Cost-effectiveness assessment of an RFID passenger monitoring system for improved emergency evacuation

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This paper presents a cost-effectiveness assessment of a novel passenger monitoring system based on RFID technology for implementation onboard passenger ships. Such a system will be able to detect and keep track of passengers onboard the ship in emergency situations in order to provide crucial decision support to the officer in charge of evacuation. This will lead to increased safety and security on passenger ships. A methodology in line with Formal Safety Assessment is employed in order to assess the cost-effectiveness of the system, involving a thorough risk analysis.

KEY WORDS

Maritime safety and security; passenger ships; evacuation; decision support systems; risk analysis; cost-effectiveness assessment.

INTRODUCTION AND BACKGROUND

The overall aim of this paper is to investigate the cost-effectiveness and feasibility of using new technology related to on-board communication, monitoring and decision support systems in an onboard emergency response system for passenger ships. The objective of such a system is to provide the officer in charge of the emergency evacuation on a ship with relevant information to help him take decisions, i.e. real time information on passenger location and status. This is aimed at improving the evacuation procedure and increasing the safety of passengers in cases of fire and flooding.

Many studies and reports have identified the need to improve the evacuation procedure with respect to mustering passengers to safe areas, counting and accounting for passengers, and controlling and guiding their movements. An accident investigation report on the grounding and sinking of the *Queen of the North*, which resulted in the deaths of two passengers, identified the need for improvements in mustering and accounting for passengers and stated that “Until technology is introduced into the preparation for abandonment phase, this stage will continue to be a weak link in the abandonment process - to the detriment of passenger and crew safety” (Transportation Safety Board of Canada 2008). Other accidents such as the fire on the *Scandinavian Star* in 1990, which resulted in 158 deaths, demonstrate the difficulties that crew have with accounting for passengers in an emergency (NOU 1991). A report on the accident describes how the captain had reported to the on-scene commander that all crew and passengers had left the ship in the lifeboats, when in fact there were still survivors on board waiting to be rescued and a large number of passengers had died as a result of the fire and smoke.

The master, ship officers, and crew are put in a very stressful and intense situation when faced with an emergency where they must make decisions to ensure the safety of a large number of passengers. The stress can result in negative reactions, as described by Kristiansen (2005), which include losing the ability to deal adequately with complicated problems. Not knowing the exact location of passengers and whether they require assistance adds an additional complication to an emergency situation. A generic chain of events with respect to passenger response and movement to an order to proceed to muster or assembly stations, as shown in Fig. 1, illustrates the need for crew assistance and ship sweeping. This phase could be carried out more efficiently if it was known in advance where passengers were located. After the sweep, there is the need for an accurate count of passengers at the muster stations.

The feasibility of a passenger detection and monitoring system that provides real-time information on the location of all passengers as well as an automatic counting of passengers at muster stations and when embarking lifeboats and other Life Saving Appliances (LSA) is being investigated within MarNIS, and this paper presents a cost-effectiveness assessment of that system.

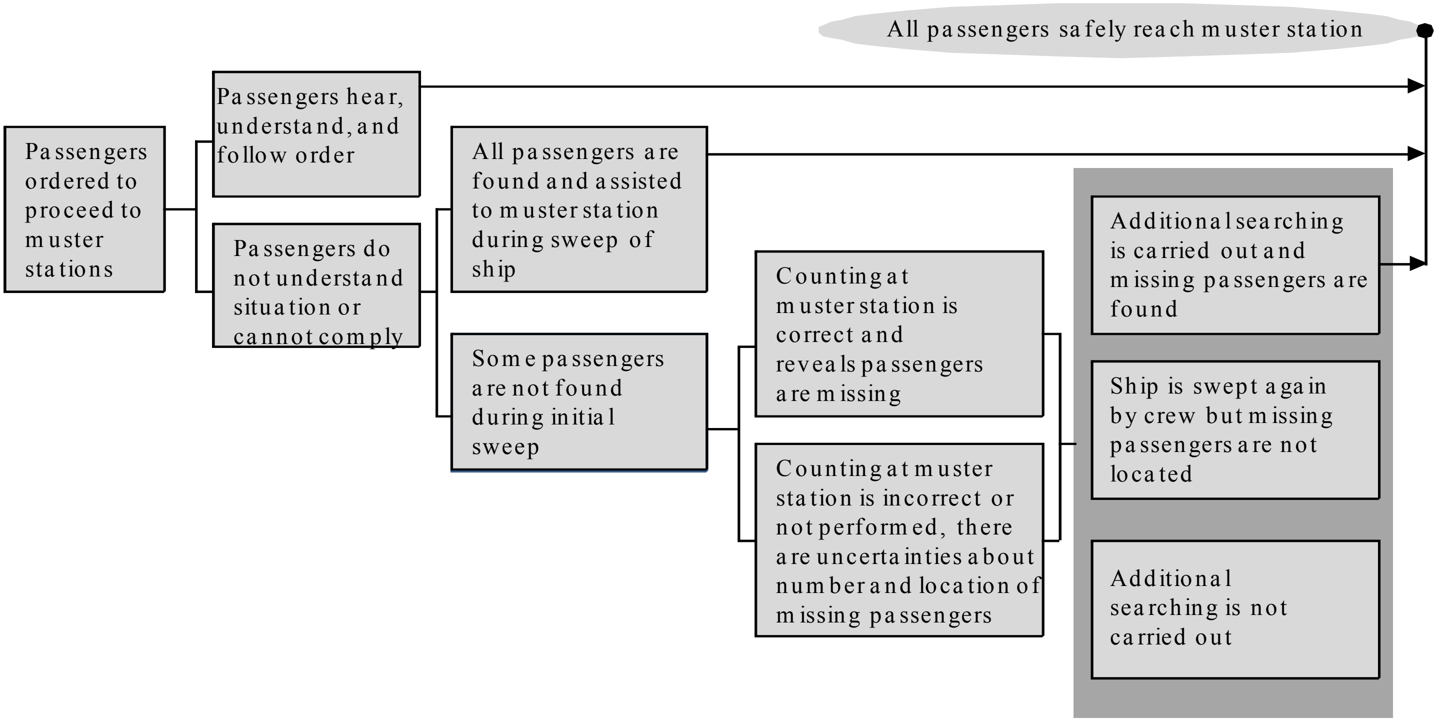

Fig. 1: Generic chain of events regarding passenger movement to muster stations

MarNIS project

MarNIS is an EU-funded integrated research project in the 6th framework program with the aim of developing maritime navigation and information services on a pan-European basis. The overall objective of MarNIS is to improve maritime safety, security and environmental protection of the environment as well as improved efficiency and reliability and improved economic, legal and organizational aspects of sea transport.

The MarNIS concept integrates several maritime operational services in different MOS centers, most notably Vessel Traffic Management (VTM), Search and Rescue (SAR) and Oil Pollution Preparedness Response and Co-operation (OPRC). This should be achieved using emerging information and communication technologies.

One part of the MarNIS project is considering emergency response on board, and within this theme a passenger detection and monitoring system is being investigated. This should be integrated in decision support systems onboard the ship in order to provide useful information for the master in the event of an emergency situation that requires evacuation from the ship. It is this system that is subject to cost-effectiveness assessment in this paper.

Passenger Monitoring System

A functional analysis identified three main types of functions required by an integrated passenger detection and monitoring system (Corrignan and Breuillard, 2007a; Corrignan and Breuillard, 2007b; Breuillard et al., 2007). These include functions that aid situational awareness; that assist with decision making, and that mitigate consequences; as shown in Fig. 2 (Corrignan and Breuillard, 2007b).

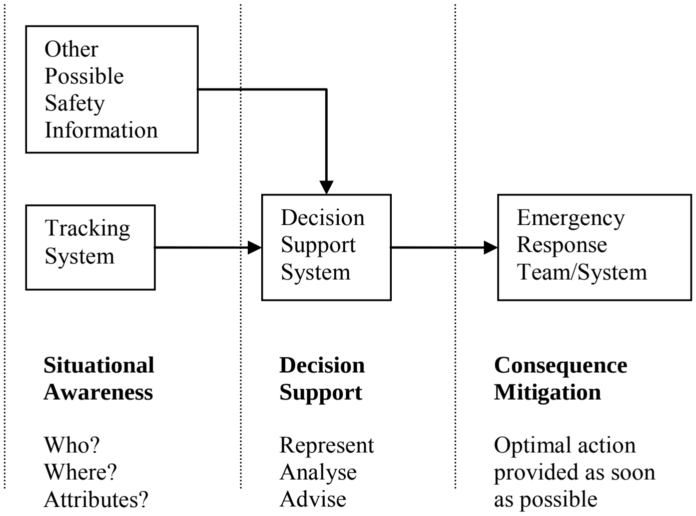

Fig. 2: Main functions of a passenger tracking system

Functions that aid situational awareness provide the crew with information that allows them to better know and understand what is happening on board the vessel. The decision support functions may simply process the situational awareness information and present it in a way that aids decision making or they may be more intelligent functions. An intelligent system is capable of analyzing different options available to the crew and suggesting which is best. Examples of consequence mitigation functions include remotely checking if compartments are empty, remotely closing compartment doors, or perhaps guiding passengers to safety.

