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Masterthesis

Safety of Passengers during Evacuation Processes - Alternative Escape Routes

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List of abbreviation

BG-Verkehr	Berufsgenossenschaft für Transport und Verkehrswirtschaft
CA	Cellular Automata
CLIA	Cruise Lines International Association
CSSF	Cruise Ship Safety Forum
EU	European Union
FSEG	Fire Safety Engineering Group
GL	Germanischer Lloyd
IMO	International Maritime Organization
LSA	Life Saving Appliances
MSC	Maritime Safety Committee
PS	Portside
RTD	Response Time Distribution
SAR	Search and Rescue
SB	Starboard
SDC	Sub-Committee on Ship Design and Construction
SHEBA	Ship Evacuation Behaviour Assessment facility
STCW Convention	Standards for Training, Certification, and Watchkeeping for Seafarers Convention
TNO	Netherlands Organisation for Applied Scientific Research

1 Introduction

Within the last years the demand and supply for cruises has risen steadily. The market share of the cruising industry increased significantly with the result that cruise liners became bigger in size. The growth of the industry is very rapid, because of that it is questionable whether safety rules and regulations are still appropriate for ships carrying thousand of passengers. In case of an emergency it is a hard challenge to evacuate people in a safe and fast manner like recent events have shown.
The question which arises is: Is there potential to improve safety on passengers ships to evacuate passengers and crew members in case of an emergency as safe and fast as possible?
Until now no rule or guideline requires a compulsory evacuation analysis for all passenger ships. Consequently, it is uncertain whether the safety precautions on cruise liners are sufficient to ensure an evacuation in a proper time range.
This is one more reason to investigate on the safety during evacuation processes. Within this thesis the need of alternative escape route concepts and their impact on the overall evacuation process will be investigated and assessed.

First of all, most important research projects in recent years and their results are presented to give an overview about the topic safety on passenger ships in general and collect approaches for possible concepts for alternative escape routes.
Furthermore, relevant rules and regulations like SOLAS and FSS-Code will be considered. The decisive rule for the evacuation analysis will be MSC/Circ.1238.

To assess the alternative escape route concepts evacuation simulations are conducted. Base of investigations is an example passenger ship, which was planned according to current rules and regulations. Two typical zones are chosen from the example vessel. These zones represent a typical arrangement of a cruise liner with passenger and crew cabin decks, public spaces and open decks.
The evacuation simulation is done with the simulation software Aeneas. To evaluate the alternative escape routes concepts the modifications are implemented in the model. The results of the initial cases and the modifications are compared and assessed. Within the evaluation maximum, minimum and significant travel times as well as recordings of the evacuation processes, evacuation curves and density plots are taken into account. This data provides information about the possibility to evacuate people faster and safer than previously.

The modifications which will be considered within this thesis cover five approaches. The first one is changed dimensions of escape route components. It is examined if under circumstances modified dimensions can already improve the evacuation processes.
Within the second modification on heel support systems is investigated. One research project collected data of passenger behaviour under heel and trim conditions. These results are the basis for the provisions of a support system to improve the evacuation process when the declination of the ship changes.
The third modification includes additional escape route components like doors or stairways. Moreover, the impact of redirecting people over an alternative escape route is investigated.
The fourth investigation considers alternative rescue systems. One new rescue system is the ResCube, which enables an evacuation of passengers on six decks in parallel. Another alternative rescue system could be evacuation slides to transport people faster from the cabin deck to the

embarkation deck.
The last investigation takes individual parameters into account. Two different approaches are investigated. Within the first one all passengers are distributed on the cabin decks during the night case according to their age. The second approach investigates on the influences of the parameter response time distribution given by MSC/Circ.1238 and the research project Safeguard.

In conclusion recommendations for promising improvements on passengers ships to achieve a safe and fast evacuation process will be given. Therefore, the best opportunity is an intelligent guiding system, because it improves the evacuation process significantly. Moreover, an evacuation analysis for all passengers ships according to MSC/Circ.1238 should become compulsory. This regulation is analysed according to currency and transferability of data as well.

