboard engines and fuelled by gasoline (petrol). An operating profile using reasonable assumptions has been analysed in order to obtain a rough order-of-magnitude estimate of the fuel consumption and thus emissions of this fleet of small craft. A sensitivity analysis has been carried out, using realistic extremes of these assumptions, in order to test the range for the uncertainties surrounding the use of intra-atoll craft[c].

3.1.2 Calculation of Baseline Emissions

The IMO has issued Guidelines for Voluntary Use of the Ship Energy Efficiency Operational Indicator (EEOI)[7] which seeks to "establish a consistent approach …….. in the evaluation of the performance of [ships] with regard to CO_2 emissions". This guideline sets the emissions from consumption of **diesel and gas oil** at:

3.206 tonne CO_2/ tonne of fuel.

Diesel gives off other emissions, although in much smaller quantities than CO_2. The factors used in this analysis[10] in kg / tonne of fuel, are:

CO_2 emission	3,206
NOx emission	50.5
CO emission	2.63
HC emission	2.63
Particulates	2.3
SO2 emission	21.0

[c] See Section 3.2.4- Fuel Consumption & Emissions- Intra-atoll small Craft

Intra-atoll small craft are in general powered by outboard fuelled with gasoline (petrol). A commonly used emission factor for **gasoline** used for transport purposes[8] is:

2.36 kg CO_2-e/ litre of fuel

This factor is a CO_2 -equivalent factor, and takes into account the more minor emissions.
(Note that the gasoline emission factor is in units of volume (litres), whereas that for diesel is in units of mass (tonnes or kg)).

3.2 Baseline Fuel Consumption and GHG Emissions

3.2.1 Distances Covered & Fuel Consumption- Commercial Ships

Distances covered and total fuel consumption estimates for all domestic commercial ships in RMI (but excluding intra-atoll small craft) are shown in Table 7. Some data was not available, but for the most part, data obtained by interview with operators indicates that in FY2017, the total distance steamed by these ships was about:

112,500 nautical miles.

In doing so it is estimated that for both main engines and auxiliaries, the ships consumed at least:

1,711,188 litres of diesel,

This amounts to about 15 litres per nautical mile (4 US gallons /nm).

3.2.2 CO_2 Emissions – Commercial Ships

The CO_2 emissions from the whole of RMI's domestic commercial shipping (but excluding intra-atoll small craft) is about:

4,600 tonnes CO_2.

Of this, MISC's ships emit 2,700 tonnes CO_2 (including 52 tonnes CO_2-e boat gasoline emissions), 63% of the total.

3.2.3 Other Polluting Emissions

The emissions of other pollutants from all domestic commercial ships in RMI (but excluding intra-atoll small craft) are at lower levels:

NOx emission	72 t
CO emission	4 t
HC emission	4 t
Particulates	3 t
SO2 emission	30 t

Table 7: Distances, Fuel Consumption & Emissions by Shipping Activity, Operator & Ship

Shipping Activity	Operator	Ship	Distance pa (nm)	Consumption (litres pa)	CO2 emissions (t CO2)
MISC	MISC	mv Kwajalein	14,555	322,655	864
		mv Aemman	11,054	184,406	494
		mv Majuro	17,039	348,710	933
		mv Ribuuk Ae	6,887	133,303	357
MISC Total			**49,535**	**989,074**	**2,648**
Commercial Trading Ship	PII	LC Jerbal	2,070	15,778	42
		LC Michelle K	1,880	26,613	71
		Melissa K	4,728	25,747	69
	E.U.L.G.	mv Lady E	2,380	58,289	156
	Kaitol Reimers	mv Mata	3,780	164,648	441
	Ms. Resslynn Latak	LCT Resslynn	7,270	98,350	263
	Takao Domnick	mv Jejnica	-		-
		LCM Chase D	6,882	57,143	153
	TCPA	mv Tobolar	750	40,151	107
Commercial Trading Ships Total			**29,740**	**486,719**	**1,303**
Small Inter-Atoll Ships	PII	mv Kuban	5,658	17,240	46
		mv Lele	4,142	12,629	34
	Kilang Jitiam	Tobwe Mili	186	284	1
	Mayor Bernard ChongGur	Miko	5,300	13,248	35
	Mayor Joel Jitiam	Iju in Rak	6,110	17,633	47
	Robert Pinho	LC Christina	1,590	2,271	6
	RRE	Four X	3,735	14,148	38
Small Inter-Atoll Ships Total			**26,721**	**77,452**	**207**
Fishing Support	MIMRA	fv Timur	2,830	9,188	25
		fv Jebro	3,848	12,494	33
		fv Laintok	-		-
		fv Lentanur	-		-
Fishing Support Total			**6,678**	**21,682**	**58**
Tourism	RRE	mv Indies Traders	-	68,130	182
		mv Windward	-	68,130	182
Tourism Total			**-**	**136,260**	**365**
Service craft/ Tugs	PII	MT Ratak II	-		-
		MT Ralik II	-		-
	KALGOV'T	Tarlan 04	-		-
Service craft/ Tugs Total			**-**		**-**
Grand Total			**112,674**	**1,711,188**	**4,581**

3.2.4 Fuel Consumption & Emissions- Intra-atoll small Craft

A large number of small craft are owned privately on outer islands. Very little data was able to be obtained on the operational patterns of these. However, the number of boats was obtained from the 2011 census, and a typical amount of use of the boats was obtained anecdotally by the data collection team through interviews with 60 outer island residents (20% of motorized boat owners). The boats would be used for both fishing and for transport from place to place. A profile of operations has been set up using a set of assumptions that could reflect the boats' use. However, its accuracy is probably no better than +/- 40%. A sensitivity analysis to demonstrate the realistic range of consumption and emissions has been carried out below.

The 2011 census reports that motorized boats totalled 582, of which 269 were located in Majuro, and 313 on outer islands. These are typically powered by a 25hp or 40hp outboard using gasoline (petrol) as fuel. The census number of non-motorized boats was 680, of which 130 were in Majuro, and 550 were located in outer islands.

The responses from the 60 residents of outer islands regarding their use of the boats indicate that they more often use their canoes (non-motorized) to go fishing and other daily activities, averaging around 5 to 6 hours per day, while motorized boats are used about 3 to 4 hours daily. The split of activities between fishing and transport was not established. However, the overall fuel consumption for the motorized intra-atoll fleet has been estimated using the following assumptions:

- Transit to destination, say 10 nm
- Return, 10 nm
- Transit speed; 15 knots, time transiting 1.33 hrs
- Total time boat in use: 3.5 hours per day   Range: 3 hrs to 4 hrs
- Therefore, time fishing/ idling: 2.16 hours

Engines typically in use:

- Yamaha Enduro 40hp: say, 50% of fleet
- Yamaha 25hp   say, 50% of fleet

Average consumption rate:

- Cruising:
  - 40hp engine: 8.7 l/h (2.3 gal/hr)
  - 25hp engine: 6.0 l/h (1.6 gal/hr)
  - Average: 7.35 l/h (1.9 gal/hr)
- Trolling/ idling:
  - 40hp engine: 0.67 l/h (0.2 gal/hr)
  - 25hp engine: 0.67 l/h (0.2 gal/hr)
  - Average: 0.67 l/h (0.2 gal/hr)
- Consumption for 3.5 hr trip
  - Cruising: 1.33 hr @ 7.35l/h   9.80 litres
  - Trolling/idling: 2.16hrs @ 0.67l/h   1.45 litres
  - Total for trip: (at avg 3.21 l/h (0.8 gal/hr))   11.25 litres per trip (3.0 gal/trip)

Utilisation:

- Proportion of fleet in regular use, say 75%   Range: 50% to 100%
- Number of days used per week, say 5   Range: 4 to 6 days/ week

Total consumption:

- Number of small motorized craft   582 boats
- Proportion in regular use, 75%   436 boats
- Boat-days per year, 5*52*436   113,500 boat-days
- Consumption per day   11.25 litres
- Annual consumption   1,277,000 litres pa +/-40%

CO_2 emissions   **3,038 t CO_2 -e** +/- 40%

Uncertainties and Sensitivity: The main uncertainties for these assumptions are the number of boats in regular use, their daily use and number of days used per week. As indicated above, the least use that could realistically be assumed might be 3 hours per day for 4 days a week, and for only 50% of the fleet of motorized boats. This results in emissions of 1,597 t CO_2 –e (53% of the estimated amount). The greatest use might be 4 hours per day for 6 days a week, and for 100% of the fleet. In this scenario the emissions would be 4,965 t CO_2 –e (63% more than the estimated amount). These are extremes. A reasonable probability of occurrence of 95% (2 standard deviations) is about +/- 40%.

3.2.5 Fuel Consumption and CO_2 Emissions- baseline Year FY2017

The total fuel consumption and CO_2 emissions for domestic commercial shipping (including intra-atoll small craft) in the Marshall Islands in the baseline year, FY2017 are estimated to be about:

Fuel Consumption

Diesel	**1,711,000 litres**
Gasoline	**1,277,000 litres**
Total	**2,988,000 litres**

CO_2 emissions **7,600 tonnes CO_2**

See Table 8 and Figure 2.

The largest emitters of CO_2 are the 500 or so intra-atoll small craft. These small craft are estimated to contribute about 40% of the emissions. But note that the accuracy of this estimate is only +/-40%. The range of proportion of emissions from these small craft is therefore from 24% to 56% of all domestic commercial ship emissions.

The next greatest emissions come from the larger commercial trading ships, 35% from the 4 MISC ships and 17% from the 9 other larger ships.

The 11 small inter atoll ships, tourism vessels and fishing support ships for which fuel consumption data was available make up the remaining 9%.

Table 8: All Domestic Commercial Shipping Fuel Consumption & CO_2 Emissions, FY2017

Shipping Activity	Distance pa (nm)	Consumption (litres pa)	CO2 emissions (t CO2)
MISC	49,535	989,074	2,648
Commercial Trading Ships	29,740	486,719	1,303
Small Inter-Atoll Ships	26,721	77,452	207
Fishing Support	6,678	21,682	58
Tourism vessels	-	136,260	365
Intra-Atoll Small Craft		1,277,000	3,038
Grand Total	**112,674**	**2,988,188**	**7,619**

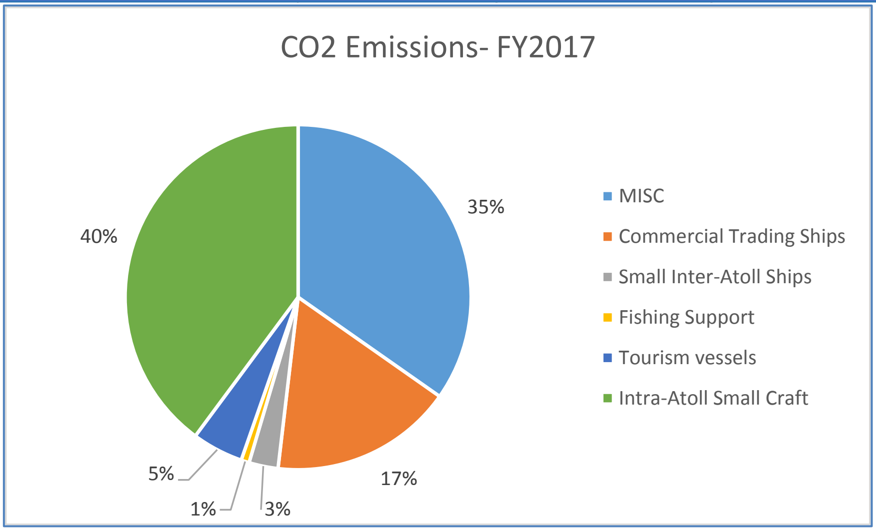


Figure 2: Proportions of CO_2 Emissions – All Domestic Commercial Ships, FY2017

3.2.6 **Domestic Shipping in the Context of RMI Transport Emissions**

RMI's inventory of greenhouse gases is set out in the Second National Communication of the Republic of the Marshall Islands to the UNFCCC[2]. The data is for the period 2000 to 2010, and has been extrapolated for the years 2014. 2015 and 2016 in a recent study into electricity sector targets[9]. That study calculated the total petrol and diesel emissions for transport (land, air and sea) to be about 35,000 t CO_2 in 2016. This baseline study's estimate of domestic commercial shipping emissions is 7,619 t CO_2 in 2017. Allowing for the year difference between these estimates, domestic commercial shipping emissions are about 1/5th of the total RMI transport emissions.

4 Baseline Analysis – MISC Fleet

4.1 Analysis Model

4.1.1 Purpose & Use of Model

The TOR call for a baseline of operating costs, operating schedules and routes, as well as investigation of alternative routes or operation methods for RMI's domestic commercial shipping with a view to reducing fuel expenses and GHG emissions. The project is to derive operating costs and GHG emissions for all existing routes and calculate costs and emissions on alternative routes / shipping / operation arrangements.

The TOR proposes that this be achieved by development of excel-based templates that will allow updating the operation and efficiency parameters of RMI's domestic commercial shipping in order to derive the operational costs and GHG emissions, both in terms of the alternative operating arrangements and of new renewable energy and energy saving (low carbon) technologies to be proposed. The analysis model that has been developed for this purpose is described below.

Data was not able to be obtained in sufficient detail for such an analysis for any ships except for those operated by the Marshall Islands Shipping Corporation (MISC). However, the MISC services provide the major part of shipping services to outer islands, and are representative of the operations of all the larger ships in the domestic commercial fleet. A full analysis using the model has therefore been confined to the services of the MISC fleet only.

4.1.2 Structure of Model

The model has two main components:

- Ship Module
- Voyage Module

A summary description follows. A full description of the model, its inputs and methodology is set out in Appendix 3.

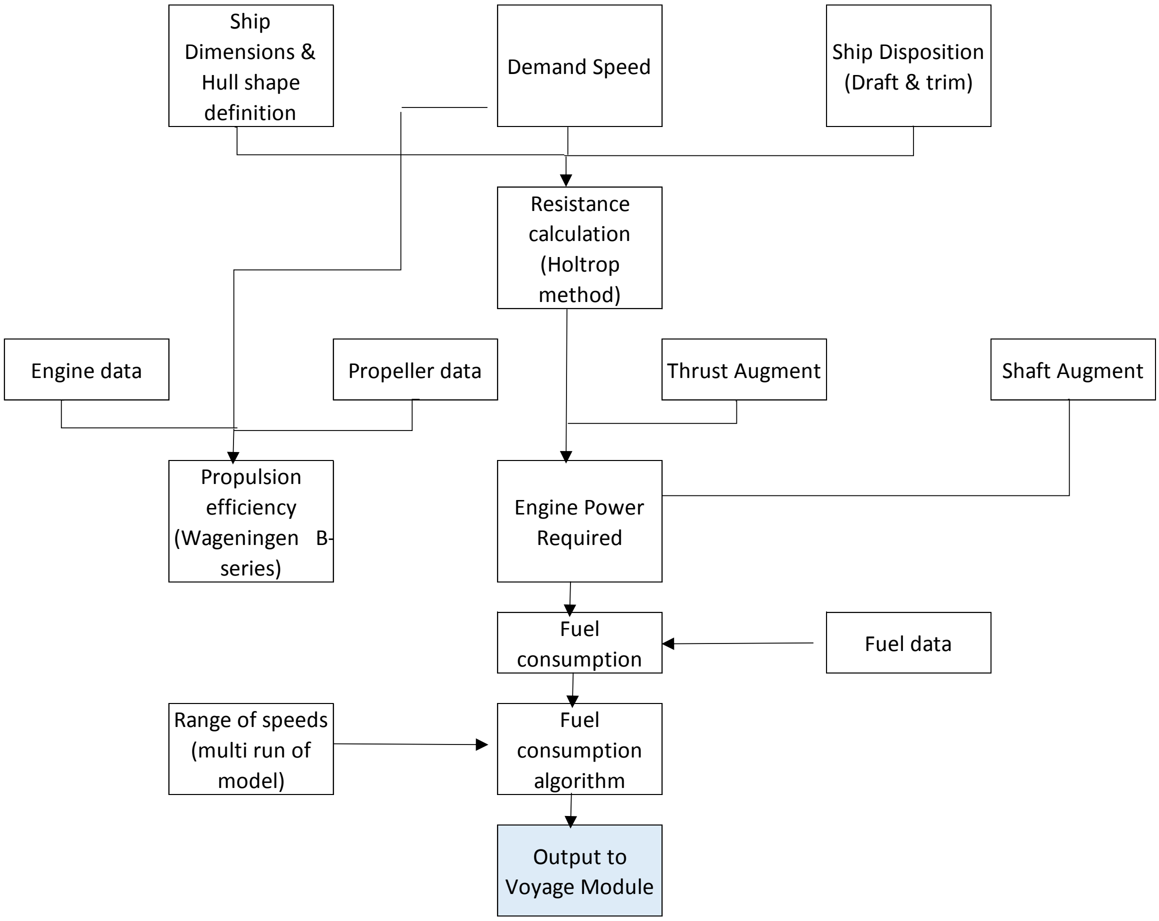
Ship Module

Purpose: To obtain speed/ fuel consumption relationship for input into the voyage module

Method: Calculates resistance of ship, and therefore engine power required and fuel consumption for any given speed.

Flexibility: Can calculate engine power required when propulsive power is augmented by other sources of energy such as wind or solar energy. Can substitute fuels other than fossil fuels.

Reference	Ship Module v1.0.xlsx'
Purpose:	To obtain speed/ fuel consumption relationship for input into the voyage module
Method :	Calculates resistance of ship, and therefore engine power required and fuel consumption for any given speed.
Flexibility:	Can calculate engine power required when propulsive power is augmented by other sources of energy such as wind or solar energy. Can substitute fuels other than fossil fuels.



Voyage Module
Purpose: To calculate

- fuel consumption;
- GHG emissions; and
- operating costs

for the voyages undertaken by a given ship.

Method: Calculates the steaming time, entering and leaving port, cargo working time and delays/ idle time for each voyage leg of all voyages described in the inputs. From these data, the fuel consumption, GHG emissions and operating costs are calculated.

Flexibility: Can take into account:

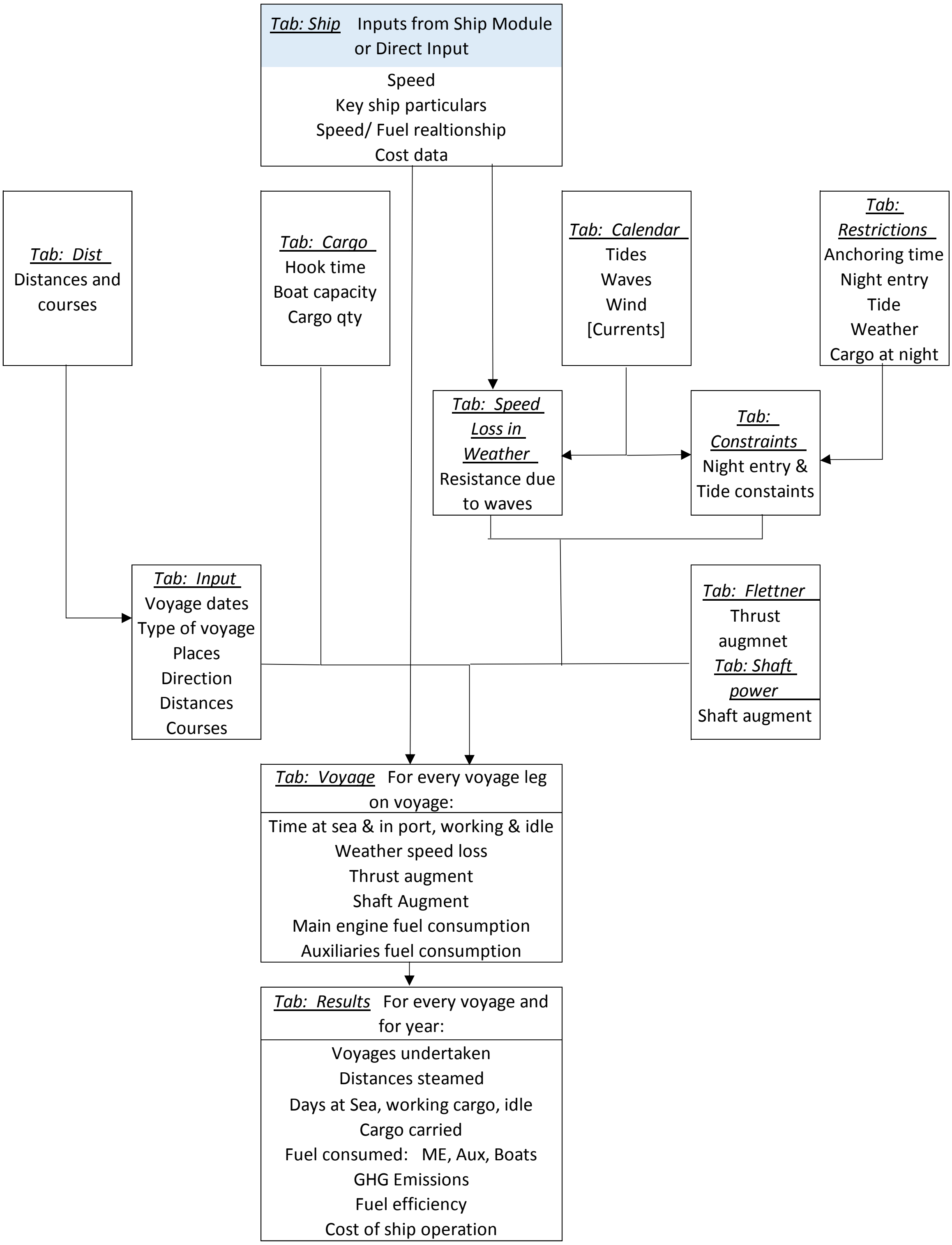
- Navigational and cargo working restrictions and constraints
- Wind and wave conditions
- Tides
- Propulsion augmentation, both thrust and shaft power

Reference Voyage Module v1.0.xlsx'

Purpose: To calculate fuel consumption, GHG emissions and operating costs for the voyages undertaken by a given ship. The ship fuel consumption characteristics can be inserted or calculated in the Ship Module.

Method : Calculates the steaming time, entering and leaving port, cargo working time and delays/ idle time for each voyage leg of all voyages described in the inputs. From these data, the fuel consumption, GHG emissions and operating costs are calculated

Flexibility: Can take into account navigational and cargo working restrictions and constraints, wind and wave conditions, tides, propulsion augmentation, both thrust and shaft power. If there is insufficient ship data to run the Ship Module, an estimate of the speed/ fuel consumption relationship can be substituted into the Voyage Module



4.1.3 **Outputs/ Results**

For each ship, the key outputs of the model are:

- Number of voyages undertaken
- Time on voyages
- Distance steamed
- Cargo carried
- Fuel consumed
- Cost of ship operation
- Cost of fuels
- GHG emissions
- Operating costs

4.1.4 **Ship Module Inputs**

Data inputs:

Operating data:

- Demand speed
- Draft on voyage
- Trim on voyage

Power Augmentation:

- Thrust device, eg Flettner
- Shaft device, eg electric motor through gearbox

Ship data:

See Table 26 for details

- Particulars.
- Hull form definition
- Hull roughness parameters
- Engine(s) & propeller(s)
- Auxiliaries consumption

4.1.5 **Voyage Module Inputs**

Voyage Description

- Start and finish date and time
- Type of voyage, eg charter
- Places visited in sequence
- Direction: outbound, inbound or turning point. Determines cargo loaded and discharged.
- Distance between places
- Course on passage between places

Distances & courses (optional)

- Tables of distances and courses between places

Port & Cargo Handling Data

- Hook cycle time/ boat round trip time
- Sling load/ boat capacity

- Cargo quantity per port call

Operating Features & Constraints

- Anchoring time
- Night time entry
- Tide restrictions
- Weather delays
- Working cargo in darkness

Environmental data

- Tides
- Waves
- Wind

Alternative Powering

- Wind powered thrust augment
- Wind and/ or solar powered electrical shaft augment

4.2 Results of MISC Baseline Analysis

A detailed analysis has been carried out for the MISC shipping services. The fuel consumption of the MISC ships has been modelled from 'the bottom up', and compared with and calibrated by the actual fuel consumption derived from MISC's financial records, a 'top down' approach

4.2.1 Voyages undertaken

Voyages undertaken are loosely classified by the geographical sector visited; Northern, Central, Western, Eastern and Southern.