Some of the most important functions that should be provided by the system are listed below, in prioritized order:

1. Automatic counting of passengers at muster stations
2. Automatic counting of passengers at the embarkation of lifeboats and LSA
3. Identifying people onboard the ship with special needs during an emergency evacuation (e.g. people with disabilities, elderly people or children)
4. Assisting in the ship sweeping phase
5. Avoiding congestions along the escape routes, e.g. by providing decision support when advising which staircase to use
6. Checking that all crew are in place

Some of the effects or benefits would be saving evacuation time, saving crew time and consequently reducing the time that persons in affected areas are exposed to toxic gasses and smoke in a fire scenario.

An initial literature review described some general problems related to evacuation and emergency response and provided an overview of information that would be useful for an on-board decision support system (Hifi et al. 2007). Available technologies for detecting, tracking, and monitoring people were described and reviewed. An overview of feasibility and limitations for on-board use was also provided, and some general system specifications were provided. Further investigation of available wireless technologies suggested that Radio Frequency IDentification (RFID) may be the most appropriate technology for the passenger tracking system. Possibly, a hybrid solution with RFID in combination with other technologies may also be an alternative.

Radio Frequency IDentification Technology

The basic concept of RFID is quite simple. A transponder, i.e. a microchip with an antenna, is placed on an item and a reader, i.e. a device with one or more antennas, can read the data on the microchip using radio waves. The reader passes the information on to a computer network so that the information on the transponder can be processed. An RFID transponder is sometimes referred to as a tag.

There are two main categories of RFID systems: passive and active systems. Passive RFID tags do not have a transmitter but simply reflect back energy received from the reader antenna. Active tags have their own transmitter and a power source such as a battery. The characteristics of passive and active systems are quite different and these differences need to be considered when determining what kind of system is most suitable for specific applications.

Some of the major differences between active and passive RFID systems include read range, energy requirements, and cost. Active systems have a longer read range (typically between 20 to 100 meters) than passive systems (up to 10 meters). Active tags can also be read much more reliably than passive tags. There are two types of active RFID tags – those that are read with proprietary receiver units, supplied by specific vendors, and those that can be identified and located using regular Wi-Fi network access points (Moen and Jelle, 2007). The Wi-Fi compatible active tags, referred to as Wi-Fi RFID, comply with IEEE 802.11 standards.

Active tags require an energy source (usually a battery) which will limit the active lifetime and will also require maintenance. Furthermore, active tags are understandably much more expensive than passive tags. The price of an active tag ranges from USD 10 to USD 50 or more whereas passive tags are much cheaper, i.e. in the order of 10 – 40 cents. Active Wi-Fi location tags cost on average USD 60 in 2007 (Bulk, 2007). The cost of acquiring and installing the readers also needs to be considered. Wi-Fi RFID systems may not require any additional readers or receivers if there is good coverage with an existing Wi-Fi network, whereas a passive system and active RFID systems that use proprietary readers will require the installation of readers to cover the area of interest. Therefore costs depend very much on the type of infrastructure that is already in place and on the desired functionality of the system.

RFID tags may be embedded in plastic cards or bracelets or sandwiched between an adhesive layer and a paper layer to create a printable RFID label, depending on the application. Special packaging to resist heat, cold and other harsh conditions is possible, but the packaging of the transponder adds significantly to the cost of a tag. For example, the price of short range passive wristbands is in the order of about USD 1 and up.

Passive tags operate at different frequencies: low frequency (typically 124, 125 or 135 kHz), high frequency (typically 13.56 MHz) and ultra-high frequency (typically between 860 – 960 MHz), and the radio waves behave differently at these frequencies. Generally, low frequency waves can penetrate walls well, but cannot penetrate metal. With increased frequency, the waves become less able to penetrate materials and tend to bounce off objects. Waves in the UHF band are also absorbed by water and are influenced by metal and water. Typical read ranges increase for increasing frequencies and low frequency tags have a typical read range of 0.33 meters, high frequency tags up to 1 meter and UHF tags from 3 – 10 meters.

The type of RFID system that would be most suitable for a passenger detection and monitoring system would be a trade-off between different characteristics and costs. On the one hand, it may seem that an active RFID system with dedicated proprietary receivers would be most suitable due to the higher reliability and read range of the tags, but this would also come at a higher cost due to the significantly more expensive tags and the need for installation of receivers throughout the ship. Possibly, active tags would need to be re-usable for this to be a viable option. On the other hand, the limited range of passive tags and the fact that the signals are affected by water and metal (human bodies contain a lot of water and ships are generally made of steel) means that the number of readers would need to be increased significantly for a passive system.

An active Wi-Fi RFID system could be the least expensive option if there is currently complete Wi-Fi network coverage on the ship. The trend for new cruise ships is to have complete wireless local area network coverage. This would significantly reduce the cost as compared to passive and active systems that require the installation of dedicated readers. Many older ships and even some cruise ferries have wireless local area networks (WLAN) covering part of the ship area. For these ships, additional access points (AP) would have to be purchased and installed to extend the coverage over the entire ship, which would increase the cost as compared to ships with complete WLAN coverage. Even ships that currently have complete coverage may need additional access points to achieve the desired accuracy for locating tags.

If active tags are used with a dedicated receiver system, the passenger monitoring system would be able to detect and monitor tags from which it receives signals. If the signals are received by at least three reader antennas, the exact location of the tag can be determined by triangulation. Active Wi-Fi RFID tag location systems generally work by either having tags send a signal or "beacon" to the Wi-Fi access points, or by having the tag engage in two-way communication with the access points (Bulk, 2008). For the second method, the tags take power readings of surrounding access points and then communicate with the location engine through an access point. Calibration is required and a location algorithm is used.

For a passive system, due to its limited range, tags would more realistically only be identified and counted when crossing a gate, i.e. nearby a reader at a door, for example. Hence, a passive system could be used to keep track of passengers within different zones of the ship whereas an active system could be used to track down the specific location (within the selected system's accuracy range) of every passenger onboard the ship. The accuracy for locations varies with the system used and for some types of systems would depend on the number of Wi-Fi access points installed on the ship.

In addition to the RFID tags and readers, there is also the need for middleware and middleware servers to filter and process the data and finally for the application that will utilize the RFID data in the detecting and monitoring of passengers, possibly integrated with other on-board decision support systems.

How to embed the tag in a way that a 1-1 relationship with a passenger is ensured should also be carefully considered. The best solution would possibly depend on whether the ship is a ferry or a cruise liner. For ferries where passengers do not need to stay overnight, it might be suitable to use RFID labels as boarding cards (as has been tried by Singapore Cruise Centre for improved boarding procedures (NEC 2008)) and to instruct passengers to keep them with them throughout the journey. However, for cruise vessels where the passengers stay onboard for several days and are likely to change clothes several times during their stay, it might be better to embed the RFID tag in a bracelet or wristband that the passengers are required to wear for the whole duration of the cruise. This would need to be waterproof etc. and would presumably be more expensive than an RFID label. Incorporating the tag within a state room key card or a "cruise card" used for paying for services on board and for embarking and disembarking at ports of call may also be a way of ensuring that the passengers carry the tag most of the time, even though this approach would be less reliable.

For the purpose of this cost-effectiveness assessment, it is assumed that an active system will be needed in order to obtain an appropriate level of reliability and also to be able to monitor the location of each passenger, also within a zone. Furthermore, it is assumed that the tags will be embedded in a bracelet or wristband and that the passengers will stay overnight. Finally, it is assumed that the RFID bracelets can be re-used if collected on disembarkation, but a certain loss should be expected. These assumptions will naturally affect the cost estimates presented in a subsequent section of this paper.

Cost-Effectiveness Methodology and Criteria

Although the need for a passenger detection and monitoring system in emergency situations has been identified by many, there has not been any quantification of expected safety benefits which have been compared to the costs associated with such a system. Risk analysis and modeling is necessary to estimate the potential safety benefits of such as system. This has been carried out as part of the cost-effectiveness assessment and is described further in this paper.

In order to carry out a cost-effectiveness assessment of the passenger monitoring system, the methodology consistent with the Formal Safety Assessment approach will be used (Norway, 2000; IMO, 2007). The passenger monitoring system is regarded as a risk control option and the associated cost-effectiveness will be estimated. According to this approach, cost-effectiveness for measures towards saving human lives will be expressed in terms of the Gross Cost of Averting a Fatality (GCAF) and the Net Cost of Averting a Fatality (NCAF), as defined by eqs. 1~2.

$$GCAF = \frac{\Delta\, Cost}{\Delta\, Risk} \tag{1}$$

$$NCAF = \frac{\Delta Cost - \Delta EconomicBenefit}{\Delta Risk} \tag{2}$$

As can be seen from the equations above, the GCAF and the NCAF differ in that the NCAF also accounts for additional economic benefits apart from a reduction in risk to life. Such benefits may be in terms of reduced accident costs such as reduced ship damages, reduced environmental damages, reduced downtime, loss of reputation etc. However, acknowledging that the passenger monitoring system will only have an effect on the number of fatalities in a casualty and does not have any potential to avert accidents or mitigate such accident costs, it is realized that for this particular risk control option GCAF = NCAF, and for the purpose of this particular study, the cost effectiveness will simply be expressed in terms of the Cost of Averting a Fatality (CAF).

Hence, cost-effectiveness assessment involves estimating the ΔCost, which is the cost associated with implementing the system, and the ΔRisk, which represents the risk reduction in terms of reduced fatality rates achievable from implementing the system.

