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Study of Marine Communications Systems and Selection Procedures for Implementing Solutions

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Instructor: Ville Leino, Technical Manager - Marine Operations
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Helsinki Metropolia University of Applied Sciences ABSTRACT

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The project was appointed by Eniram Ltd, an IT company which offers the maritime industry solutions in the form of turnkey packages installed aboard ships to aid crews in enhancing many aspects of vessel performance. The need for a study and comparison was identified into different ship-to-shore communications methods for transmitting the data acquired from Eniram's onboard system modules to Eniram's office for processing. The objective was to provide a clear procedure for selecting the most appropriate solution for implementation aboard a ship, on a per-customer basis.

Through research into marine communications, the communications industry as a whole, and interviews with Eniram, the project described the relevant characteristics of the possible communications methods and their feasibilities in being employed for Eniram's purposes. These were according to each vessel's operational factors, as well as implementation and financial considerations discussed from a general project planning viewpoint.

The project resulted in the production of a set of procedural guidelines, or a solution map, that stipulate in a systematic manner the information that needs to be collated for each ship installation, the factors that need to be formulated from this information, and the consequent logical decisions required to be made when selecting the optimal solution for a vessel.

Keywords	marine communications, mobile communications, mobile satellite services, ship-to-shore communications

Contents

Abbreviations

ADU	Above Deck Unit
BDU	Below Deck Unit
CFM	Comfort Factor Monitor
CS	Coding Scheme
CSM	Cargo Securing Monitor
DSM	Dynamic Stability Monitor
DTA	Dynamic Trimming Assistant
E-SMS	Extended Safety Management System
EDGE	Enhanced Data Rates for GSM Evolution
FMS	Fleet Management System
FSS	Fixed Satellite Service
GEO	Geostationary Earth Orbit
GMDSS	Global Maritime Distress Safety System
GRT	Gross Registered Tonnes
GSM	Global System for Mobile Communications
HRM	Hull Roughness Monitor
ISDN	Integrated Services Digital Network
ISL	Inter Satellite Link
LA	Link Adaptation
LEO	Low Earth Orbit
LES	Land Earth Station
MCS	Modulation and Coding Scheme
MEO	Medium Earth Orbit
MES	Mobile Earth Station
MS	Mobile Station
MSS	Mobile Satellite Service
NCC	Network Control Centre
NOC	Network Operations Centre
RD	Remote Diagnostics
RDM	Remote Diagnostics and Maintenance

RFI	Request for Information
RFQ	Request for Quote
RR	Remote Reporting
TCO	Total Cost of Ownership
VET	Vessel Emission Tracker
VMP	Vessel Management Platform
VPN	Virtual Private Network
WLAN	Wireless Local Area Network

1 Introduction

This project was assigned by Edec Oy, a technical design and consultancy service working predominantly in the marine industry, as a technological comparison for its spin-off company, Eniram Ltd. Eniram was founded in 2005 when a necessity for integrating maritime operational procedures and information from onboard vessel systems was identified. With a rich heritage in the Finnish shipbuilding industry, Eniram consists of marine system experts, captains, naval architects, software architects and programmers. Their objective is to offer the marine industry a technologically advanced portfolio of tools that aid crews in improving vessel performance. [1]

Eniram's software-based vessel management systems function through the analysis of high-precision measurements of a vessel's operational parameters and data acquired from integrating with the vessel's automation systems. This enables the provision of extremely accurate informational support for the ship's officers, designed to aid officers in their decision-making processes in many areas of a vessel's operation.

Eniram's requirement is a study and comparison of different methods for defining remote ship-to-shore and shore-to-ship data connections for the purposes of communicating between the Eniram office and its onboard vessel systems. With a clear view of these methods, and the provision of a guideline (or solution map), the most appropriate solution can be selected and implemented.

The target is the eventual implementation of communications solutions that offer the most efficient and cost-effective methods of remotely connecting to all ships fitted with Eniram's products. This will enable Eniram to assess its products' performances, detect any problems, highlight any possible improvements and enable software updates when necessary. Primarily, fleet-wide data acquisition in order to facilitate the optimisation of shipping companies' fleet operations will be possible. To do this from shore, rather than dispatching an engineer to the vessel wherever it may be in the world, would save time and expense.

Preferably, the primary method for this data connection would be to employ an existing communications system aboard each vessel. It may transpire that such a system does not exist or its use is not permitted, in which case the feasibility of acquiring and installing a new communications system dedicated to the above purposes must also be evaluated.

Ultimately, when Eniram has analysed and perfected the operation of the remote communication link, the entire system will be commissioned and handed over to the relevant shipping company. This will empower them to monitor their vessels' performances from their own headquarters.

2 Theoretical Background

2.1 Satellite Services

The type of satellite service that relates to marine communications is termed a Mobile Satellite Service (MSS). It enables global voice and data communications through satellite systems and Mobile Earth Stations (MESs) aboard ships, as well as on land and in aeroplanes. The alternative to an MSS is a Fixed Satellite System (FSS) which employs fixed terminals in satellite communications and is therefore restricted to purely terrestrial applications, such as domestic satellite television.

Satellite systems hold many advantages, especially in marine communications. They provide the freedom of mobile communication, independent of location and terrestrial infrastructures, with the widest geographical areas of coverage. Wide bandwidths are also provided through the microwave bands used by satellite systems compared to lower frequency bands used in radio and TV applications. For example, the microwave C and Ku frequency bands have an available spectrum of 1 GHz each which can be further increased, or reused, through various techniques. When demand dictates, Earth Stations can be rapidly deployed to utilise a satellite connection, compared to a terrestrial communications network requiring ground construction works for cable-routing to an added facility. Additionally, a total satellite service is possible from a single provider, whereas terrestrial networks are often divided in their operation by regional and national companies. [2]

A satellite communications system consists of three major components: the space segment, the ground segment and the terminals. The space segment contains the satellites which are commissioned and run by satellite operators, the major operators including Inmarsat, Intelsat and Eutelsat. A communications satellite is a microwave repeater station that permits users to deliver or exchange information in various forms. Each satellite covers an area of the Earth's surface which increases with increasing orbit height and the wider the beam used. For a particular satellite service, the choice of orbits and the positioning of the satellites within the orbits must guarantee continuous coverage of the service area, i.e. for a global service, the full surface of the Earth must be covered.

The ground segment consists of a network of Land Earth Stations (LESs) which are operated by telecommunications companies and comprise fixed, land-based Earth stations providing the link between the satellite network and the international telecommunications network. For each satellite system or region there operates a Network Control Centre (NCC) which monitors and controls all satellite communications. The Network Operations Centre (NOC) communicates with all NCCs and transfers operational information throughout the system.

In contrast to a LES which is part of the ground segment, a Mobile Earth Station (MES) is a terminal device installed on a ship to enable the user to communicate with land-based or marine subscribers via satellite. The MES equipment comprises the Above Deck Unit (ADU), containing the antenna unit which includes a radome and a stabilised antenna dish with tracking electronics and RF equipment; and the Below Deck Unit (BDU), containing the main communications unit and power supply unit.

2.1.1 Satellite Orbits

There exist three main types of orbits in which communications satellites operate around the Earth, named Low Earth Orbit (LEO), Medium Earth Orbit (MEO) and Geostationary Earth Orbit (GEO), characterised by their altitudes above the Earth's surface, as illustrated in figure 1 below.

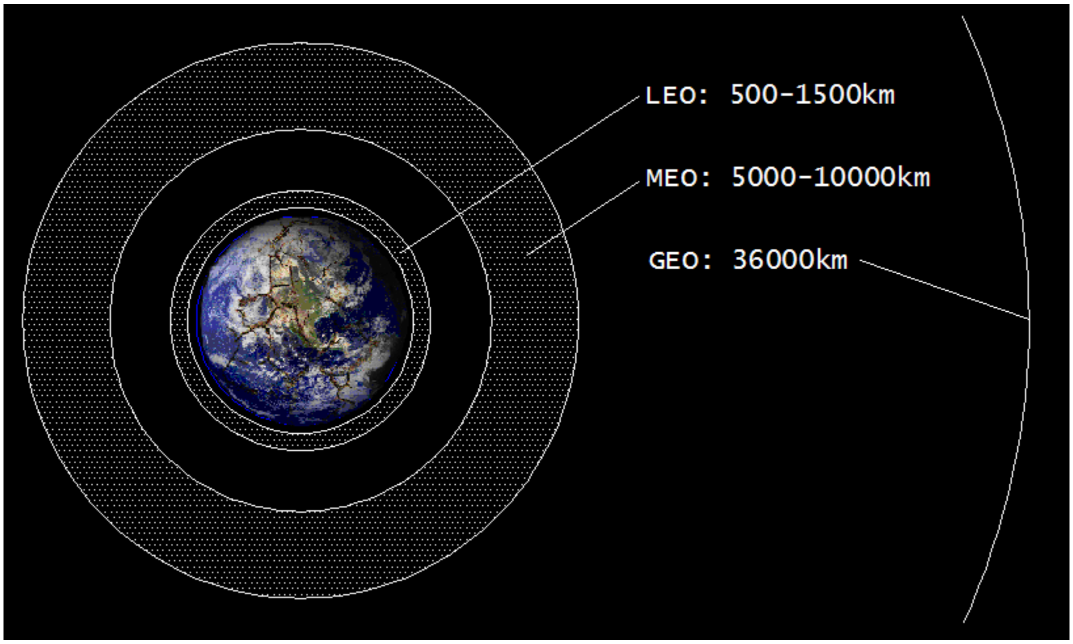

Figure 1. Scale diagram of the LEO, MEO and GEO altitudes from Earth

Communication satellites are commonly placed in the geostationary orbit (GEO) which is the outermost orbit in figure 1, termed because the satellites appear stationary from a fixed observation point on Earth. A GEO is achieved by placing a satellite into a circular orbit directly above the Earth's equator at a distance of 36000 km, so that the period of the satellite's orbit is synchronous to the Earth's period of revolution (approximately 24 hours). An orbit that has a period of 24 hours but is inclined at an angle to the equator does not appear stationary from a point on Earth, and is termed geosynchronous.