Table 9: Atolls/Islands per Sector

Central	Northern	Western	Southern	Eastern
Ailinglaplap Atoll	Ailuk Atoll	Enewetak Atoll	Ebon	Arno Atoll
Jabat Atoll	Aur Atoll	Lae Atoll	Jaluit Atoll	Mili Atoll
Lib Atoll	Likiep Atoll	Ujae Atoll	Namdrik Atoll	
Namu Atoll	Maloelap Atoll	Wotho Atoll	Kili Island	
	Mejit Island	Kwajalein Atoll		
	Utirik Atoll			
	Wotje Atoll			

In fact, many voyages overlap sectors; the services provided are very demand-driven, rather than adhering to strict schedules.

A summary of the voyages undertaken by MISC's four ships in FY2017 is set out in Table 10.

Table 10: MISC Voyages by Shipping Sectors, FY2017

Sector	Aemman	Ribuuk Ae	Majuro	Kwajelein	Grand Total
Northern	1	3	4	7	15
Northern/ Central				1	1
Northern/ Western		1			1
Central	3	1	1	1	6
Central/ Western	4		2		6
Western			16	3	19
Eastern		4	1		5
Eastern/ Northern		1			1
Southern/ Central		1			1
Southern	6	1	5		12
Drydock		1		1	2
Grand Total	**14**	**13**	**29**	**13**	**69**

Visits to individual atolls are summarised in Table 11

Table 11: MISC Ship calls at Atolls, FY2017

Atoll	Aemman	Ribuuk Ae	Majuro	Kwajalein	Total
Ailinglaplap	7	2	2	2	**13**
Ailuk	1	1	3	7	**12**
Arno		4		1	**5**
Aur	1	4	2	3	**10**
Bikini			1		**1**
Ebon	6	2	2		**10**
Enewetak			1	2	**3**
Jabat	6	1		2	**9**
Jaluit	9	3	3	1	**16**
Kili	5	1	7		**13**
Kwajelein/Ebadon/Santo	3				**3**
Kwajelein/Mejjatto	2	1	5	1	**9**
Lae	5	2	2	2	**11**
Lib	5		1		**6**
Likiep	1	1	1	5	**8**
Maloelap	1	5			**6**
Mejit	1	1		8	**10**
Mili		2			**2**
Namdrik	4	1	2		**7**
Namu	9		5	2	**16**
Rongelap			4		**4**
Ujae	5		2	2	**9**
Utirik	1		2	6	**9**
Wotho	5		2	2	**9**
Wotje	1	2	4	8	**15**
Total	**78**	**33**	**51**	**54**	**216**

4.2.2 **Transport Task Achieved**

Cargo

General Cargo: The actual cargo quantities transported has not been recorded. However, outbound general cargo data for about 56% of field trips was available in hard copy form on bills of lading, and this has been analysed as a sample to allow an estimate of the total picture.

Some key assumptions made for this estimate are:

- The proportions of cargo per atoll from the sample apply across the board for each atoll for the whole year, ie a pro rata approach.
- The estimated total for the year is divided by the number of calls at places on each atoll to determine the average cargo quantity for each visit to each place on that atoll. This becomes the input cargo quantity into the baseline analysis.

- Charter voyage cargo volumes were not able to be obtained. The analysis of outbound cargo volumes for charters has been assumed to be at the average quantity per voyage on the recorded field trips. It has been assumed that charter voyages did not bring any inbound cargoes on their return to Majuro.

Copra: Copra quantities loaded at each atoll were obtained from Tobolar. The total quantity brought to Majuro by each ship, including MISC's ships was also obtained from Tobolar. With suitable adjustments for copra uplifted from Arno and Mili by other than MISC ships, the total uplifted by MISC ships was prorata apportioned to each atoll total to estimate the quantity loaded by MISC at each atoll. As with the general cargo, the estimated total for the year is divided by the number of calls for copra at places on each atoll to determine the average copra quantity for each visit to each place on that atoll. This becomes the input copra quantity into the baseline analysis.

The resulting cargo transport task for FY2017 is summarised in Table 12:

Table 12: MISC Cargo Transport Task, FY2017

	Outbound cargo			Copra		
Atoll	No of visits	per year	per place-visit	No of visits	per year	per place-visit
Ailinglaplap	32	555	17	19	954	50
Ailuk	13	61	5	2	82	41
Arno	5	5	1	9	77	9
Aur	17	275	16	11	147	13
Bikini	1	113	113		-	-
Ebon	13	133	10	7	467	67
Enewetak	3	338	113		-	-
Jabat	6	53	9	4	52	13
Jaluit	18	597	33	15	255	17
Kili	10	57	6	5	5	1
Kwajalein	39	383	10	8	67	8
Lae	9	128	14	3	68	23
Lib	4	79	20	1	44	44
Likiep	10	122	12	4	124	31
Maloelap	31	213	7	16	244	15
Mejit	9	47	5	3	118	39
Mili	10	34	3	11	181	16
Namdrik	7	166	24	5	332	66
Namu	21	136	6	11	358	33
Rongelap	2	226	113		-	-
Ujae	8	53	7	3	75	25
Utirik	9	121	13	2	65	32
Wotho	9	76	8	3	28	9
Wotje	15	350	23	4	216	54
Grand Total	**301**	**4,318**		**180**	**3,958**	

Note that Tobolar's records show the uplift by MISC ships in FY2017 was 4089 tons, 3% more than the above estimate. The difference is not significant in terms of fuel consumption and ship operating costs[d].

Passengers

Overall passenger numbers have been recorded, but not their destination or origin atolls. MISC's financial records show the number of passengers carried and a list of atolls visited on each voyage. Table 13 shows a summary of the inbound and outbound passengers by ship and sector.

[d] Cargo handling time is calculated in units of 1 hour. Typically, the time at a place to discharge general cargo is less than 5 hours, and to load copra less than 10 hours. An error in general cargo volumes would need to be greater than 20%, and for copra greater than 10% before it would show up in the analysis.

Table 13: MISC Passenger Transport task, FY2017

Sector	No of voyages	Out Bound				In Bound				Total Out Bound	Total In Bound
		Aemman	Ribuuk Ae	Majuro	Kwajelein	Aemman	Ribuuk Ae	Majuro	Kwajelein		
Northern	15	161	70	207	194	60	350	45	502	632	957
Northern/ Central	1				6				-	6	-
Northern/ Western	1		-				-			-	-
Central	6	70	52	2	39	71	4	-	17	163	92
Central/ Western	6	171		180		417		80		351	497
Western	19			5	88			-	16	93	16
Eastern	5		18	-			42	-		18	42
Eastern/ Northern	1		24				25			24	25
Southern/ Central	1		84				94			84	94
Southern	12	330	41	107		145	70	324		478	539
Drydock	2		-		-		-		-	-	-
Grand Total	**69**	**732**	**289**	**501**	**327**	**693**	**585**	**449**	**535**	**1,849**	**2,262**

4.3 Summary of Results

The results for MISC's operations in FY2017, shown below in Table 17, are discussed following.

4.3.1 Voyages undertaken

The four ships undertook 70 voyages in total. Two of these were dry dock voyages to Fiji, for Ribuuk Ae at the beginning of the year and for Kwajalein at the end. In total, the ships steamed a total of 49,535 nautical miles (nm).

4.3.2 Time on voyages

The split of time is shown in Table 14 and Figure 3. As can be seen, the time spent between voyages in Majuro is greater than 50% of the time.

Table 14: MISC Ships Time on Voyages, FY2017

	Total ship-days	Percentage of Time
At sea	254	17%
Working Cargo	259	18%
At atolls/ In port, idle	204	14%
Total voyage time	717	49%
Days between Voyages	743	51%

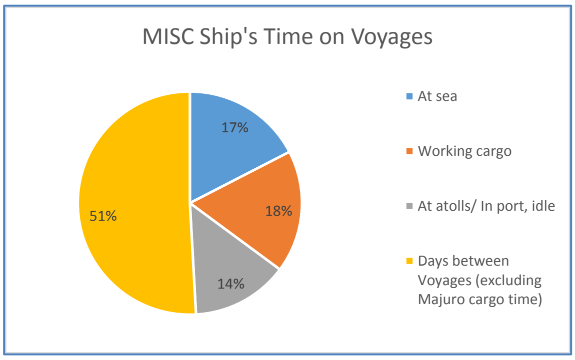


Figure 3: MISC Ships - Time on Voyages, FY2017

4.3.3 Speed and Engine Power on Voyages

The speed at which the ships operate is available anecdotally from the ships' staff. Some of the masters and chief engineers have advised the engine rpm and resulting service speeds and consumption that they operate at. Additionally, Raffael Held, a member of the GIZ team, undertook passages on three of the MISC ships, Aemman, Ribuuk Ae and Majuro on which he observed speed and fuel consumption[11]. Kwajalein was in Majuro during the Consultant's first visit, and the opportunity was taken to conduct a speed trial on Majuro lagoon to accurately measure the speed/ consumption relationship for that ship. See Appendix 5.

The actual fuel consumption for the year was not recorded for the MISC ships. However, the fuel delivered to the ships was. Within the error resulting from not knowing the difference between fuel on board at the beginning and end of the year, the quantity delivered has been used as a proxy for quantity consumed.

The consumption calculated by the model, using the service speed observed and obtained anecdotally was compared with the quantity delivered to each ship. The speed of the ship and the rate at which the auxiliary engines consumed fuel was then adjusted in order to result in the model's calculation providing the same quantity as actually delivered; that is, the model inputs were calibrated to reflect the actual situation.

Table 15: Calibration of MISC Ships Speed/ Fuel Consumption Assumptions

Ship	Kwajalein	Aemman	Majuro	Ribuuk Ae
FY2017 actual consumption (US gallons)	85,822	48,318	92,637	35,500
Calculated consumption (US gallons)				
at service speed of	9.66	8.22	9.55	8.00
and Auxiliaries condition factor of	0.80	0.80	0.85	0.80
Aux consumption at sea	56.0	38.7	48.2	29.0
ME	42,400	23,051	64,802	9,268
Auxiliaries	42,846	28,458	28,935	19,272
Total	85,245	51,509	93,737	28,540
Shortfall (Excess) consumption	577	(3,191)	(1,100)	6,960
Re-calibrated consumption (US gallons)				
at service speed of	9.66	7.50	9.55	8.50
and Auxiliaries condition factor of	0.80	0.80	0.90	0.75
Aux consumption at sea	56.0	38.7	48.2	35.0
ME	42,400	19,740	64,802	11,617
Auxiliaries	42,846	28,980	27,327	23,601
Total	85,245	48,720	92,129	35,219
Shortfall (Excess) consumption	577	(402)	508	281
%age shortfall (excess)	0.7%	-0.8%	0.5%	0.8%

Changed data shown as [highlighted]

From this analysis, it would appear that only Kwajalein is being operated at or near its engine continuous service rating (85% of MCR). The other three are being operated at quite markedly reduced power settings. This in itself will result in fuel savings and reduced emissions for any given transport task, compared with operations at higher speeds/ power. The model calculates that at the above demand speeds, the percentages of 'in service' maximum power are:

Ship	*Kwajalein*	*Aemman*	*Majuro*	*Ribuuk Ae*
Demand Service Speed	9.66 kts	7.5 kts	9.55 kts	8.5 kts
% of 'in service' power*	85%	46%	54%	36%

- 'In service' maximum power is power achieved in service at 100% of rated RPM, calculated by using the rated SFOC at that RPM.

These speeds are the 'demand speed' that would be experienced in calm conditions. The actual speed achieved on passage is affected by weather conditions, by as much as 30% or 40% in head seas. A typical voyage of Aemman, voyage 8 in FY2017 to the Southern Sector illustrates this effect. Table 16 shows the ships head, the wave conditions encountered and the resulting speed loss on that voyage.

Table 16: Example of Speed Loss in Weather

Route		Ship's head	Ships demand speed, V	Wave height	BN	True wave direction	Wave Direction relative to ship	Speed loss	Ship's actual speed
from	to		Knots	m					Knots
Uliga	Jaluit	225	7.50	1.84	4.9	247	022	29%	5.33
Jaluit	Namdrik	265	7.50	1.77	4.9	042	137	12%	6.60
Namdrik	Ebon	150	7.50	1.83	4.9	052	262	12%	6.60
Ebon	Toka	320	7.50	1.75	4.7	047	087	9%	6.85
Toka	Ebon	140	7.50	1.82	4.9	048	268	12%	6.60
Ebon	Namdrik	330	7.50	2.15	5.1	052	082	16%	6.31
Namdrik	Kili	085	7.50	1.53	4.7	120	035	19%	6.11
Kili	Mejrirok	075	7.50	1.54	4.7	180	105	9%	6.85
Mejrirok	Narmej	345	7.50	1.49	4.4	206	221	6%	7.05
Narmej	Imroj	145	7.50	1.49	4.4	206	061	6%	7.05
Imroj	Uliga	045	7.50	1.48	4.4	076	031	14%	6.47

Table 17: Results for MISC Ships Operations, FY2017

		Actual voyages FY2016				
Ship		Kwajalein	Aemman	Majuro	Ribuuk Ae	Total
Voyages undertaken						
No of Voyages		14	14	29	14	71
Distance steamed	nm	14,555	11,054	17,039	6,887	49,535
Time on Voyages						
(Including Majuro cargo time, but excluding idle time in Majuro between voyages)						
At sea	days	69	69	81	35	254
Working cargo	days	56	95	53	55	259
At atolls/ In port, idle	days	44	78	31	51	204
Total days on voyages	days	169	242	166	140	717
Days between Voyages (excluding Majuro car	days	196	123	199	225	743
Cargo carried						
General cargo outbound	tons pa	1,150	1,419	1,239	510	4,318
Copra inbound	tons pa	756	2,181	376	646	3,958
Fuel Consumed						
Diesel						
Fuel consumption, ME (t)	Litres	160,484	74,715	245,277	43,971	524,447
	US Gallons	42,400	19,740	64,802	11,617	138,559
	l/nm	11.0	6.8	14.4	6.4	10.6
Fuel consumption, Aux (t)	Litres	162,171	109,691	103,433	89,332	464,627
	US Gallons	42,846	28,980	27,327	23,601	122,754
	l/h	18.5	12.5	11.8	10.2	13.3
Total Diesel consumption	Litres	322,655	184,406	348,710	133,303	989,074
	US Gallons	85,245	48,720	92,129	35,219	261,313
Gasoline						
Consumption rate	Litres/voyage nm	0.45	0.45	0.45	0.45	0.45
Gasoline consumption	Litres	6,550	4,974	7,668	3,099	22,291
	US gallons	1,730	1,314	2,026	819	5,889
Lube Oil						
Consumption rate	litres/ 100 litres of fuel consumed	0.67	0.67	0.67	0.67	0.67
Lube oil consumption	Litres	2,151	1,229	2,325	889	6,594
	US gallons	568	325	614	235	1,742
GHG Emissions -CO2	Tonnes CO2					
Main Engine(s)		430	200	657	118	1,404
Auxiliaries		434	294	277	239	1,244
Boats		15	12	18	7	53
Lube Oil		-	-	-	-	-
Total		879	505	952	364	2,700
Fuel Efficiency (litres per 100 ton-miles)						
Cargo ton-miles	t.nm pa	27,729,006	39,802,060	27,520,789	7,960,645	103,012,501
Diesel fuel consumed	litres pa	322,655	184,406	348,710	133,303	989,074
Diesel fuel/ 100 ton-miles	Litres/100 t.nm	1.16	0.46	1.27	1.67	0.96

Annual cost (US$)		Kwajalein	Aemman	Majuro	Ribuuk Ae	Total
Annual depreciation		228,000	185,000	228,000	92,000	733,000
Provision for extended period costs (DD)		53,610	53,610	53,610	53,610	214,439
Period Operating costs (excl depreciation)		200,693	206,026	149,112	154,176	710,007
Cost per Voyage (foods etc)		35,614	25,967	36,045	22,733	120,359
Cargo costs (copra stevedoring)		5,478	15,814	2,727	4,681	28,699
Fuel costs		-	-	-	-	-
Diesel		249,743	142,735	269,910	103,180	765,567
Gasoline		8,098	6,150	9,480	3,832	27,559
Lube oils		3,694	2,111	3,992	1,526	11,324
Total fuel costs		261,534	150,996	283,382	108,538	804,449
Total Annual Cost		784,929	637,413	752,874	435,737	2,610,954
Total Cost excl depreciation		556,929	452,413	524,874	343,737	1,877,954

4.3.4 Fuel Consumed

Diesel: The total diesel consumed in FY2017 was 989,074 litres (261,313 US gallons), of which 524,447 litres (53%) was for propulsion in the main engines, and 464,627 litres (47%) was for electricity generation by the ships' auxiliary generators.

The overall main engine consumption rate for the fleet was 10.6 litres per nautical mile, and for the auxiliaries was 13.3 litres per hour. The resulting fuel efficiency, measured as litres of diesel fuel per 100 ton-miles of transport effort, was 0.96 l/100 t.nm.

The individual ships' rates are shown in Figure 4, Figure 5 and Figure 6.

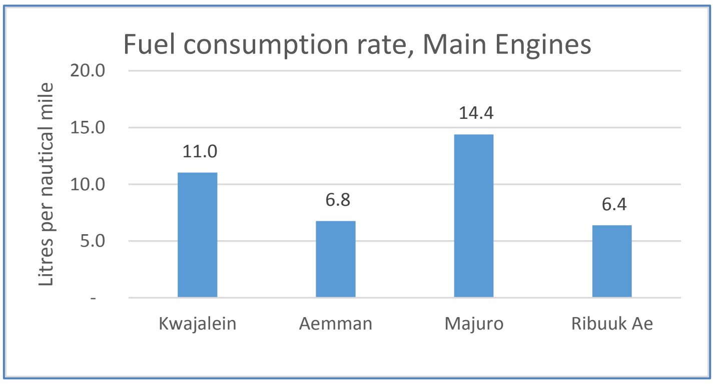


Figure 4: MISC Ships - Fuel Consumption Rate, Main Engines

The low consumption rate per mile for Ribuuk Ae reflects the much smaller engines in this ship, as well as operation at reduced power. Aemman's low consumption is primarily because the engines are operated at reduced power. Aemman is only marginally smaller than Kwajalein, and if it were operated at the same speed as Kwajalein, the consumption rates would be almost the same. Majuro's consumption is high compared with Kwajalein, because its hull shape, which is considerably 'fatter' than Kwajalein, leads to higher resistance.

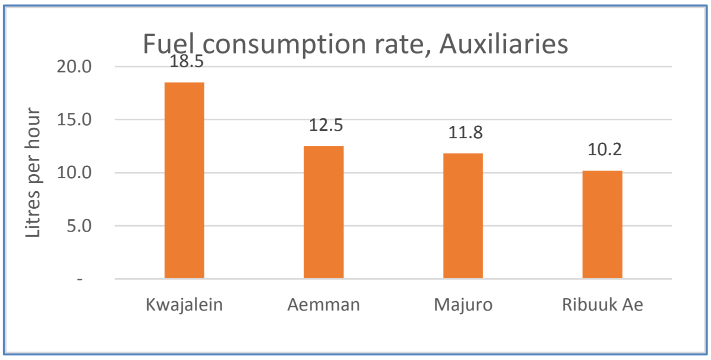


Figure 5: MISC Ships - Fuel Consumption Rate, Auxiliaries

Kwajalein has higher auxiliary consumption than the three other ships. It has a greater passenger capacity, so the electrical load is higher for this reason.

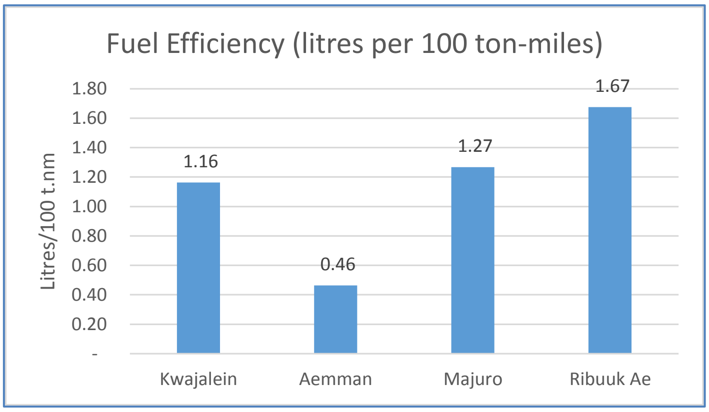


Figure 6: MISC Ships - Fuel Efficiency

The fuel efficiency is based on the distance steamed multiplied by the cargo quantity carried. This multiple is a measure of the productivity of the ship. From Table 17 it can be seen that Aemman's ton-miles are greater than the other ships, it carried more cargo than the other ships, and its fuel consumption is very low. The resulting consumption per 100 t.nm is thus very efficient, at 0.46 l/100t.nm. It is worth noting that if Kwajalein had undertaken Aemman's transport task, at Aemman's reduced speed, it too would have had a very low consumption per 100 t.nm.

On the other hand, although Ribuuk Ae has a very low total fuel consumption, it is a much smaller ship, and thus its cargo carried was very much less than the other three. Combined with less annual distance than the other ships, the ton-miles is small, pushing up its overall consumption per 100 t.nm. This demonstrates the economies of scale of larger ships compared with smaller ships.

Gasoline: The model bases the ships' boats outboard engine fuel consumption on a rate of 0.45 litres per voyage nautical mile. The total for FY 2017 was 22,291 litres (5,889 US Gallons).

Lube Oil: The model bases the engine lube oil consumption on a rate of 0.67 litres per 100 litres of fuel consumed. The total for FY2017 was 6,594 litres (1,742 US Gallons).

4.3.5 **GHG Emissions**

The greenhouse gas emission of greatest concern is CO_2. The emission rates used in the model for CO_2[10] are:

- Diesel: 3.206 kg CO_2/ kg fuel
- Gasoline: 2.36 kg CO_2-e/ litre of fuel

Based on the model's calculation of fuel consumption, the CO_2 emissions from MISC ships for FY2017 are shown in Table 18 and Figure 7:

Table 18: MISC Ships - GHG Emissions, FY2017

Fuel	Machinery	GHG emissions (tonnes CO_2)
Diesel:	Main engines	1,404
	Auxiliaries	1,244
Gasoline:	Ships' boats	53
Total, MISC fleet		**2,700**

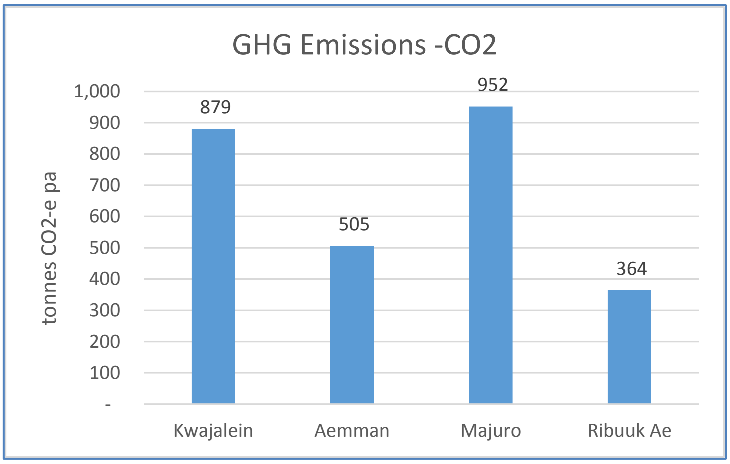


Figure 7: MISC Ships - GHG Emissions, FY2017

4.3.6 Financial Results

The actual cost of operation of the MISC ships was analysed to produce unit rates:

- Annual Depreciation. Based on estimate of proportion of depreciation for Ships shown in RMI Government Financial Statements.
- Daily extended period costs. Eg, dry dock provision (cost/ 5yrs/365days)
- Daily Operating Cost (excluding depreciation)
- Cost per Voyage, Foods etc
- Cost per ton of cargo (excluding charters)
- Cost of fuels. Cost per litre

The operating data calculated by the model has been combined with these unit rates to produce the costs for each ship shown in Table 19, and graphically in Figure 8.