In order to establish the costs associated with implementing the system, a costing model incorporating all initial and future costs needs to be established. All future costs should be depreciated to a Net Present Value (NPV) using an appropriate depreciation rate, for instance 5%. Such a generic costing model is illustrated in Fig. 3 (Vanem and Skjong 2006). The list of cost elements in this figure might not be exclusive, and all cost elements influenced by the implementation of the system should in principle be included. Some of the cost elements in Fig. 3 may also prove to be irrelevant for the passenger monitoring system.

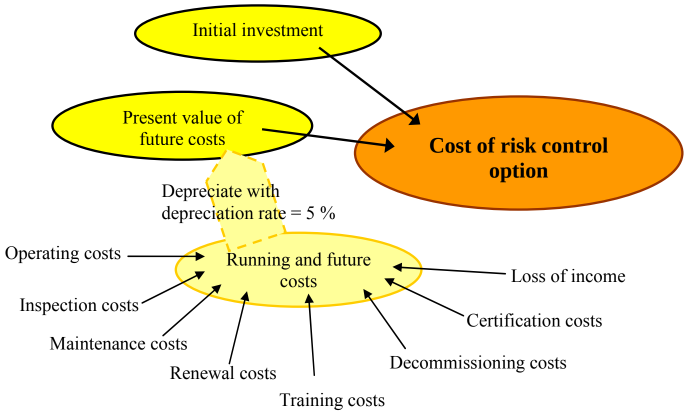

Fig. 3: Costing model for the cost-effectiveness assessment

A risk analysis must be performed which considers all relevant risk and hazards in order to estimate the expected risk reduction. For the passenger monitoring system this means that all the main accident scenarios that might lead to emergency evacuation from a passenger ship should be analyzed. For the purpose of this study, a risk analysis will be carried out using event trees for the main accident scenarios and utilizing available casualty statistics from the Lloyd's Register – Fairplay (LRFP) database. Where appropriate, results from previous risk analyses will be exploited.

The estimated CAF values will be compared to pre-established cost-effectiveness criteria. For the purpose of this study, a CAF value of USD 3 million per (statistical) averted fatality will be assumed. This is in agreement with current practice and recent decisions related to maritime safety within the International Maritime Organization (Norway 2000). This value has previously been used in relation to evaluation of mandatory requirements through statutory regulations. Hence, the passenger monitoring system will be deemed cost-effective if associated with a CAF value less than USD 3 million.

Overall Assumptions

In order to carry out this cost-effectiveness assessment, some general assumptions need to be made. The system that will be subject to this assessment has not been installed or tested on a ship to date. There are some similar systems currently available commercially but they have not been adapted or tested for the specific use envisioned for this study. Functional requirements have been determined and a conceptual design has been undertaken, but the system is not fully developed. Hence, the cost-effectiveness assessment presented herein is inevitably based on a number of assumptions and should be regarded as preliminary. When the system is developed further for ship board use and any of the assumptions made cease to be valid, updates should be made to the assessment and the conclusions. This applies to assumptions related to both the effectiveness and the benefit of the system as well as the cost estimates.

When performing this cost-effectiveness assessment, it has been assumed that the system works reliably, i.e. that it is possible to tag all the passengers, that all passengers wear their tag at all times whilst on board the vessel and that the system will be able to detect and monitor all passengers as long as they are onboard the ship. Hence, 100% reliability of the system is assumed. It is also assumed that the additional information this system delivers to the master will influence the decisions that are taken related to the evacuation process. It is acknowledged that these are optimistic assumptions.

The estimation of the effectiveness of the system, i.e. the reduced fatality rates in emergency evacuations that are achievable from implementing the system, is based on expert opinion coupled with an interrogation of available historic accident data to determine some generic accident scenarios. No detailed calculations or simulations have been carried out to obtain these estimates and it is assumed that the estimates based on expert opinion are adequate.

It may be possible to integrate the onboard system with the Maritime Operational Services (MOS) centers. Hence, in an emergency situation it might be possible to display the results from the passenger monitoring system in a nearby MOS centre and on the bridge on the vessel simultaneously. This may provide additional decision support. However, this effect has not been considered in this assessment. Furthermore, additional functionality that may be included in a final product, keeping in mind that the system is not yet fully developed, or integration with other decision support systems onboard the ship have not been considered. Notwithstanding, the assumptions on the effectiveness of the system with respect to risk reduction tend to be somewhat optimistic overall, as discussed in the risk analysis section of this paper.

Assumptions need also be made regarding the cost of the system. In particular, because no such system has currently been installed or tested on a ship, cost estimates should be considered somewhat crude and preliminary. Emphasis has been on identifying the most relevant cost elements and to obtain reasonable estimates on these. As the technology matures and the system is further developed for ship board use, some of the cost estimates may need to be updated.

For example, acquisition and installation costs may be somewhat uncertain at this point, but it is assumed that such a system can and will be developed for ship board use and that it will become commercially available at a cost that is approximately what has been estimated. It is noted that the cost estimates are made for the cost when such a system is commercially available, and the cost should not be directly related to the development cost of the system. For any new systems, the first installation will be quite expensive but will presumably decrease with the following installations. Hence, the cost estimates that would be relevant to this study are the cost of the system after such an introduction phase when the system will be readily available.

Cost estimates were developed for two types of RFID real time location systems: an active RFID system that uses proprietary readers and an active Wi-Fi RFID system that uses existing wireless local area network access points and infrastructure on the ship. Both types of systems would have the same functionality - only the means of collecting the real time location information differs. The cost estimates for the system using proprietary, dedicated readers are based on a comparison with similar systems that have been used for monitoring inmates in a jail complex (Selamat and Majlis 2006). Hence, it is assumed that a passenger monitoring system onboard a ship can be achieved at a similar cost, and also that the RFID technology can function within a ship made of steel. The cost estimates for the RFID Wi-Fi location system are based on preliminary discussions with commercial system providers.

An on board test done during development of the MAEVIS (Muster and Evacuation Information System)[1] computer based muster and evacuation system has shown that active tags can successfully be read at muster stations on board a ship (MEC, 2008; Leeson, personal communication). This system uses active tags to generate lists of present and missing passengers at muster stations. It is not designed to track passengers throughout the ship so can not be directly compared on a cost basis but it demonstrates the feasibility of using RFID tags on board passenger ships. A tracking system requires a greater number of readers throughout the ship and the means of showing the location of passengers and crew wearing tags to bridge crew and other safety crew members responsible for mustering and evacuation.

This cost-effectiveness assessment assumes that the passengers will be tracked by some kind of bracelet or card with an RFID transmitter. Other technologies could also be used, and have been discussed, but the estimates used herein are based on RFID tags. Furthermore, it is assumed that the tags are re-used and that they will be collected after each trip to be used for the next. However, a certain loss rate will be assumed so the cost of replacement tags is considered.

Notwithstanding the fact that this assessment is based on a number of assumptions and therefore that the results should be considered as uncertain, it is still believed that the results and the conclusions that can be derived from them will be meaningful. It will provide a crude estimate of the cost-effectiveness of such a system that will be useful in determining the feasibility. Furthermore, the various preliminary estimates may easily be updated as more information becomes available and the technologies mature and the results and conclusions could easily be updated accordingly.

The cost-effectiveness of the passenger detection and monitoring system is only assessed for a newbuilding - i.e. retrofitting the system into an existing vessel has not been considered, and it is assumed that this would be considerably less cost-effective, depending on the age of the vessel and the remaining years in service. Further, it has been assumed that the newbuilding will have a wireless local area network installed that provides coverage throughout the entire ship area. The estimates were for the installation of the system on a generic passenger ship that accommodates 3000 persons (passengers and crew). A typical lifetime of a passenger vessel is assumed to be 30 years. Therefore the lifetime of the system is expected to be 30 years when installed on a newbuilding.

COST ESTIMATES

In this section the cost estimates are presented. These estimates should be considered preliminary because the technology and the system is still under development. Similar systems have, however, been used in settings such as off-shore installations, hospitals, and prisons. When the technology has been tested on ships and the system is further developed for shipboard application, some of the estimates pertaining to some of the cost elements may need updating.

Cost estimates were obtained for both an active RFID system that uses proprietary readers and for an active Wi-Fi RFID system that uses the ship's existing WLAN access points. The systems were considered to have the same functionality.

The focus was placed on identifying the most important cost elements, and these have been grouped in two main categories: initial costs that pertain to the acquisition and installation of the system and running costs that occur throughout the operational life of the system. Each of these is again divided into different elements. Based on the different cost estimates and an assumed depreciation rate of 5%, a net present value (NPV) of all initial and future investments related to the system is estimated.

Initial Acquisition and Installation Costs

Active Wi-Fi RFID tag location system: Acquisition and installation costs were assumed to include the following components: tags; software for engines/systems to estimate and track locations, manage tag data, display locations, etc.; and exciters or additional access points as required to obtain the desired location accuracy. Costs were estimated for a ship with 3000 persons (crew and passengers). It was assumed that the

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[1] Company website: http://www.maevis.net

ship would have a suitably compatible Wi-Fi local area network with coverage for the entire ship, which is the trend for new cruise ships. The cost of installing and maintaining the WLAN network was not considered to be part of the Wi-Fi RFID location system costs.