The geostationary property of a communications satellite is very useful in FSS applications as it enables Earth stations to be always pointed in the same direction, ridding the need for a tracking system and a moveable antenna to follow the movement of the satellite in space. MSS applications inherently require Earth stations that are capable of tracking the position of the satellite.

A single GEO satellite can cover a large area of the Earth (almost an entire hemisphere) within which Earth stations can be linked via the same satellite. This large coverage area means that only three GEO satellites separated by 120 degrees of longitude can achieve almost global coverage. It is not possible for GEO satellites to cover the polar regions as at these higher latitudes the satellites will appear too low on the horizon. This low elevation introduces increased attenuation of the signals due to their longer trans-atmospheric path.

The high range between a GEO satellite and an Earth station makes the design of the link quite stringent in terms of providing adequate received signal power. The range also introduces a round-trip propagation delay via the satellite of approximately 0.25 seconds between a pair of Earth stations. Additionally, heavy signal processing may be required due to weak signal levels, which can further increase the delay to one second between two Earth stations [Leino V, Eniram Ltd, 9 September 2008, personal communication].

Non-geosynchronous satellites are situated in orbits lower than 36000 km and hence have periods of revolution shorter than 24 hours. This means that a non-geosynchronous satellite always appears to move past a point on the Earth and, therefore, multiple satellites are required in a non-geosynchronous satellite network to provide continuous coverage of a given region of the Earth.

The lowest of satellite system orbits are termed Low Earth Orbits (LEOs) and consist of altitudes ranging from 500 to 1500 km [2], which equates to an orbiting period of only 1.6 to 1.9 hours. LEOs are not constrained to the equatorial plane and can be inclined at any angle and can therefore orbit in the polar plane. LEO satellites require signals to traverse significantly shorter distances than GEO satellites, and therefore minimise the power required and reduce round-trip propagation delays to a few milliseconds.

The short orbital periods of LEO satellites produce brief durations (typically a few minutes) during which a single LEO satellite can serve a particular Earth station. This introduces the necessity for LEO satellites to hand off connections, while they are still in progress, to other satellites by way of Inter Satellite Links (ISLs). Since LEO satellites have smaller coverage areas, they are required to handle fewer subscribers and the requirements of the satellite communications equipment are more relaxed. However, substantially more satellites are required to provide global coverage.

A compromise between LEO and GEO is the Medium Earth Orbit (MEO) with altitudes ranging from 5000 to 10000 km [3], equating to orbital periods of 3.4 to 5.8 hours. For higher MEO altitudes, a MEO satellite has a much longer period and thus tends to 'hang' over a given region on the Earth for a few hours, and global coverage can be achieved with 10-15 satellites. Transmission distance and propagation delay are greater than for LEO but still significantly less than for GEO.

The advantages and disadvantages of the three types of orbit employed by satellite networks are displayed in table 1 below.

Table 1. Advantages and disadvantages of GEOs, LEOs and MEOs (Information gathered from Lutz et al. (2000) [3])

Orbit	Advantages	Disadvantages	Providers
GEO	Mature satellite technology Constant propagation delay No satellite handover (ISL) Few satellites needed for global coverage	No coverage at polar regions Low elevation at high altitudes High free space signal loss High signal latency	Eutelsat Inmarsat Intelsat SES
LEO	Small coverage areas, i.e. smaller, lower capacity satellites Low signal latency Low free space signal loss High elevation at high altitudes Coverage at polar regions	Small coverage areas, i.e. many satellites needed, therefore many ESs or ISLs Full constellation needed for operation Complex satellite control Short satellite lifetime Earth stations require fast tracking Variations in signal latency Short satellite visibility	Globalstar Iridium
MEO	Compromise between GEO and LEO Moderate number of satellites needed State-of-the-art satellite technology Acceptable signal latency Good satellite elevation at higher altitudes Few Earth Stations without ISL required		Galileo GLONASS ICO NAVSTAR-GPS

As can be seen from table 1, MEOs combine the advantages of both GEOs and LEOs. With regards to marine satellite communications, it is worth noting that any vessels operating in the polar regions and requiring satellite connectivity, will not benefit from a GEO satellite network.

2.1.2 Satellite Coverage Areas

A satellite's coverage area, also known as a footprint, is the area of the Earth's surface for which the satellite can provide sufficient signal strength for communications between itself and Earth stations in the area. The coverage area is dependent on the satellite's altitude, so it follows that LEO satellites have the smallest coverage areas and GEO satellites the largest. When a satellite system is required to provide communications for a service area larger than a single satellite's coverage area, multiple satellites will be employed to form a constellation.

The beam from a satellite antenna covers an area with the maximum signal strength in the centre of the area, directly below the satellite, and decreasing signal strengths further out from the centre. As well as global beams, highly focussed spot beams can be generated which offer a much smaller coverage area but reduced the size requirement of the receiving antenna. Therefore, the smaller the beam-size, the greater the signal strength on Earth and the smaller the receiving antenna can be, enabling handheld MESs to operate. Many of these spot beams can be used to fill a coverage area, creating a cellular architecture with overlapping beams separated by different frequency bands.

For example, Iridium, a LEO satellite system, employs a constellation of 66 satellites arranged into six polar orbits of eleven satellites each at an altitude of 780 km to provide completely global coverage with each satellite using 48 spot beams [4]. In contrast, the latest Inmarsat-4 GEO satellite system employs a constellation of four satellites for global coverage (except for the polar regions) using one global beam, 19 wide spot beams and over 200 narrow spot beams per satellite [5].

2.1.3 Global Maritime Distress Safety System (GMDSS)

The Global Maritime Distress Safety System (GMDSS) is an internationally ratified set of procedures and equipment needed to implement search and rescue at sea, providing automatic distress alerting and locating, search and rescue coordination, maritime safety information broadcasts and bridge-to-bridge communications. The system was developed by the International Maritime Organisation (IMO) after a need for improvements in maritime safety and distress communications was identified. In turn, IMO amended its International Convention for the Safety of Life at Sea (SOLAS) to require all ships subject to it to install GMDSS equipment. [6]

The GMDSS equipment requirements for a ship depend upon the ship's area of operation and the communication service available in that area to provide continuous alerting. There are four areas of operation defined, termed sea areas A1, A2, A3 and A4. Sea area A1 is an area within the radio coverage of at least one VHF coast station. Sea area 2 is an area, excluding sea area 1, within the coverage of at least one MF coast station. Sea area 3 is an area, excluding sea areas A1 and A2, within the coverage of an Inmarsat geostationary satellite. Sea area A4 is an area outside sea areas A1, A2 and A3; effectively the polar regions. [7]

It is important to note that ships operating in A3 sea areas have a requirement to carry Inmarsat MES equipment. GMDSS recognises three types of Inmarsat MES terminals: the Inmarsat B, C and Fleet F77. The Inmarsat B and F77 provide ship-shore, ship-ship and shore-ship voice, telex and data services, including prioritised functionality between the ship and rescue coordination centres. Since the Fleet F77’s data capability does not meet GMDSS requirements, it needs to be incorporated with the Inmarsat C system which provides the same services but in a store-and-forward manner. Interestingly, in relation to shipping operations in U.S. waters, there have not been any A1 or A2 sea areas declared as of yet. Therefore, until these are established, ships operating near U.S. coastlines must adhere to GMDSS satellite equipment requirements. [6]

2.2 Inmarsat

Inmarsat was founded in 1979 as an intergovernmental agency with the objective of establishing a satellite communications network for the maritime industry that enabled ships to remain in constant communication [8]. Presently, Inmarsat is the world leader in providing Mobile Satellite Services (MSS), enabling global voice and data communications through satellite systems and portable terminals on land, ships and aeroplanes [8]. The term MSS is used in contrast to Fixed Satellite Systems (FSS) which employs fixed terminals in satellite communications and is therefore restricted to terrestrial applications, such as domestic satellite television.

Inmarsat operates a network of GEO satellites and its latest generation of global mobile satellite services has entered the IP-based broadband era, providing constant and simultaneous voice and high-speed data connectivity. The family is divided into land-based, aeronautical and maritime variants, respectively named Broadband Global Area Network (BGAN), SwiftBroadband and FleetBroadband.

FleetBroadband, launched at the end of 2007, building on the already proven success of Inmarsat's Fleet service, composed of the 77, 55 and 33 variants, by offering more than three times the bandwidth than that of Fleet 77. Fleet, launched in 2002, has already become the global standard for satellite communications systems installed on deep-sea vessels. [9]

2.2.1 FleetBroadband

Being the first broadband MSS offered to the maritime industry, FleetBroadband is the only service that currently enables voice calls simultaneously to other data connections. It was designed specifically as an IP-based system, in alignment with the Internet, as opposed to its predecessor systems based on Integrated Services Digital Network (ISDN) technology. ISDN is a circuit-switched technology that requires connections to be established and taken down for communication to take place. The features of the FleetBroadband service are displayed in table 2 below.

Table 2. Features of FleetBroadband (Information gathered from FleetBroadband overview brochure (2007) [10])

Advantages	Capability of rapid deployment across a fleet and global operation of terminals
	IP-based design enables seamless integration with head-office networks and support for latest IP services
	Backward compatibility with circuit-switched predecessor services, i.e. ISDN
	Standardised user interface across all vendor equipment
	Choice of two terminals and ability to select data rate (FB250 & FB500)
	Provision of security through VPNs and ISDN cryptos
Capabilities	Standard IP: email and internet access via secure VPN connection at ≤432kbps
	Streaming IP: on-demand data rates at ≤256kbps; selectable for application
	Voice: capability of simultaneous voice calls and data access, voicemail & Group 3 fax support via voice channel
	ISDN: 64kbps data rate supported for legacy applications
	SMS: ability to send/receive text messages up to 160 characters
Applications	Email
	Real-time electronic chart & weather updates
	Remote intranet/internet access
	Secure communications
	Large file transfers
	Vessel/engine telemetry
	SMS and instant messaging
	Videoconferencing
	Store and forward video

As can be seen from table 2, the FleetBroadband system offers many more capabilities than required by Eniram's data needs, but if the system is already present on a customer vessel it would provide very good satellite connections for Eniram to utilise. The relevant features of FleetBroadband pertaining to Eniram's communication requirements are as follows:

- System designed specifically for the marine industry
- IP-based design; remote intranet/internet access via VPN connections; ISDN supported; large file transfers; secure communications
- Standard IP: up to 284 kbps (FB250 terminal); up to 432 kbps (FB500 terminal)
- Streaming IP: 32/64/128 kbps (FB250); 32/64/128/256 kbps (FB500)
- ISDN: 64 kbps (FB500 only)

2.2.2 Fleet 77, 55 and 33

Inmarsat Fleet's premier service, F77, is an integrated global communications solution offering data, voice and fax connections targeted at large-sized vessels. For data transmissions, the F77 service enables emailing, Virtual Private Network (VPN) access, the transfer of large data files and videoconferencing. Data security features such as antivirus software, firewalls and VPN protocols are also supported.