Table 19: Operating Costs for MISC Ships Operations, FY2017

Annual cost (US$)	Kwajalein	Aemman	Majuro	Ribuuk Ae	Total
Annual depreciation	228,000	185,000	228,000	92,000	733,000
Provision for extended period costs (DD)	53,610	53,610	53,610	53,610	214,439
Period Operating costs (excl depreciation)	200,693	206,026	149,112	154,176	710,007
Cost per Voyage (foods etc)	35,614	25,967	36,045	22,733	120,359
Cargo costs (copra stevedoring)	5,478	15,814	2,727	4,681	28,699
Fuel costs	-	-	-	-	-
Diesel	249,743	142,735	269,910	103,180	765,567
Gasoline	8,098	6,150	9,480	3,832	27,559
Lube oils	3,694	2,111	3,992	1,526	11,324
Total fuel costs	261,534	150,996	283,382	108,538	804,449
Total Annual Cost	784,929	637,413	752,874	435,737	2,610,954
Total Cost excl depreciation	556,929	452,413	524,874	343,737	1,877,954

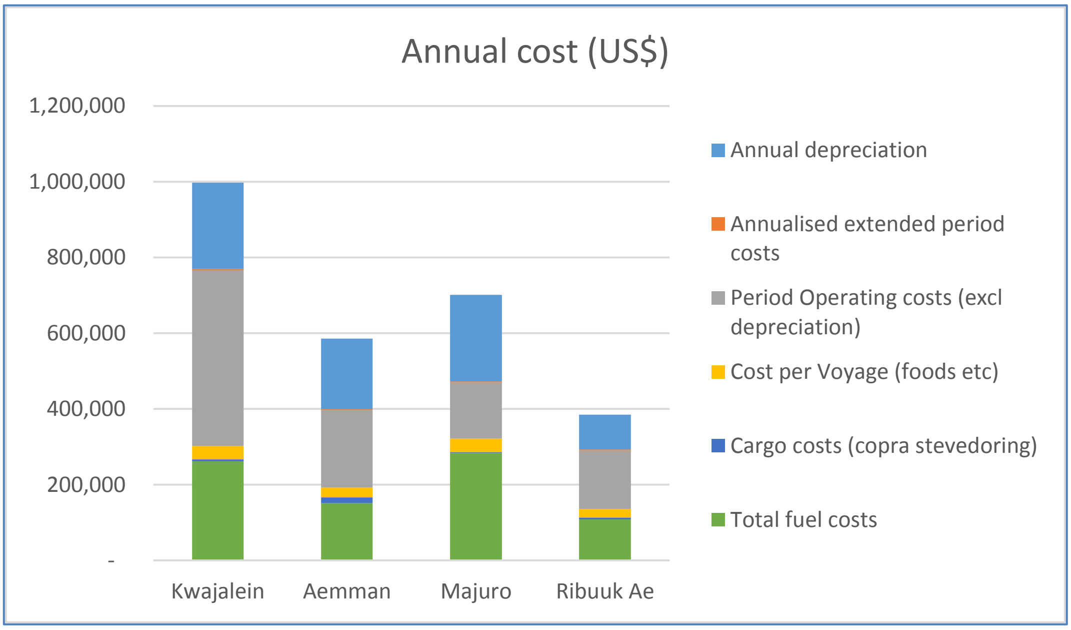


Figure 8: MISC Ships - Operating Costs, FY2017

Fuel costs for the fleet are significant, 30% of the total annual cost, and 42% of the cost excluding depreciation.

5 Alternative Operating Routes & Practices

The TOR call for investigation of alternative routes or operation methods for RMI's domestic commercial shipping with a view to reducing fuel expenses and GHG emissions. The model has been used to calculate costs and emissions on alternative routes and operational practices, that is, measures to improve fuel efficiency. Full details of the alternatives are set out in Appendix 6, and are summarised below.

5.1 Alternatives Considered

The analysis falls into three groups:

5.1.1 Alternative routes and scheduling

- Centralised Copra Collection
- Majuro Turn Round

5.1.2 Operating Practices

- Shipping Operations
    - Slow steaming for Just in Time Arrival
    - Reduced Operational Speed
    - Single engine operation for twin-screw ships
- Ship maintenance
    - Dry Docking
    - Hull and Propeller Cleaning
    - Engine Tuning & Shaft Alignment
- Low-Emission Fuels
    - Fossil Fuel derived fuels- LNG and Methanol
    - Hydrogen
    - Bio-derived fuels
    - Recycled fuel oils
- Infrastructure Improvements
    - Aids to Navigation (AtoNs)
    - Reef Channels

5.1.3 Alternative sources of propulsion

Examples of the following hypothetical new technologies have been analysed.

- Direct forward thrust onto the ship
    - Sails or foils
    - Kites
    - Flettner rotors
- Application of power onto the propeller shaft
    - Wind, through a wind turbine, or
    - Solar energy through photo-voltaic cells
- Provision of electrical power to meet the ship's electrical demand
    - Wind, through a wind turbine, or
    - Solar energy through photo-voltaic cells.

5.2 Alternative Operating Practices to Consider

The above operating routes and practices that show reasonable improvement in financial operating costs, fuel consumption/ GHG emissions or both are:

5.2.1 Majuro turn round

In FY2017, the four MISC ships were in Majuro for a total of 699 days, almost two ship-years. This suggests that a reduction in number of ships in the fleet could be considered. If Ribuuk Ae's tasks were taken up by Kwajalein and Aemman, the following conclusions could be drawn:

- Although main engine fuel consumption would increase, reflecting the use of the larger ships, auxiliary fuel consumption would reduce as a result of one less ship in operation.
- The overall diesel consumption would improve by 37,949 litres, a 3.8% reduction
- The GHG emissions would reduce by 3.8% as a result, by 103 tonnes CO_2.
- The cost of ship operations would reduce by US$232,000, more than 10% of the fleet operating cost.
- It would be possible to dispose of Ribuuk Ae at its present market value.

5.2.2 Slow steaming for Just-in-Time, Slow Steaming Generally & Single Engine Operations

Adopting the combined practices of slow steaming to arrive at dawn off a port constrained by daylight navigation only, and slow steaming generally, at say 0.5kt slower than normal, could result in an annual GHG emissions reduction and cost saving in the order of 300 to 500 tonnes CO_2 and US$100,000 respectively over the whole fleet.

Twin Screw ships that are operating at engine powers below 50% of MCR can be operated on one engine, to take advantage of a more efficient fuel consumption rate at higher engine powers. For example, Majuro's SFOC is 2% higher at 50% of MCR compared with full power.

5.2.3 Hull Cleaning & Propeller Polishing

This practice would result in fleet savings of the order of US$50,000pa and CO_2 emission reductions of the order of 200 tonnes CO_2 pa. The indications are that in-water hull cleaning and associated propeller polishing are worthwhile investigating further.

5.2.4 Engine Tuning

This measure has a small benefit compared with other measures. However, three of the ships have engines from the same manufacturer, Yanmar, one engine each in Kwajalein and Aemman, and two in Majuro. It may well be worthwhile investigating the cost of a visit by a Yanmar technician to tune all four engines, perhaps in conjunction with a training session on planned maintenance.

5.2.5 Low Emission Fuels

The most promising low-emission fuels are bio-derived fuels and recycled fuel oils. As a group, the reduction of GHG emissions compared with diesel is of the order of 50% to 75%. At the present state of the technology, these fuels would typically be blended 10%/ 90% with diesel, giving a reduction in GHG emissions in the range 5% to 7.5%. Their use depends on the acceptability to engine manufacturers, and the implications on engine warranties. The most promising type for RMI is likely to be recycled fuel oils, because of the ease of supply and transportation from sources such as Singapore and San Francisco. The cost of such fuels is more or less the same as unblended diesel.

5.2.6 Overall Potential

If applied to the MISC fleet, these five changes to operational procedures and maintenance practices could result in cost savings up to US$400,000 pa, and CO_2 emission reduction of up to 900 tonnes CO_2 pa. See Table 20. Both Hull Cleaning and Engine Tuning have implementation costs associated with them, but even taking these into account, all these practices might well be worthwhile.

Table 20: Alternative Operating Practices to Consider

Measure	Fuel saving	CO_2 reduction (t CO_2)	Cost Saving (US$pa)	Comment
Majuro Turn Round	3.8%	103 t	$232k	May allow disposal of one ship
Slow steaming	5%-15%	300 - 500 t	$100k	Possibly already being practiced
Hull & Prop cleaning	7%	200 t	$50k	
Engine Tuning	1%	25t	$6k	
Low-emission fuels	-	135- 200 t	-	10% blend with diesel
Total		**~900t**	**$400k**	

If applied to the MISC fleet, this level of emission reduction represents a significant 33% reduction in the FY2017 CO_2 emissions levels, from 2,700 t CO2 to 1,800 t CO_2, through just operational practices alone. The greatest potential lies in consideration of slower operating speeds, ie slow steaming and low-emission fuels blended with diesel, neither of which have any additional direct costs.

An operating cost reduction of $400,000 is a 20% reduction in the nearly $2 million that it costs to operate the MISC ships each year.

5.3 Less Promising Alternative Operating Practices

Some of the alternative operating practices looked at were less promising. Either the fuel savings are low or the capital cost is high, or a combination of both. Details are in Appendix 6. Table 21 shows the outcomes for this group of options.

Table 21: Less Promising Alternative Operating Practices

Measure	Fuel saving	CO_2 reduction (t CO_2)	Cost Saving (US$pa)	Comment
Centralised Copra Collection	Does not appear to be attractive, either financially or for GHG emission reasons			
Single engine operation for twin-screw ships	Needs to be considered on a ship-by-ship basis. Ribuuk Ae & Majuro are twin screw. Could be looked at for them.			
Dry Docking	2.4%	65t	Abt $25k	Cost of additional dockings & voyages much higher than direct fuel savings
Aids to Navigation	1.1%	40t	Abt $10k	High capex, possibly justified by voyage turn times & safety concerns, but not by fuel savings/ emission reductions
Reef Channels	1.4%	40t	Abt $15k	High capex. Savings minimal
Total		**~145t**	**Abt $50k**	

5.4 Alternative Sources of Propulsion

GIZ's project has as one of its objectives, consideration of alternative sources of propulsion, both for intra-lagoon small craft and for larger ships such as the MISC ships. The model developed as part of this baseline study allows consideration of the benefits of alternative sources of propulsion on larger ships.

Alternative sources of propulsion can be in combination with conventional fossil fuelled engines – hybrid propulsion through augmenting the fossil fuelled propulsion - or instead of fossil fuelled engines. The most likely energy sources are:

- Wind energy
- Solar energy
- Carbon- low or neutral fuels such as bio-fuels

or combinations of these, both with and without fossil fuels.

The ship and voyage models have been used to calculate the fuel savings and emission reductions from use of wind energy using Kwajalein as an example. Two methods have been looked at:

- direct thrust from a Flettner rotor, and
- shaft power from an electric motor through the gearbox, powered by a wind turbine.

No capital or operating costs have been assessed, so these results tell only part of the story, but are included in order to demonstrate the model's use for GIZ's ongoing work. Details are set out in Appendix 6 and summarised in Table 22.

Table 22: Savings from Alternative Sources of Propulsion

Measure	Fuel saving	CO_2 reduction ($t\ CO_2$)	Cost Saving (US$pa)	Comment
Thrust Augmentation (Flettner)	1.5%	12t	$4k	Small benefits compared with the capital cost. May be significant savings at lower service speeds.
Shaft Power Augmentation (Electric motor through gearbox)	3.3%	29t	$8k	Also small benefits, although the relatively low capital cost of installing a system might make it worth considering

5.5 Operating Practices for Small Craft

The present practice of using gasoline fuelled outboard engines results in high expenditure and large GHG emissions for the small size of tasks undertaken. There is a wide range of alternative low carbon solutions, both traditional and modern. Modern solutions are likely to be more efficient and safer than traditional solutions, but there is a desire to use traditional methods. There may be a need for a mix of both. Bearing in mind that up to 500 gasoline outboard craft may need to be replaced, mass production of new craft may be needed. Capital cost is a barrier, but this will be partially offset by fuel savings. Some of the options that might be considered are:

- Modern, low carbon small craft
  - PV cell/ electric outboards
  - Small Flettners
  - Wind foils & Soft sail craft
  - Bio fuel outboards
- Traditional small craft
  - Proas
  - Catamarans

6 Recommendations

6.1 Shortcomings of MISC Operations

- MISC does not have a proper Management Information System
- The ships are not properly fitted with performance measuring devices
- One manager is managing both cargo operations and ship maintenance, resulting in:
  - 'as needs' maintenance as repairs, rather than planned maintenance
  - little attention to the operational efficiency of the ships

6.2 Recommendations to Improve Operating Efficiency

6.2.1 Introduce Performance Monitoring

- Install fuel flow gauges on both inflow and outflow of main engines and auxiliaries
- Consider installation of torsion meters to measure engine power output
- Set up routine collection of performance data such as:
  - Fuel consumption
  - Speed
  - Weather conditions
- Link all these to the ships' data computers

6.2.2 Carry Out Performance Analysis

- Set up a performance analysis system
- Set up a cargo and passenger data collection system
- Link this to an overall Management Information System, linked also to the financial management system
- Use performance monitoring results to analyse changes in performance
- Act on outcome of performance analysis to correct operational methods

6.2.3 Management Functions

- Split the responsibility for cargo operations and ship maintenance between two managers by employing a Marine Engineering Superintendent (or a ship management firm to carry out this function)
- Introduce a management information analyst (what used to be called a management accountant). For example, a graduate in business administration with accountancy skills.

6.2.4 Ship Operations Efficiency Initiatives

- Investigate slow steaming techniques
  - Just in time arrivals
  - Slower demand speeds on passage
  - Single engine operations for Majuro and Ribuuk Ae
- Improve turn round times in Majuro
  - Engage with Tobolar to speed up copra discharge, including consideration of 'free out' discharge and demurrage payments
- Investigate the use of low-emission fuels blended with diesel
- Optimise trim to reduce resistance
- Carry out frequent in-water hull cleaning and propeller polishing
- Get Yanmar engines on Kwajalein, Majuro and Aemman tuned by Yanmar technician
- Shaft alignment
- Set up proper planned maintenance systems, based on systems provided by shipyards for Majuro and Kwajalein.

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TA-8345 REG: Establishment of the Pacific Region Infrastructure Facility Coordination Office

Establishing Baseline Data to Support Sustainable Maritime Transport Services

APPENDICES

Appendix 1. The Domestic Commercial Fleet

1 Overview

Domestic commercial ships in RMI fall into 7 groups:

- MISC fleet
- Other large commercial trading ships
- Smaller inter-atoll ships
- Fishing support ships
- Tourism ships
- Service craft/ tugs
- Intra-lagoon small boats

Intra-lagoon small boats are not required to be registered, but were counted in the 2011 census and are in general powered by outboard motors. All other ships should be registered, but not all are. Those that have been identified, registered or not, are shown in Table 23.

Table 23: Domestic Commercial Ships in the Marshall Islands

Name	Owner/ Operator	Vessel Type	Main use in FY2017	Year Build	Gross Tonnage	LOA (m)	Number of engines	each at Rated Power (kW)	Rated RPM	Service Speed (kts)	Consumption at Service speed (l/h)	Main Engines/ Comments
MISC Ships												
mv Kwajalein	MISC	Landing Craft	Field trips	2013	583	45.6	1	478	1500	9.6	95	Yanmar 6RY17W
mv Majuro	MISC	Cargo/ Pax	Charters	2013	416	40.4	2	478	1500	9.5	144	Yanmar 6RY17W
mv Aemman	MISC	Cargo/ Pax	Field trips	2004	409	45.0	1	441	900	8.5	96	Yanmar 6N18A-DV
mv Ribuk Ae	MISC	Cargo/ Pax	Field trips	1996	175	33.5	2	317	1800	8.5	46	Cummins KT19-M
Other Commercial Trading Ships												
LCT Resslynn	Ms. Resslynn Latak	Landing Craft	Fuel & Cargo	2007	450	36.5		333		7	95	Cummins NT855 8cyl
mv Lady E	E.U.L.G.	Cargo/ Pax		1966	698	50.3	2	888		9		Caterpillar 2-D398 12 cyl
mv Tobolar	TCPA			1980	315	32.4						One trip only in FY2017
mv Mata	Kaitol Reimers	Cargo/ Pax	Cargo & Pax	1976	60	19.5	2	333		8.5		Detroit 671 V1271
Melissa K	PII	Cargo/ Pax	Cargo & Pax	1992	36	16.2		238		8	44	Caterpillar
LC Jerbal	PII	Landing Craft	Cargo & Pax; projects	1969	108	22.6	2	622		8	61	12v71 Detroit
LC Michelle K	PII		Cargo & Pax; projects	1994		61.6	2	400		8	113	Caterpillar Cat D3412
mv Jejnica	Takao Domnick	Fishing/ Cargo		1980	34	17.1						
LCM Chase D	Takao Domnick	Landing Craft		2012	240	28.0						
Small Inter-Atoll Ships												
mv Kuban	PII	Cargo/ Ferry	Cargo & Pax	2000	5	12.2		260		8	24	Cummins 1/6 inline
mv Lele	PII	Cargo/ Pax	Charters- Cargo & Pax	1999	7	15.2		260		9	27	Yanmar
Four X	RRE		Cargo & Pax	1972		11.8		407		14.5	55	John Deere inline
Iju in Rak	Mayor Joel Jitiam		Cargo & Pax			14.6		370		10.5	30	GM Detroit 8cyl inline
LC Christina	Robert Pinho	Mini landing craft	Cargo & Pax			9.8	2	111		13		Outboard Yamaha 4
Miko	Mayor Bernard ChongGum		Cargo & Pax			9.8	2	111		17		Outboard Yamaha 4
Tobwe Mili	Kilang Jitiam	LGC boat; cargo & pax				10.7		185		16		Yamaha; only 1 trip in 2017
Fishing Support												
FV Timur	MIMRA	Fishing/ Cargo	Servicing Fish bases	2010	12	13.9		266		14	45	
FV Jebro	MIMRA	Fishing/ Cargo	Servicing Fish bases	2010	12	13.9	1	265		14	45	Sister of Timur
FV Laintok	MIMRA	Fishing/ Cargo		1999	14	16.0						Based in Ebeye
FV Lentanur	MIMRA	Fishing/ Cargo		1999	14	16.6						Based in Ebeye
Tourism												
mv Indies Traders	RRE	Diving/ Survey	Tourism	1978	95	21.3		148		8		
mv Windward	RRE	Diving/ Survey	Tourism; Cargo	1992	202	23.0		222		8		Cummins; Diving Chamber
Service craft/ Tugs												
Tarlan 04	KALGOV'T	Search & Rescue		2015	9	16.6						
MT Ratak II	PII	TugBoat		1971	282	33.2						
MT Ralik II	PII	TugBoat		1970	334	33.2						
Not accounted for (but on Register)												
mv. Koba Maron	Anjua Loeak	Non-Commercial		1988	41	23.5						
mv Lae	Lae Local Gov,t	Cargo/ Fishing		1980	64	23.0						
LCM 82	MOPW	Landing Craft		1967	900	38.4						
DeepBlueSea	Heinkey Lomwe	Smal lFish Carrier		1996	4	7.7						
mv Barijet	Langmos Hermios	Fishing		1997	12	13.7						

2 MISC Ships

A comprehensive compilation of the technical details and descriptions of MISC's ships can be found in GIZ's baseline data, which is set out in Raffael Held's BSc Thesis[11]. A summary of the most salient points has been extracted from GIZ's data and is shown in Table 24. A list of the particulars required to carry out resistance calculations for the model developed as part of this project are set out in Appendix 3.

Table 24: MISC Vessels' Main Particulars

Ship	Kwajalein	Aemman	Majuro	Ribuuk Ae
Year of Delivery	2013	2005	2013	1996
Type	General Cargo-Pax.	General Cargo-Pax.	Landing Craft-Pax.	General Cargo-Pax.
Gross tonnage	583	534	416	175
Length overall [m]	49.85	48.55	44.09	31.1
Breadth [m]	9	8.5	10.8	7.7
Design Draft [m]	3.21	3.2	2.1	2.6
Main Engine	1 x Yanmar, 6RY17W: 478 kW x 1500min^{-1}	1 x Yanmar 6N18A-DV: 441kW x 900min^{-1}	2 x Yanmar 6RY17W: 478kW x 1500min^{-1}	2 x Cummins KT19-M: 317kW x 1800min^{-1}
Auxiliary Engine	2 x Yanmar 4HAL2-TN1: 116kW x 1800min^{-1}	1 x Yanmar 6CHL-TN, 73.6kW x 1800min^{-1}, 1 x A-6BG1: 68.4kW x 1800min^{-1}	2 x Yanmar 4HAL2-TN1: 116kW x 1800min^{-1}	2 x Cummins, DR1462-RX: 112kW x 2200min^{-1}
obs. F.O. Cons., ME (t/d) *[kg/h]* {avg. RPM_{ME}, obs.}	1.78 [74.1] {1330min^{-1}}	2.05 *[85.3]* {650min^{-1}}	3.10 *[129.3]* {1300min^{-1}}	0.8 *[33.2]* {PS: 900min^{-1}, Stb.:1350min^{-1}}
obs. F.O. Cons., AE (t/d) *[kg/h]*	0.25 [10.6]	0.19 *[8.0]*	0.18 *[7.5]*	0.31 *[12.9]*
obs. Speed, underway	9-10kt	8-9kt	9-10.5kt	6-7kt
Cargo Hold Volume [m^3]	804.08	799.37	91.22	279
Passenger capacity	150	200	50	100

Operational areas

The MISC ships are licenced by the Ministry of Transportation & Communications (MOTC) to operate with a restriction to near coastal trade within RMI Exclusive Zone.

Speed/ Fuel Consumption Relationship

The key data required to be able to calculate fuel consumption and GHG emissions is the speed/ fuel relationship for at least the normal service speed and ideally for a range of speeds. Ships staff, the Master and Chief Engineer, are a good source of this data. This information inevitably includes the effects of weather speed loss, and usually is quoted as a consumption for a range of weather dependent speeds, for example 96 litres per hour at 8 to 9 knots.

Speed Trial of Kwajalein

In order to get a more accurate estimate for at least one MISC ship, a speed trial was conducted for Kwajalein. See the speed trial report attached as Appendix 5. Eight runs were made on Majuro lagoon, two each at a fixed engine rpm setting, and the fuel consumption and speed were accurately measured. The weather conditions were ideal; very light winds and no waves. This enabled the consumption in calm water to be obtained.

This accurate data was able to be used to derive the hull roughness speed loss by using the model resistance and propulsion calculations. Comparison of the RPM/ Fuel consumption data also enabled the engine condition efficiency to be derived by comparison with the engine test bed data, which was obtained from the engine manufacturer, Yanmar.

Fuel Consumption Data for Other Ships

If the actual consumption for a speed in calm water cannot be measured, the hull roughness needs to be estimated. The model has an algorithm that uses the age of the ship and time out of dry dock to estimate the two components of roughness, corrosion and fouling. The results of the speed trial for Kwajalein indicate that this algorithm is reasonably accurate in the case of that ship.

	Kwajalein	Aemman	Majuro	Ribuuk Ae
Hull roughness (µm)	1260	1890	1260	1935
Engine condition efficiency	11.2% to 12.9%			

If the engine model is known, the engine RPM/ Brake Power/ Fuel Consumption relationships can be obtained from the manufacturer's engine specifications. This needs to be modified to reflect the in-service condition of the engine. For this project, the engine data was obtained for all four MISC ships. The engine condition efficiency measured for Kwajalein was applied to the data for the other ships to estimate the in-service RPM/ Brake Power relationship. This is needed in order to calculate the propeller efficiency and thus the brake power requirement for ship speed specified and the ships resistance calculated in the model. Using the test bed engine specific fuel consumption data, the in-service fuel consumption for that RPM and ship speed can then be calculated.