Examples of commercial Wi-Fi RFID real time location providers include Ekahau[2] and Aeroscout[3], and both of these suppliers were contacted for information on feasibility and preliminary cost. Information from the literature was also used to come up with an average cost estimate. The average price of an RFID Wi-Fi location tag, according to Bulk (2007), is USD 60. This is consistent with prices provided by suppliers, although there are variations based on the functionalities associated with tags, such as call buttons, and the number of tags purchased at one time. For a system to show the real time location of 3000 persons, the tag cost would be approximately USD 180,000. When other system components including software, middleware, and purchase and installation of exciters or additional network access points are estimated and added in, an approximate total system cost of 700,000 USD is obtained. This estimate should be considered as approximate and it would be necessary to look in detail at a specific ship to get a more accurate estimate. It would be necessary to do testing on the specific ship to determine the exact number of exciters (if required by the selected system) or additional Wi-Fi access points required.

Active RFID system with dedicated receivers: Acquisition and installation costs that were assumed for the system with dedicated readers were limited to the following components: Tags, system software including middleware and system hardware including servers, monitors, RFID readers with antennas and cabling. In addition, there would be an installation cost. However, if installed on a newbuilding together with the installation of other onboard systems, this cost may be significantly reduced.

One approach to estimate the initial cost of such a system would be to break down the system in various components, count the number of different components and assume reasonable component prices. For example, typical prices for active and passive RFID tags, RFID readers and antennas are presented in RFID Journal (2008). General arrangement plans for a typical passenger ship could be studied in order to estimate the number of RFID readers that would be necessary. However, since the technology has not yet been tested or installed on board a ship, such estimates would be highly uncertain.

An alternative approach, which is deemed more suitable, is to compare with the costs of other available systems that are similar, albeit not identical to the passenger monitoring system that will be subject to assessment.
Following this second approach, reference is made to an RFID-based system for tracking and monitoring inmates that is currently available. According to Alanco (2008), such a system for tracking and monitoring more than 2000 inmates and more than 450 staff members at a jail complex can be delivered at a cost of USD 3.3 million. Even though such systems are not directly comparable, the number of persons to be tracked is a similar order of magnitude as the passenger monitoring system Therefore, USD 3.3 million could serve as a reasonable estimate for the cost of such a system. It is assumed that this cost would include all initial costs related to software, hardware and installation. The system utilizes long range active RFID technology.

For the purpose of this cost-effectiveness assessment, it is assumed that a passenger detection and monitoring system can be delivered at similar costs as the inmate monitoring system that is currently available, and initial acquisition and installation costs of USD 3.3 million is assumed. This estimate should of course be updated as the technology matures and the particular system is being further developed.

Operational Costs

In addition to the initial investment associated with acquisition and installation of the system, there are a number of cost elements that are expected to occur at various intervals throughout the lifetime of the system, including maintenance, renewal cost of damaged and worn out tags and other equipment, software licensing and support; and training costs for the crew to be properly trained to use the system correctly and efficiently. No other running costs were assumed for the purpose of this study.

Active Wi-Fi RFID tag location system. The operational costs vary depending on the system supplier selected. There were differences with respect to licensing and support as well as with respect to tags. Some types of tags have rechargeable batteries while others require batteries to be replaced after a specific interval. An average cost estimate was used. Operational costs were estimated for various categories as follows:

- Annual support, maintenance and renewal costs: The type of costs included in this item varies by supplier and specific type of system selected. The average NPV for this cost element was estimated to be USD 400,000.

- Tag replacement and renewal cost was also considered. An average tag price of USD 60 was assumed (Bulk, 2007), and this was assumed to include embedding within a wristband or key card and necessary maintenance throughout its operational life. The tags are assumed to be reusable, but a loss of 10% per year was assumed, either due to tags being damaged or lost. It was assumed that the return of most tags could be assured by having a gate or alarm system at the end of each voyage when passengers leave the vessel, to ensure tag return is not forgotten. Presumably any tags left on board after completion of the voyage could be found using the real time location system.

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[2] Company website: http://www.ekahau.com
[3] Company website: http: //www.aeroscout.com

A tag life of 4 years was assumed. This could be conservative, as some suppliers estimate tags will last longer. To date, however, tags have not been employed in a cruise ship environment where the tag will typically be re-issued for 50 voyages per year. With these assumptions, and assuming a generic passenger ship with 3000 people on board it is assumed that 3000 tags need to be purchased every four years and an additional 300 should be purchased every year. With an average tag cost of USD 60, this corresponds to a cost of USD 180,000 every four years to purchase 3000 tags. An annual cost of USD 18,000 is estimated for replacement of 10% of tags per year due to damage or loss. Using a depreciation rate of 5%, this amounts to an NPV of approximately USD 900,000 for tag renewal and replacement.

- Training costs also need to be taken into account as it may be assumed that the full benefit from the system cannot be reaped without regular training on the proper use of the system. It is assumed that the master and other crewmembers will need to attend periodic training courses and for the purpose of this study, it is assumed that a two-day training course will be needed every second year for 8 persons on every vessel that implements this system. It is further assumed that regular tests and on-board drills are needed, but no additional costs are assumed for this. Currently, as the system is not commercially available, there are no training courses available for the passenger monitoring system. However, it may be assumed that the costs would be comparable to similar courses for other on-board systems. Costs related to training were considered also in the comprehensive cost-effectiveness study on ECDIS [Denmark et al., 2007; Vanem et al., 2007], and these estimates may be used as a reference in estimating the training cost for the passenger monitoring system. According to this recent study course fees for 3 – 5 days ECDIS courses vary between USD 550 to USD 1600 and average course duration of 4 days and average course fee of USD 1000 was assumed. For the passenger monitoring system, it is assumed that a two-day course will be sufficient, and therefore an average course fee of USD 500 will henceforth be assumed. In addition to the actual course fee, there are additional travel costs, board and lodging and overtime compensation associated with sending personnel on courses. For the ECDIS course, these were estimated to USD 2500, but since the passenger monitoring course is assumed to be shorter, this estimate is reduced to USD 1750 for this course. Thus, a total cost of USD 2250 per participant per course is assumed for training courses. With 8 crewmembers for each ship, this amounts to a cost of USD 18,000 which will incur every second year. However, it may be assumed that half of the crew attends the course in alternating years, so that the cost is effectively USD 9000 per year. Summing up throughout the lifetime of the ship and estimating the corresponding net present value using a depreciation rate of 5%, training costs corresponds to a NPV ≈ USD 150,000. This cost will be assumed for training for the purpose of this cost-effectiveness study.

Operational costs for active RFID tag location system with proprietary Readers were estimated for the following cost elements: Maintenance cost, base-station renewal cost, tag replacement cost and training cost, as outlined in the following.

- Maintenance costs: These costs will occur throughout the lifetime of the system. Average annual maintenance costs of USD 2000 are assumed (this is four times as much as what was assumed as annual maintenance costs for a dual ECDIS system and for a system for automatic logging of information in Norway (2005), but it is acknowledged that the system in question is much more complex. The estimate is still assumed to be conservative). This corresponds to a NPV for this cost element of approximately USD 32,000.

- Base-station renewal costs: It is assumed that some base-stations may be replaced from time to time. On average, it is assumed that all base stations will be replaced every fifteen years (which is the typical service life for an RFID reader). For the purpose of this assessment, it is assumed that all base-stations will be replaced at the same time, i.e. 15 years after initial installation of the system. Studying the general arrangement plans for a typical passenger ship with capacity of 3000 people, it is possible to estimate how many RFID readers would be needed to cover the whole ship. Assuming such a ship with a total of 15 decks and 7 main vertical fire zones, it is assumed that 200 long range RFID readers will be sufficient. This corresponds to between 2 – 4 RFID base-stations per fire zone per deck, depending on the complexity and the layout of the spaces. Furthermore, RFID Journal (2008) states that the typical price of an RFID reader range from USD 500 to USD 3000 (this may or may not include antenna and cabling). Thus, an estimated RFID reader cost of USD 1000 seems reasonable. Assuming the system to contain 200 base-stations with a per unit cost of USD 1000, including antennas, this corresponds to a cost of USD 200,000 occurring after 15 years of operation. This would correspond to a NPV of approximately USD 96,000.

- Tag replacement and renewal: According to RFID Journal (2008), the price of an active tag ranges from USD 10 to USD 50 or more, and for the purpose of this cost-effectiveness assessment, a cost of USD 30 per tag will be assumed for tags used with proprietary readers. These tags tend to have a lower cost than tags for systems communicating with Wi-Fi networks. This cost is assumed to also include embedding within a wristband and necessary maintenance throughout its operational life. The tags are assumed to be reusable, but a loss of 10% per year is assumed. It is assumed that all tags would have to be replaced after 4 years. With these assumptions, and assuming a generic passenger ship with 3000 people onboard it is assumed that 3000 tags need to be purchased every four years and an additional 300 should be purchased every year. With the assumed price of a tag, this corresponds to a cost of USD 90,000 every four years and an additional annual cost of USD 9,000. Using a depreciation rate of 5%, this amounts to an NPV for the cost of tags of approximately USD 500,000.

- Training costs: The same estimates as used for the Wi-Fi RFID tag location system were used for the system using proprietary readers. This corresponds to an NPV of approximately USD 150,000. The assumptions used for this estimate are as described previously for the Wi-Fi RFID system.

Total Costs – Net Present Value

The net present value of the different cost elements for the two types of real time passenger location systems are summarized in Table 1. It can be seen that the overall costs are dominated by the initial investments associated with acquisition and installation and by the cost of RFID tags. Hence, in order to drive the costs down, RFID technologies in general and tags in particular need to be less expensive.