F77 offers two options for data connectivity: the circuit-switched Mobile ISDN channel with transfer rates of 64 or 128 kbps; or the packet-switched Mobile Packet Data Service (MPDS) with the same transfer rates but allowing the continuous connection of ships to terrestrial networks with payment for the volume of data exchanged rather than the duration of the link used.

Mobile ISDN is best suited for applications where data throughput and speed are important, including large data file transfer, including FTP and digital images, and secure voice and data communications. MPDS is more suitable for interactive, short-burst data and web-based applications, such as Internet and private network access and vessel telemetry. [11]

The fact that Inmarsat's Fleet solutions are integrated communications platforms, in that they offer voice and fax services as well as data, they are suitable for many markets such as merchant, fishing, government and leisure where multiple capabilities are required. These capabilities include e-mail, messaging, data file transfer, Internet and private network access, videoconferencing, store-and-forward video, vessel telemetry and many other marine applications. Again, the multitude of capabilities suggests a solution that is overqualified for the purposes of Eniram's simpler data requirements, but in the event of a Fleet 77 system already installed on a vessel it would offer data transfer characteristics as follows:

- Well-established marine system
- IP support; Internet and private network access; data file transfer (incl. FTP); secure communications
- Mobile ISDN: up to 64 kbps; 128 kbps option
- MPDS: 64/128 kbps (packet based)

Inmarsat's F55 service is very similar to F77, with the main differences being a smaller antenna and Below Deck Equipment (BDE), at a lower cost, and is therefore targeted at medium-sized vessels. Its data transfer characteristics are listed below [12]:

- IP and FTP support; secure connections
- Mobile ISDN: up to 64 kbps
- MPDS: up to 64 kbps

Inmarsat's F33 service is the most economical of the Fleet family, offering the smallest sized antenna and BDE, and suitable for smaller vessels. Its data characteristics are [13]:

- IP compatibility
- Circuit-switched: 9.6 kbps
- MPDS: 64 kbps

2.2.3 Other Inmarsat Systems

In 1982, Inmarsat-A became the first marine MSS to be introduced by Inmarsat, an analogue system allowing voice, fax, telex, email and data communications at a maximum rate of 9.6 kbps and later increased to 64 kbps. The MES equipment comprised a very large and heavy antenna (1350 mm and 100 kg), and therefore tended only to be installed on larger ships. Inmarsat-A was withdrawn from service in 2007.

The digital Inmarsat-C system was introduced in 1991 primarily for fax, telex, email and data communication purposes using a store-and-forward technique, and excluding any voice capabilities. It employs considerably smaller MES equipment (130 mm and 7 kg) including an omni-directional antenna which doesn't require any tracking and moveable parts. Additionally, Inmarsat-C was accepted by IMO as meeting the requirements of the GMDSS, a compulsory system for vessels above 300 GRT. [14]

It is important to note here that if a vessel is fitted with an Inmarsat-C MES and employs it for GMDSS purposes, no other application or interface can be connected to it, in which case it would preclude Eniram from utilising it for data communications. A further limitation is the fact that Inmarsat-C employs a store-and-forward technique when transmitting data which can introduce considerable delays.

In 1993, Inmarsat-M was introduced, allowing digital voice, fax, email and data communications with relatively cheaper and smaller MES equipment (650mm and 20 kg) than that of Inmarsat-A, thereby making it suitable for smaller vessels. In 1994, Inmarsat-B was introduced with the same system architecture as Inmarsat-M and the same sized MES antenna as Inmarsat-A, employing digital technology for higher quality communications at up to 64 kbps. In 1997, Inmarsat mini-M was launched, a variant of Inmarsat-M but incorporating smaller and lighter MES equipment (260 mm and 4 kg). [14]

In summary of all the Inmarsat systems introduced so far, table 3 below displays their characteristics in relation to data communication and other operational factors.

Table 3. Comparison of Inmarsat satellite systems (Information gathered from Inmarsat product literature [10,14])

Inmarsat System	Data Rate / kbps					GMDSS	Coverage	Year	Notes
	IP	MPDS	ISDN	HSD	MSD				
Fleet Broadband	284 (FB250) 432 (FB500)	-	64 (FB500)	-	-	No	Global	2007	
Fleet 77	-	64	64 128 (option)	-	-	Yes	Global Spot	2002	
Fleet 55	-	64	64	-	-	No	Spot	2003	
Fleet 33	-	28 (uplink) 64 (down)	-	-	9.6	No	Spot	2003	
Inmarsat B	-	-	-	64	9.6	Yes	Global	1994	
Inmarsat C	-	-	-	-	-	Yes	Global	1991	Store & forward data; omnidirectional antenna
Inmarsat M	-	-	-	-	2.4	No	Global	1993	
Inmarsat mini M	-	-	-	-	2.4	No	Spot	1997	

2.3 SeaMobile Enterprises

SeaMobile was founded with a view to providing a comprehensive range of wireless communications, connectivity and content services to the marine sector, further bolstered by its acquisition in 2006 of Maritime Telecommunications Network (MTN), now the MTN Satellite Services division of SeaMobile, and its established VSAT satellite services [15]. It claims to serve over 350 vessels worldwide of all types by providing connectivity to their voice and data networks [16].

The MTN Satellite Services division delivers voice and data connectivity to its customers through common bidirectional satellite connections provided by its DirectNet service [17], employing stabilised VSAT antenna technology (where 'stabilised' refers to an installation designed to adjust its orientation and keep track of a satellite's location relative to a ship's movements) to provide global coverage on the C-band and regional coverage areas on the C-band and Ku-band [18].

DirectNet's network architecture is consists of a terrestrial backbone composed of gateway Earth stations and Points of Presence (POPs) located in the North American and European continents and the Far East, interconnected by T1/E1 and DS3 lines, providing different connectivity options in the Earth segment for its customers. [17]

In the Space segment, SeaMobile promotes its DirectNet service as being 'always on' and guaranteeing bandwidth on demand, with a dedicated minimum bandwidth set by its Committed Information Rate (CIR), and a possible highest rate given by its Maximum Information Rate (MIR), so that unlimited connectivity for the customer is attainable at a fixed monthly fee.

2.4 Public Land Mobile Network (PLMN)

2.4.1 Global System for Mobile Communications (GSM)

The Global System for Mobile Communications (GSM) standard was developed with the initial goal of creating a European-wide cellular mobile telephone system. Development work began in 1982 and since the first network was launched in 1991 in Finland, GSM has become unarguably the most popular mobile phone standard in the world, implemented in 220 countries and territories, by over 860 mobile phone operators [19]. GSM is deemed 2G technology, in that both the signalling and speech channels operate digitally, as opposed to its 1G analogue network predecessors.

The global presence of GSM, and the existence of international roaming agreements between operators, enables subscribers to use the services almost anywhere in the world, as long as the mobile phone, or Mobile Station (MS), has multi-band capabilities and is able to switch between the major GSM frequency bands. For instance, the Caribbean and Central American region is known for its diverse implementation of GSM frequencies, so that during a sea cruise a quad-band MS may be necessary for guaranteed GSM connectivity. The four major GSM frequency bands utilised throughout the world are displayed in table 4 below:

Table 4. The four major GSM frequency bands

GSM System	Frequency Band (MHz)	
	Uplink	Downlink
GSM-850	824-849	869-894
GSM-900	890-915	935-960
GSM-1800	1710-1785	1805-1880
GSM-1900	1850-1910	1930-1990

GSM employs the Frequency Division Duplex (FDD) principle, seen from table 4 by the different frequency bands for the uplink and downlink. Frequency Division Multiple Access (FDMA) divides the frequency bands into 200 kHz Radio Frequency (RF) channels, and Time Division Multiple Access (TDMA) divides each RF channel into eight timeslots to form a TDMA frame, giving eight full-rate physical channels for user voice and data per RF channel [20]. Using the primary GSM-900 band as an example, each link direction gives a frequency bandwidth of 25 MHz which divides into 124 RF channels spaced at 200 kHz, and a total of 992 physical channels.

2.4.2 General Packet Radio Service (GPRS)

GSM's capabilities were extended in 2001 with the launch of the General Packet Radio Service (GPRS) which uses GSM's radio resources more efficiently in its provision of a packet-switched mobile data service. Packet-switching optimises the use of radio resources in that they are only used during actual transmission and reception of data to and from any MS, as opposed to a dedicated, circuit-switched channel for each MS, as is the case with GSM. Data applications used on MSs generally create traffic that is bursty in nature, i.e. their bit rates vary considerably with time, and GPRS enables several of these data connections to be multiplexed to a GSM physical channel [21].

GPRS is generally designated a 2.5G technology and was designed to operate over the GSM infrastructure, alongside existing GSM services. The main advantage of GPRS is its provision of multi-slot allocations in the TDMA frame for a single MS, when transmitting/receiving data. According to the GPRS coding scheme being used, the data rate per timeslot ranges from 9.05-21.4 kbps, giving a theoretical maximum rate of 171.2 kbps when all eight slots are allocated to an MS [22].

According to the current radio conditions, the Link Adaptation (LA) mechanism of the network selects which of the four GPRS coding schemes (CSs) is to be employed. The coding schemes are termed CS-1 to CS-4, shown in table 5 below.