Technical Information and Drawings

Technical data on the three newer ships, Kwajalein, Majuro and Aemman is held ashore in MISC's office including plans and drawings, manuals and other documents such as stability books and trials reports. Data required to carry out the analysis for this project was therefore readily available for these three ships. Sufficient data was able to be obtained for analysis of Ribuuk Ae by using the basic data available and estimates based on the consultant's experience. It was not practical to obtain drawings and plans for insertion into this report, but they are readily available.

Navigation Equipment & Safety Equipment

The ships are fitted with the basic navigation equipment and safety equipment required to carry out their function. A list of navigation equipment and safety equipment is contained in the GIZ baseline data[11].

Ships' Condition

The ships are in working condition, although not at the level that would be expected for the two newer ships; these are only four years old. Kwajalein had just returned from dry dock when visited, and it is evident that several non-essential items of repair were not attended to. For example, the cement flooring in the working alleyway on the main deck was cracked, and water would be able to get underneath, causing a potential corrosion problem. It is also a trip hazard.

Some bridge equipment was not operational on the ships. For example, auto pilots were broken, and on one ship, the gyro compass and magnetic compass were not operational, and the ship was using a portable boat compass taped to the bridge consol.

The two new ships were provided with a planned maintenance system on delivery. No documentation recording adherence to the plans could be found. It appears that the ships are being maintained and repaired on an as-needs basis. This is a false economy; attending to maintenance as planned avoids greater repair costs and ship down time in the future.

These are signs that the cost of required ship maintenance is greater than is budgeted for. Some attention is needed to return the ships to an effective planned maintenance system.

3 Other Domestic Commercial Ships

There was not much information available for the private sector and local government owned ships. Interviews were carried out with owners and operators which provide an overview of transport tasks undertaken and fuel consumption for each ship in FY2017. Some basic technical data was obtained during these interviews and was available from the domestic ship register. The technical information obtained is presented in Table 23 above.

4 Intra-lagoon Small Craft

There are numerous small intra-lagoon boats located on all atolls and islands. Very little data is available regarding their use, but the number of such boats was recorded in the 2011 Census. These boats are in general powered by outboard motors using gasoline as fuel, typically a 25hp or 40hp outboard. Fuel consumption for these sizes is about 6.0 and 8.7 l/h respectively (1.5 and 2.3 US gallons /hr). Information on the number in regular use and their intensity of use has not been able to be obtained. .

Atoll	No of boats in census
Ailinglaplap	27
Ailuk	3
Arno	20
Aur	13
Bikini	-
Ebon	13
Enewetak	27
Jabat	1
Jaluit	25
Kili	1
Kwajalein	60
Lae	2
Lib	1
Likiep	21
Majuro	269
Maloelap	16
Mejit	4
Mili	26
Namdrik	7
Namu	7
Rongelap	-
Ujae	1
Ujelang	-
Utirik	14
Wotho	2
Wotje	22
Total	582

Figure 9: Intra-Lagoon Small Craft

Appendix 2. Cargo Operations by Ships' Boats

1 General Cargo Operations in Outer Islands

At most outer islands, cargo is discharged to ship's boats and transferred to shore. On the three larger MISC ships, the boat load limits inside lagoons are 2 pallets of general cargo of about 1 ton each on or 2.5 tons of copra in bags. The maximum safe passenger load is 20 persons. When operating to ocean beaches or in bad weather, the Masters typically restrict the loads to 1 pallet (1 ton) or 1.5t of copra, with passenger limits of about 10 persons.

Ribuuk Ae has smaller ship's boats. These can carry 2 pallets of general cargo (as with the larger boats), but copra is restricted to 2 tons and passenger numbers to 15 persons. On ocean beaches or in bad weather, 1 pallet, 1 ton of copra or 10 passengers.

The time required for boat round trips varies from place to place. In an interview with two of MISC's masters, Captain First Lussier (Ribuuk Ae) and Captain Fuisenga Sualau (Aemman), the boat times were discussed for a list of landing places. The landing places were also classified as to location – lagoon, ocean or alongside. See Table 25**Error! Reference source not found.**.

2 Copra loading in Outer Islands

Loading copra is the reverse of discharge of general cargo. Copra collection usually occurs on the return trip as it is not desirable to mix general cargo with copra; there is the potential for contamination of general cargo, for example by cockroaches in copra.

Copra is collected from a wide range of places, often the beach adjacent to a grower's home. The cost of intra-lagoon transport mitigates against centralising copra collection. See the section in Appendix 6 on Centralised Copra Collection for an explanation and analysis, but in summary, the cost of transporting copra to a central place is higher than the cost of taking the ship to the individual beaches.

Copra is carried in bags each with about 100 pounds (45kg) capacity. These are loaded loose into slings laid in the bottom of the ships' boats. The normal load is about 25 bags (2.5 tons) in larger ship's boats, and 20 bags (2 tons) in Ribuuk Ae's smaller boats. In poor weather, or for ocean landings, these limits reduce to about 15 and 10 bags respectively. The copra bags are stowed loose in the ships' holds.

Table 25: Boat Round Trip times to Beaches

Atoll	Port	Boat trip times (minutes)					Ocean, lagoon or alongside
		To shore	at shore	back to ship	at ship	Total; round trip	
Ailinglaplap	Airuk	10	20	10	20	60	Ocean
	Buoj	10	20	10	20	60	Ocean
	Jabwan	10	20	10	20	60	Ocean
	Jah	5	20	5	20	50	Lagoon
	Jeh	5	20	5	20	50	Ocean
	Kattiej	5	20	5	20	50	Ocean
	Mejil	5	20	5	20	50	Lagoon
	Woja	15	20	15	20	70	Lagoon
	Enewe	5	20	5	20	50	Lagoon
Ailuk	Ailuk	5	20	5	20	50	Lagoon
	Enejelar	5	20	5	20	50	Lagoon
Arno	Arno	5	20	5	20	50	Ocean
	Bikarej	60	20	60	20	160	Lagoon
	Ine	5	20	5	20	50	Ocean
	Tinak	5	20	5	20	50	Ocean
	Tutu	5	20	5	20	50	Ocean
	Ulien	5	20	5	20	50	Ocean
Aur	Aur	5	20	5	20	50	Lagoon
	Bikien	2	20	2	20	44	Lagoon
	Tabal	2	20	2	20	44	Lagoon
Bikini	Bikini	5	20	5	20	50	Lagoon
Ebon	Ebon	30	20	30	20	100	Lagoon
	Enekion	30	20	30	20	100	Lagoon
	Toka	30	20	30	20	100	Lagoon
Enewetak	Enewetak	5	20	5	20	50	Lagoon
Fiji	Suva	1	5	1	5	12	Alongside
Jabat	Jabat	10	20	10	20	60	Ocean
Jaluit	Bokanake	30	20	30	20	100	Lagoon
	Imiej	10	20	10	20	60	Lagoon
	Imroj	5	20	5	20	50	Lagoon
	Jabwor	1	5	1	5	12	Alongside
	Jaluit	30	20	30	20	100	Lagoon
	Mejrirok	30	20	30	20	100	Lagoon
	Narmej	5	20	5	20	50	Lagoon
Kili	Kili	5	20	5	20	50	Ocean
Kwajalein	Carlson	5	20	5	20	50	Lagoon
	Ebadon	10	20	10	20	60	Ocean
	Ebeye	1	5	1	5	12	Alongside
	MejattoJ	15	20	15	20	70	Lagoon
	Santo	15	20	15	20	70	Lagoon
Lae	Lae	20	20	20	20	80	Lagoon
Lib	Lib	5	20	5	20	50	Ocean
Likiep	Jebal	5	20	5	20	50	Lagoon
	Likiep	5	20	5	20	50	Lagoon
	Liklal	15	20	15	20	70	Ocean
	Melang	5	20	5	20	50	Lagoon
Majuro	Delap	1	53	1	5	60	Alongside
	Majuro	1	5	1	5	12	Alongside
	Uliga	1	5	1	5	12	Alongside
Maloelap	Airok	5	20	5	20	50	Lagoon
	Jang	5	20	5	20	50	Lagoon
	Kaben	5	20	5	20	50	Lagoon
	Taroa	5	20	5	20	50	Lagoon
	Wolot	5	20	5	20	50	Lagoon
Mejit	Mejit	10	20	10	20	60	Ocean
Mili	Enajet	20	20	20	20	80	Ocean
	Lukonwor	45	20	45	20	130	Ocean
	Mili	30	20	30	20	100	Ocean
	Nallu	20	20	20	20	80	Lagoon
	Tokewa	20	20	20	20	80	Lagoon
Namdrik	Namdrik	25	20	25	20	90	Ocean
Namu	Loen	15	20	15	20	70	Lagoon
	Mae	10	20	10	20	60	Lagoon
	Majkin	10	20	10	20	60	Lagoon
	Namu	5	20	5	20	50	Lagoon
Rongelap	Rongelap	5	20	5	20	50	Lagoon
Ujae	Ujae	20	20	20	20	80	Lagoon
Ujelang	Ujelang	5	20	5	20	50	Lagoon
Utirik	Utirik	5	20	5	20	50	Lagoon
Wotho	Wotho	20	20	20	20	80	Lagoon
Wotje	Nibun	5	20	5	20	50	Lagoon
	Wormej	5	20	5	20	50	Lagoon
	Wotje	7	20	7	20	54	Lagoon

Appendix 3. Model

1 Structure of Model

A model has been developed to calculate the fuel consumption, GHG emissions and operating costs for ships operating in the Marshall Islands. The model is in a template form so that it can be replicated for use in other places.

The model has two main components:

- Ship Module
- Voyage Module

These modules are contained in two files:

- 'Ship Module v1.1.xlsx'
- 'Voyage Module v1.1.xlsx'

2 Ship Module

Purpose: To obtain speed/ fuel consumption relationship for input into the voyage module

Method: Calculates resistance of ship, and therefore engine power required and fuel consumption for any given speed.

Flexibility: Can calculate engine power required when propulsive power is augmented by other sources of energy such as wind or solar energy. Can substitute fuels other than fossil fuels.

See Flow Diagram in Figure 10.

Methodology

Definition of operating scenario

Three key parameters that relate to the voyage scenario being considered need to be defined:

- *Demand speed*. The desired speed on passage. The actual speed achieved may be reduced by adverse weather, and might in some favourable conditions be increased by a moderate following wind.
- *Operating draft and trim*. The ship disposition can be defined by the operating draft and trim. The model adjusts the calculated resistance according to the changes in parameters such as displacement, underwater surface area, block and prismatic coefficient, transom submergence that are affected by draft and trim.
- *Power augmentation*. The model has been developed so that power from energy sources such as wind or solar energy can be taken into account.

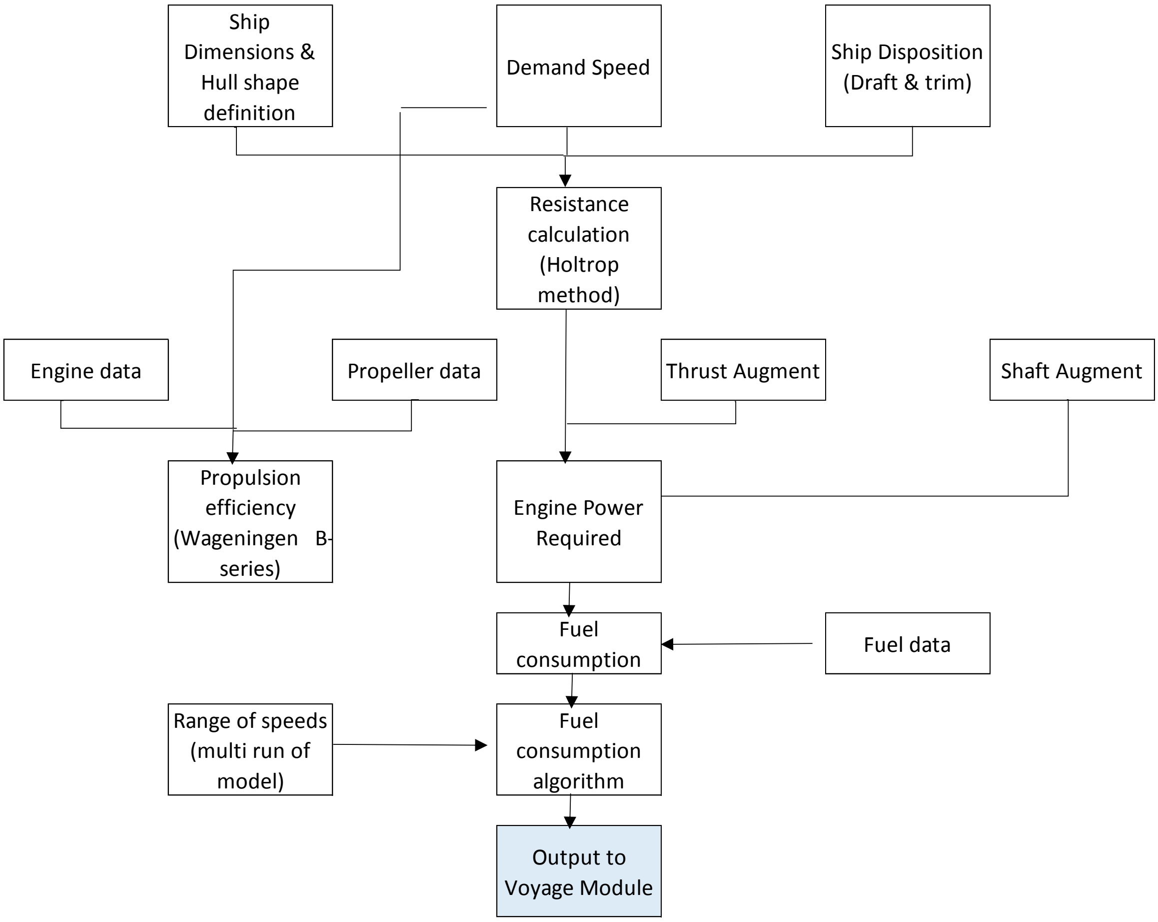
Ship data:

The input parameters that are required are listed in Table 26, along with data for the four MISC ships. They define:

- Ship particulars.
- Hull form
- Hull roughness
- Engine(s) & propeller(s)
- Main Engine fuel consumption
- Auxiliaries fuel consumption

Figure 10: Flow Diagram - Ship Module

Reference — Ship Module v1.0.xlsx'
Purpose: — To obtain speed/ fuel consumption relationship for input into the voyage module
Method : — Calculates resistance of ship, and therefore engine power required and fuel consumption for any given speed.
Flexibility: — Can calculate engine power required when propulsive power is augmented by other sources of energy such as wind or solar energy. Can substitute fuels other than fossil fuels.



Calculation of ship's resistance

The model uses the Holtrop- Mennen method to calculate ship resistance[12 & 13]. The operating draft and trim are used to adjust the input particulars to suit the ship's disposition on the voyage. The method takes account of hull form and appendages such as bulbous bow, bow thruster, transom stern, twin or single screw. The components of resistance - frictional, wave making, appendages and correlation for roughness - are combined to arrive at the total resistance.

Effective Power Required

The effective power required is the product of total resistance and speed through the water. Any augment from thrust devices such as sails are deducted, leaving the required propeller-delivered power.

Propeller & Hull Efficiency

The efficiency of a propeller is a function of the propeller dimensions and characteristics, the speed of rotation, and the velocity of water inflow into the propeller disc.

The model uses data derived from tests of a series of propellers (the B-Series) at the Netherlands Ship Model Basin in the 1970s. The propeller characteristics of the series are expressed in dimensionless form as thrust and torque coefficients (K_T and K_Q), and speed of advance, J[14]. The coefficients for a given propeller allow the open water efficiency of that propeller to be calculated.

The water inflow velocity is affected by the hull shape and proximity of the propeller. Two hull efficiency parameters can be estimated, the Thrust Deduction Fraction, t, and the Wake Fraction, w.

Engine Power Requirement
Combining the effective power required with the hull and propeller efficiency determines the engine output required for the speed demanded. The propeller efficiency is a function of its speed of rotation, so the model uses an interactive process to arrive at a match between the ship speed, propeller/ engine rotation speed and engine power output.

Fuel consumption
The manufacturer's engine data for engine rotation speed, power output and fuel consumption rate is used to calculate the fuel consumption. Firstly, the engine condition is compared with the 'test bed' results for the engine. From this, a condition factor can be applied to the data so that an in-service consumption for a given engine output power can be arrived at.

The engine condition factor is best arrived at by measuring fuel consumption and engine power output using a torsionmeter or carrying out speed trials in properly controlled conditions. These are not always achievable, so a substitute is to compare actual consumption with engine speed (RPM) either through observation or measured by shipboard instrumentation. The consumption can be converted to power output by using the test bed specific fuel consumption for that RPM. The power derived is a reasonably accurate estimate of power, so the engine condition factor can be obtained.

The model then carries out a series of calculations at a range of ship demand speed. The resulting table is interpolated by curve fitting to a 5^{th} order polynomial over the expected operating speed range. This becomes the input into the voyage calculations.

Main Engine & Auxiliary Data
Engine RPM, Output Power (Pb) and Specific Fuel Oil Consumption (SFOC) data are input into tab 'MainEngine'. Auxiliary engine consumption data are input into tab 'Auxiliaries'.

Operating Cost Data
Operating cost data is input into tab 'CostData'.

Table 26: Resistance & Propulsion Input Data- MISC Ships

		Ship		*Kwajalein*	*Aemman*	*Majuro*	*Ribuuk Ae*
Ship data							
LWL	m	Waterline length		46.58	45.36	41.30	31.00
LBP	m	Between Perpendiculars		44.00	42.85	40.00	30.00
B	m	Moulded beam		9.00	8.50	10.80	7.70
D	m	Moulded depth		5.15	5.10	3.00	3.60
T	m	Loadline draft		3.21	3.20	2.10	2.60
Δ	t	Moulded Displacement at loadline draft		938.7	908.1	718.3	477.1
TPC	t/cm	Tonnes per cm immersion		3.57	3.39	4.38	2.15
		Speed loss due to hull roughness					
		Hull form data					
c_{stern}		Stern shape parameter		10	10	10	10
A_{MS}	m^2	Transverse Projected Area		*61.6*	*40.95*	*77.05*	*55.45*
C_M		Midship Coeff.		0.95344	0.96400	0.97390	0.95000
Cwa		Waterplane coefficient		0.86277	0.89600	0.98200	0.90000
LCB_{Aft}	m	Distance of LCB from AP		22.09	22.92	19.70	15.30
WSA	m2	Total wetted surface, including appendages (can leave blank; model will calculate)				527.54	
S_{app}	m^2	Total wetted surface of appendages	(see below)	30.00	30.00	13.84	7.00
$1 + K_2$		Effective form factor of appendages	(see below)	1.56	1.56	2.56	2.29
		Bulbous bow & Transom					
h_B	m	Height of the centroid of the area A_{BT} above the base line			1.7	0	0
A_{BT}	m^2	CSA of bulb in the vertical plane intersecting the stem contour at the \			3	0	0
A_T	*	Immersed area of the transom at zero speed		2.87	2.87	1.72	0.00
		Hull roughness factor					
k_s	mE-06	Hull roughness (microns)		See Hull Roughness calculations below			
		Engine & Propeller					
		Number of main engines & propellers		1	1	2	2
D	m	Propeller diameter		1.900	1.900	1.500	1.650
P	m	Propeller pitch		1.310	1.293	*1.034*	*1.138*
Z		No of blades		4	4	4	3
		Boss ratio		0.124	0.124	0.100	*0.100*
		Shaft centreline height		1.150	1.250	0.7900	*0.875*
Ae/Ao		Expanded blade area ratio		See BAR calculation below			
		Gearbox ratio		5.04	3.04	3.48	5.60
Es		Shaft & gearbox efficiency		0.95	0.95	0.95	0.93
Peng rated	kW	Rated engine power		478	441	478	317
	rpm	Engine speed at 100% rated power		1,500	900	1,500	1,800

Fuel Consumption, Auxiliaries							
	kg/h	At sea		19.9	12.2	15.0	11.9
	kg/h	In port, working cargo		25.3	16.5	24.5	16.1
	kg/h	In port, idle		17.9	9.4	9.2	12.4
	kg/h	Between voyages		10.5	5.5	3.9	5.3

Appendage Resistance				*Kwajalein*	*Aemman*	*Majuro*	*Ribuuk Ae*
			1+k2 value	*Area of appendages*			
		Rudder behind stern (single screw)	1.5	12.0	12.0		
		Rudders behind skeg (twin screw)	2.0				4.0
		Twin-screw balance (spade type) rudd	2.8			6.0	
		Shaft brackets	3			2.0	1.0
		skeg	2.0				
		strut bossings	3			2.0	1.0
		Hull bossings	2	6.0	6.0		
		Shafts	2			2.0	1.0
		Stabilizer fins	2.8				
		Dome	2.7				
		Bilge keels	1.4	12.0	12.0	1.8	
		Total area of appendages		30.0	30.0	13.8	7.0
		(1+k2)eq		1.56	1.56	2.56	2.29

Blade Area ratio		Keller's formula for Ae/Ao in Hol;trop					
		=K+(1.3+0.3*Z)*T/(D^2*(Po+rho*g*h-Pv))		*Kwajalein*	*Aemman*	*Majuro*	*Ribuuk Ae*
K		twin screw		0.1	0.1	0.1	0.1
		single screw					
Z		No of blades		4	4	4	3
D	m	Propeller diameter		1.900	1.900	1.500	1.650
T	N	Propeller thrust / propeller					
Po-Pv	N/m2	Po-Pv					
ρ	kg/m3	Density of water					
g	$m.s^{-2}$	Acceleration due to gravity					
h		depth of shaft centreline below surfac	m	1.425	1.950	1.210	1.725
Ae/Ao		**Blade Area Ratio**					

Hull Roughness				*Kwajalein*	*Aemman*	*Majuro*	*Ribuuk Ae*
		Year built		2013	2005	2013	1996
		Year for analysis		2017	2017	2017	2017
		Age of ship					
		last Dry Docking		2013	2014	2013	2017
		Years since last hull clean					
	μm/yea	Rate of corrosion		140	140	140	140
	μm/yea	dropping by		5	5	5	5
	μm/mor	Rate of fouling		12.5	12.5	12.5	12.5
	μm	Corrosion, initial year		150	150	150	150
	μm	Increase in Corrosion at year for analysis					
	μm	Fouling since last hull clean					
	μm	**Total hull roughness**					

Power Augmentation
Two forms of power augmentation are allowed for:
- Thrust augment
- Shaft augment

Thrust augment
This reduces the effective power that has to be delivered *by the propeller*. The resulting reduction in engine power output can be calculated by the model. These reduced outputs are also curve fitted using a 5^{th} order polynomial for a range of thrust augment forces. The relationship between varying thrust augments (including zero augment) for the range of ship speeds are then interpolated by using a 3^{rd} order polynomial.

Shaft augment
In contrast to thrust augment, shaft augment does not change the power that has to be delivered by the propeller. Instead, the power that has to be delivered *by the engine* is reduced by the amount of input into the gearbox from the electrical power source.

3 Voyage Module

Purpose: To calculate
- fuel consumption;
- GHG emissions; and
- operating costs

for the voyages undertaken by a given ship. The ship fuel consumption characteristics can be directly inserted or calculated in the Ship Module and imported into the Voyage Module.

Method: Calculates the steaming time, entering and leaving port, cargo working time and delays/ idle time for each voyage leg of all voyages described in the inputs. From these data, the fuel consumption, GHG emissions and operating costs are calculated.

Flexibility: Can take into account:
- Navigational and cargo working restrictions and constraints
- Wind and wave conditions
- Tides
- Propulsion augmentation, both thrust and shaft power

If there is insufficient ship data to run the Ship Module, an estimate of the speed/ fuel consumption relationship can be substituted into the Voyage Module.

Limitations: The voyage module analysis the performance of an individual ship over any number of voyages that it may undertake. In order to analyse a fleet of ships, the voyage activity of each ship needs to be separately analysed. For example, the FY2017 performance of the MISC fleet that is set out in this report needed all four ships to be analysed separately, and the results for each summed. Similarly, if a secondary hub service were to be investigated, the voyages of the ships undertaking such a network would need to be analysed separately, although with some careful modelling to link voyage module files, the start dates for each ship could be linked to others in the network.