Table 1. Net present value of identified cost components

Cost component	NPV: Wi-FI tag system	NPV: system with proprietary reader
Acquisition and installation	700,000	3,300,000
Support, maintenance and renewal	400,000	128,000
Tags	900,000	500,000
Training	150,000	150,000
Total cost	2,150,000	4,078,000

Adding up the various cost components that have been considered, all depreciated to a net present value using a depreciation rate of 5%, one arrives at the crude estimates in eqs. 3 ~ 4. Again, it is stressed that these estimates should be updated as the technology evolves, but they are deemed adequate for performing a cost-effectiveness assessment of the system.

$$NPV_{\text{Wi-Fi RFID Tag System}} = \text{USD } 2.15 \text{ million} \quad (3)$$

$$NPV_{\text{RFID with Proprietary Readers}} = \text{USD } 4.1 \text{ million} \quad (4)$$

RISK ANALYSIS – RISK REDUCTION FROM A PASSENGER MONITORING SYSTEM

This section describes a high-level risk analysis pertaining to passenger ships that was carried out to estimate the risk reduction potential. The analysis was limited to encompass ships engaged in international trade and only ships greater than 4000 GT were considered. Furthermore, both cruise ships and ro-ro passenger ferries were included in the study.

For the purpose of this study, casualty statistics for the years 1990 – 2006 were interrogated, i.e. over a period of 17 years. Quantified risk estimates in terms of potential loss of lives (PLL) were based on a passenger ship with N = 3000 people on board (including crew and passengers).

Fleet at Risk

The size of the fleet of all passenger ships (including cruise and ferries) greater than 4000 GT for the years 1990 to 2006 according to Lloyd's Register – Fairplay's world fleet database is presented in Table 2. According to these numbers, the risk analysis that is to be performed covers a total of 19,769 shipyears for passengers ships above 4000 GT.

Table 2. Number of passenger ships > 4000 GT, 1990 - 2006

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	Total
Fleet	968	992	1024	1056	1069	1099	1126	1155	1185	1212	1230	1263	1289	1291	1272	1266	1272	19769

Identification of Main Accident Scenarios

According to casualty statistics for passenger ships from LRFP a total of 826 accidents were reported between 1990 and 2006 for ships greater than 4000 GT. The distribution of accidents per year and per accident type according to the statistics is presented in Table 3.

Table 3. Distribution of accidents on year and accident type for passenger ships > 4000 GT

Year	Col.	Cnt.	Fire/ Exp.	Gnd.	Fnd.	Hull/ m.d.	Other	Total
1990	4	4	11	6		3		28
1991	12	3	9	4		4		32
1992	5	6	6	6	1			24
1993	6		2	5				13
1994	4	1	7	6	1	1		20
1995	1		6	6		1		14
1996	1	4	5	10		2		22
1997	7	2	7	4	1	11		32
1998	6		8	4	1	9		28
1999	4	6	11	9		5		35
2000	6	6	8	5	4	11		40
2001	6	5	5	5	1	13	1	36
2002	9	10	17	10	2	35	1	84
2003	14	15	14	15	1	42		101
2004	16	12	8	11	1	43		91
2005	13	27	15	13		58	3	129
2006	12	14	14	12	1	44		97
Total	126	115	153	131	14	282	5	826
Freq.	6.4×10^{-3}	5.8×10^{-3}	7.7×10^{-3}	6.6×10^{-3}	7.1×10^{-4}	1.4×10^{-2}	2.5×10^{-4}	4.2×10^{-2}

It can be seen that about 99.4% of all accidents can be ascribed to one of six main accident categories, i.e. collision, contact, fire and explosion, grounding, foundering and hull and machinery damages. Other accident categories that are responsible for the remaining 0.6% are war damages or other damages due to hostile acts and accidents that cannot be classified due to insufficient information.

The last row in Table 3 presents accident frequencies in terms of accidents per shipyear for each of the main accident categories.

The number of fatalities in maritime casualties may also be extracted from the casualty database, and fatalities are reported for 29 of the 826 accidents. A total of 1328 fatalities have been reported as a result of maritime accidents for passenger ships greater than 4000 GT between 1990 and 2006, all of which can be ascribed to the main six accident categories that have been identified. The distribution of fatalities on accident type and number of fatalities in an accident is presented in Table 4. The total number of fatalities for each main accident category is presented in Table 5 together with the experienced fatality frequencies per shipyear according to the casualty statistics that were interrogated.

Table 4. Distribution of number of fatalities in maritime accidents for passenger ships > 4000 GT

# fatalities	Col.	Cnt.	Fnd.	Fire/ Exp.	Hull/ m.d.	Gnd	Total
1	2	1	1	8	1	1	14
3	1			1	1		3
4	1						1
8				2			2
14				1			1
64			1				1
82						1	1
94			1				1
117						1	1
140	1						1
158				1			1
194				1			1
414				1			1
Total	5	1	3	15	2	3	29

Table 5. Reported fatalities in maritime accidents, passenger ships > 4000 GT (1990 – 2006)

	Col.	Cnt.	Fnd.	Fire/ Exp.	Hull/ m.d.	Gnd	Total
Reported fatalities	149	1	159	807	4	200	1328
Frequency	7.5 x10^{-3}	5.1 x10^{-5}	8.0 x10^{-3}	4.1 x10^{-2}	2.0 x10^{-4}	1.0 x10^{-2}	6.7 x10^{-2}

A similar table can also be produced for number of missing persons in maritime accidents. This is presented in Table 6. These numbers stem from 13 accidents where people were reported missing, the biggest number of missing people being reported for the Estonia accident.

Table 6. Missing people in maritime accidents, passenger ships > 4000 GT (1990 – 2006)

	Col.	Cnt.	Fnd.	Fire/ Exp.	Hull/ m.d.	Gnd	Total
# missing	7	0	887	590	0	350	1834
Frequency	3.5 x10^{-4}	0	4.5 x10^{-2}	3.0 x10^{-2}	0	1.8 x10^{-2}	9.3 x10^{-2}

Assuming that those reported missing were actually fatalities, the sum of the number of reported fatalities and number of missing people would correspond to the number of experienced fatalities in maritime accidents. Hence, the numbers from Table 5 and Table 6 are added in Table 7.

Table 7. Total number of fatalities in maritime accidents, passenger ships > 4000 GT (1990 – 2006)

	Col.	Cnt.	Fnd.	Fire/ Exp.	Hull/ m.d.	Gnd	Total
# fatalities	156	1	1046	1397	4	550	3162
Frequency	7.9 x10^{-3}	5.1 x10^{-5}	5.3 x10^{-2}	7.1 x10^{-2}	2.0 x10^{-4}	2.8 x10^{-2}	1.6 x10^{-1}

It can be read from these tables that almost half of the fatal accidents were fire/explosion accidents and that more than 99.8% of the fatalities may be ascribed to the four main accident categories collision, foundering, fire/explosion and grounding. Hence, for a high-level risk analysis such as the one that will be undertaken herein, it may be deemed sufficient to analyze the risk from these four main accident scenarios. Contributions to fatality rates from other scenarios may be assumed negligible in comparison. Risk analyses of these four accident scenarios will be presented as the basis for the cost-effectiveness assessment of the passenger monitoring system.

Risk Analysis of Main Accident Scenarios

Several previous risk analyses have been published that consider the main accident scenarios for passenger ships as identified above. Hence, event trees already exist for many of the accident scenarios, which have been developed in previous projects and it is not deemed necessary to develop new ones. Most notably, the risk analyses presented herein will refer to the risk models for collision, grounding and fire and explosion that were developed in the FIRE EXIT project (Vanem and Skjong, 2004a; Vanem and Skjong, 2004b). These risk models are deemed most relevant, as the focus of the FIRE EXIT project was also on emergency evacuation from passenger ships. However, the risk models will be updated according to updated casualty statistics and new knowledge whenever appropriate. For the foundering accident scenario, no suitable risk model exists and a simple risk model will be developed.

Collision Risk Analysis. A collision risk model was established within the FIRE EXIT project in order to estimate the risk associated with evacuation due to collision. This risk model, which was quantified based on interrogation of casualty statistics, previous studies and an investigation on average attained subdivision indices for passenger ships, is reproduced in Fig. 4 (Vanem and Skjong 2004b). The initial probability of collision is updated according to the new casualty statistics, i.e. 6.4×10^{-3} collisions per shipyear according to the estimate in Table 3. The other aspects of the risk model will be adopted for this study without any further changes

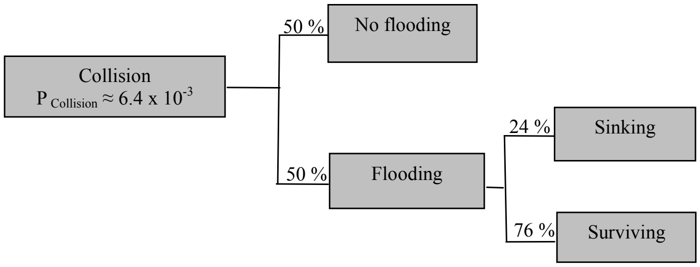

Fig. 4: Risk model for collision of passenger ships

The risk model as illustrated by Fig. 4 estimates the probability of not surviving a collision event and thus the probability of the need for an emergency evacuation. The initial collision probability is updated according to updated casualty statistics (1990 – 2006) to arrive at the following probability of initiating an emergency evacuation due to collision (eq. 5):

$$P_{\text{evacuation}} = 7.7 \times 10^{-4} \text{ per shipyear} \qquad (5)$$

Given that the ship will not survive, the consequences of the accident will be dependent on the time to sink and the evacuation process. Due to insufficient data the consequent part of the risk model was established based on expert opinion, elicited in a Delphi session. The results from this exercise is reproduced in Table 8, which gives a probability distribution for time to sink, conditioned on a collision the ship will not survive and an associated expected fatality rate in terms of the % of people onboard (Vanem and Skjong 2004b). A similar exercise which also distinguished between accidents in mild and harsh environments was reported by Vanem et al. (2007b) and the results were demonstrated to compare reasonably well with known actual sinking accidents of passenger ships.