Table 5. Properties of the GPRS coding schemes (Information gathered from Seurre et al. (2003) [22])

CS	Code Rate	Data Rate (kbps)
4	1.0	21.4
3	~0.75	15.6
2	~0.67	13.4
1	0.50	9.05

Each CS offers a different level of coding, so that in bad conditions CS-1 affords the highest protection, thus the lowest code rate and the lowest data rate per TDMA frame timeslot; in good conditions CS-4 provides no redundancy and the highest data rate per timeslot.

The multi-slot class of an MS defines the maximum number of timeslots that can be allocated per TDMA frame during uplink and downlink transmissions, specified by the number of timeslots in reception, the number of timeslots in transmission, and the maximum sum of timeslots the MS is able to receive and transmit per TDMA frame.

2.4.3 Enhanced Data Rates for GSM Evolution (EDGE)

Enhanced Data Rates for GSM Evolution (EDGE) is a high-speed mobile data standard introduced into GSM in 2003. It is officially designated as a 3G standard, but is generally referred to as 2.75G when considered as a further transition from GSM to 3G mobile networks; being faster than the 2.5G services of GPRS and High-Speed Circuit-Switched Data (HSCSD) but not always reaching 3G data rates in practice.

In its packet-switched form, EDGE is termed Enhanced GPRS (EGPRS) and is based on the same core network architecture as GPRS but increases the data rates that can be achieved by the introduction of new Modulation and Coding Schemes (MCSs) in the radio interface, thereby improving the use of packet-switched applications such as Internet connections. EGPRS can potentially offer triple the data rates of GPRS: from 8.8 to 59.2 kbps per physical channel (depending on the MCS employed), giving a theoretical maximum throughput of 473.6 kbps when all eight timeslots are allocated to an MS [22].

Similarly to GPRS, the LA mechanism selects one of nine EGPRS MCSs according to prevailing radio conditions, presented in table 6 below.

Table 6. Properties of the EGPRS modulation and coding schemes (Information gathered from Stuckmann (2003) [21])

MCS	Modulation Scheme	Code Rate	Data Rate (kbps)
9	8PSK	1.0	59.2
8	8PSK	0.92	54.4
7	8PSK	0.76	44.8
6	8PSK	0.49	29.6
5	8PSK	0.37	22.4
4	GMSK	1.0	17.6
3	GMSK	0.80	14.8
2	GMSK	0.66	11.2
1	GMSK	0.53	8.8

As can be seen from table 6, MCS-1 to MCS-4 employ Gaussian Minimum Shift Keying (GMSK) as the modulation scheme, the same as used by GSM and GPRS, providing similar code and data rates as the CSs used in GPRS. EGPRS offers a new modulation scheme called 8-state Phase Shift Keying (8PSK), as employed by MCS-5 to MCS-9 that enable EGPRS to achieve the higher data rates per timeslot during good radio conditions.

An EGPRS MS is described by two multi-slot classes: its GPRS multi-slot class, as described for GPRS MSs, and its EGPRS multi-slot class which is specified in the same manner.

2.4.4 3G Technology

Third generation mobile systems are designed for higher data rates enabling multimedia communication such as high-quality images and video; and enhanced access to information and services on public and private networks. The 3G family of mobile phone standards have been defined by the International Mobile Telecommunications-2000 project (IMT-2000), founded by the International Telecommunication Union (ITU) in 1999, including the continuing evolution of GSM networks and radio access technologies, the specification for which is the responsibility of the 3rd Generation Partnership Project (3GPP).

IMT-2000 defines the minimum data rate requirements for 3G technologies as 2 Mbps for stationary users and 348 kbps for faster moving users [23], and has approved six radio interface technologies, as displayed in table 7 below.

Table 7. IMT-2000 approved radio interfaces (Information gathered from ITU (2005) [23])

Interface Name	Technology	Note
IMT-DS Direct Spread	UTRAN-FDD	UMTS Terrestrial Radio Access Network - Frequency Division Duplex
IMT-TC Time Code	UTRAN-TDD	UMTS Terrestrial Radio Access Network - Time Division Duplex
IMT-SC Single Carrier	GERAN	GSM/EDGE Radio Access Network
IMT-MC Multi Carrier	CDMA2000	Code Division Multiple Access 2000
IMT-FT Frequency Time	DECT	Digital Enhanced Cordless Telecommunications
IP OFDMA WMAN	WiMAX	Worldwide Interoperability for Microwave Access (IEEE 802.16)

The 3GPP has defined a number of 3G interfaces that are displayed in table 7: the GERAN and the Universal Mobile Telecommunications System (UMTS) which exists in its two forms of UTRAN-FDD and UTRAN-TDD. UMTS employs new Code Division Multiple Access (CDMA) technologies for its different variants, incurring a higher cost for operators to convert to, whereas GERAN retains GSM's TDMA method, initially offering operators a more cost-attractive evolution path before eventually installing UMTS equipment. The UTRAN and GERAN have been designed for interoperability and share the same evolved GSM core network, and together account for the most popular 3G implementation in Europe.

Since the first deployment of UMTS in 2001, it has evolved to enable higher data rates through the development of a new set of 3.5G standards termed High Speed Packet Access (HSPA), comprising the downlink standard HSDPA introduced by 3GPP in 2002 and the uplink standard HSUPA introduced in 2004. The evolution of the GSM/UMTS family of technologies through their data rates is illustrated in figure 2.

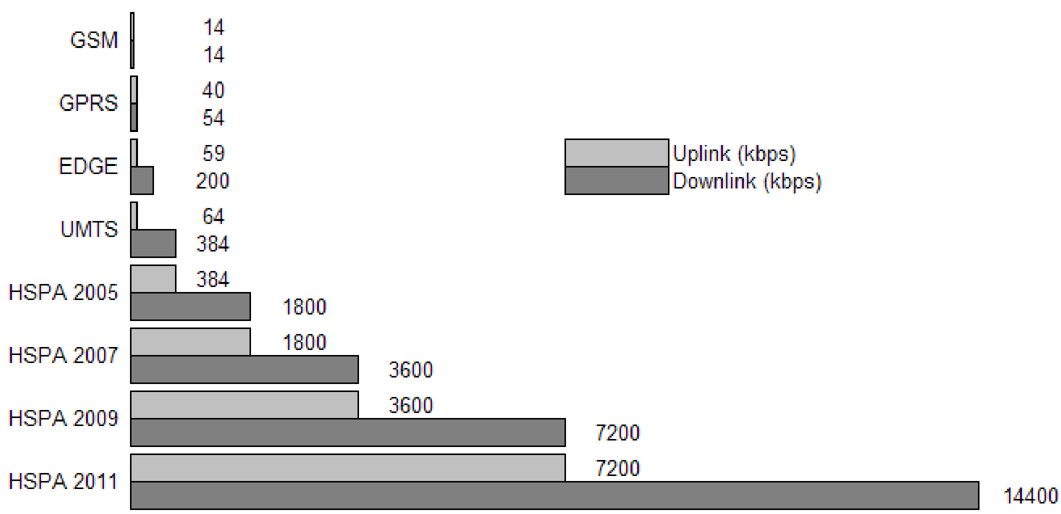

Figure 2. Uplink and downlink data rates for the GSM/UMTS family (Information gathered from Kreher & Rüdebusch (2007) [24])

The data rates in figure 2 represent theoretically possible values and remain somewhat lower in real deployments. Further development termed HSPA+ was introduced by 3GPP in 2007 and when deployed will enable speeds of 22 Mbps in the uplink and 42 Mbps in the downlink.

CDMA2000, in competition and incompatible with UMTS, is standardised by the 3GPP2 and is the successor to the cdmaOne 2G system. According to market analysis [11]: CDMA2000 is deployed in over a hundred countries by almost 300 operators; the leading 3G solution in N America, Japan and S Korea, and the most widely used in emerging markets; and serves 450 million users, i.e. two thirds of the current 3G global market. Similarly to UMTS, CDMA2000 has been undergoing an evolution path which has brought improved data rates since its conception in 2001, as illustrated in figure 3.

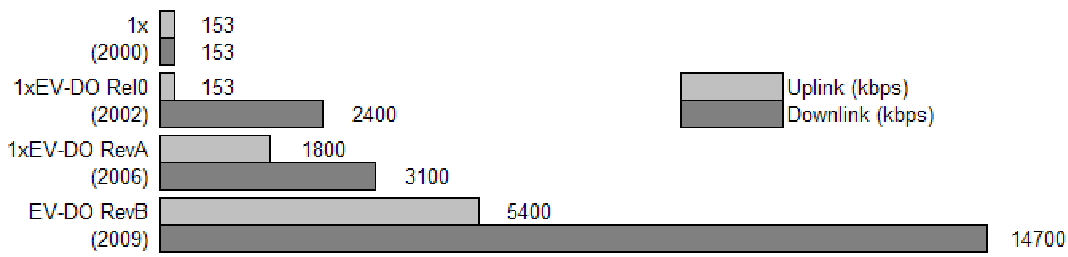

Figure 3. Uplink and downlink data rates for the CDMA2000 family (Information gathered from CDG (2008) [25])

CDMA2000 1x was the first IMT-2000 approved technology to be deployed in 2000, but was considered 2.5/2.75G. Since 1x, CDMA2000 has developed true 3G capabilities through the introduction of 3GPP2's Evolution-Data Optimised (EV-DO) standards, with the latest Revision B enabling peak rates of 5.4 Mbps in the uplink and 14.7 Mbps in the downlink.

Mobile WiMAX is based on the IEEE 802.16e-2005 standard for mobility in high-speed wireless broadband connections, approved by IMT-2000 in 2007, and currently allowing a channel capacity of 40 Mbps shared between end users who will typically experience data rates of 1-5 Mbps. [26] The original Fixed WiMAX (IEEE 802.16-2004) is usually deployed on a city-wide Wireless Metropolitan Area Network (WMAN) scale, whereas the newer Mobile WiMAX that conforms to 3G requirements can be deployed on a regional and national Wireless Wide Area Network (WWAN) scale [27]. WiMAX can complement Wi-Fi (IEEE 802.11), which is a Wireless Local Area Network (WLAN) technology, so that WiMAX provides wider area access and Wi-Fi provides local area access; devices with Wi-Fi/WiMAX modems can automatically select the best connection method according to availability at a certain location [26].