See Flow Diagram in Figure 11.

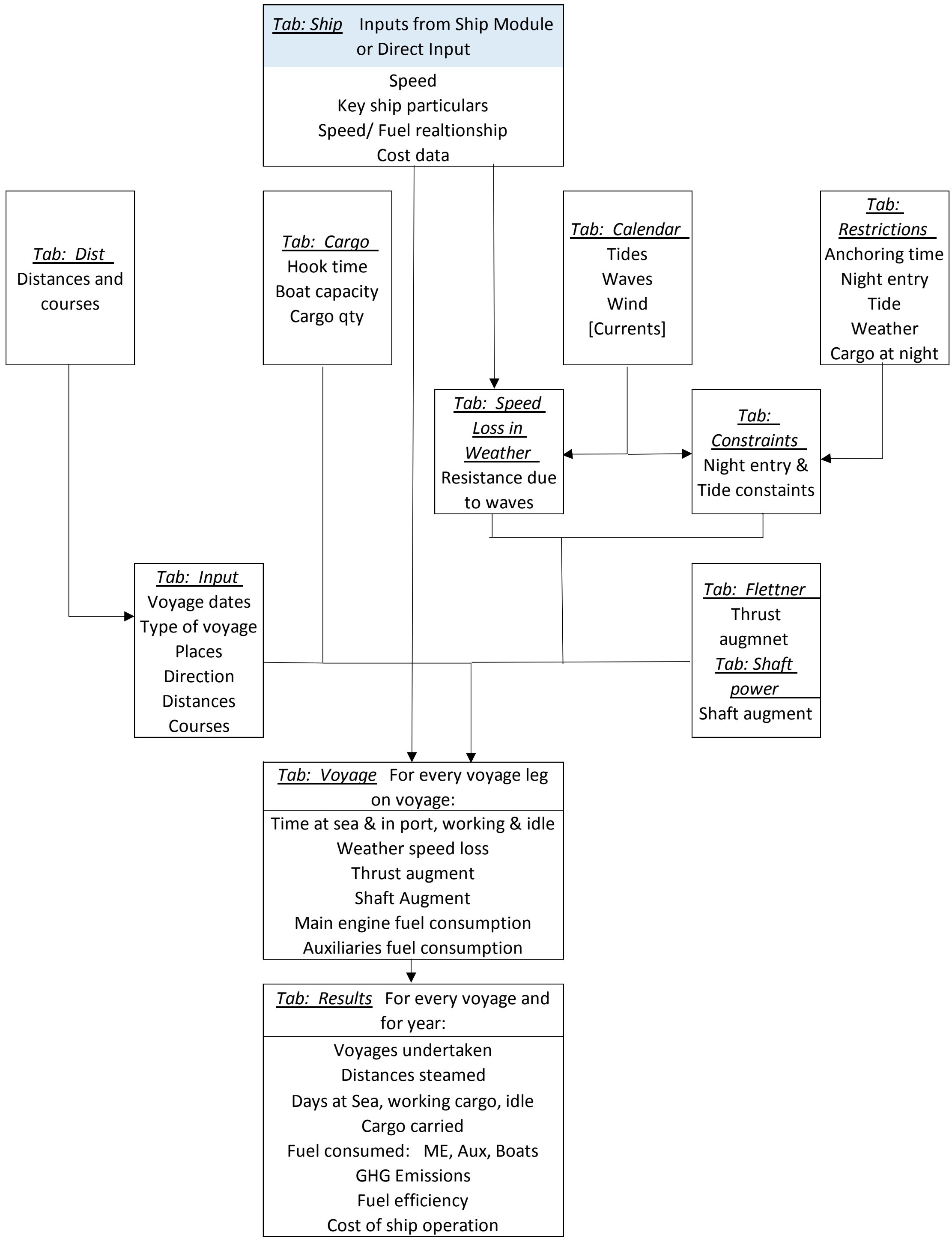
Figure 11: Flow Diagram- Voyage Module

Reference — Voyage Module v1.0.xlsx'

Purpose: To calculate fuel consumption, GHG emissions and operating costs for the voyages undertaken by a given ship. The ship fuel consumption characteristics can be inserted or calculated in the Ship Module.

Method: Calculates the steaming time, entering and leaving port, cargo working time and delays/ idle time for each voyage leg of all voyages described in the inputs. From these data, the fuel consumption, GHG emissions and operating costs are calculated

Flexibility: Can take into account navigational and cargo working restrictions and constraints, wind and wave conditions, tides, propulsion augmentation, both thrust and shaft power. If there is insufficient ship data to run the Ship Module, an estimate of the speed/ fuel consumption relationship can be substituted into the Voyage Module



Ship Characteristics
Tab: Ship
The User can choose between Input from the Ship Module and Direct Input of key values.

- Operating data
  - Demand speed
  - Power augmentation
- Ship Particulars (needed for speed loss in weather calculations)
  - LWL
  - Volumetric displacement
  - Block coefficient
  - Transverse projected area above WL
- Fuel consumption data
- Operational Cost Data

Voyages undertaken
An input template is prepared that contains the voyages that are the subject of the analysis. The template is copied into the input sheet in the model

Definition of Voyages
Tab: Input
Each voyage has the following features defined:

- Start and finish date and time
- Type of voyage. If the voyage has both outbound and inbound cargoes, this field is left blank. If the voyage is restricted to outbound cargoes only (ie, ballast return) any text describing the voyage, for example 'Charter', is input. The model then assumes no cargo is loaded for any voyage leg defined as inbound, ie only time for embarking or landing passengers is allowed for.

- Places visited in sequence
- Direction: outbound ('out'), inbound ('in') or turning point ('turn'). Determines cargo loaded and discharged.
- Distance between places. Obtained from distance tables (see below) or can be manually input
- Course on passage between places. Obtained from course tables (see below) or can be manually input

Voyage calculation
Tab: Voyage
Calculations for each voyage are made for each voyage leg defined in the input:

Time at Sea & Main Engine Fuel Consumption

- Desired speed is as defined in the ship input, adjusted so that ship slow steams to places where it cannot enter prior to dawn. A limit of slow steaming speed can be imposed, for example 4 knots.
- Weather speed loss is calculated. The effect of waves on ships speed is calculated through an algorithm that takes into account ship's course relative to wave direction, wave height, ship's hull block coefficient, length and desired speed[15].
- Wind resistance. In a similar fashion to wave speed loss, the effect of wind on ship resistance is calculated taking account of wind speed and direction, and the transverse cross sectional area of the ship above the waterline. This is combined with any wind thrust augment that is obtained from a thrust augment device such as sails, kite or a Flettner rotor.

- Thrust augment. If a thrust device such as a sail, kite or Flettner is fitted, the model looks at the relative wind for each voyage leg, for which the thrust can be calculated. The model is at present set up to calculate the thrust from a Flettner rotor. This is combined with the wind resistance to find a net thrust on the ship. The product of this net thrust and ship speed is the propulsive power produced. This is then deducted from the total propulsive power to arrive at the power required from the propeller, and thus from the engine(s). The model uses the net thrust as an input into the speed/ consumption algorithm derived in the ship resistance and powering module, to calculate the fuel consumption.
  The same method can be used for any direct thrust augment, for example sails, foils or kites. The lift and drag data for the device will be need so that it can be inserted in the model in place of the equivalent data for Flettners that is presently in the model.
- Shaft augment. If a shaft augment device, such as an electric motor, is fitted, the model deducts the power delivered by the device to the shaft (through a power input into the gearbox) from the power that needs to be provided by the engine(s). The model calculates the fuel that would be saved, at the SFOC rate of the engine, and deducts that from the fuel consumption for the power that the engine would otherwise have had to produce.
- Main Engine fuel consumption. The model uses the speed/ consumption algorithms developed by the ship resistance and propulsion module. For each voyage leg, the inputs are the desired speed and the net thrust on the ship from wind and thrust devices. Any operating power required, to rotate a Flettner for example, is added to the power demand. Any shaft augment power is deducted.

Time in Port

- Arrival time. The ETA (estimated time of arrival) is calculated from the voyage leg elapsed time. If the ship then needs to await daylight before anchoring or berthing, this is added, along with the time to anchor/ berth, giving ETB (estimated time of berthing).
- Time working cargo and passengers. The cargo to be loaded or discharged is obtained from the cargo data, along with the rate of cargo handling, so that the time working can be calculated. Any time lost due to constraints are added; weather, darkness, or tide. Two hours are allowed for passenger transfers if the total cargo time is less than two hours.
- ETD & ATD. The ETB plus the elapsed time in port are summed to give the ETD (estimated time of departure). If the ship has to await daylight before departing, this is added to arrive at the ATD (actual time of departure).

Auxiliaries Fuel Consumption

- The voyage leg total elapsed time is split into time at sea, in port working cargo and in port idle. The auxiliaries' fuel consumption for each of these is obtained from the ship data in the ship module, and the total auxiliaries' fuel consumption for each voyage leg is calculated.

Total Fuel Consumption

- The total fuel consumption, main engine(s) and auxiliaries, is summed for all voyage legs in the voyage.

Distances & courses (optional)

Tab: 'dist'

The model provides tables of distances and courses between places which the input template refers to for each voyage leg. For complex schedules and voyages such as in the Marshall Islands, it is worthwhile compiling these tables. In simpler cases, the course and distance could be inserted directly into the input template.

Port & Cargo Handling Data

Tab: 'Cargo'
This tab is the inputs for port and cargo handling data. Separate calculations are carried out for outbound and inbound cargo.

- Hook cycle time/ boat round trip time. The model allows input at each place of call of the time alongside ship and on shore handling cargo to and from boats, and the transit time between anchorage and the beach. Similarly, it allows for inputs of time to load slings, lift to/from shore, unload slings and return when handling at a wharf.
- Sling load/ boat capacity. The boat capacity is determined by location of cargo handling; inside a sheltered lagoon or offshore in the ocean. The type of cargo can also be specified according to the influence on sling capacity. Weather influence on sling capacity can also be specified.
- Tons per hour. From hook cycle time and sling load, the rate of cargo handling is calculated.
- Cargo quantity per port call. The model requires the quantity per port call. Cargo data for each place can be reduced to quantity per port call and used as input.
- Working time. Cargo working time is calculated from the cargo quantity per call, divided by the tons per hour.

Operating Restrictions & Constraints
Tab: 'Restrictions'
Restrictions and constraints on operations at each place are set out in this tab.

- Anchoring or berthing time
- Night time entry. 'yes' or 'no' as to whether ships can enter or depart through reef passages or from anchorages/ berths at night.
- Tide restrictions. Many beaches are restricted as to state of the tide when boat operations can take place. In general, water depths are too low, or reef shelves too great for cargo to be loaded or unloaded at low tide. If the place is tide restricted, the model looks up the tide tables for the day in question, and restricts the cargo operations between 2.5 hours before low tide and 2.5 hours after low tide, leaving a 7 hour window at the top of the tide for cargo operations.
- Weather delays. For each place the probability of weather delays, and their duration are specified. The delay is the product of probability and duration. A random calculation flag can be set at value 1 so that the probability is calculated randomly. If the flag is not set (ie, is set at zero), then the probability is calculated uniformly.
- Working cargo in darkness. If a place cannot work cargo during hours of darkness, for example at a place that has waves sufficient to make boat-work in the dark too hazardous, then cargo work is restricted to daytime only.

Tab: 'Constraints'
For each place on the voyage itinerary, and for each hour the ship is there, the model looks to see if night-time cargo working constraints and/ or tide constraints apply. If work is restricted by either of these constraints, the model assumes no work takes place. This continues until the working time for the ship visit has been met. The total elapsed time is then fed as an input into the voyage leg calculation.

Environmental data
Tab: 'calendar'
Each day of the period being analysed is set out in a table. In the case of the baseline for Marshall Islands shipping, the days from October 1, 2016 to September 30, 2017 are set out.

- Tides. The 1st and 2nd low tides for each day in this date range have been inserted.
- Waves. Wave height and direction data that has been obtained from a wave buoy off Majuro has been inserted, as being representative of the Marshall Islands as a whole[16].

The average for each day of the year of available data from 2010 to 2016 was used. (Note: wave buoy was not operational continuously over this period, but each day of the year was recorded at least once)

- Wind. Similarly, wind data for Majuro airport has been inserted. Data was not available for 2016, so data for the same days in 2017 were used for the period October 1 to December 31, 2106. The actual data for the period January 1, 2017 to September 30, 2017 was used. The source was NOAA[17].
- Currents. Currents have not been incorporated into the model, but they can easily be. The speed made good through water can then be translated into speed and distance made good over the ground.
- Sun and moon rise and set. Provision for times of sun- and moon rise and set has been made, although the model does not at present use this data. The model is presently set up with sunrise and sunset at 0640 and 1840 hrs respectively.

Alternative Powering

Tab: 'Flettner'

- Wind powered thrust augment. The physical attributes of a small Flettner are used as inputs; surface area, diameter of the cylinder, rotor speed, and lamda/ CL, CD relationships. The apparent wind is calculated from the ship and wind speeds and directions. The lift and drag are calculated, and the thrust in the forward direction determined. This is fed into the voyage leg calculation.

  A similar procedure can be followed for any other thrust device, such as sails or a kite.

Tab: 'Shaft Power'

- Wind and/ or solar powered electrical shaft augment. The model assumes that power is added to the propeller shaft(s) by an electric motor coupled to a gearbox input onto the shaft. The power input can be specified in the tab 'Shaft Power'

Results

Voyages undertaken

- No of voyages. This is a count of the input voyages.
- Distance steamed. The distances calculated for each voyage.

Time on voyages

- Days at sea. The amount of time that the ship is on passage between places. This value is used in the calculation of main engine(s) fuel consumption.
- Days working cargo (including Majuro cargo time). The amount of time that the ship is working cargo. The auxiliary fuel consumption when working cargo takes account of the additional power required when working cargo winches and hold fans.
- Days on voyage in port, idle (excluding time between voyages in Majuro). The time when waiting for port entry or departure, or waiting for tide, weather, light or other constraints to change so as to allow cargo operations. The ship may be at anchor, or drifting when no anchorage is available. The fuel consumption of auxiliaries is lower than when underway, as engine pumps etc are not consuming power. The ship's basic 'hotel' load is the demand.
- Total days on voyages (including Majuro cargo time). The sum of the above times.

- Total days between voyages. Days between voyages (excluding time in Majuro working cargo), calculated by subtracting the total number of days on voyages from 365 days. This is a measure of the down time of the ship, which might otherwise be utilised undertaking additional voyages. The auxiliaries fuel consumption rate when idle between voyages is used to calculate the fuel consumption.

Cargo carried

- General Cargo Outbound. The quantity carried on each voyage, as determined by the input cargo volumes for each place of call.

- Copra inbound. Similarly, the quantity of inbound cargo, in the case of the Marshall Islands, copra, from each place of call.

Fuel consumed

This is the heart of the computations. The fuel consumed determines the quantity of Greenhouse Gas (GHG) emissions. Fuel consumption data is expressed in both litres and US gallons.

Diesel

- Fuel consumption, Main engine(s). The model calculates the consumption as the product of the distance steamed and the fuel consumption per nautical mile at the actual speed achieved on each passage. The actual speed achieved takes account of weather speed loss and any slow steaming in order to arrive at dawn for example. The fuel consumption is calculated using the algorithms in the ship module. It takes account of any wind resistance. If the ship has power augmentation, this is also accounted for in the algorithms.

- Fuel consumption, Auxiliaries. The model calculates the auxiliary fuel consumption according to the time on voyages for four states of electrical power use; at sea, in port working cargo, in port idle, and between voyages. The fuel consumption rates are set out in the ship module.

- Total Diesel consumption. The sum of main engine and auxiliaries consumption.

Gasoline

- Consumption rate. Gasoline is used by ships boats for their outboard engines. Based on the annual consumption for MISC ships, the boats appear to consume about 0.45 litres per nautical mile of the parent ship's voyage.
- Gasoline consumption. Product of the above consumption rate and the total ship's voyage distance.

Lube Oil

- Consumption rate. Based on a typical consumption rate of 1 gram lube oil for every 150 grams of fuel.
- Lube oil consumption. Product of Diesel quantity consumed and the consumption rate.

GHG emissions

CO_2 emissions are shown for each ship, covering

- Main engine(s)
- Auxiliaries
- Boats
- Lube oil

Emissions are expressed as tonnes of CO_2 emitted (tonnes CO_2).

Fuel Efficiency
The fuel efficiency per ton-mile of transport task is calculated for each ship, expressed as litres of diesel consumed per 100 tons of cargo carried * nautical miles steamed.

Cost of ship operation
Unit costs
Unit costs are shown for:

- Annual depreciation
- Daily extended period costs, eg Dry docking (cost/5yrs/365 days)
- Daily fixed operating cost
- Cost per Voyage, Foods etc
- Cargo costs (Copra stevedoring)
- Cost of fuels
    - Diesel
    - Gasoline
    - Lube oils

Annual cost
The annual costs and their proportions of the whole for the above items are calculated. The key total annual costs are shown for:

- Total fuel costs
- Total Annual Cost
- Cost excluding depreciation

Appendix 4. Replicating Data Collection & Analysis

1 Data Collection

The data items that are required are:

- Ship data
- Voyage data
- Cargo data
- Cost data
- Environmental data

2 Ship Data

In order to calculate the GHG emissions and operating costs, it is necessary to know at least the speed/ fuel consumption relationship of the ship(s) being analysed. Ideally, the full capability of the Ship Module that is described in Appendix 3 would be used. This is an accurate method for calculating the fuel consumption, a 'bottom up' approach, but it requires knowledge of the ship's particulars to quite a detailed level. The use of the ship module enables variations in the ship's speed and load condition (draft and/ or trim) to be considered. Augmentation of the ship's propulsion by wind or solar energy, or use of bio fuels, can also be investigated. Follow the process set out in Appendix 3, where the assumptions and range of applicability are set out. Sources are typically the ship operator's technical files, and often, the information that is kept on the ships themselves.

If the opportunity presents itself, a speed trial will enable fuel consumption and speed to be measured in controlled conditions. See Appendix 5 for methodology. If this is not practical, Appendix 3's notes on the Ship Module sets out methodology for the speed/ consumption relationship to be derived from engine specifications and data.

If detailed ship particulars are not available, the process can be short cut by adopting a 'top down' approach. For this, what is required is information on the total fuel consumed in the period being analysed, sourced from the ship operator's records. This takes the analysis directly to the GHG emissions calculation. However, it does not allow for investigating other circumstances or scenarios.

3 Voyage Data

The Voyage Module of the model calculates the time and distance for each voyage leg and port visit. In order to do this, the places called at on each voyage need to be listed, together with information relating to distances and course between ports on the voyage, cargo handling rates and navigational and cargo handling restrictions and constraints. Factual information such as distances and courses can be sourced from Google Earth or similar. Cargo handling rates and navigational and cargo handling restrictions and constraints are best obtained by interview with ship operations management and ship's masters. Follow the process set out in Appendix 3.

4 Cargo Data

The quantity of cargo carried is used to determine the amount of time spent in port. Note that this does not need to be too accurate. Cargo handling time is calculated in units of 1 hour. Typically, the time at a place to discharge general cargo is 5 hours to 10 hours. An error in cargo volumes estimates would need to be greater than 10% before it would show up in the analysis.

Potential sources of cargo data are; the commercial manifests compiled from bill of lading information, stevedoring data, port authority data. If data is unavailable or considered too unreliable, a proforma time can be inserted into the analysis as a substitute.

5 Cost Data

Ship operating costs can be defined in unit costs of the following type:

- Daily cost of fixed period costs
  - Crew wages
  - Routine repairs and maintenance
  - Insurances
  - Auxiliary engine fuel consumption
  - Provision for longer term periodic costs such as dry docking
  - Depreciation allowance
- Costs incurred on a per voyage basis
  - Food for crew
  - Food and other consumables for passengers
- Costs incurred on a port call basis
  - Port charges
  - Ship's boats fuel consumption
- Distance related costs
  - Main engine fuel consumption
  - Main engine lube oil consumption

Most ship operators will have sets of accounts that itemise expenditure sufficiently to be able to split expenditure into these categories. The voyage analysis will provide the unit quantities for days in service (at sea, in port working cargo, in port idle), voyages undertaken, number of ports called at and distances steamed.

6 Environmental Data

Ship performance is effected by weather conditions. In order to accurately calculate fuel consumption, the wind and wave conditions that the ship experiences need to be defined. Except for very specific analyses that might be looking at weather implications, it will generally be sufficient to specify data in approximate terms. Seasonal data, such as quarterly data, will usually suffice. If historical daily data is available, then this can be used. If the ports visited have tidal constraints, the tide data will be needed.

Sources for this environmental data are meteorological offices, airports, port authorities and international sources such as US NOAA. See references 16 and 17 for NOAA sources.

Appendix 5. Speed Trial Plan & Report - mv Kwajalein

Speed Trial Plan

PRIF: Establishing Baseline Data to Support Sustainable Maritime Transport Services

In association with GIZ and MISC

MV Kwajalein

PRINCIPAL PARTICULARS

LENGTH O.A	49.85	M	
BREADTH MLD	9.00	M	
DEPTH MLD	5.13	M	
DRAUGHT for Trial	[3.05]	M	TBC

IMO NO	**9681728**	DATE	**23.Nov.2017**
DEPT		SHIP TYPE	**PASSENGER/CARGO SHIP**
HULL NO		SHIP NAME	**M.V KWAJALEIN**
APPROVED BY		NAME OF DRAWING **SPEED TRIAL PLAN**	
CHECKED BY			
PREPARED BY	**Mark Oxley**		
		SCALE	DRAWING NO.
		REV:	

Table of Contents

1. Introduction

1.1 General

This document details the procedure of the speed trial to obtain the relationship between fuel consumption, engine speed and ship's speed to be conducted onboard the Passenger/ Cargo Ship "M.V KWAJALEIN" for Its Owners, Marshall Islands Shipping Corporation and for PRIF's project, Establishing Baseline Data to Support Sustainable Maritime Transport Services, in association with GIZ. The trial is to be conducted in a suitable location within Majuro Lagoon.

Specifically, the items that are addressed in this Trials Procedure are as follows;

- The trial location;
- The environmental conditions during the trial;
- A protocol for the procedures on the trial day is given, including suggested duties and co-ordination measures;
- A list of the items that are proposed to measured is given and the alternative methods for getting this data are highlighted;
- A set of tables for manually recording data is given;
- A list of equipment required for the trial is also given

1.2 Vessel General Information

Name of Vessel	:	M.V Kwajalein
Type of Vessel	:	Passenger/Cargo Ship
Owner	:	Marshall Islands Shipping Corporation
Builder	:	Kegoya Dock Co Ltd
Yard Hull No	:	S-1151
LR No	:	
Date of Keel Laying	:	4 April 2013
Date of Launching	:	10 July 2013
Classification Society:	:	NK
Class notation	:	NK NS* (Passenger ship/ General Cargo) MNS*

1.3 Principal Particulars of The Vessel

Length Overall	L_{OA}	49.85	m
Breadth, MLD	B_{MLD}	9.00	m
Depth, MLD	D_{MLD}	5.15	m
Draft (Design)	d	3.20	m
Speed (Trials, 110% MCR)		11.043	knots
Main Engine	Model:	Yanmar 6RY17W x MGN91BL	
	Power (MCR)	: 1 x 478 KW @1500 RPM	
Propeller	Type	: 4 blades FPP	
	Unit	: 01 nos.	
	Diameter	: 1900 mm	
	Pitch:	: 1310 mm	

2. Trial Objectives and Description

2.1 Objective

The object of the trial is to determine the relationship between fuel consumption, engine speed and ship's speed. The speed, consumption and RPM data are referenced to the service loaded condition at Draft [3.05] M under normal operating conditions with the removal of any external factors that may affect this such as weather or tide. In order to do this it is necessary to determine the consumption/ speed characteristics of the vessel along with other measured parameters.