Table 8. Probability estimates for time to sink and associated expected fatality rates, collision

Available time for evacuation (min)	< 5	5-10	10-15	15-30	30-60	60-90	> 90
Probability	0.23	0.24	0.16	0.17	0.08	0.06	0.06
Expected fatality rate	96%	88%	80%	63%	40%	20%	7%

For a passenger ship with 3000 people on board, this corresponds to an average expected fatality rate from collision events of $PLL_{\text{collision}} = 7.7 \times 10^{-4} \times 2145.9 = 1.65$ fatalities per shipyear. Comparing this to the fatality frequency that has actually been experienced since 1990 (Table 7), the outcome from the risk model exceeds actual experience by far. This can be explained by the fact that the risk model includes consideration of catastrophic events that may occur even if not yet materialized, i.e. major collisions with rapid capsize. Fortunately, such events have not occurred but this does not mean that the risk from such scenarios is negligible. Another important factor is that the fatality rate achieved from the risk modeling and presented above are for passenger ships with 3000 people on board, whereas a substantial part of the fleet that was included in the statistical data is much smaller than this.

When it comes to the passenger monitoring system, it is realized that this will not be effective in saving lives in all evacuation scenarios. For ships that experience rapid capsize following the collision, it is assumed that the passenger monitoring system will not have an effect, as there will hardly be enough time for everyone to abandon ship before the capsize. For the purpose of this analysis it is therefore assumed that the ship need to survive at least 90 minutes following the collision for the passenger monitoring system to have an effect of reduced risk of fatalities.

According to the risk model and the risk analysis adopted for the purpose of this study, there is a probability of 0.06 for the ship to survive more than 90 minutes conditioned on receiving a collision damage it cannot survive. The frequency of such an event is then estimated to 4.6×10^{-5} per shipyear. Furthermore, it is assumed that in an emergency situation with more than 90 minutes available for evacuation, the expected fatality rate will be 7% of the people on board. For a large passenger ship with 3000 people on board, this corresponds to an expected fatality rate of 210.

It might seem somewhat optimistic to assume that the passenger monitoring system will prevent all fatalities that would otherwise occur in the scenario described above (time to capsize/sink > 90 minutes). However, for the purpose of this study, it will be assumed that all fatalities in these scenarios will be prevented, and it is acknowledged that this is an optimistic estimate. Hence, an optimistic estimate for the life-saving effect of the passenger monitoring system in collision scenarios for a passenger ship with 3000 people on board is (eq. 6):

$$\Delta\text{Risk}_{\text{collision}} = 9.7 \times 10^{-3} \text{ fatalities per shipyear} \qquad (6)$$

Foundering Risk Analysis. No previous, relevant risk models for foundering are known and foundering was i.a. not considered by the FIRE EXIT project. However, foundering was identified as one of four main accident scenarios to consider herein, and therefore a simplified risk model for foundering will be established, based on the casualty statistics presented in Tables 2 ~ 6.

Foundering accidents includes accidents where ships are lost due to heavy weather or structural failure without a preceding collision, grounding, contact, fire or explosion, deliberate act (e.g. terrorism) or hull or machinery damage. Thus, many foundering events are associated with little causal information. This makes it somewhat more difficult to construct detailed risk models and event trees for such accidents. However, common for all foundering accidents is that the ship sinks, necessitating timely evacuation and abandonment of the ship. Failure to abandon ship in time will lead to fatalities. Hence, the simple risk model illustrated by Fig. 5 may be utilized. The probabilities inserted into this risk model are taken from casualty statistics as presented in Tables 2 ~ 6.

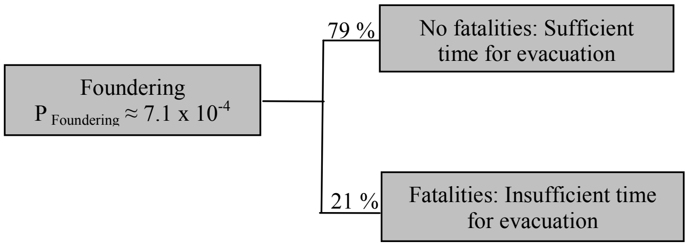

Fig. 5: Risk model for foundering of passenger ships

According to this risk model and available statistics, the frequency of fatal foundering accidents involving passenger ships is 1.5×10^{-4} per shipyear.

In order to estimate the expected consequences in foundering scenarios were there is not enough time for everyone to abandon ship, the three reported foundering accidents that caused fatalities will be further studied. These are the ones listed in Table 9. All of the fatal foundering accidents have quite high fatality rates. Possible explanations for this could for example be insufficient time available for safe evacuation or heavy weather or heavy list that renders ordered evacuation difficult. Heavy weather would also seriously hamper search and rescue operations. Assuming that these accidents are representative, with an average fatality rate of 349, the risk from foundering accidents would be estimated to PLL foundering = 5.2×10^{-2} fatalities per shipyear.

Table 9**.** Fatal foundering accidents on passenger ships > 4000 GT, 1990 - 2006

Vessel name (year of accident)	Reported fatalities	Reported missing	Total number of fatalities
ESTONIA (1994)	94	758	852
PRINCESS OF THE ORIENT (1998)	64	86	150
MERCURY-2 (2002)	1	43	44
	159	887	1046

In the *Estonia* accident, there was heavy weather and the ship developed a list of more than 20° after about 20 minutes, and a 45° list after about 30 minutes (SSPA Consortium 2008). The ship was on her side after about 45 minutes, and sank approximately one hour after she began taking on water. Coordinated mustering and evacuation activities were not carried out by the crew due to the rapidly developing situation, and the list made it difficult for passengers to reach the upper decks.

The *Princess of the Orient* accident occurred in heavy weather with strong waves (tropical storm), and the ship was reported to quickly develop a list due to heavy cargo shift and then so capsize and sink in less than one hour. The Philippine Coast Guard's Board of Marine Inquiry stated that the abandon ship procedure was not executed by the officer in charge or by the deck and engine officers (Republic of the Philippines). There was no announcement on the public address system.

Also the *Mercury-2* accident occurred in heavy weather and the foundering was attributed to cargo shift. The ship was reported to sink 5 hours after sending an SOS call.

It is difficult to estimate the effect of a passenger monitoring system on such accidents as the ones above. Indeed in two of the accidents the crew had not been able to initiate the evacuation and abandonment plan, and certainly did not carry out structured sweeping and clearing of the ship. Presumably, during evacuation in such harsh conditions and with a heavy list the biggest problem is not to know the whereabouts of all passengers onboard the ship, but rather for as many of them as possible to be able to escape. It could be argued that the passenger monitoring system would most likely not be effective in such accidents. However, for the purpose of this cost.-effectiveness assessment, it may be assumed that a reduction in fatality rates of 1% could be achievable, and this is regarded as an optimistic estimate. Assuming this, the expected risk reduction achievable from the passenger monitoring system in foundering scenarios is estimated to (eq. 7):

$$\Delta \text{Risk}_{\text{foundering}} = 5.2 \times 10^{-4} \text{ fatalities per shipyear} \qquad (7)$$

Fire and Explosion Risk Analysis. The FIRE EXIT project developed risk models for fire scenarios onboard passenger ships, with particular attention to the evacuation process (Vanem and Skjong 2004a). For the purpose of this assessment, it is deemed appropriate to adopt these risk models. However, some modifications will be made. The initial fire frequency will be updated according to new casualty statistics (Table 3), i.e. an initial fire/explosion frequency of 7.7×10^{-3} per shipyear. It is observed that this frequency lies between the frequencies that were used for cruise and roPax by FIRE EXIT. For the purpose of the current study, a joint risk model for all passenger ships will be considered. For the various probability estimates within the risk model, the statistical analysis carried out in the FIRE EXIT project will be exploited in order to estimate probabilities for all passenger ship fires.

Hence, the risk model illustrated by Fig. 6 will be used in the current study. It is noted that by unsuccessful evacuation is meant that lives are lost in the fire due to poor evacuation performance. If no lives are lost that can be ascribed to the evacuation process itself, the evacuation will be considered successful even if there should be fatalities in the accidents which could not have been prevented by evacuation, e.g. from an initial blast or onset of the fire. Nevertheless, the purpose of this study is to assess the effectiveness of a passenger monitoring system that can aid in the evacuation process, and the definitions above seems useful in this context.