DECT has achieved most of its success in the domestic cordless telephone market during the 1990s and, to some extent, in corporate applications, but has failed in being implemented widely in public wireless networks, despite its inclusion in the IMT-2000, and has fallen behind the more popular 3G technologies enjoying widespread deployment today. DECT technology today concentrates on domestic broadband applications through the CAT-iq brand. [28]

2.4.5 4G Technology

4G is, as of yet, an unofficial term used to describe the next evolutionary step in wireless communications beyond current 3G technologies, providing all-IP voice, data and multimedia integrated services at even higher data rates (100 Mbps – 1 Gbps), predicted for deployment during the next decade.

The latest standardisation work by the 3GPP in mobile network technologies is named Long Term Evolution (LTE), further building on the GSM/EDGE/UMTS/HSPA family. LTE defines a new high-speed radio access method termed the Evolved-UTRAN (E-UTRAN) and a new IP-based core network in order to provide full user mobility with improved performance; 75 Mbps in the uplink and 300 Mbps in the downlink. [29] 3GPP has recently specified a further development of the E-UTRAN, termed LTE Advanced, which is considered to wholly fulfil 4G requirements by its objective of realising peak data rates of 1 Gbps in the downlink and 500 Mbps in the uplink [30].

As the main competitor to LTE, the evolution of WiMAX is looking to achieve 4G capabilities through the introduction of the new IEEE 802.16m standard in 2009, giving rise to WiMAX II, providing channel capacities of over 300 Mbps to be shared between users [26]. WiMAX evolution is considered to have a head-start over LTE, but as LTE is the natural progression of the GSM technologies that account for 85% of global mobile subscribers, upgrading to LTE is seen as a more cost-effective direction for operators. This stems from taking advantage of the ability to integrate the new system with their existing 3G infrastructures, leading to the expectation that LTE is to become most successful technology in the longer term. [31]

2.5 Other Ship-to-Shore Communications

Two other possibilities remain for ship-to-shore data communications, both able to be implemented when a ship is moored at a harbour with appropriate facilities: a physically-cabled shore connection from the quayside to the ship, and a wireless connection employing WLAN access points on the quayside and ship. The presence of these communications systems depends on the port itself, but generally in larger ports where larger vessels are accommodated, shore connections exist in order to supply electrical power and often include data connections by way of copper cabling or optical fibre. An alternative to shore data connections is the use of WLAN technologies, defined by the IEEE 802.11 family of standards; the relevant properties of which are illustrated below in table 8.

Table 8. IEEE 802.11 family of WLAN standards. (Information gathered from O'Hara & Petrick (2005) [32])

WLAN Standard	Operating Frequency (GHz)	Maximum Data Rate (Mbps)
802.11a	5.0	54
802.11b	2.4	11
802.11g	2.4	54
802.11n	2.4 & 5.0	300

The 802.11b standard is the most widely implemented wireless technology, but offers the lowest data rate of 11 Mbps and operates in the unlicensed 2.4 GHz frequency range and can therefore be subject to interference from other electronic devices that operate in the same range. The 802.11a standard provides a greater throughput and operates in the licensed range of 5 GHz and is therefore not subject to interference from other devices, but suffers a reduction in access point coverage areas and greater signal attenuation. The 802.11g standard extends the data rate capability of the 802.11b standard to the same as that offered by 802.11a, but still operates in the unlicensed 2.4 GHz range. The 802.11n standard, due to be finalised in 2009, will offer significantly increased data rates over the previous standards, as well as complete backwards-compatibility by operating in both of the previously mentioned frequency ranges. [32]

3 Eniram Products

As mentioned in the Introduction, Eniram's software-based vessel management solutions function through the analysis of high-precision measurements of a vessel's operational parameters and data acquired from integrating with the vessel's automation systems, enabling the provision of extremely accurate informational support for officers. This support concentrates on three separate management areas: performance optimisation, emission control, and safety and comfort.

The optimisation of a vessel's performance involves computer-aided guidance for the ship's officers. Acting as a decision-support tool, Eniram's solutions present measurement analysis results to the bridge crew, enabling them to take appropriate actions in the operation and manoeuvring of the ship so as to increase its performance and, consequently, reduce fuel consumption.

Emission control involves the monitoring of emissions, waste and other forms of pollution created by a vessel in order to help in reducing these pollutants, thereby reducing port and fairway dues.

The monitoring of safety and comfort aboard a vessel is very important in shipping operations, encompassing such areas as: the management of safety-related systems; the provision of decision-support for officers during emergency situations; and the monitoring of various factors that affect the vessel's structural condition and human comfort levels. For example, aiding officers to operate the ship in such a manner as to maintain passenger comfort levels at acceptable levels will invariably increase the revenue of a passenger ship; by preventing sickness, the spending habits of passengers will not decline.

Eniram's solutions that provide the benefits of reduced fuel consumption and emissions, ultimately contribute to increased environmental performance. This has been of growing importance to shipping operators in recent years with the introduction of increased operational standards.

Vessel Management Platform (VMP): The foundation of Eniram's product portfolio is the VMP which, as its name suggests, is the platform for launching all of Eniram's other products. The VMP integrates itself to a vessel's existing automation systems in order to accurately process relevant data needed by a particular product, in real-time. The VMP also manages power supplies to other system components, data-logging services, and highly flexible user interfaces for the different products that can be installed. [33]

Eniram's products are otherwise known as modules and all function on the VMP. There are thirty-two modules in total and almost half of them are currently commercial or in the pilot stage [34]. A number of important modules are introduced in the following sections.

Dynamic Stability Monitor (DSM): The stability of a vessel is an important safety factor and it is possible for changes in stability, due to faulty tank operations, shifting cargo and hull icing, to occur unnoticed by the crew. By measuring a vessel's rolling period, the DSM provides clear indication to the crew of any stability changes relative to the initial stability at the beginning of a voyage. This indication enables the crew to react quickly and execute corrective measures in the event of a sudden deterioration in stability. [35]

Cargo Securing Monitor (CSM): Different vessel movements are difficult to perceive from the bridge and it is possible for some of these movements to cause failures in cargo fastenings and cargo to shift. The CSM measures the movements and vibrations of the vessel and presents this information to the bridge crew so that corrective actions can be quickly taken in the event of movements reaching predetermined limits for the safe transportation of cargo. The main benefits of this module to ship operators is the minimisation of cargo damage and, hence, insurance protection. [36]

Comfort Factor Monitor (CFM): The comfort of passengers has recently been recognised to play an important role in the amount of sales revenue generated on a vessel: the more comfortable passengers are, the more likely they are to spend money aboard, for example on food and drinks. Classification societies have of late developed formulae for deriving passenger comfort factors based on a vessel's operational state [37]. The CFM keeps a constant watch on a vessel's movements and is able to detect certain types of movement and vibrations that are known to cause adverse effects on human comfort. A vessel's crew is able to react to the CFM's warnings and adjust the vessel's motions accordingly. As well as increasing passenger comfort levels and encouraging passenger spending, the CFM heightens the crew's attentiveness to safety and reduces possible damage to the vessel by warning of harmful vibration frequencies. [37]

Extended Safety Management System (E-SMS): The E-SMS, consisting of six separate modules, gathers information from a vessel's safety and security systems, continually monitoring the safety condition of the vessel's operation. In the event of an emergency, E-SMS aids the crew by displaying the current situation alongside the vessel's appropriate safety procedures, thereby enabling the crew to quickly make the correct reactive decisions in a crisis. [38]

Dynamic Trimming Assistant (DTA): The operational efficiency of a vessel is very much affected by its trim, the vertical angle between the vessel's longitudinal axis and the waterline. Any deviation from the optimum trim will increase drag on the submerged hull, so that the vessel's propulsion will need to work harder to maintain the same speed. This results in increased fuel consumption. The DTA dynamically measures the attitude of a vessel to a high degree of precision and displays the current trim to the crew through its user interface. It also displays the optimum trim to be attained; calculated using previously acquired data from past voyages and current, real-time data. In this way, the crew is able to constantly keep the vessel at optimum trim and save on fuel. [39]

Hull Roughness Monitor (HRM): The drag of the hull as it travels through water increases with time due to marine growths on the surfaces and corrosion. It is expensive to clean the hull and propellers through dry-docking, brushing, painting and polishing; and the ideal frequency of these hull cleaning operations is difficult to determine. HRM monitors a vessel's performance parameters and calculates thereof the power needed to move the vessel through the water. The trends in this information help to optimise the intervals between hull cleaning, thereby making considerable financial savings. [40]

Vessel Emission Tracker (VET): By gathering data from a vessel's machinery automation system and navigation system, and by detecting the presence of different gases, the VET maintains a log of emissions and waste for the vessel. This is necessary for the compliance of maritime environmental regulations. Furthermore, managing a vessel's emissions provides information towards adjusting the engines for improved efficiency. [41]

4 Communication Modes

Eniram has identified three possible modes for data connections to seagoing vessels, each with its own communications requirements [Leino V & Pyörre J, Eniram Ltd, 17 April 2008, personal communication]. They have been named here as Remote Reporting (RR), Remote Diagnostics (RD) and Remote Diagnostics and Maintenance (RDM), and are described in the following sections.

4.1 Remote Reporting (RR)

Remote reporting is the periodical transmission of vessel performance statistics, consisting of approximately 500 diagnostic parameters and several simple logs, as well as some performance statistics of the module itself, and is thereby limited in data throughput. In fact, depending on the module that is reporting, the daily amount of data for transmission can be in the range of 10-100 kB. This data is presented in the form of figures and graphs in a report in pdf-format by the onboard module in question. It is a unidirectional communication from ship to shore.