Overall, the following factors can affect the determination of the reference speed during the course of a speed trial:

- Draught and trim (referred to as the 'loading condition') affect the power required to propel the ship at a given speed.
- Other factors which affect the power and speed are wind, waves, water currents and water depth.
- The effect of wind, waves and water currents are minimized by performing two runs, at the power, in opposite directions. Post-trial analysis will allow the effect of wind, waves and current to be removed by understanding the performance of the vessel in each opposing direction
- Water depth effects will be minimised by running trials in deep water (greater than 15m). Majuro Lagoon has a depth of about 45m.

2.2 Trial Description

Figure 1 shows the layout of the intended trial course which will form a figure-of-eight.

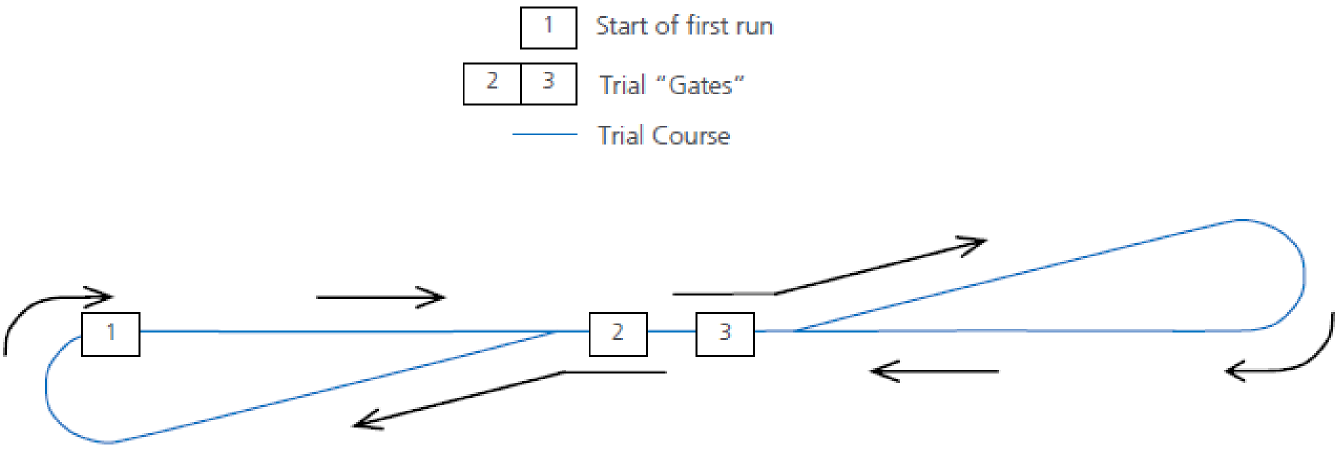


Figure 1 Intended Trial Course

The table below summarizes the various steps that form each trial run:

Step	Action	Comments
1	Vessel **approaches trial run** at Point 1 as shown in Figure 1. Power setting at Point 1 to be set to target value and maintained.	Approach run to be large enough in order to achieve steady speed.
2	Vessel enters **'measured distance'** at Point 2 at constant speed and with minimum use of rudder until end of 'measured distance' at Point 3.	GPS used to track actual start and finish of the 'measured distance'.
3	Vessel exits **'measured distance'** at Point 3 and maintains steady conditions during run-out.	In order to obtain additional data in case of unreliable data at the start of the 'measured distance'.
4	Vessel turns off the preceding constant heading using a small rudder angle then continues for a further distance before executing turn.	The turn should use less than 10° helm and using fixed rate of turn rather than fixed helm in order to prevent undesirable large speed loss due to closing of the turn.
5	Once reciprocal heading is achieved, repeat processes 1 to 3.	Power will be kept constant for repeat run.
6	Once turned off second run, power setting will be changed to the next target value.	Power setting is maintained until next set of double runs is completed.

Table 2 — Trial Process

3. Outline of Trial Procedures

3.1 Course

The trial course is shown in Figure 1. The dimensions of the intended course are as follows:

Approach run length	2 nm
'Measured distance' length	4 nm
Run-out	0.5 nm
Turn-off heading and distance	15° for 2nm
Turn diameter	0.5 to 1.0 nm
Length x Width of trial area	6 nm x 2 nm

Table 3 — Trials Layout

All the measurements will be taken in the same area of water without allowing the trials area to drift.

To the extent possible, the trial course location will be selected to account for any vessel drift that will occur due to wind or current and if these are small, then any waves as well. If winds are stronger then it is normal practice to select the headings to be 'into and out of the wind. If winds are light, then the headings should be selected to be into and out of the current. At all times, vessel operations will take into account factors that may affect the safety of the vessel such as available space.

The vessel will be steered on the same heading and reciprocal heading for each 'measured distance', with minimum use of rudder (ideally less than 1.5°) otherwise this may affect the speed of the vessel in the trace recorded.

The direction of the 'measured distance' will be kept the same throughout the trial. The objective is that the vessel achieves steady conditions prior to entering, and during, the 'measured distance'.

3.2 Number of Runs and Power Settings

The following table summarizes the proposed runs and power settings.

Run	% MCR	RPM	Run Heading	Comments
1	50%	1191	Heading 1	Lower power range
2			Heading 2	
3	75%	1363	Heading 1	Mid power range
4			Heading 2	
5	85%	1421	Heading 1	Upper power range (NOP)
6			Heading 2	
7	75%	1363	Heading 1	Repeat of 75%
8			Heading 2	

Table 4 — Trials Runs

The total estimated time to conduct this trial is about 3 to 4 hours, assuming that no runs need to be repeated and that there are no delays between runs.

3.3 Control Measures

Vessel Loading Condition:

To obtain this information it is proposed that the draughts are read immediately before departure for the trial. Draught measurements will be read using a small boat and 3 to 4 photos of each draught mark will be taken for record purposes (port and starboard at FP, and AP).

Water Samples:

It is also necessary to obtain a sample of the water at the time of reading the draught marks as follows:

- Alongside: A water sample is to be taken by the trial's crew at the same time as the draught marks are read. The sea water temperature is to be recorded
- At the Trials Area: A water sample is to be taken from the sea water cooling pipe or sea chest as appropriate at the beginning , middle and end of the trials (3 samples). A check will be made of the density and temperature of the sample using a hydrometer and suitable thermometer.

Anemometer Readings:

As shipboard anemometers can be inaccurate and affected by disturbed flow due to the above water profile, the anemometer readings will be continually measured during the trial turns. These readings will be analysed to ensure consistent readings.

Other Measures:

In addition to the above, all equipment used for data collection will be checked to be within calibration in accordance with manufacturer's instructions and/or certificate of validity of calibration will be provided.

3.4 Trials Schedule

The trial will be conducted on 23 Nov 2017.

4. Selection of Trials Area

4.1 General Comments

The trials will be conducted in Majuro lagoon.

This location has been selected to provide:

- Sufficiently deep water;
- The minimum vessel traffic in the area;
- Minimum transit time to the trial area;

4.2 Weather

- The trial will proceed within the weather limits set out in ISO 15016:2015.

5. Trial Preparation and Items for Measurement

5.1 Installation and Checking of Trials Equipment

The installation items of ship's own equipment that will be used for measurement purposes during the trial are as follows:

- Global Positioning Satellite unit
- Fuel Flow Meters
- Engine speed indicators
- Anemometer
- Echo Sounder
- Gyro Compass
- Rudder Angle

5.2 Items to be Measured During Trial

The table below the items to be measured during each trial run and a backup method. The time of the recordings will be synchronized with the ship's GPS before the trial.

Item	Measurement Location	Backup Input Option
Shaft RPM	ECR/WH	Manual recording of values displayed on unit at approx 1 min intervals
Fuel Flow	WH	Manual recording of values displayed on Engine monitoring unit at start and finish of Measured Distance and at approx 1 min intervals
Ship GPS Position	Bridge	Use ship's own GPS data direct from bridge equipment at start and finish of measured distance. Manual recording as backup at approx. 1 min intervals on 'measured distance'
Relative Wind Speed and Direction	Bridge	Manual recording of values displayed on Bridge instruments at approx 1 min intervals on 'measured distance'

Water Log Speed ??	Bridge	Manual recording of values displayed on Bridge instruments at approx 1 min intervals on 'measured distance'
Gyro Output (heading)	Bridge	Manual recording of values displayed on Bridge instruments at approx 1 min intervals on 'measured distance'
Echo Sounder (Depth)	Bridge	Manual recording of the trials location depth

Table 6 — Measurement Items

6. Conduct of Trial on Day

6.1 Pre-Meeting

Once the trials team is onboard, a meeting with all relevant parties shall be held to set out the scheme of the trial, its objectives, confirm roles and responsibilities, agree any outstanding actions and to resolve any outstanding queries.

MISC shall facilitate this meeting.

6.2 General

Communication will be provided by use of ship's radios/ telephones between the bridge and the engine room to tell the Engine room when the 'measured distance' has started and finished and for the Engine room to provide results to the bridge at the end of each run.

6.3 Roles

The following roles will be filled:

<u>Bridge:</u>

- Ship's Master - Has overall responsibility for the vessel and the safe and efficient Conduct of the trial
- MISC Liaison: Chief of Operations in attendance.
- Trials Officer (Mark Oxley) - stationed on bridge, will manage the conduct of the trial in conjunction with the ship's Master and collect relevant data.
- Helmsman - A skilled helmsman is required to steer the ship on the required heading with minimum use of rudder
- Additional bridge trials personnel - For manually recording items such as wind speed, direction, rudder angle etc, during trial run.

<u>Engine Controls:</u>

- Engineer - Responsible for the running of the engine room and ensuring that the power levels, once set, are not adjusted during the trial run.
- Trials Engineer (Raffael Held) - Stationed in WH and acquiring engine speed, power and fuel flow data.
- Additional engine room personnel - To assist with record keeping and communication with bridge.

6.4 Run In

1. Helm limited to +/-1°. Short deviation from course preferable to use of larger rudder angles.
2. GPS start recording.
3. Trials Officer to tell Trials Engineer Start recording power and revs. (Start of Run In) and confirm with all parties:
   a. Run Number
   b. Power setting (in terms of both nominal %MCR and actual target rev setting.
   c. Run Direction
4. Fuel flow and RPM readings are to be continuously recorded from this point.

5. On Bridge, note to be kept of Wind speed, Wind direction, Sea Sate, Sea Direction, revs, pitch, engine setting and rudder angles used.

6.5 On 'Measured distance'

1. Helm limited to +/-1°.
2. Trials Officer to inform Trials Engineer once 'On Measured distance' - annotate record.
3. Note run number, direction, time of start of measured distance.
4. Note to be taken on bridge every 1 minute of Wind speed, Wind direction, revs, fuel flow, engine setting and rudder angle.
5. Note to be taken of sea state and direction on run.
6. At end of 'measured distance', Trials Officer to inform Trials Engineer 'Off measured distance'- annotate record.
7. At end of 'measured distance' run out, Bridge to inform Trials Engineer 'End Run-out'- annotate record.

6.6 Turn Off from Measured distance

1. Helmsman to use 10° helm to change course by approximately 15°.
2. Bridge to use GPS to report speed over ground, then as soon as possible commence recording of new data.
3. Trials Engineer to report nomnal % MCR and revs.

6.7 Turn Back On to Measured distance

1. Helmsman to use 10° helm to reverse course.
2. Trials Officer to inform Trials Engineer 'Turning for measured distance'.
3. GPS continue recording.
4. Note taken on Bridge of helm angle etc

6.8 Turn Back On to Next Measured distance etc

1. Procedures above are repeated for return measured distance

6.9Turn Back Off from Measured distance - Start of Next

1. Engine to be set to next power setting.
2. Helmsman to use 10° helm to change course by approximately 15°.
3. Bridge to use GPS to report speed over ground, then as soon as possible commence recording of new data.
4. Trials Engineer to report Nominal % MCR and revs.

7. Trials Analysis Procedure

7.1 ISO Standard

The trials conducted will be analyzed according to the IS0 15016:2015 Standard procedure.

7.2 Results

The corrected results will be analysed by the PRIF consultant to provide fuel consumption data for the Project: Establishing Baseline Data to Support Sustainable Maritime Transport Services

8. Manual Trials Records

Manual records of the trials conduct and where necessary / appropriate manual back-up recording of data will be taken. Suitable pro-forma for these records for both engine and bridge parameters are attached.

8.1 Draft Measurement:

Prior to the Speed trial, ship's drafts at fore and aft shall be checked. A small boat will be available to take the readings.

Position	Port Side	Starboard side
Fore	M	M
Aft	M	M

8.2 Speed Trial Data on Each Run:

The following data shall be recorded during the speed trial at MCR 50%, 75%, 85% Engine Load on each run

Observation Items	Acceptable Measurement Device	Record Location	Remarks
Sea Water density	Hydrometer	On Board	(Begining, Middle, End of the trial)
Sea Water Temperature	Thermometer	During Trial	(Begining, Middle, End of the trial)
Water Current speed	Doppler speed log	Wheel House	
Relative Wind Direction (deg.)	Wind direction & wind speed Indicator	Wheel House	
Relative Wind Speed (m/sec)	Wind direction & wind speed Indicator	Wheel House	
Water Depth (m)	Eco Sounder Digital Indicator	Wheel House	
Wave Height (m)	Calculate according to wind scale observation by class, owner, shipyard representative	Wheel House	
Wave Direction		During trial	
Course Direction (deg.)	Gyro Compass Or GPS	Wheel House	
Start time	GPS	Wheel House	
Finished time	GPS	Wheel House	
Ship Speed (knots)	GPS / Doppler Speed Log Indicator	Wheel House	
Engine Speed (rpm)	Rpm measuring device	Engine room	
Rudder Angle (deg)	Rudder Angle Indicator	Wheel House	
Fuel Mass (Kg)	Flow meter	Engine room	
Air Temperature	Thermometer	On Board	
Speed Trial Location	GPS	During Trial	

*********END*********

MV KWAJALEIN - SPEED TRIALS REPORT

Reference Documents

Ref 1 Speed Trial Procedure, Dated 22 November 2017

Ref 2 BSI-ISO 15016-2015 Guidelines for Ship Trials

Ref 3 'Speed Trials Results Kwajalein 17 11 23(1).xlsx', Record of Speed Trial, 23 Nov 2017

Vessel Particulars

The vessel particulars were reported in Ref 1.

Conduct of Trials

The trials were conducted in the Majuro Lagoon on 23 November 2017. Conditions on the day were fine weather, with slight seas and a breeze of up to 8 kts.

The trials were conducted in accordance with the approved procedure stated in Ref 2.

Ship's Draught and Displacement

The ship had recently returned from a voyage, and was almost fully laden with cargo. Its draft was marginally less than full summer draft of 3.20m. The water density was seawater (1.025 t/m^3). The average draught was 2.98 m, with a stern trim of 0.85 m and a very slight list to port (0.1m over the beam of 9.0m). The corresponding displacement was 862 t, 91% of maximum displacement. The ship proceeded to the trials site.

Given that this condition represents actual in-service conditions, it is considered that no post-trials correction for displacement is necessary.

Trials Data

The trials data is presented in Ref 3 and summarized in Addendum 1, for ship speeds corresponding to 50%, 75%, and 85% of main engine power, as ordered by the propulsion control system. The key points from the trials data sheets are presented in the table below.

Note that the shaft power was not measured. The ship is fitted with fuel flow meters which were used to measure fuel consumption. The speed and distance over the ground were measured by GPS.

There was a difference between measured and calculated data for distance over the ground. The calculated data, based on observed GPS instantaneous speed at 1 to 2 minute intervals, was considered more reliable than the distance over the ground reading from the GPS display. The data chosen for presentation has therefore been based on the calculated distance over the ground.

Results Summary

Nominal Load		50%	75%	85%
RPM		1189	1362	1420
Speed	kn	8.63	9.59	9.93
Fuel	lt/hr	55.7	83.3	94.7
	lt/nm	6.46	8.69	9.54

Water Depth

Majuro lagoon is relatively deep. The area chosen for trails runs is about 45m deep. It is not necessary to apply a correction for shallow water effects.

Temperature and Salinity

The salinity is that of seawater. The water temperature is not materially different from that of the standard. In the speed range of interest, the effect is very small in comparison to the total resistance. It is also noted that to accurately apply a correction for temperature and salinity, it is necessary to have data concerning propulsive efficiency and/or estimation of total resistance from towing tank results.

Given that any correction would be very small, and the lack of propulsive efficiency data, it is considered unnecessary to apply a correction for temperature and salinity effects.

Wind and Current

The ship is fitted with an anemometer installed in a clear air location at the top of the mast, and the apparent wind speed recorded during trials ranged between 1 to 3 kts down wind and 11 kts to 15 kts into the wind. The apparent wind angle was typically within 0-25 deg of the ships heading, and ranging to 35 degrees off the heading in two instances.

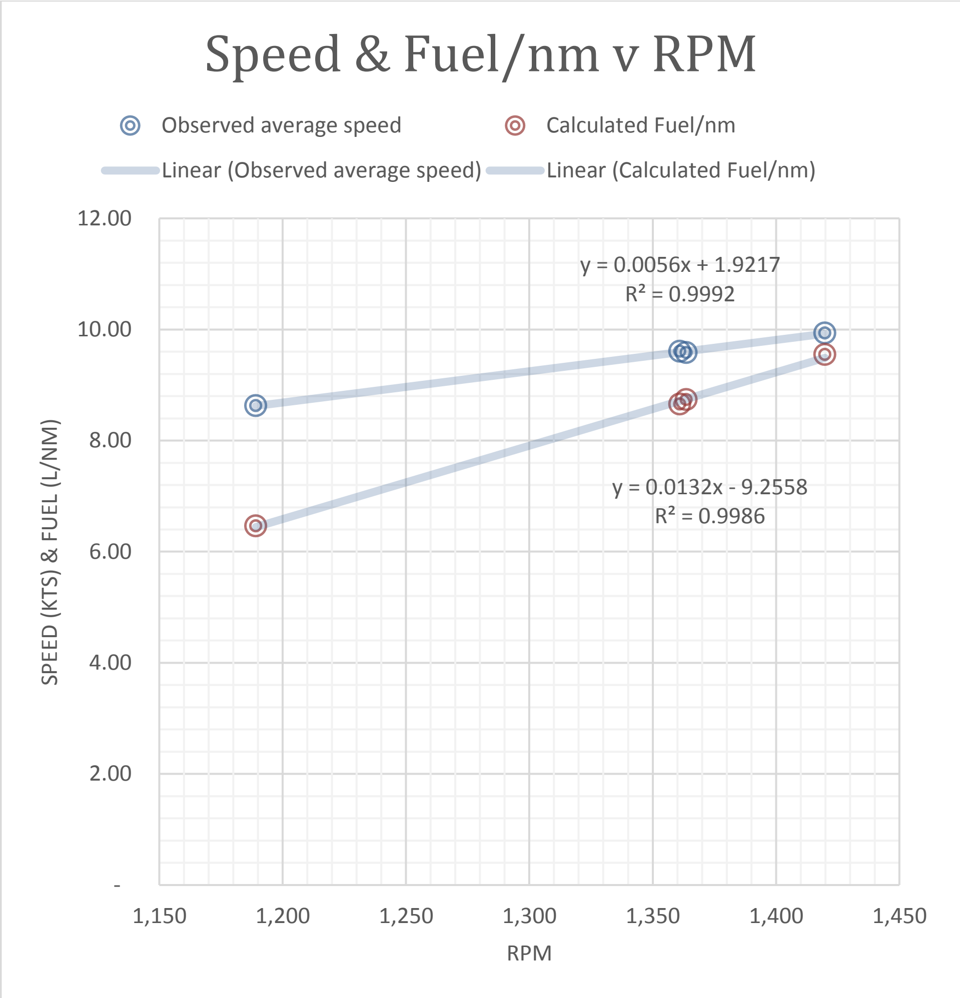
In summary, and after allowing for the ship speed, the true wind during the trial period was typically 3 to 5 kts and from a direction within 20-30 degrees of the ship's heading. Taking the above factors into account, the practice of averaging runs in opposite directions is considered to be a sufficiently accurate method to allow for the effects of wind.

The master advised that there are virtually no currents in the part of the lagoon where the trials took place. The averaging of runs is considered to be a satisfactory method to allow for any current effects.

Wave and Swell

Sea conditions were very slight, mainly ripples of wind waves over a fetch of less than 8 nm. The wind velocities were very small and the lagoon is protected from swells. It is not considered necessary to apply any correction factor.

Speed & Consumption Curve
The speed and consumption curve for the ship has been derived from the discussed data and is present below.



Electrical Generation
The standard mode of operation on this ship is take electrical power from Auxiliary Generators. During the trials period all systems including HVAC and galley were operated in a normal seagoing manner. The electrical load recorded was 24 kW. The fuel flow for the generators is independent of the fuel supply to the main engine.

Report By

Mark Oxley, FRINA
Naval Architect
23 November 2017

Addendum 1- Trials Data

Speed Trials results

MV Kwajalein

Location: **Majuro Lagoon**

Date: 23 Nov 17

Results

Power setting	Note	50%			75%			85%			75%			Average of 75%
RPM setting		1,191			1,363			1,421			1,363			
Run number		*1*	*2*		*3*	*4*		*5*	*6*		*7*	*8*		*3.4.7.8*
Direction	1	*Out*	*Return*	*Average*	*Out*	*Return*	*Average*	*Out*	*Return*	*Average*	*Out*	*Return*	*Average*	
Average RPM	2	1,190	1,188	1,189	1,360	1,362	1,361	1,421	1,419	1,420	1,366	1,361	1,364	1,362
Distance over ground	3	4.00	2.00		2.00	2.00		2.00	2.00		2.00	2.00		2.00
Measured Average speed	4	8.42	8.39	8.40	9.81	9.41	9.61	10.17	9.72	9.94	9.90	9.36	9.63	9.62
Observed average speed	5	8.89	8.37	8.63	9.84	9.37	9.61	10.21	9.65	9.93	9.88	9.28	9.58	9.59
Calculated distance	6	4.22	1.99	3.11	2.01	1.99	2.00	2.01	1.99	2.00	2.00	1.98	1.99	1.99
%age diff, Obs & Calc distance		-5.6%	0.3%	-2.6%	-0.3%	0.4%	0.1%	-0.4%	0.6%	0.1%	0.2%	0.8%	0.5%	0.3%
Fuel consumed	7	26.1	13.5	19.8	16.7	17.9	17.3	18.5	19.6	19.1	16.9	17.9	17.4	17.3
Fuel/hour	8	54.9	56.4	55.7	82.1	84.0	83.1	94.2	95.3	94.7	83.5	83.7	83.6	83.3
Observed Fuel/nm	9	6.525	6.725	6.625	8.370	8.925	8.648	9.260	9.805	9.533	8.430	8.940	8.685	8.666
Calculated Fuel/nm	10	6.181	6.745	6.463	8.346	8.962	8.654	9.224	9.868	9.546	8.449	9.015	8.732	8.693
%age diff, Obs & Calc distance		5.3%	-0.3%	2.5%	0.3%	-0.4%	-0.1%	0.4%	-0.6%	-0.1%	-0.2%	-0.8%	-0.5%	-0.3%

Notes

1 Out: with wind. Return: against wind
2 RPM: Average of records from Engine Monitor at 1 minute intervals
3 Distance over ground: records started at 0.00nm and finshed at the stated value, as measured by GPS
4 Measured Average speed: Distance over ground/ stopwatch time
5 Observed average speed: Average of records of speed over ground from GPS at 1 to 2 minute minute intervals
6 Calculated distance: distance over ground calculated by multiplying stop watch time and observed average speed.
7 Fuel consumed: Difference in Fuel meter reading at 0.00nm and at end of measured distance
8 Fuel/hour: Fuel consumed / stopwatch time
9 Observed Fuel/nm: Fuel consumed / distance over ground (3)
10 Calculated Fuel/nm: Fuel consumed / calculated distance (6)

Appendix 6. Alternative Routes & Scheduling

1 Alternative routes and scheduling

Two alternatives have been investigated:

- Centralised Copra Collection
- Majuro Turn Round

Centralised Copra Collection

Copra is typically collected on the return voyage by calling a second time at places that produce copra. It is often not practical to load copra on outbound calls; the copra cargo is usually contaminated with cockroaches, and would infest the general cargo.