The risk model in Fig. 6 estimates the frequency of unsuccessful evacuations due to fire, i.e. scenarios where fatalities occur which could have been prevented by more effective evacuation. According to the model with the updated probabilities, this frequency is 5.12 x 10^{-4} per shipyear. However, the risk model does not estimate the consequences of poor evacuation in terms of expected number of fatalities in such scenarios. In order to investigate this in more detail, the fatal fire incidents reported in the casualty database will be studied.

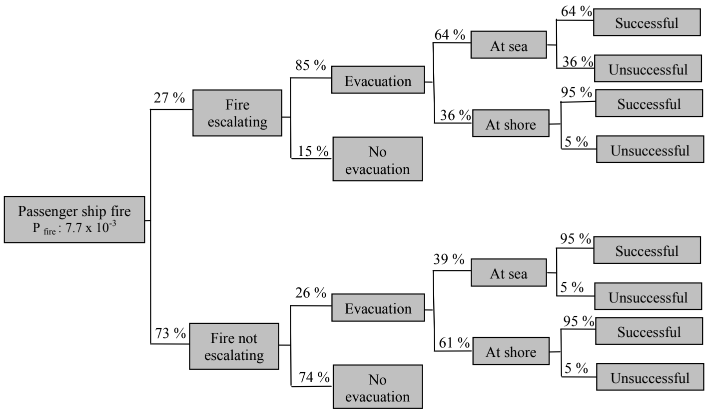

Fig. 6: Risk model for fire and explosion of passenger ships

Table 10 lists all fatal fire accidents from the casualty database, and includes one additional known accident that for some reason was not included in the statistics[4]. In total, 19 fire accidents will be looked at in more detail.

For some of these accidents it was determined that the fatalities could not be ascribed to poor evacuation performance, and these will not be considered further. It is clear that e.g. fatalities due to an initial explosion could not have been prevented by the passenger monitoring system, and these accidents is therefore not relevant in the current study. For some of the accidents it was not possible to determine from the accident reports whether the fatalities were related to evacuation. These will still be considered. Whether the fatalities could be related to evacuation or not is indicated in the last column of Table 10.

Table 10**.** Fatal fire accidents on passenger ships > 4000 GT, 1990 – 2006

Vessel name (year of accident)	Reported fatalities	Reported missing	Total fatalities	Evacuation related
FAIRSTAR (1990)	1	0	1	NO
NORRONA (1990)	1	0	1	Possibly
SCANDINAVIAN STAR (1990)	158	0	158	YES
QUIBERON (1992)	1	0	1	NO
AL-QAMAR AL-SAUDI AL-MISRI (1994)	8	13	21	YES
ACHILLE LAURO (1994)	3	1	4	YES
FALSTER LINK (1994)	1	0	1	Possibly
UNIVERSE EXPLORER (1996)	5	0	5	YES
SUPERSTAR GEMINI (1997)	1	0	1	NO
SUPERFAST III (1999)	14	0	14	NO
PRINSESSE RAGNHILD (1999)	1	0	1	NO
GURGEN 2 (2000)	0	1	1	NO
AL SALAM PETRARCA 90 (2002)	1	0	1	NO
NORWAY (2003)	8	0	8	NO
SUPERFERRY 14 (2004)	194	0	194	Terrorist attack[5]
AL-KAHFAIN (2005)	0	1	1	NO
STAR PRINCESS (2006)	1	0	1	Possibly
AL SALAM BOCCACCIO 98 (2006)	414	574	988	Partly[6]
	812	590	1402	

Extracting only the accidents from Table 10 where poor

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[4] The fire onboard the *Universe Explorer* in 1996 caused 5 fatalities, but seems to be missing in the accident data. It is relevant to the current study on the passenger monitoring system, and is therefore included.

[5] This was not an accident, but rather a terrorist attack. This accident is therefore wrongly categorized as a fire/explosion accident. However, since the passenger monitoring system could have had an effect in the subsequent fire, this incident will still be considered in this analysis.

[6] No organised evacuation process was initiated in this accident, and even though the fatality rate could have been reduced by proper evacuation, it is not deemed that the passenger monitoring system would be very effective in this particular accident. Hence, this accident will not be considered when estimating the risk reducing effect of the system.

evacuation performance was a contributing factor to the fatality rates, the accidents in Table 11 remain. Assuming those accidents as representative for the consequences of poor evacuation from fires on passenger ships, an average fatality rate of 48 may be estimated. Combined with the estimated frequency of poor evacuations from fire as estimated above, one arrives at the following estimated risk associated with such scenarios: $\text{PLL}_{\text{poor evacuation from fire}} = 2.5 \times 10^{-2}$ fatalities per shipyear.

Table 11**.** Fatalities due to poor evacuation from fire, passenger ships > 4000 GT, 1990 - 2006

Vessel name (year of accident)	Number of fatalities	% of people on board
SUPERFERRY 14 (2004)	194	21 %
SCANDINAVIAN STAR (1990)	158	33 %
AL-QAMAR AL-SAUDI AL-MISRI (1994)	21	4 %
UNIVERSE EXPLORER (1996)	5	0.5 %
ACHILLE LAURO (1994)	4	0.4 %
STAR PRINCESS (2006)	1	0.026 %
FALSTER LINK (1994)	1	?
NORRONA (1990)	1	?
Total	385	
Average	48	

It may seem unrealistic to assume that all fatalities ascribed to unsuccessful evacuation could have been prevented by the passenger monitoring system. Presumably, most of the single fatalities and fatalities in accidents with only a few fatalities could have been prevented, but for disasters such as the *Scandinavian Star* and the *Superferry 14* it is assumed that only a certain percentage of the fatalities could have been prevented. For the purpose of this high-level study, it is assumed that 10% of the fatalities in such major disasters, up to 50% of fatalities in somewhat less catastrophic accidents such as the *Al-Qamar Al-Saudi Al-Misri* and 80% of fatalities in accidents with single or few fatalities can be avoided with the passenger monitoring system. It is acknowledged that the uncertainties associated with these crude estimates are high, but they will be assumed as best estimate. Presumably, they tend to be on the optimistic side.

Assuming the above as representative, an overall risk reduction of 14% is achievable from the passenger monitoring system. Therefore, the contribution from fire scenarios to the risk reduction that may be expected for the passenger monitoring system is estimated to be (eq. 8):

$$\Delta\text{Risk}_{\text{fire}} = 3.5 \times 10^{-3} \text{ fatalities per shipyear} \quad (8)$$

Grounding Risk Analysis. The FIRE EXIT project also established a simple grounding risk model in order to estimate the risk associated with evacuation situations due to groundings. This risk model is reproduced in Fig. 7 (Vanem and Skjong 2004b). The various elements in this risk model were quantified based on interrogation of casualty statistics, grounding damage statistics and previous studies, as described in Vanem and Skjong (2004b). The initial probability of grounding is updated according to the new casualty statistics, i.e. 1.03×10^{-2} collisions per shipyear will be replaced with 6.6×10^{-3} collisions per shipyear according to the estimate in Table 3. The other aspects of the risk model will be adopted for this study without any further changes.

According to the risk model, there will be an annual probability of the need for an emergency evacuation in grounding accidents of 6.9×10^{-5} per shipyear. However, it is distinguished between two different evacuation scenarios, i.e. where the ship sinks gracefully (upright) and where it capsizes. These will naturally have very different consequences in terms of number of fatalities since the available evacuation times are expected to be different as well as the overall evacuation conditions (i.e. the presence of significant angles of trim in the capsize scenario).

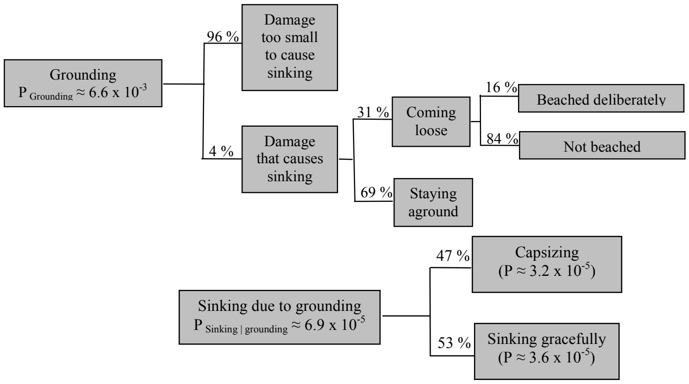

Fig. 7: Risk model for grounding of passenger ships

Given that the ship will sink or capsize, the consequences of each scenario will be dependent on the time to sink and on the evacuation process. This was also investigated in FIRE EXIT, and due to insufficient data the consequent part of the risk model was established based on expert opinion, elicited in a Delphi session. The results from this exercise is reproduced in Table 12, which gives a probability distribution for time to sink and an associated expected fatality rate in terms of the % of people onboard for both scenarios sinking upright and capsize (Vanem and Skjong 2004b).

For a passenger ship with 3000 people on board, the results from this risk model correspond to an average expected fatality rate from grounding events of $\text{PLL}_{\text{grounding}} = 6.9 \times 10^{-5} \times (0.47 \times 1862 + 0.53 \times 912) = 9.4 \times 10^{-2}$ fatalities per shipyear. Compared to the fatality rates that have actually been experienced since 1990, this estimate seems to exceed experience by a factor of about 3. This can be explained by the fact that the risk model includes catastrophic scenarios that has not yet occurred and is therefore not reflected in the casualty statistics. However, risk contributions from such scenarios are not negligible. Furthermore, the fleet of passenger ships that forms the basis for the casualty statistics includes a significant percentage of ships with less than 3000 people on board.