4.2 Remote Diagnostics (RD)

RD involves extensive data acquisition of a vessel's performance with respect to the systems that a module is responsible for, as well as the remote monitoring of the module itself, including the tracking of equipment usage its performance. This information provides a useful profile of a system's normal behaviour, i.e. its expected performance over a long time period, and therefore a useful baseline to compare similar, newly installed systems. Furthermore, a module's diagnostic information can identify a potential problem so that actions can be taken to find a swift resolution. This requires a unidirectional communication from ship to shore and consists of the transmission of raw data for subsequent analysis at the Eniram office.

4.3 Remote Diagnostics and Maintenance (RDM)

RDM involves the same functionality as RD, but with the added ability to perform remote maintenance actions to correct any faults that are detected. In other words, it affords visibility into a system's performance and a pre-emptive approach to its optimisation, thus improving its reliability and availability. This also avoids incurred costs and time losses when dispatching an engineer to the vessel's location for unscheduled repairs. The benefits brought by RDM consist of monitoring certain system parameters, analysing this data by comparing it to the expected behaviour and identifying trends, detecting or predicting faults, and performing corrective actions or ordering new parts in advance of a failure.

Therefore, RDM requires bidirectional communication: the transmission of monitored system parameters from ship to shore, and the transmission of maintenance actions and system updates from shore to ship; and a higher bandwidth. Furthermore, as Eniram's solutions run on a Linux operating system, a remote private network access technology capable of tunnelling over TCP/IP is required, e.g. SSH or VPN, to fully utilise the capabilities of RDM.

4.4 Future Requirements

By increasing the bandwidth available to the communication link, real-time monitoring can be enabled whereby the ship owner's shore office has an identical display to that onboard the ship's bridge, giving a real-time depiction of the ship's status to headquarter personnel. This creates more detailed monitoring capabilities and a complete, up-to-date description of the fleet's status. Following from the above requirements, this future requirement could be denoted Remote Real-Time Monitoring (RRTM).

Another possible capability in the future, in the case where a module offers guidance to the crew (for example the DTA), would be for the module to produce a report on how effectively the vessel's crew has responded to the module's guidance during a voyage. [Pyörre J, Eniram Ltd, 14 October 2008, personal communication]

The functions and characteristics of the above requirements are summarised in table 9 below.

Table 9. Eniram's communication requirements

Communication Mode	Functions	Data Requirements	Direction
Remote Reporting RR	Transmission of limited performance figures and logs.	10-100 kB/day	Uni
Remote Diagnostics RD	Transmission of full system diagnostics in raw data format. Analysis of raw data performed on shore.	5 MB/hour	Uni
Remote Diagnostics & Maintenance RDM	Transmission of full system diagnostics in raw data format. Analysis of raw data performed on shore. Transmission of maintenance operations from shore.	5 MB/hour	Bi
Future	RDM with improved pre-processing of data before transmission.	100 kB - 2 MB /hour	Bi

At the moment, the RD and RDM methods would operate by the transmission of raw data with very little or no pre-processing. It is the intention of Eniram to eventually avoid the transmission of raw data by introducing efficient data pre-processing techniques and therefore reduce the data throughput requirements to a range of 100 kB to 2 MB per hour [Leino V, Eniram Ltd, 9 September 2008, personal communication].

5 Project Plan

For the purposes of Eniram's requirements for the provision of the communication modes for its customers, it is essential for a definitive project plan to be composed, based on the careful planning of all activities from the conception of potential solutions to their operation. The stages of the project plan are illustrated in figure 4 below.

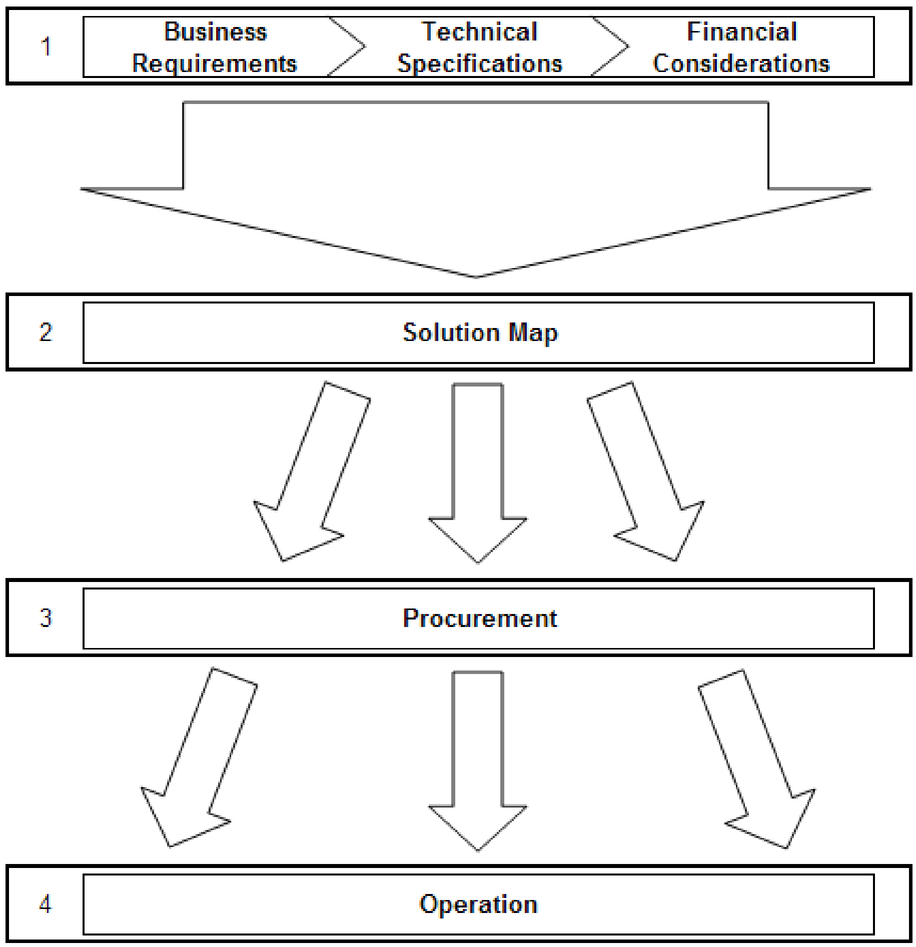

Figure 4. Project Plan

As can be seen from figure 4, the first stage is to state the considerations and restrictions in selecting appropriate solutions by analysing Eniram's and its customers' requirements on general business, technical and financial levels. This is a once-only activity at the beginning of the project and need not be repeated for every customer of Eniram.

With the initial analysis in place, the second stage can be initiated, comprising the creation of the Solution Map, a single document which will assist Eniram personnel in effectively identifying the correct type of solution for a particular customer and their data requirements.

If the solution identified by the Solution Map requires a new installation, then the procurement stage can commence by sending Requests for Quotes (RFQs) to appropriate suppliers, the replies to which are then evaluated and the successful company selected. When a solution incorporates existing communications equipment aboard a vessel, the procurement stage is obviously not required, but the implementation of the solution still needs to be considered in the operational stage.

The operational stage takes into consideration important factors in the implementation of the chosen solution, including (if necessary) site surveys, shipping and delivery, installation, acceptance testing and commissioning, training and documentation. The operational stage also consists of support and maintenance arrangements.

5.1 Business Requirements

On the business level, a statement is needed that defines the problem, the desired results and the method for achieving them. Through discussions with Eniram personnel, the business requirements were determined and are presented below.

Eniram requires a study into different telecommunication services for realising remote ship-to-shore data connections for the purposes of communicating with its VMS modules. Appropriate telecommunication services need to be evaluated in order to confirm that they are able to fulfil the requirements of the three communication modes identified by Eniram: RR, RD and RDM.

Eniram's customers, specifically shipping operators who have ordered Eniram's vessel management solutions, will specify which communication modes they wish to purchase, according to their individual management needs. Therefore, documentation is necessary in order to aid Eniram in its decision-making processes when selecting and implementing the appropriate telecommunications service for each customer.

Eniram's customers will ultimately benefit from the improvements in their vessels' performances attained through the installed VMS modules, therefore it is paramount that the data obtained from Eniram's systems are communicated to them in as efficient and economical method as possible. Various factors require consideration when applied to a ship's data communication requirements, as outlined below [Leino V & Pyörre J, Eniram Ltd, 19 June 2008, personal communication]:

Firstly, the type of vessel has a bearing on its data communications capabilities in that a large cruise ship is invariably much better equipped for satellite Internet connectivity, purely because of the ship's scale and the communications demands of its corporate functions and the expectations of its paying passengers; compared to a cargo ship which traditionally would only operate a satellite connection for emergency purposes. This means that in the event of a high-bandwidth satellite connection requirement, gaining permission and successfully utilising an already existing communications system would be easier to achieve on a cruise ship than a cargo ship. On gaining a new customer and establishing their requirements, Requests for Information (RFIs) can be sent by Eniram in order to ascertain what communication systems are already installed on the customer's ships and whether they can be utilised.

Secondly, the geographical areas of operation of each vessel directly dictate the types of communication services that can be used and the frequencies and timeframes of when communication can occur. For example, a vessel operating predominantly in the Arctic regions will not be able to employ a satellite system that operates via geostationary satellites because of their poor beam coverage of the polar regions. Instead, a satellite system employing LEO or MEO satellites, with polar coverage, will need to be considered.

Furthermore, when for example a PLMN communication requirement is identified, the geographical route of a vessel and the times at which it is located within a base station's coverage area becomes important. The route of a passenger ferry between Helsinki and Stockholm remains on the most part close to land and hence maintains good mobile phone network connectivity, whereas an intercontinental cargo vessel will be out of coverage for long periods of time. In the latter case, data transmission will only be possible when the vessel is approaching or at a port of call, and the time period between ports may be as high as three weeks; unless an MSS is employed.

5.2 Technical Specifications

With the business requirements clearly defined, the technical issues can then be addressed by stating the purpose, functions and details of the various possible solutions and their capabilities. This involves answering questions on their intended uses, applications, access issues, capacities, inter-operability issues and performance parameters.