The ships pick up copra at beaches closest to the individual growers' places. This avoids the necessity for the grower to incur costs by transporting his or her produce to a centralised place. An on-board copra agent purchases the copra, paying a price dependant on weight and moisture content. Many growers then use the cash earned to purchase goods from the shop on board the ship. Their option otherwise if they do not have cash savings is to sell to a local merchant, or to obtain credit from the merchant by using copra as collateral pending future sale when the ship returns. This either reduces the return or increases the risk to the grower, and incurs a local transportation cost.

The consequence is that the ships spend a considerable time moving slowly from beach to beach, loading cargo at a reduced load rate compared with handling a larger quantity at one place. This is reflected by a longer period for the return voyage, with increased fuel consumption and costs.

The idea of centralising copra collection at one place on each atoll has been addressed in the past[18]. Copra collection sheds have been built, but had mostly fallen into disuse prior to that 2001 ADB study. The impediment to the idea appears to be the cost of local transport, and the desire for growers to sell directly to the Tobolar agent on the ship, in order to maximise their return. This subject was looked at in detail in 2005 in a further ADB TA on the conduct of the copra trade that resulted from the 2001 project[19].

Results

The model developed for this project has been used to look at the benefits of centralising copra collection. In FY2017, Aemman transported the most copra, approximately 2000 tons out of a total of 5500 tons brought by all ships to Tobolar. The FY2017 voyages of Aemman have been modified in the model by assuming a call at only one place on each atoll on its return voyages. Out of its 14 voyages, 5 fitted the pattern of making return calls to uplift copra. The key outcomes from the model results are shown in Table 27. The annual fuel consumption improves from 184,406 litres to 176,921 litres, a reduction of 7,485 litres with a resulting decrease in CO_2 emissions by 20 tonnes CO_2 pa, and a reduction in cost of US$11,793. Time saved for the full year is 16 days.

Against this, the marginal cost of local transportation to a central point, based on 10 nm round trips intra-atoll in small outboard boats at $18 per trip[e], carrying 2.5 tons per trip is about $7 per ton. The Aemman carried 2181 tons in FY2017, resulting in an annual cost of about US$15,000 if the copra

[e] Based on a 40hp outboard with fuel consumption of 8.7 l/h, operating at 7 knots, thus consuming 1.24 l/nm. A 10 nm round trip would therefore consume 12.4 litres. At US1.45 /litre ($5.50 per gallon), the cost of fuel for the round trip is US$18.

Table 27: Centralised Copra Collection

		Centralising Copra Collection	Actual voyages FY2016
Ship		Aemman	Aemman
Voyages undertaken			
No of Voyages		14	14
Distance steamed	nm	10,639	11,054
Time on Voyages			
(Including Majuro cargo time, but excluding idle time in Majuro between voyages)			
At sea	days	66	69
Working cargo	days	84	95
At atolls/ In port, idle	days	75	78
Total days on voyages	days	226	242
Days between Voyages (excluding Majuro car	days	139	123
Fuel Consumed			
Diesel			
Fuel consumption, ME (t)	Litres	71,404	74,715
	US Gallons	18,865	19,740
	l/nm	6.7	6.8
Fuel consumption, Aux (t)	Litres	105,517	109,691
	US Gallons	27,878	28,980
	l/h	12.0	12.5
Total Diesel consumption	Litres	176,921	184,406
	US Gallons	46,743	48,720
Gasoline			
Consumption rate	Litres/voyage nm	0.45	0.45
Gasoline consumption	Litres	4,788	4,974
	US gallons	1,265	1,314
Lube Oil			
Consumption rate	litres/ 100 litres of fuel consumed	0.67	0.67
Lube oil consumption	Litres	1,179	1,229
	US gallons	312	325
GHG Emissions -CO2			
Main Engine(s)	Tonnes CO_2	191	200
Auxiliaries		282	294
Boats		11	12
Lube Oil		-	-
Total		485	505
Fuel Efficiency (litres per 100 ton-miles)			
Cargo ton-miles	t.nm pa	29,968,811	39,802,060
Diesel fuel consumed	litres pa	176,921	184,406
Diesel fuel/ 100 ton-miles	Litres/100 t.nm	0.59	0.46

Annual cost (US$)		Aemman	Aemman
Annual depreciation		185,000	185,000
Provision for extended period costs (DD)		53,610	53,610
Period Operating costs (excl depreciation)		206,026	206,026
Cost per Voyage (foods etc)		25,967	25,967
Cargo costs (copra stevedoring)		10,131	15,814
Fuel costs		-	-
Diesel		136,941	142,735
Gasoline		5,919	6,150
Lube oils		2,026	2,111
Total fuel costs		144,886	150,996
Total Annual Cost		625,620	637,413
Total Cost excl depreciation		440,620	452,413
Difference in Cost		(11,793)	

were centralised. This is more than the cost saving and fuel consumption/ emissions resulting from the ship calling directly at growers' places.

Conclusion

This outcome would be repeated for the other ships. The concept of centralising copra collection at atolls does not appear to be attractive, either financially or for GHG emission reasons.

Majuro Turn Round

The MISC ships spend a large proportion of time in Majuro. The actual total time spent in Majuro by all four ships was 699 days, equivalent to nearly 2 ship-years. Some of this time is spent loading and discharging cargo, but even allowing for this, it would appear to be excessive. It might be possible to consider reducing the fleet size by at least one ship.

In order to investigate this, the model has been used to simulate all of Ribuuk Ae's voyages being spread between Kwajalein and Aemman. Majuro has been assumed to continue as it actually did, as most of its voyages were charters, not field trips. The change in results is shown in Table 28.

Table 28: Replacing Ribuuk Ae with Kwajalein & Aemman

		Actual voyages FY2016					Replacing Ribuuk Ae with Kwajalein & Aemman			
Ship		**Kwajalein**	**Aemman**	**Majuro**	**Ribuuk Ae**	**Total**	**Kwajalein**	**Aemman**	**Majuro**	**Total**
Voyages undertaken										
No of Voyages		14	14	29	14	71	21	20	29	70
Distance steamed	nm	14,555	11,054	17,039	6,887	49,535	16,301	14,396	17,039	47,736
Time on Voyages										
(Including Majuro cargo time, but excluding idle time in Majuro between voyages)										
At sea	days	69	69	81	35	254	76	90	81	247
Working cargo	days	56	95	53	55	259	86	123	53	262
At atolls/ In port, idle	days	44	78	31	51	204	73	98	31	202
Total days on voyages	days	169	242	166	140	717	235	311	166	712
Days between Voyages (excluding Majuro car	days	196	123	199	225	743	130	54	199	383
Fuel Consumed										
Diesel										
Fuel consumption, ME (t)	Litres	160,484	74,715	245,277	43,971	524,447	198,190	96,223	245,277	539,690
	l/nm	11.0	6.8	14.4	6.4	10.6	12.2	6.7	14.4	11.3
Fuel consumption, Aux (t)	Litres	162,171	109,691	103,433	89,332	464,627	183,010	124,993	103,433	411,436
	l/h	18.5	12.5	11.8	10.2	13.3	20.9	14.3	11.8	11.7
Total Diesel consumption	Litres	322,655	184,406	348,710	133,303	989,074	381,200	221,216	348,710	951,125
Gasoline										
Consumption rate	Litres/voyage nm	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Gasoline consumption	Litres	6,550	4,974	7,668	3,099	22,291	7,335	6,478	7,668	21,481
Lube Oil										
Consumption rate	litres/ 100 litres of fuel consumed	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67
Lube oil consumption	Litres	2,151	1,229	2,325	889	6,594	2,541	1,475	2,325	6,341
GHG Emissions -CO2										
Main Engine(s)	Tonnes CO_2	430	200	657	118	1,404	531	258	657	1,445
Auxiliaries		434	294	277	239	1,244	490	335	277	1,101
Boats		15	12	18	7	53	17	15	18	51
Lube Oil		-	-	-	-	-	-	-	-	-
Total		879	505	952	364	2,700	1,038	607	952	2,597
Fuel Efficiency (litres per 100 ton-miles)										
Cargo ton-miles	t.nm pa	27,729,006	39,802,060	27,520,789	7,960,645	103,012,501	39,482,574	62,605,676	27,520,789	129,609,039
Diesel fuel consumed	litres pa	322,655	184,406	348,710	133,303	989,074	381,200	221,216	348,710	951,125
Diesel fuel/ 100 ton-miles	Litres/100 t.nm	1.16	0.46	1.27	1.67	0.96	0.97	0.35	1.27	0.73

Annual cost (US$)	Kwajalein	Aemman	Majuro	Ribuuk Ae	Total	Kwajalein	Aemman	Majuro	Total
Annual depreciation	228,000	185,000	228,000	92,000	733,000	228,000	185,000	228,000	641,000
Provision for extended period costs (DD)	53,610	53,610	53,610	53,610	214,439	53,610	53,610	53,610	160,829
Period Operating costs (excl depreciation)	200,693	206,026	149,112	154,176	710,007	200,693	206,026	149,112	555,831
Cost per Voyage (foods etc)	35,614	25,967	36,045	22,733	120,359	53,421	37,096	36,045	126,562
Cargo costs (copra stevedoring)	5,478	15,814	2,727	4,681	28,699	7,827	18,937	2,727	29,491
Fuel costs	-	-	-	-	-	-	-	-	-
Diesel	249,743	142,735	269,910	103,180	765,567	295,058	171,226	269,910	736,194
Gasoline	8,098	6,150	9,480	3,832	27,559	9,069	8,009	9,480	26,558
Lube oils	3,694	2,111	3,992	1,526	11,324	4,364	2,533	3,992	10,889
Total fuel costs	261,534	150,996	283,382	108,538	804,449	308,491	181,768	283,382	773,640
Total Annual Cost	784,929	637,413	752,874	435,737	2,610,954	852,042	682,438	752,874	2,287,354
Total Cost excl depreciation	556,929	452,413	524,874	343,737	1,877,954	624,042	497,438	524,874	1,646,354

Results

- Total Voyages reduce by one and distance steamed reduces; Ribuuk Ae would not have needed to dry dock.
- The same number of domestic voyages and scheduling could be maintained, but with larger, newer and more comfortable ships for passengers, ie an improvement in service standards.
- Although days on voyages reduce by only 5 days, days between voyages reduce from 743 to 383, a gain of 360 days. Over the 70 voyages, this is an average of 5.5 days per turnround. With improved stevedoring efficiency at Delap, the task might well be possible with one less ship.

Conclusions

The outcome would be:

- Although main engine fuel consumption would increase, reflecting the use of the larger ships, auxiliary fuel consumption would reduce as a result of one less ship in operation.
- The overall diesel consumption would improve by 37,949 litres, a 3.8% reduction
- The GHG emissions would reduce by 3.8% as a result, by 103 tonnes CO_2.
- The cost of ship operations would reduce by US$232,000, more than 10% of the fleet operating cost.
- It would be possible to dispose of Ribuuk Ae at its present market value.

2 Operating Practices

Methods for energy improvement / fuel-efficient operation of ships

IMO's 'Guidance on Best Practices for Fuel-Efficient Operation for Ships' MEPC.213 (63) provides details of a number of energy improvement methods for potential adoption. The Maritime Technology Cooperation Centre for the Pacific (MTCC-Pacific) has adapted this to the Pacific context. The following is a summary extracted from MTCC-Pacific's *Ship Energy Efficiency Management Plan (SEEMP) Guideline*[20]].

Item	***Category***		***Improvement method***		***Description***
3.1	Fuel efficient Operation	→	a. Improved voyage planning	→	Careful planning and execution of voyages.
			b. Weather routing	→	Weather routing has a potential for efficiency savings on specific routes
			c. Just in time	→	Good early communication with the next port to get maximum notice of berth availability and facilitate the use of optimum speed.
			d. Speed optimization	→	Optimizing the speed at which fuel use per tonne nautical mile is at a minimum level for that voyage
			e. Optimized shaft power	→	Improve efficiency by operating at a constant shaft RPM. The use of automated engine may be beneficial.

Item	***Category***		***Improvement method***		***Description***
3.2	Optimized ship handling	→	a. Optimum trim b. Optimum ballast c. Optimum propeller and propeller inflow considerations d. Optimum use of rudder and heading control systems (autopilots)	→ → → →	Improve fuel saving by operating at optimum trim and steering condition Ballasting with consideration of the requirements to meet optimum trim and steering condition, and also with good cargo planning New developments in propeller design for retrofitting of later designs and improvement to the water inflow to the propeller in order to increase propulsive efficiency power. Reducing the distance sailed 'off track' and minimize losses due to rudder resistance, alternative method through retrofitting of improved rudder blade design.
3.3.	Hull maintenance			→	Optimize the smoother hull shape by new technology coating system, management of cleaning intervals, regular in-water inspection
3.4	Propulsion system	→	Propulsion system maintenance	→	Systematic minimization of heat and mechanical loss.
3.5	Waste heat recovery			→	Waste heat recovery systems use thermal heat losses from the exhaust gas for either electricity generation or additional propulsion with a shaft motor
3.6	Improved fleet management			→	Better utilization of fleet capacity can often be achieved by improvements in fleet planning.
3.7	Improved cargo handling			→	Cargo handling matched to ship and port requirements
3.8	Energy management			→	Review energy and managing the electrical services on board to remove potential unexpected loss energy.
3.9	Fuel Type			→	Potential use of emerging alternative fuels
3.10	Other measures			→	Computer software to calculate fuel consumption, development of renewable energy technology, use of shore power.

Several of these methods for energy improvement are applicable to the MISC fleet, and are addressed in the following sections. The measures have been placed into three categories:

- Shipping Operations
- Ship Maintenance
- Infrastructure improvements

Kwajalein has been used as the example for each of these measures, but the results would apply to all four ships in MISC's fleet.

3 Shipping Operations

Slow steaming for Just in Time Arrival

MTCC-Pacific Guideline Item 3.1c
Over the normal speed range for a ship, fuel consumption per nautical mile improves with a reduction in ship speed. If a berth is unavailable, or as is often the case in the Marshall Islands a

lagoon cannot be entered until daylight, slow steaming to arrive on time will reduce overall fuel consumption compared with arriving earlier and anchoring.

The model has been programmed so that the reduced speed required to arrive just in time is calculated, subject to a practical minimum speed. Kwajalein's voyages for FY2017 have been re-run, using a 4 knot minimum slow speed, thus adjusting the speed and arrival time where otherwise the ship would arrive before dawn at atolls where lagoon entry is restricted to daylight only. In Table 29 this scenario is compared with no adjustment to speed, with the ship arriving in darkness and having to anchor or drift till dawn.

Table 29: Slow Steaming to Arrive at Dawn

		Arriving at Dawn	Actual voyages FY2016
Ship		**Kwajalein**	**Kwajalein**
Voyages undertaken			
No of Voyages		14	14
Distance steamed	nm	14,555	14,555
Time on Voyages			
(Including Majuro cargo time, but excluding idle time in Majuro between voyages)			
At sea	days	91	69
Working cargo	days	56	56
At atolls/ In port, idle	days	39	44
Total days on voyages	days	186	169
Days between Voyages (excluding Majuro car	days	179	196
Fuel Consumed			
Diesel			
Fuel consumption, ME (t)	Litres	133,854	160,484
	l/nm	9.2	11.0
Fuel consumption, Aux (t)	Litres	167,153	162,171
	l/h	19.1	18.5
Total Diesel consumption	Litres	301,007	322,655
GHG Emissions -CO2			
Main Engine(s)	Tonnes CO_2	358	430
Auxiliaries		447	434
Boats		15	15
Lube Oil		-	-
Total		821	879
Fuel Efficiency (litres per 100 ton-miles)			
Cargo ton-miles	t.nm pa	27,729,006	27,729,006
Diesel fuel consumed	litres pa	301,007	322,655
Diesel fuel/ 100 ton-miles	Litres/100 t.nm	1.09	1.16

Annual cost (US$)		Kwajalein	Kwajalein
Fuel costs		-	-
Diesel		232,987	249,743
Gasoline		8,098	8,098
Lube oils		3,446	3,694
Total fuel costs		244,530	261,534
Total Annual Cost		767,925	784,929
Total Cost excl depreciation		539,925	556,929
Difference in Cost		(17,004)	

Results

- Time at sea increases but idle time at atolls decreases.
- Total fuel consumption reduces by 21,648 litres pa, a 6.7% decrease
- GHG emissions reduce by 58 tonnes CO_2
- Fuel efficiency per ton-nm improves from 1.16 to 1.09 l/t-nm
- The annual cost of operation decreases by US$17,004.

Conclusion

This is for one ship. If the practice were adopted over the whole fleet, the annual GHG emissions reduction and the saving would be in the order of 200 tonnes CO_2 and US$60,000 respectively.

Reduced Operational Speed

MTCC-Pacific Guideline Item 3.1d

Reducing the operational service speed would reduce overall fuel consumption. This needs to be offset by making sure that service levels are not compromised. However, with the amount of spare time idle in Majuro, taking longer for voyages would not compromise service levels noticeably.

Kwajalein's voyages for FY2017 have been re-run, using a service speed that is 0.5 knots slower than its present service speed, ie 9.16 knots instead of 9.66 knots. See Table 30.

Table 30: Service Speed 0.5kt Slower

		Service Speed 0.5kt Slower	Actual voyages FY2016
Ship		Kwajalein	Kwajalein
Voyages undertaken			
No of Voyages		14	14
Distance steamed	nm	14,555	14,555
Time on Voyages			
(Including Majuro cargo time, but excluding idle time in Majuro between voyages)			
At sea	days	73	69
Working cargo	days	56	56
At atolls/ In port, idle	days	44	44
Total days on voyages	days	173	169
Days between Voyages (excluding Majuro car	days	192	196
Fuel Consumed			
Diesel			
Fuel consumption, ME (t)	Litres	136,513	160,484
	l/nm	9.4	11.0
Fuel consumption, Aux (t)	Litres	163,348	162,171
	l/h	18.6	18.5
Total Diesel consumption	Litres	299,861	322,655
GHG Emissions -CO2			
Main Engine(s)	Tonnes CO_2	365	430
Auxiliaries		437	434
Boats		15	15
Lube Oil		-	-
Total		818	879
Fuel Efficiency (litres per 100 ton-miles)			
Cargo ton-miles	t.nm pa	27,729,006	27,729,006
Diesel fuel consumed	litres pa	299,861	322,655
Diesel fuel/ 100 ton-miles	Litres/100 t.nm	1.08	1.16
Annual cost (US$)		**Kwajalein**	**Kwajalein**
Fuel costs		-	-
Diesel		232,100	249,743
Gasoline		8,098	8,098
Lube oils		3,433	3,694
Total fuel costs		243,630	261,534
Total Annual Cost		767,025	784,929
Total Cost excl depreciation		539,025	556,929
Difference in Cost		(17,904)	

Results

- Time at sea and overall days on voyages increased by just 4 days over the full year
- Total diesel consumption reduces by 22,794 litres pa, a reduction of 7.1%
- Resulting GHG emissions reduction of 61 tonnes CO_2
- Fuel efficiency per ton-nm improves from 1.16 to 1.08 l/t-nm
- The annual cost of operation decreases by US$17,904.

Conclusion

If the practice were adopted over the whole fleet, the annual GHG emissions reduction and the saving would be similar to just in time arrival, in the order of 200 tonnes CO_2 and US$60,000 respectively.

Reduced Operational Speed and Slow steaming for Just in Time Arrival

MTCC-Pacific Guideline Items 3.1c & 3.1d

Combining both the above operational practices increases the benefits, as shown in Table 31:

Table 31: 0.5kt Slower Speed & Arrival at Dawn

		0.5kt Slower + Arrive at dawn	Actual voyages FY2016
Ship		**Kwajalein**	**Kwajalein**
Voyages undertaken			
No of Voyages		14	14
Distance steamed	nm	14,555	14,555
Time on Voyages			
(Including Majuro cargo time, but excluding idle time in Majuro between voyages)			
At sea	days	95	69
Working cargo	days	56	56
At atolls/ In port, idle	days	38	44
Total days on voyages	days	189	169
Days between Voyages (excluding Majuro car	days	176	196
Fuel Consumed			
Diesel			
Fuel consumption, ME (t)	Litres	116,839	160,484
	l/nm	8.0	11.0
Fuel consumption, Aux (t)	Litres	168,078	162,171
	l/h	19.2	18.5
Total Diesel consumption	Litres	284,917	322,655
GHG Emissions -CO2			
Main Engine(s)	Tonnes CO_2	313	430
Auxiliaries		450	434
Boats		15	15
Lube Oil		-	-
Total		778	879
Fuel Efficiency (litres per 100 ton-miles)			
Cargo ton-miles	t.nm pa	27,729,006	27,729,006
Diesel fuel consumed	litres pa	284,917	322,655
Diesel fuel/ 100 ton-miles	Litres/100 t.nm	1.03	1.16
Annual cost (US$)		**Kwajalein**	**Kwajalein**
Fuel costs		-	-
Diesel		220,532	249,743
Gasoline		8,098	8,098
Lube oils		3,262	3,694
Total fuel costs		231,892	261,534
Total Annual Cost		755,287	784,929
Total Cost excl depreciation		527,287	556,929
Difference in Cost		(29,642)	

Results

- Overall days on voyages increases by 20 days over the full year
- Total diesel consumption reduces by 37,738 litres pa, a reduction of 11.7%
- Resulting GHG emissions reduction of 101 tonnes CO_2
- Fuel efficiency per ton-nm improves from 1.16 to 1.03 l/t-nm
- The annual cost of operation decreases by US$29,642.

Conclusion

Adopting the combined practices over the whole fleet could result in an annual GHG emissions reduction and cost saving in the order of 400 tonnes CO_2 and US$100,000 respectively.

Single Engine Operation of Twin-Screw Ships

Twin Screw ships that are operating at engine powers below 50% of MCR can be operated on one engine, to take advantage of a more efficient fuel consumption rate at higher engine powers. For example, Majuro's SFOC is 2% higher at 50% of MCR compared with full power. Combined with a demand speed reduction of 0.5 knot, the fuel saving would be of the order of 10%.

4 Ship maintenance

Dry Docking

Ships are dry docked for four main reasons:

- For survey of underwater components such as stern tube and rudder shaft
- For maintenance of components that cannot be accessed in water, such as stern tube, rudder, propeller, sacrificial anodes and hull surface coatings
- To blast the hull surface in preparation for re-coating, and
- For repair to under water damage

The maximum period between dockings is usually determined by the survey cycle, 4 to 5 years for most cargo ships. Fuel consumption is very dependent on underwater hull surface condition; over time, corrosion causes an increase in hull roughness which can add 5% to 10% to the ship's resistance. Effective blasting of the hull surface when dry docked can reduce this additional resistance. More frequent docking, so that the hull roughness can be minimised, can be financially advantageous, but needs to be offset against the cost of docking and ship's time out of service.

The annual increase in corrosion roughness can be anything up to 150µm per year, depending on the initial surface preparation and coating, and the level of cathodic protection. The accumulated corrosion can be reduced by about 50% by effective blasting. The effect of docking at 2 yearly intervals is compared with the present 4 year interval in Table 32.

Table 32: More Frequent Dry Docking

		2 yr'ly Dry Docking	Actual voyages FY2016
Ship		**Kwajalein**	**Kwajalein**
Fuel Consumed			
Diesel			
Fuel consumption, ME (t)	Litres	152,852	160,484
	l/nm	10.5	11.0
Fuel consumption, Aux (t)	Litres	162,171	162,171
	l/h	18.5	18.5
Total Diesel consumption	Litres	315,023	322,655
GHG Emissions -CO2			
Main Engine(s)	Tonnes CO_2	409	430
Auxiliaries		434	434
Boats		15	15
Lube Oil		-	-
Total		859	879
Fuel Efficiency (litres per 100 ton-miles)			
Cargo ton-miles	t.nm pa	27,729,006	27,729,006
Diesel fuel consumed	litres pa	315,023	322,655
Diesel fuel/ 100 ton-miles	Litres/100 t.nm	1.14	1.16
Annual cost (US$)		**Kwajalein**	**Kwajalein**
Fuel costs		-	-
Diesel		243,835	249,743
Gasoline		8,098	8,098
Lube oils		3,607	3,694
Total fuel costs		255,540	261,534
Total Annual Cost		778,935	784,929
Total Cost excl depreciation		550,935	556,929
Difference in Cost		(5,995)	

Results

- Total diesel consumption reduces by 7,632 litres pa, a reduction of 2.4%
- Resulting GHG emissions reduction of 20 tonnes CO_2
- Fuel efficiency per ton-nm improves a little from 1.16 to 1.14 l/t-nm
- The annual cost of operation decreases by US$5,995.