Table 12**.** Probability estimates for time to sink and associated expected fatality rates, grounding

Available time for evacuation (min)	< 5	5–10	10–15	15–30	30–60	60–90	> 90
Probability if capsize	0.13	0.14	0.23	0.20	0.18	0.07	0.05
Expected fatality rate	88%	82%	73%	63%	47%	15%	5%
Probability if gracefully sinking	0.02	0.08	0.15	0.22	0.16	0.30	0.07
Expected fatality rate	85%	78%	62%	43%	23%	5%	0.3%

The recent ferry disaster in the Philippines in June 2008, the grounding and capsizing of the *M/V Princess of the Stars*, resulted in approximately 800 passengers dead or missing. This is more than the combined fatalities from the three fatal grounding incidents included in the accident statistics for 1990 - 2006: It is an example of a catastrophic scenario that is not reflected in the statistics. If the *Princess of the Stars* accident had been included in the casualty statistics for grounding the historic accident rates would increase to an estimated PLL of 6.8 x 10^{-2}, which compares quite close to the $PLL_{grounding}$ estimated from the risk model. This example serves to illustrate how sensitive accident statistics are to the occurrence of a single, catastrophic accident.

Two other recent sinking due to grounding incidents that resulted in fatalities are examples of incidents where a passenger monitoring and tracking system may have prevented fatalities. The first incident, the sinking of the *Queen of the North*, which occurred in March 2006 on the west coast of Canada, resulted in the loss of two passengers. The ship sank upright about 80 minutes after grounding. The crew had conducted a search of the cabins and public spaces. After mustering, an accurate count was not performed and even after boarding life rafts it was unclear whether all passengers had been accounted for, as passenger counts were inconsistent (Transportation Safety Board of Canada 2008). It is likely that there would have been additional efforts made to find the passengers if there had been awareness that they were missing. The second incident was the grounding of the *Sea Diamond* off Santorini in 2007. The ship remained afloat for approximately 15 hours. Two passengers remain missing and unaccounted for, and are assumed fatalities. An accident investigation report has not yet been released for this incident but it may also be a case where a passenger location and tracking device may have prevented fatalities.

When it comes to the passenger monitoring system, it is realized that this will not be effective in saving lives in all evacuation scenarios. For ships experiencing rapid capsize or sinking following the grounding incident, it is assumed that the passenger monitoring system will not have an effect, as there will hardly be enough time for everyone to abandon ship before it is too late. For the purpose of this analysis it is therefore assumed that the ship needs to survive at least 60 minutes following the collision for the passenger monitoring system to have an effect of reduced risk of fatalities.

According to the risk model and the risk analysis adopted for the purpose of this study, there is a probability of 0.05 for the ship to survive more than 90 minutes conditioned on receiving a grounding damage that causes capsize and a probability of 0.07 if the damage causes upright sinking. The frequencies of such events are then estimated to 1.6 x 10^{-6} and 2.6 x 10^{-6} per shipyear respectively. Furthermore, for these two scenarios with more than 90 minutes available for evacuation expected fatality rates are 5% and 0.3% respectively. For a large passenger ship with 3000 people on board, this corresponds to expected fatality rates of 150 and 9 respectively.

The risk model also predicts a probability of 0.07 for the ship to survive between 60 and 90 minutes if it capsizes and a probability of 0.30 if it sinks gracefully. Hence, the frequencies of such events are estimates to 2.3 x 10^{-6} and 1.1 x 10^{-5} per shipyear respectively. For these scenarios, expected fatality rates are 15% and 5% respectively, corresponding to 450 and 150 fatalities respectively for a passenger ship carrying 3000 people.

It is optimistic to assume that the passenger monitoring system will prevent all fatalities that would otherwise occur in the scenarios described above (time to capsize or sink > 60 minutes). However, for the purpose of this study, it will be assumed that all fatalities in these scenarios will be prevented, and it is acknowledged that this is an optimistic estimate. Hence, an optimistic estimate for the life-saving effect of the passenger monitoring system in grounding scenarios for a passenger ship with 3000 people on board is (eq. 9):

$$\Delta \text{Risk}_{\text{grounding}} = 3.0 \text{ x } 10^{-3} \text{ fatalities per shipyear} \qquad (9)$$

Risk Reduction Achievable from Passenger Monitoring System

Summarizing the expected risk reduction from the risk analyses of the four most important accident categories above, the following total expected risk reduction achievable from implementing the passenger monitoring system on a representative passenger ship is estimated (eq. 10):

$$\Delta \text{Risk}_{\text{total}} = 1.7 \text{ x } 10^{-2} \text{ fatalities per shipyear} \qquad (10)$$

The most significant contribution to this estimate stems from the collision scenario, which represents more than 57% of the expected risk reduction. It is noted that the estimated risk reduction in equation Eq. 10 is believed to be an optimistic estimate.

Assuming an average lifetime of 30 years for a typical passenger ships, the above annual risk reduction would correspond to an expected risk reduction of 0.51 prevented fatalities per ship throughout the ship's lifetime.

COST-EFFECTIVENESS OF THE PASSENGER TRACKING AND MONITORING SYSTEM

Having estimated both the cost of a passenger monitoring system and the expected safety benefits that can be achieved, these figures may be combined in order to calculate the cost-effectiveness in terms of the expected cost of averting a fatality (CAF).

Assuming a passenger monitoring system utilizing active Wi-Fi RFID tags (in conjunction with a ship board wireless local area network), the CAF value is found from dividing the estimated overall cost in eq. 3 with the overall expected achievable risk reduction presented above. Hence, the CAF value associated with the passenger monitoring system would be (eq. 11):

$$\text{CAF} = 4.2 \text{ million USD/fatality} \tag{11}$$

Assuming a passenger monitoring system utilizing the more expensive option (one where it is not possible to use an existing ship board wireless local area network) with active RFID tags and proprietary readers, the CAF value is found from dividing the estimated overall cost in eq. 4 with the overall expected achievable risk reduction presented above. Hence, the CAF value associated with the passenger monitoring system using dedicated readers would be (eq. 12):

$$\text{CAF} = 7.9 \text{ million USD/fatality} \tag{12}$$

These estimates should be considered very crude due to the uncertainties in the cost estimates and risk reduction estimates, but it is still believed to be the best available estimate on the cost effectiveness of such a passenger monitoring system.

CONCLUSIONS AND RECOMMENDATIONS

This paper has presented a cost-effectiveness assessment of a novel passenger detection and monitoring system utilizing RFID technology. Such a system would be of help in an emergency situation requiring evacuation from the ship.

According to the assessment that is outlined in this paper, the cost of averting a fatality (CAF) associated with such a system is in the order of USD 4.2 million or USD 7.9 million for the two alternative solutions that has been investigated herein. Compared to the criteria for cost-effectiveness, USD 3 million, it is found that the passenger monitoring system is not cost effective for either of the alternative solutions.

This conclusion is based on a number of assumptions and some of the estimates are highly uncertain, particularly those pertaining to the cost of the system. Thus, if better estimates become available as the technology matures and the system is being developed, this cost-effectiveness assessment should be updated. Also, the price of RFID technology is expected to drop as RFID applications become more commonplace. From the assessment presented herein, it is found that with the current cost-effectiveness criteria, such a system would need to be available at a lifetime cost of less than USD 1.53 million (NPV) for the system to be cost-effective. The Wi-Fi RFID real time location systems, with an estimated NPV of USD 2.15 million, are not too far from this figure and further developments may result in them being cost-effective.

Also the cost-effectiveness criteria of USD 3 million should be updated from time to time, and as society as a whole becomes less tolerant towards risk, this criteria may expectedly increase. Increases in gross domestic products and other societal indicators should also be a reason to update risk acceptance criteria from time to time (Skjong and Ronold, 2002; Skjong and Vanem, 2004; Ditlevsen and Friis-Hansen, 2008; Ditlevsen, 2008). However, the current criteria would need to be increased by 30% in order to render the passenger monitoring system cost-effective. This is not foreseen to happen in the near future.

Thus, it is concluded that the passenger monitoring system with the function of tracking passengers throughout the ship, as described herein, does not represent a cost-effective risk control option at this point in time. It is therefore argued that this system should not be implemented based on safety considerations alone. However, it is noted that it is possible that further technology and system development for ship board use may result in a system that may turn out cost-effective in the near future. Further, future investigation may be warranted to obtain more detailed estimates. Lower cost RFID system with reduced functionality, perhaps with only the ability to monitor passengers at specific locations such as muster stations, could also be an alternative solution and it is emphasized that this is not what has been evaluated in this study. Potentially, similar systems may prove to be cost-effective and the conclusion put forward in this paper only applies to the particular systems that have been subject to assessment.

In addition to the safety considerations, there could, however, be other good arguments for implementing a passenger monitoring and tracking system onboard a passenger ship. RFID tagging of passengers may have other benefits, and as such it might represent a promising option for owners from a commercial perspective. For example, NEC (2008) reports that an RFID system has been implemented at Singapore Cruise Centre, resulting in less congestion, more reliable departure times and improved boarding procedures. Other additional uses of such a system could be for payment in bars, shops, etc. onboard the ship or for tracking luggage, inventory, etc. Thus, the passenger monitoring system might be attractive to owners and operators of passenger ships even though this assessment concludes that it is not cost-effective considering only the safety benefits and its potential to reduce risk to life at sea.

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