The technical specifications are the principal sources of information for composing the RFQs, sent to prospective suppliers of the various solutions during the procurement stage. The information contained in the RFQs should sufficiently aid the prospective suppliers in understanding exactly what solution is required and their returned quotes will state how they are able to fulfil the requirements and the costs involved.

Furthermore, a full or partial approach to producing the technical specification must be chosen. A full specification involves rigidly detailing the requirements in order to tightly control the solution possibilities. The disadvantages of this approach are that it can reduce the number of prospective suppliers and narrows the opportunities for them to suggest creative alternatives, as well as placing the responsibility of the correct implementation on the purchaser. It is more advantageous to employ the partial approach whereby the technical requirements are stated in looser terms so that prospective suppliers can use their own creativity in providing their solution proposals.

Important performance factors for consideration and inclusion in the technical specifications are detailed are outlined in table 10 below.

Table 10. Factors for inclusion in technical specifications

Factors	Remarks
Uses	Data types required to fulfil the communication needs.
Applications	Applications required to fulfil the communication needs.
Availability	How often communication is required. Maximum acceptable downtime in case of failure.
Reliability	Minimum acceptable time between failures (MTBF). Maximum recovery time in case of failure. Latency issues in transmission of data.
Security	Eniram always encrypts data sent via any link. Physical security.
Redundancy	Alternative communication methods in case of failure. Disaster recovery plan.
Capacity	Number of installation sites and their locations. Bandwidth requirement (upllink and downlink). Dedicated or shared bandwidth.
Scalability	Projected increase in applications, installations and bandwidth.
Coverage	Areas covered by communication service. Frequency bands.
Inter-Operability	Interfaces required with other systems and networks.
Equipment	Equipment needed to achieve required communication. Availability of equipment already installed onboard.
Power	Power supplies typically always available aboard vessels. Addition of consumers inconsequential.

Various factors displayed in table 10 will also become relevant during the composition of the Solution Map.

5.3 Financial Considerations

As well as serving the communications needs, the solution needs to be economical to purchase and operate. In considering the costs and expenses of the solution, it is prudent to account for all expenditures over its whole lifetime. This includes the solution's initial costs: procurement, delivery, implementation and user training; its running costs: operation, support, maintenance, repair, human resources and logistical costs; and the teardown costs: decommissioning, disposal and replacement. It is then helpful to divide these costs into one-time or recurring categories to illustrate how the cost of the solution is distributed over time, as displayed in table 11 below.

Table 11. Possible one-time and recurring costs

One-Time	Recurring
Design and engineering	Bandwidth
Site survey	Service provider charges
Purchase of equipment	Power
Shipping	Service and maintenance
Installation and commissioning	Monitoring and evaluation
Activation	User support
Spares	Project management
Technical and user training	

Much of the cost information shown in table 11 will derive from the suppliers' quotes.

5.4 Solution Map

In creating the Solution Map, the issues raised in the initial analysis together with the evaluations of possible communication services are consolidated into a single document, in the form of a decision table, which will assist Eniram personnel in effectively identifying the correct type of solution for a particular customer and their data requirements. Generally, a decision table is a visual and analytical decision support tool which is simple to understand and interpret by displaying the principal factors involved in the decision process for selecting and introducing a new solution.

The Solution Map has to cover all conceivable communication requirements and can be followed logically through a series of conditions and decisions, in order to reach the most suitable type of solution for a particular customer. It is intended as a universal tool, in that it can be consulted for each prospective customer as a starting point in identifying their ideal solution.

From the initial analysis of the functional and technical requirements of a general solution, preliminary conditions can be collected as a basis for the creation of the Solution Map. These conditions and their bearings on the decision process are displayed below in table 12.

Table 12. Preliminary conditions of solution map

Conditions		Notes
Communication Mode	Remote Reporting (RR)	Requires UNI-directional data connection and a LOW volume of data
	Remote Diagnostics (RD)	Requires UNI-directional data connection and a HIGH volume of data
	Remote Diagnostics & Maintenance (RDM)	Requires BI-directional data connection and a HIGH volume of data
VMS Modules	No. of modules installed aboard ship	The higher the no. of modules from which data is generated, the higher the data volume
	Amount of data generated by modules	Estimate of data volume generated per unit of time
Existing Onboard Comm Systems	Satellite Service	Determine whether any existing satellite link can provide required data communication
	PLMN Service	Determine whether any existing PLMN link can provide required data communication
	Permission to Use System	Is there permission to use the existing link for data connection? Is there permission to use a bidirectional link?
Geographical Area of Operation	Route	Determine duration of voyages and proximity to coastlines
	Satellite coverage	Determine which MSSs provide coverage for route
	PLMN coverage	Determine which PLMN services provide coverage for route
	Frequency of port calls	Determine how often port facilities can be used for data connections

From the preliminary conditions in table 12, most importantly, the volume of data created per voyage is ascertained, as well whether a ship's existing communication systems can be utilised for the transfer of data and the geographical route of the ship. If it is possible to utilise an existing communication system aboard a ship, then it will be required to establish the total bandwidth capability of that system and how much of it is available for Eniram's use, as well as how often a data connection is possible due to the ship's route.

If a ship owner permits the use of existing communications systems, usage of them will typically be limited by firewalls and filters, especially when large internal networks exist for a vessel [Leino V, Eniram Ltd, 9 September 2008, personal communication]. It may also be necessary for separate permission to be obtained from a shipping company if a bidirectional link is required to a vessel, due to Eniram's experience of facing reticence on the part of some companies in allowing such capabilities for security reasons [Pyörre J, Eniram Ltd, 14 October 2008, personal communication].

If all necessary permissions are granted and there is sufficient bandwidth and opportunities to transfer Eniram's VMS data, then the implementation of the communication solution can commence. If, however, it is not possible to utilise any existing communications services aboard a ship, due to no permission or insufficient bandwidth capabilities, then it will be required to consider the installation of a new communication service. This process will also be part of the Solution Map and will be based on the evaluations of different services, the result of which will determine the prime communication service for Eniram's purposes according to the outcomes of the preliminary conditions.

5.5 Procurement

For each customer, once a suitable type of solution has been identified using the Solution Map, a competitive approach to procurement will be followed by sending RFQs to multiple prospective suppliers. The returned suppliers' quotes will be compared with each other in order to ascertain the most effective and economical solution for the customer's requirements.

It may be possible to purchase the solution as a complete service, whereby a single supplier can provide the whole solution, or as a component service, whereby different parts of the solution are provided by different suppliers.

A sufficient evaluation scheme needs to be defined in order to compare the different quotes received from suppliers, incorporating unambiguous business, technical and financial criteria. Mandatory criteria that have to be met by a supplier should include the experience of supplier, the financial standing of the supplier and equipment guarantees.

Other, non-mandatory, criteria are used to compare the quality of the proposed solutions and include: the overall performance of the proposed communications link in comparison with the requirements laid out in the technical specifications; the technical characteristics of the terminal equipment; the quality of the implementation schedule to meet the target dates set for receiving services; and the quality of the proposed acceptance testing and commissioning plan.

On passing all criteria, a proposal shall be accepted on the basis of a combination of its promised technical performance and its financial attractiveness.

5.6 Operation

When the supplier has been selected, the implementation and operation of the solution can commence. The creation of an implementation plan with a carefully reviewed schedule will ensure that all activities, resources, roles and responsibilities of Eniram and supplier personnel are clear and attainable.

The implementation of the solution consists of site surveys, shipping and delivery, installation, acceptance testing and commissioning, and training and documentation, each with various considerations as listed below.

Site Survey: In the case of having to install new communication equipment onboard the vessel, the ADU and BDU have to be located according strict considerations. Therefore, it is important to have access to ship drawings to aid in undertaking detailed surveys of the installation sites for each vessel. The main considerations in siting the equipment are: an unobstructed line of sight for the antenna in order to track the direction of the satellite; the avoidance of interference between the frequencies used by the satellite equipment and those of other onboard systems; the cabling distance between the outdoor antenna and the BDE needs to be within a specified limit.

Shipping and Delivery: A logistical problem occurs in the delivery of the equipment to each vessel, in that a suitable port will need to be selected from each vessel's route itinerary and the equipment will need to arrive there punctually, wherever the vessels are in the world. Other considerations include: deciding on air or sea freight, insurance and customs clearance. It should be established as to who is responsible for the customs issues and inevitable delays taken in to consideration, especially as delivery will be made to different countries with varying customs regulations.

Installation: Where the solution supplier isn't local to the installation port, as will invariably be the case, the cost of installation can increase considerably due to flights and accommodation for installation personnel. To avoid this, if possible, it should be insisted in the RFQ that any prospective provider use local labour for site surveys, installation and commissioning. The different tasks involved in installing the solution include: assembly, antenna mounting, BDE installation, cabling and connections, power-up, device configuration and tracking system setup.

Acceptance Testing and Commissioning: After installation, the solution should be verified as working in compliance with all technical specifications, with the correct integration of all system components in order to provide end-to-end connectivity. This is achieved through acceptance testing consisting of a battery of acceptance tests and their procedures, typically agreed on with the supplier prior to the solution's acquisition. A sufficient timeframe will be required after installation in order to confirm the correct operation of the solution and perform any fine-tuning, before signing off with the supplier. Common acceptance testing procedures include: powering the system to ensure all equipment starts up, testing the communications link for the ability to receive and transmit data, and testing for correct routing and network connections.

Training and Documentation: Detailed documentation of the overall solution and how its components interface will be required by Eniram personnel, as well as manuals for all items of installed equipment. Additionally, a decision will need to be made on how many Eniram personnel will receive basic training on the solution's installation and operation, preferably on site during the installation phase, so that a knowledgeable core of people is created with efficient problem-solving skills and the ability to realise any other changing operational issues.

Post-implementation, the operational life of the solution is mainly concerned with support and maintenance issues listed below.

Bandwidth Monitoring: This involves measuring the amount of bandwidth received from the service provider and how much of that is used, as well as studying the usage patterns. This will ensure that Eniram will get the exact amount of bandwidth that was specified, help keep track of the bandwidth's performance, i.e. any down periods, and help make informed decisions on any changing bandwidth requirements.