Hull and Propeller Cleaning

MTCC-Pacific Guideline item 3.3
Hull and propeller blade roughness and fouling can add 5% to 10% or more to the fuel consumption of a ship. Fouling takes place when a ship is idle for long periods, and when it is in waters conducive to growth such as tropical waters. Both these conditions apply to the MISC ships.

A common practice is to clean hulls and polish propellers 'in water' using divers. If done properly, the hull surface can be restored so that it is close to the underlying corrosion condition. The effect of hull cleaning at 6 monthly intervals is compared with cleaning only at dry docking in Table 33:

Table 33: In-Water Hull Cleaning

		6 monthly in-water cleaning	Actual voyages FY2016
Ship		Kwajalein	Kwajalein
Fuel Consumed			
Diesel			
Fuel consumption, ME (t)	Litres	140,651	160,484
	l/nm	9.7	11.0
Fuel consumption, Aux (t)	Litres	162,171	162,171
	l/h	18.5	18.5
Total Diesel consumption	Litres	302,823	322,655
GHG Emissions -CO2			
Main Engine(s)	Tonnes CO_2	377	430
Auxiliaries		434	434
Boats		15	15
Lube Oil		-	-
Total		826	879
Fuel Efficiency (litres per 100 ton-miles)			
Cargo ton-miles	t.nm pa	27,729,006	27,729,006
Diesel fuel consumed	litres pa	302,823	322,655
Diesel fuel/ 100 ton-miles	Litres/100 t.nm	1.09	1.16
Annual cost (US$)		Kwajalein	Kwajalein
Fuel costs		-	-
Diesel		234,392	249,743
Gasoline		8,098	8,098
Lube oils		3,467	3,694
Total fuel costs		245,957	261,534
Total Annual Cost		769,352	784,929
Total Cost excl depreciation		541,352	556,929
Difference in Cost		(15,578)	

Results

- Total diesel consumption reduces by 19,832 litres pa, a reduction of 6.1%
- Resulting GHG emissions reduction of 53 tonnes CO_2
- Fuel efficiency per ton-nm improves from 1.16 to 1.09 l/t-nm
- The annual cost of operation decreases by US$15,578.

This practice would result in fleet savings of the order of US$50,000pa and CO_2 emission reductions of the order of 200 tonnes CO_2 pa.

Conclusion on Docking Period & In-Water Cleaning

Frequent in-water cleaning appears to have greater benefits than more frequent dry docking. This analysis does not look at the cost of carrying out either measure, but taking a ship out of service for docking, plus the voyage costs there and back are very high compared with in-water cleaning.

The indications are that in-water hull cleaning and associated propeller polishing are worthwhile investigating further.

Engine Tuning & Shaft Alignment

Marine engines are measured for performance at the factory of manufacture on the ‘test bed’. They are tuned optimally, and are of course in pristine condition. Performance rarely ever attains this level again. Typically, an engine that is well maintained and tuned will operate at about 92% of its test bed condition. Kwajalein’s speed trial indicated that its engine was operating at about 87% to 89% of its test bed condition. This loss of condition could possibly be recovered by re-tuning of the engine by the engine manufacturer’s technicians.

A similar gain can be achieved by checking and correcting shaft alignment. Shaft friction is increased if the shaft is out of alignment.

The gain from a 3% improvement in engine power or shaft re-alignment is shown in Table 34

Table 34: Engine Tuning

		Engine tuning, 3% improved	Actual voyages FY2016
Ship		Kwajalein	Kwajalein
Fuel Consumed			
Diesel			
Fuel consumption, ME (t)	Litres	158,331	160,484
	l/nm	10.9	11.0
Fuel consumption, Aux (t)	Litres	162,171	162,171
	l/h	18.5	18.5
Total Diesel consumption	Litres	320,502	322,655
GHG Emissions -CO2			
Main Engine(s)	Tonnes CO_2	424	430
Auxiliaries		434	434
Boats		15	15
Lube Oil		-	-
Total		873	879
Fuel Efficiency (litres per 100 ton-miles)			
Cargo ton-miles	t.nm pa	27,729,006	27,729,006
Diesel fuel consumed	litres pa	320,502	322,655
Diesel fuel/ 100 ton-miles	Litres/100 t.nm	1.16	1.16
Annual cost (US$)		Kwajalein	Kwajalein
Fuel costs		-	-
Diesel		248,076	249,743
Gasoline		8,098	8,098
Lube oils		3,669	3,694
Total fuel costs		259,843	261,534
Total Annual Cost		783,238	784,929
Total Cost excl depreciation		555,238	556,929
Difference in Cost		(1,691)	

Results

- Total diesel consumption reduced by 2,153 litres pa, a reduction of 0.7%
- Resulting GHG emissions reduction of 6 tonnes CO_2
- Little change in fuel efficiency per ton-nm, remaining at 1.16 l/t-nm
- The annual cost of operation decreases by US$1,691.

Conclusion

This measure has a small benefit compared with other measures. However, three of the ships have engines from the same manufacturer, Yanmar, one engine each in Kwajalein and Aemman, and two in Majuro. It may well be worthwhile investigating the cost of a visit by a Yanmar technician to tune all four engines, perhaps in conjunction with a training session on planned maintenance.

Low Emission Fuels

Fuels for marine use can be grouped as follows:

- Fossil fuels – Fuel oil, diesel and gasoline (petrol)
- Fossil Fuel derived fuels- LNG and Methanol
- Liquid Hydrogen
- Bio-derived fuels
- Recycled fuel oils

Fuels have upstream (often referred to as 'well to tank') emissions and operational ('tank to propeller') emissions. Fossil fuels have a high proportion of operational emissions, whereas the emissions from liquid hydrogen, bio-derived fuels and recycled fuel oils are nearly all upstream; the emissions from extraction, production, storage and transportation. A very good description of the emissions from fuels for marine use is set out in a 2017 study by Gilbert et al at Manchester University on full cycle air emissions of alternative shipping fuels[21].

Emissions from fossil fuels such as LNG and methanol are not much different to the conventional fossil fuels, once the upstream emissions are taken into account.

Liquid hydrogen has no operational emissions, producing water vapour, but covers an enormous range of upstream emissions, depending on the energy source used to produce it. Large amounts of energy are required to crack the hydrogen (and oxygen) from water. If this energy is electricity produced from fossil fuels, and without carbon capture and storage technology (CCS), the upstream emissions can be 67% higher than conventional fossil fuels. Use of CCS brings the emissions to about that of fossil fuels, and if the energy is renewable in the form of solar, wind or hydro power, the emissions drop dramatically to about 15% of fossil fuels. This latter scenario looks to be the best for the future, but for now, it is not a practical consideration for RMI or most other places for that matter.

Bio-derived fuels can be in straight vegetable oil (SVO) form or further processed to become biodiesel. All such fuels have little or no operational emissions, putting back the CO2 that the plants extracted from the atmosphere in the first place, but there are some upstream emissions. However, in general, the total emissions are about 25% to 50% of fossil fuels. At the present stage of technology, engine manufacturers prefer to see these fuels used in blends, typically at 10% bio-fuel to 90% diesel, which results in a 5% to 7.5% reduction in emissions.

Recycled fuel oils have an emissions profile that is similar to bio-fuels. These fuels are also typically be blended 10%/ 90% with diesel, giving a reduction in GHG emissions in the range 5% to 7.5%. Their use depends on the acceptability to engine manufacturers, and the implications on engine warranties. This is most likely to be the most promising type for RMI, because of the ease of supply and transportation from sources such as Singapore and San Francisco. The cost of such fuels is more or less the same as unblended diesel. The consumption remains at the same level too, so the gain is in emission reduction.

Results

If changing to a 10%/90% blend of recycled fuel oil or bio-fuel with diesel

- Total diesel consumption remains unchanged
- Resulting GHG emissions reduction of about 5% to 7.5%, ie 135 t to 200t CO_2 for the MISC fleet, and about 1,000t CO_2 if the whole commercial fleet were to change.
- No change in the cost of operation

Conclusion

This measure has a large emission benefit compared with other measures. As three of the ships have engines from the same manufacturer, Yanmar, it may well be worthwhile holding discussions with Yanmar and fuel supply entities with a view to making a change to blended fuels.

5 Infrastructure Improvements

There are several constraints to the operation of the ships that cause delays. Chief amongst these are:

- Constraints on entering or leaving lagoons during darkness
- Tidal constraints preventing boat operations between ship and shore at low tide

Individually, these cause delays. In combination, it is even worse; a delay awaiting darkness may mean that a ship misses one of the two high tide opportunities, restricting the ship to only one 6 to 8 hour period in 24 hours for cargo handling.

Aids to Navigation (AtoNs)

There are very few aids to navigation (AtoNs) in the Marshall Islands, and those that exist are poorly maintained. See a recent report by SPC on this subject[5]. If AtoNs were installed, perhaps by using virtual beacons, it may be possible to lift the constraint on entering and leaving during darkness. Virtual beacons use GPS position fixing onto electronic charts, a relatively cheap capital investment compared with installing physical beacons. The benefits are demonstrated in Table 35:

Table 35: AtoNs for Port Entry

		AtoNs for Port Entry	Actual voyages FY2016
Ship		**Kwajalein**	**Kwajalein**
Time on Voyages			
(Including Majuro cargo time, but excluding idle time in Majuro between voyages)			
At sea	days	68	69
Working cargo	days	56	56
At atolls/ In port, idle	days	32	44
Total days on voyages	days	157	169
Days between Voyages (excluding Majuro car	days	208	196
Fuel Consumed			
Diesel			
Fuel consumption, ME (t)	Litres	159,643	160,484
	l/nm	11.0	11.0
Fuel consumption, Aux (t)	Litres	159,549	162,171
	l/h	18.2	18.5
Total Diesel consumption	Litres	319,193	322,655
GHG Emissions -CO2			
Main Engine(s)	Tonnes CO_2	427	430
Auxiliaries		427	434
Boats		15	15
Lube Oil		-	-
Total		870	879
Fuel Efficiency (litres per 100 ton-miles)			
Cargo ton-miles	t.nm pa	27,729,006	27,729,006
Diesel fuel consumed	litres pa	319,193	322,655
Diesel fuel/ 100 ton-miles	Litres/100 t.nm	1.15	1.16
Annual cost (US$)		**Kwajalein**	**Kwajalein**
Fuel costs		-	-
Diesel		247,063	249,743
Gasoline		8,098	8,098
Lube oils		3,654	3,694
Total fuel costs		258,815	261,534
Total Annual Cost		782,210	784,929
Total Cost excl depreciation		554,210	556,929
Difference in Cost		(2,719)	

Results

The benefits are not large:

- Time at sea reduced by about one day
- However, time at atolls idle reduced by 12 days, reflecting time saved by not have to anchor or drift off atoll reef entrances.
- Total voyage time reduced by 13 days
- Fuel consumption improved by 3,462 litres pa, 1.1%
- GHG emissions reduced by 9 tonnes CO_2 pa
- Annual Operating cost reduced by US$2,719.

Reef Channels

Many places in the outer islands have beaches that are gently sloping, exposing large distances of rough reef shelf at low water. Typically, the beach steepens at above half tide. This enables boat operations for 6 to 8 hours in each tide cycle, but not for the 4 to 6 hours of lower tide.

If reef channels were constructed from deep water to beaches at selected places, the shipping operations could take place without tidal constraint. A full cost-benefit study, including the environmental effects, would indicate their worth. The benefits are demonstrated in Table 36.

Results

As with AtoNs, the benefits are not large:

- Time at sea reduced by about one day
- However, time at atolls idle reduced by 15 days, reflecting time saved by not have to anchor or drift off atoll reef entrances.
- Total voyage time reduced by 16 days
- Fuel consumption improved by 4,490 litres pa, 1.4%
- GHG emissions reduced by 12 tonnes CO_2 pa
- Annual Operating cost reduced by US$3,527.

Table 36: Reef Channels

		Reef Channels	Actual voyages FY2016
Ship		**Kwajalein**	**Kwajalein**
Time on Voyages			
(Including Majuro cargo time, but excluding idle time in Majuro between voyages)			
At sea	days	68	69
Working cargo	days	56	56
At atolls/ In port, idle	days	29	44
Total days on voyages	days	153	169
Days between Voyages (excluding Majuro car	days	212	196
Fuel Consumed			
Diesel			
Fuel consumption, ME (t)	Litres	159,422	160,484
	l/nm	11.0	11.0
Fuel consumption, Aux (t)	Litres	158,743	162,171
	l/h	18.1	18.5
Total Diesel consumption	Litres	318,165	322,655
GHG Emissions -CO2			
Main Engine(s)	Tonnes CO_2	427	430
Auxiliaries		425	434
Boats		15	15
Lube Oil		-	-
Total		867	879
Fuel Efficiency (litres per 100 ton-miles)			
Cargo ton-miles	t.nm pa	27,729,006	27,729,006
Diesel fuel consumed	litres pa	318,165	322,655
Diesel fuel/ 100 ton-miles	Litres/100 t.nm	1.15	1.16
Annual cost (US$)		**Kwajalein**	**Kwajalein**
Fuel costs		-	-
Diesel		246,267	249,743
Gasoline		8,098	8,098
Lube oils		3,643	3,694
Total fuel costs		258,007	261,534
Total Annual Cost		781,403	784,929
Total Cost excl depreciation		553,403	556,929
Difference in Cost		(3,527)	

Aids to Navigation & Reef Channels

In combination, the benefits are greater. The resulting reduction in total voyage time may be the catalyst to allow a reduction in the number of ships in the total fleet. Table 37 shows the results:

Table 37: AtoNs & Reef Channels

		AtoNs + Reef Channels	Actual voyages FY2016
Ship		**Kwajalein**	**Kwajalein**
Time on Voyages			
(Including Majuro cargo time, but excluding idle time in Majuro between voyages)			
At sea	days	68	69
Working cargo	days	56	56
At atolls/ In port, idle	days	17	44
Total days on voyages	days	142	169
Days between Voyages (excluding Majuro car	days	223	196
Fuel Consumed			
Diesel			
Fuel consumption, ME (t)	Litres	159,651	160,484
	l/nm	11.0	11.0
Fuel consumption, Aux (t)	Litres	156,274	162,171
	l/h	17.8	18.5
Total Diesel consumption	Litres	315,925	322,655
GHG Emissions -CO2			
Main Engine(s)	Tonnes CO_2	427	430
Auxiliaries		418	434
Boats		15	15
Lube Oil		-	-
Total		861	879
Fuel Efficiency (litres per 100 ton-miles)			
Cargo ton-miles	t.nm pa	27,729,006	27,729,006
Diesel fuel consumed	litres pa	315,925	322,655
Diesel fuel/ 100 ton-miles	Litres/100 t.nm	1.14	1.16
Annual cost (US$)		**Kwajalein**	**Kwajalein**
Fuel costs		-	-
Diesel		244,533	249,743
Gasoline		8,098	8,098
Lube oils		3,617	3,694
Total fuel costs		256,248	261,534
Total Annual Cost		779,643	784,929
Total Cost excl depreciation		551,643	556,929
Difference in Cost		(5,286)	

Results

The combined benefits are greater:

- Time at sea reduced still only one day
- However, time at atolls idle reduced by 27 days, reflecting time saved by not have to anchor or drift off atoll reef entrances.
- Total voyage time reduced by 28 days
- Fuel consumption improved by 6,730 litres pa, 2.1%
- GHG emissions reduced by 18 tonnes CO_2 pa
- Annual Operating cost reduced by US$5,286.

Conclusion

Extrapolating this to all four ships would mean a total reduction in voyage times for all ships of the order of 100 days. Added to the existing time spent idle in Majuro may be sufficient to justify reducing the size of the fleet.

6 Alternative Sources of Propulsion

GIZ's project has as one of its objectives, consideration of alternative sources of propulsion, both for small intra-lagoon craft and for larger ships such as the MISC ships. The model developed as part of this baseline study allows consideration of the benefits of alternative sources of propulsion on larger ships.

Types of Options

Alternative sources of propulsion can be in combination with conventional fossil fuelled engines – hybrid propulsion through augmenting the fossil fuelled propulsion - or instead of fossil fuelled engines. The most likely energy sources are:

- Wind energy
- Solar energy
- Carbon neutral fuels such as bio-fuels

or combinations of these, both with and without fossil fuels.

The methods of augmenting or replacing fossil fuels are:

- Direct forward thrust onto the ship
- Application of power onto the propeller shaft
- Provision of electrical power to supply to meet the ship's electrical demand

Thrust Examples

Thrust augmentation will usually be achieved through use of wind energy. There are various forms, for example:

- Sails or foils
- Kites
- Flettner rotors

Shaft Power Examples

Shaft power augmentation is most likely to be in the form of electrical energy through a motor connected to the main shaft gearbox. The source of electrical energy could be:

- Wind, through a wind turbine, or
- Solar energy through photo-voltaic cells.

Electrical generation Examples

Electrical generation is likely to have similar energy sources to shaft power augmentation:

- Wind, through a wind turbine, or
- Solar energy through photo-voltaic cells.

Alternative Fuels

Biofuels is an example of a carbon neutral fuel. Strictly it is a lower emission fuel, as it's processing and transport emits CO_2. Biofuels may possibly be used as a 100% mixture, but more likely is a blend with fossil fuels.

Thrust Augmentation

To demonstrate the project's model capabilities, Kwajalein is run with a Flettner rotor fitted, compared with its existing configuration. The assumption is that the ship is fitted with one small rotor, 18m high by 3m diameter. See Annex J of R E Held's BSc Thesis for details[11]. The thrust developed depends on the apparent wind experienced by the ship on each leg of its voyage. The model deducts the thrust from the effective thrust required in order to achieve the specified service speed. The resulting effective thrust from the propeller is converted to engine brake power required by considering the propeller and hull efficiency at the speed of advance and propeller rpm that result. Table 38 shows the results:

Table 38: Flettner Rotor

		Flettner Rotor	Actual Voyages FY2016/17
Ship		Kwajalein	Kwajalein
Fuel Consumed			
Diesel			
Fuel consumption, ME (t)	Litres	141,626	160,484
	l/nm	9.7	11.0
Fuel consumption, Aux (t)	Litres	161,259	162,171
	l/h	18.4	18.5
Total Diesel consumption	Litres	302,886	322,655
GHG Emissions -CO2			
Main Engine(s)	Tonnes CO_2	379	430
Auxiliaries		432	434
Boats		15	15
Lube Oil		-	-
Total		826	879
Fuel Efficiency (litres per 100 ton-miles)			
Cargo ton-miles	t.nm pa	27,729,006	27,729,006
Diesel fuel consumed	litres pa	302,886	322,655
Diesel fuel/ 100 ton-miles	Litres/100 t.nm	1.09	1.16
Annual cost (US$)		**Kwajalein**	**Kwajalein**
Fuel costs		-	-
Diesel		234,441	249,743
Gasoline		8,098	8,098
Lube oils		3,468	3,694
Total fuel costs		246,006	261,534
Total Annual Cost		769,401	784,929
Total Cost excl depreciation		541,401	556,929
Difference in cost	US$pa	(15,528)	

Results

- Total diesel consumption reduced by 19,769 litres pa, a reduction of 6%
- The reduction in Main Engine fuel consumption is 12%
- Resulting GHG emissions reduction of 53 tonnes CO_2
- Fuel efficiency per ton-nm improves from 1.16 to 1.09 l/t-nm
- The annual cost of operation decreases by US$15,528.

Conclusion

This measure has significant fuel saving and emission reduction benefits but the return on investment is small or negative when the capital cost of installing a rotor is taken into account.

Shaft Power Augmentation

To further demonstrate the model's capabilities, Kwajalein is run with an electrical power source, say a wind turbine, driving an electric motor that is coupled to the propeller shaft at the gearbox. The input from the motor is assumed to be 25kW, although in reality, the input will vary with apparent wind speed. The model deducts this shaft power input from the brake power required to be delivered into the gearbox, thus reducing the main engine flywheel power required in order to achieve the specified service speed. Table 39 shows the results:

Table 39: Shaft Power Augmentation

		Shaft Augment, 25kW	Actual voyages FY2016
Ship		**Kwajalein**	**Kwajalein**
Fuel Consumed			
Diesel			
Fuel consumption, ME (t)	Litres	149,693	160,484
	l/nm	10.3	11.0
Fuel consumption, Aux (t)	Litres	162,171	162,171
	l/h	18.5	18.5
Total Diesel consumption	Litres	311,864	322,655
GHG Emissions -CO2			
Main Engine(s)	Tonnes CO_2	401	430
Auxiliaries		434	434
Boats		15	15
Lube Oil		-	-
Total		850	879
Fuel Efficiency (litres per 100 ton-miles)			
Cargo ton-miles	t.nm pa	27,729,006	27,729,006
Diesel fuel consumed	litres pa	311,864	322,655
Diesel fuel/ 100 ton-miles	Litres/100 t.nm	1.12	1.16
Annual cost (US$)		**Kwajalein**	**Kwajalein**
Fuel costs		-	-
Diesel		241,390	249,743
Gasoline		8,098	8,098
Lube oils		3,570	3,694
Total fuel costs		253,059	261,534
Total Annual Cost		776,454	784,929
Total Cost excl depreciation		548,454	556,929
Difference in Cost		(8,476)	

Results

- Total diesel consumption reduced by 10,791 litres pa, a reduction of 3.3%
- Resulting GHG emissions reduction of 29 tonnes CO_2
- Small change in Fuel efficiency per ton-nm, improving from 1.16 to 1.12 l/t-nm
- The annual cost of operation decreases by US$8,476.

Conclusion

This measure also has a small benefits, although the relatively low capital cost of installing a system might make it worth considering.

7 Conclusions on Alternative Operating Practices

The above operating practices that show reasonable improvement in financial operating costs, fuel consumption/ GHG emissions or both are:

Majuro turn round

In FY2017, the four MISC ships were in Majuro for a total of 699 days, almost two ship-years. This suggests that a reduction in number of ships in the fleet could be considered. If Ribuuk Ae's tasks were taken up by Kwajalein and Aemman, the following conclusions could be drawn:

- Although main engine fuel consumption would increase, reflecting the use of the larger ships, auxiliary fuel consumption would reduce as a result of one less ship in operation.
- The overall diesel consumption would improve by 37,949 litres, a 3.8% reduction
- The GHG emissions would reduce by 3.8% as a result, by 103 tonnes CO_2.
- The cost of ship operations would reduce by US$232,000, more than 10% of the fleet operating cost.
- It would be possible to dispose of Ribuuk Ae at its present market value.

Slow steaming for Just-in-Time & Slow Steaming Generally

Adopting the combined practices of slow steaming to arrive at dawn off a port constrained by daylight navigation only, and slow steaming generally, at say 0.5kt slower than normal, could result in an annual GHG emissions reduction and cost saving in the order of 400 tonnes CO_2 and US$100,000 respectively over the whole fleet.

Hull Cleaning & Propeller Polishing

This practice would result in fleet savings of the order of US$50,000pa and CO_2 emission reductions of the order of 200 tonnes CO_2 pa. The indications are that in-water hull cleaning and associated propeller polishing are worthwhile investigating further.

Engine Tuning

This measure has a small benefit compared with other measures. However, three of the ships have engines from the same manufacturer, Yanmar, one engine each in Kwajalein and Aemman, and two in Majuro. It may well be worthwhile investigating the cost of a visit by a Yanmar technician to tune all four engines, perhaps in conjunction with a training session on planned maintenance.

Overall Potential

These four changes to operational procedures and maintenance practices could result in cost savings up to US$400,000 pa, and CO_2 emission reduction of up to US$700 tonnes CO_2 pa. Both Hull Cleaning and Engine Tuning have implementation costs associated with them, but even taking these into account, all these practices might well be worthwhile.

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