Maintenance and Technical Support: The maintenance of equipment and systems involves performing actions to correct a fault or prevent faults from occurring, and includes repairs, upgrades, diagnostics and trouble shooting. With the RDM communication mode in place, this will be possible remotely from the Eniram office. Otherwise, any maintenance will require a physical presence at the installation site, in which case it should be decided whether the maintenance should be performed by a trained Eniram technician, a technician from the supplier or an external technician. Technical support involves aiding users to resolve any problems by themselves through advice given via telephone or email, and therefore does not require physically visiting the site.

6 Solution Map

From the discussion of preliminary conditions in section 5.4, certain factors that will be implemented in the Solution Map (SM) need to be defined. These factors can be divided into four sections: communication factors, geographical factors, equipment factors and cost factors; and the information therein will significantly aid the process of following the SM. The information gathering process required of Eniram for each installation, which will ascertain the aforementioned factors, is presented in the Information Map (IM). The IM consists of four sections, labelled IM1 to IM4, which are presented in appendix 1 and described below.

IM1: Volume of Data Generated per Module and Communication Mode

In anticipation of Eniram's requirement to calculate expected data rates produced by the modules and the available data rates of the various communications systems aboard a vessel, a worthwhile exercise would be to collate expected volumes of data generated for each of Eniram's modules according to which communication mode is employed. This can be done through experience of existing performance data as well as through predictions, and can be recorded in terms of the data generated per hour or per day, whichever is more appropriate. Individual modules and combinations of modules should be considered as there is usually a base volume of data shared between modules as well as possible additional volumes for each module [Pyörre J, Eniram Ltd, 14 October 2008, personal communication]. When completed, IM1 will provide a quick reference for the data volumes generated for particular combinations of Eniram modules and communication modes, applicable to all new vessels ordering Eniram installations.

IM2: Geographical Areas of Operation

Information can be collated on each vessel's area of operation, listing the ports of call during a voyage, the durations of each leg and, hence, the estimated volume of data generated during each leg according to the information recorded in the IM1 multiplied by the duration. When communications systems other than MSSs need to be considered, the route leg's proximity to the coast and, hence, its coverage by a PLMN can be determined, as well as the ship's time at port during which it has access via a shore connection or WLAN at each port facility.

IM3: Existing Onboard Communications Systems

Information can be collated on each vessel's existing communications systems according to whether it is an MSS, PLMN or port connection, the systems' bandwidth capabilities and the bandwidth available for Eniram's use (uplink and downlink), the times when Eniram can employ the system, and whether permission to use the system has been granted. An IM3 can be created for each vessel and the information contained can also be applied to new vessels with matching systems.

IM4: Data Transfer Costs of Onboard Communications Systems

With the information recorded on each vessel's IM3 regarding existing communications systems, their respective costs can be recorded on a vessel's IM4. Factors consist of the type of connection cost tariff (on a per unit time or per unit volume of data basis), the actual rate charged for the connection, and any relevant notes. An IM4 can be created for each vessel and the information contained can also be applied to new vessels with matching systems.

The Solution Map tabulates the steps needed in the decision process and incorporates the factors compiled in the Information Maps as the rationale behind different choices and comparisons in the process. The final Solution Map is divided into eight logical sections, labelled SM1 to SM8, and is presented in appendix 2.

7 Conclusion

The key outcomes of the project were the production of the Information Map and the Solution Map. The IM is in questionnaire form and divided into four sections, detailing the information necessary to be gathered on each vessel installation in terms of communication requirements, geographical operations, existing onboard systems and communication costs. The SM provides steps to the user on how to process the information attained and use the resulting factors in forming a decision on the most appropriate method of communications for each particular installation. The project also introduced key characteristics of the different communications methods available for ship-to-shore data connections as a theoretical background to the decision-making process.

With the information gathering process in place, the IMs will grow into a database of vessels and thereby prove useful as a reference tool for when new customers and vessels apply for Eniram's services. The SM has been verified as logically illustrating the main decisions in a solution implementation, and when adopted in the beginning of 2009 it should provide a singular, standardised method for all personnel.

Suggested methods for furthering this project would be to begin the completion of the IMs for Eniram's existing vessel installations, thereby highlighting any possible changes that may need to be made in terms of presentation and extra information. With the up-to-date IMs in place, the SM can be executed on a number of existing vessels so as to test its effectiveness and compare the suggested outcomes to the actual solutions installed. Furthermore, the construction of a database of communications providers and operators could also commence, arranged into their geographical areas of operation, service data rates, costs, and roaming charges, facilitating the overall procurement process.

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Appendix 1: Information Map

Appendix 1 contains the Information Map as described in chapter 6, the different sections of which are listed below in the order they appear.

IM1: Bandwidth requirements per communication mode and module

IM2: Geographical area of operation

IM3: Existing onboard communications systems

IM4: Data transfer costs of onboard communications systems

IM1: Volume of Data Generated per Module and Communication Mode

Communication Mode		Volume of Data Generated per Module per Unit Time									
		Module 1	Module 2	Module 3	Module 4	Module 5	Module 6	Module 7	Module 8	Module 9	Module 10
Remote Reporting	RR										
Remote Diagnostics	RD										
Remote Diagnostics & Maintenance	RDM										
(insert future mode)											
		Combo 1	Combo 2	Combo 3	Combo 4	Combo 5	Combo 6	Combo 7	Combo 8	Combo 9	Combo 10
Remote Reporting	RR										
Remote Diagnostics	RD										
Remote Diagnostics & Maintenance	RDM										
(insert future mode)											

IM2:	Geographical Areas of Operation					
Vessel:			Route:			
Port of Call	Voyage Duration (to next port)	Estimated Volume of Data Generated	Proximity to Coast (PLMN)	Time at Port	Shore Connection	Harbour WLAN

IM3:	Existing Onboard Communications Systems
Vessel:	

System Type	System Name	Permission to Use (Y/N)	System Bandwidth Details				Time Periods of Availability
			Maximum Capability		Amount Available		
			Uplink	Downlink	Uplink	Downlink	
MSS							
PLMN							
Shore Connection							
Harbour WLAN							

IM4: Data Transfer Costs of Onboard Communications Systems

Vessel:

System Type	System Name	Type of Cost Tariff		Rate of Tariff	Notes
		per Time	per Volume		
MSS					
PLMN					
Shore Connection					
Harbour WLAN					

Appendix 2: Solution Map

Appendix 2 contains the Solution Map as described in chapter 6, the different sections of which are listed below in the order they appear.

SM1: Identify Customer Order

SM2: Complete Information Maps (IM2-IM4)

SM3: Inspect Existing Onboard Communications Systems

SM4: Compare Performances of Existing Onboard Communications Systems

SM5: Select Existing Onboard Communications Systems to employ for solution

SM6: Collect Information on Prospective Communications Providers

SM7: Select New Communications System to employ for solution

SM8: Update Information Maps

SM1	**Identify Customer Order**	
→	Identify Customer	
→	Identify Name of vessel	
→	Identify Eniram Product ordered by customer	
→	Identify Modules required by product	
→	Identify Communication Mode ordered by customer	

SM2	**Complete Information Maps (IM2-IM4)**	
?	Does Eniram already serve other vessels owned by customer?	
	Y	Refer to Info Tables of other vessels to aid completion of Info Tables for new vessel
	N	Complete Info Tables afresh
!	IM1 contains Eniram-specific info and is assumed to have already been completed	
!	Information can be gathered from RFIs/interviews with customers/operators and/or previous installations	

SM3	Inspect Existing Onboard Communications Systems
↓	IM3: For each Existing Onboard Communication System:

SM3a	Calculate Volumes of Data	Result
→	IM1: Identify expected Volume of Data Generated per unit Time	V_D/t
→	IM2: Identify Voyage Duration or Time at Port	T_V
©	Calculate Volume of Data Generated (V_D) = $V_D/t \times T_V$	V_D
→	IM3: Identify Amount of Bandwidth Available for Eniram (BW_A)	BW_A
→	IM3: Identify Time Period of Availability	T_A
©	Multiply these for the Max Volume of Data that can be transmitted (V_{Dmax})	V_{Dmax}
?	Is $V_D < V_{Dmax}$?	
Y	Communication System CAN support solution; continue to SM3b	
N	Communication System CANNOT support solution; return to SM3	
!	Time Period of Availability stipulated by owner, Proximity to Coast (for PLMN coverage) and/or Time at Port (for harbour connections)	

SM3b	Calculate Cost of Data Transfer	Result
→	IM4: Identify Rate of Tariff: Cost C_t (per time) or C_v (per volume)	C_t or C_v
©	Calculate Time of Transmission (T_{trans}) = V_D / BW_A	T_{trans}
©	Calculate Cost of Transmission (C_{trans}) = $C_t \times T_{trans}$ or $C_v \times V_D$	C_{trans}

SM4	**Compare Performances of Existing Onboard Communication Systems**		Result
↓	For each Existing Onboard Communications System that CAN support solution:		
	→	Compare each C_{trans} for lowest Cost of Transmission ($C_{transMIN}$)	$C_{transMIN}$
	→	Compare other performance factors calculated SM3 and in IM2-IM4	

SM5	**Select Existing Onboard Communications System to employ for solution**	Result
→	Select best Communications System according to SM3-SM4	**Existing Solution**
!	Implementation Stage can commence	

SM6	**Collect Information on Prospective Communications Providers**		Result
↓	IM3: If no Existing Onboard Communications System available for Eniram use:		
	→	Inspect IM2 for Area of Operation and its suitability for each Type of Communication Service and coverage areas	
	→	IM1: Identify expected Volume of Data Generated per unit Time	V_D/t
	→	IM2: Identify Voyage Duration or Time at Port	T_V
	©	Calculate Volume of Data Generated (V_D) = $V_D/t \times T_V$	V_D
	→	Inspect Eniram information on prospective Communications Providers	
	→	Send RFQ to prospective Communications Providers	

SM7	**Select New Communications System to employ for solution**	Result
→	Select best Communications System according to SM6 and IM1-IM2	**New Solution**
!	Procurement Stage can commence	

SM8	**Update Information Maps**
→	Update IM3-IM4 with new information obtained