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2 Descriptions of accidents with regard on evacuation processes

Current statistics like in figure 2.1 show that in one year approximately 1.7 passenger cruise vessels are total losses. It has to be considered that the size of passenger ships becomes steadily bigger, for example the "Allure of the Seas" can carry more than 8000 passengers and crew members. In case of an accident thousands of people are in danger.
Recent accidents, e.g. Costa Concordia, shows that urgent steps need to be taken. Accidents will never be prevented, but the number of victims can be minimized.
To make the necessity of an investigation on alternative escape routes clear two ship accidents are described with regard on the weak points during the evacuation processes.

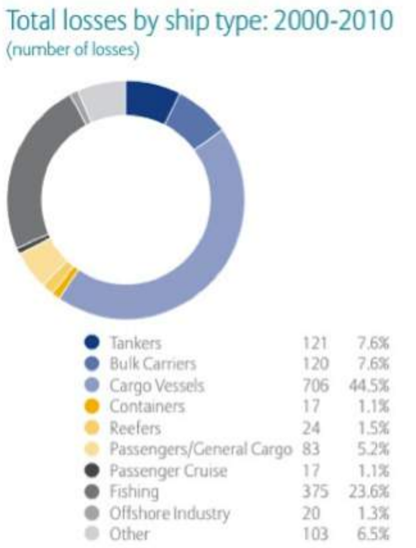

Figure 2.1: Total ship losses, Source: [28]

Fact sheets with main data of Costa Concordia and Star Princess can be found in table 12.1 and 12.2 (Annex).

2.1 Costa Concordia

2.1.1 Description of occurrence

At the 13th January 2012 the passenger ship Costa Concordia, which was launched in 2005, was on a trip through the Mediterranean Sea. On board were 4229 people, distributed in 3206 passengers and 1023 crew members. At 21:45 (local time) the ship collided with the Scole Rocks at Giglio Island in the Tyrrhenian Sea. The Master navigated the ship in very close and thus unsafe distance to the coastline. Moreover, the speed of 15.50 kts was too high for manoeuvring in shallow water. After the collision, the ship decreased in speed and heeled immediately.

In a minimum of time the ship was out of control, because of the loss of propulsion. Moreover, the rudder blocked at starboard side. Due to wind and currents the ship turned starboard and grounded at Giglio Island. This caused a breach with a length of 53 metres.
After 40 minutes the water already reached the bulkhead deck in the aft area. Consequently, the watertight compartments five and six, and later also the compartments four, seven and eight were involved. In accordance with the SOLAS requirements the ship could only withstand the flooding of two adjacent main compartments.
The SAR operation were just started at 22:16 after a person from the shore informed the authority. The Master itself communicated with the SAR Authority for the first time approximately 45 minutes after the breach and flooding occurred.
At 22:35 the Master decided to abandon the ship. However, the Master did not initiate the general emergency alarm, only announcements to go to the muster stations were made. But several passengers did not react on these announcements. This caused an enormous delay of the evacuation procedure considering the collision was already a little bit less than one hour ago.
At 22:55 the ship began to drop first lifeboats with passengers on starboard side. Half an hour later still 300 people were on board, but the Bridge Team including the Master abandoned the bridge. At midnight a heel of 40° was received and increased until 80° during the rescue operation. The rescue operation was finished at 06:17. 4194 people could get rescued whereas out of this 157 people were injured. Until the 5$^{\text{th}}$ of January three more people were rescued [1].

This incident was investigated in detail by the Ministry of Infrastructure and Transport. The results of the analysis with regard to the evacuation process will be presented in the following.

Navigation

As described above the Master navigated the ship in shallow water in night conditions with high speed with inappropriate cartography. Moreover, the attention of the Master was rather limited because of the presence of visitors on the bridge and a phone call. The bridge was adequately staffed by crew members, but nobody paid sufficient attention to the developing situation. In conclusion, a passive attitude of the whole Bridge Team is significant and expresses without any doubt an irresponsible behaviour and decision-making [1]. This raises the question of improvements in organization and the importance of the role of each crew member as well as the interaction between those.

Alarm

The General Emergency Alarm was not activated directly after the crash, only at 22:33. This caused a delay in the management of the evacuation process, which did not run straight forwarded. Detailed inquiries showed inconsistencies in crew certification, the muster list and the status of training [1].

Communication

Due to the fact that no direct orders were given from the bridge, the management of the evacuation process was hindered and delayed [1].

Evacuation

After the collision an immediate flooding occurred and the ambient conditions changed very fast. This explicitly includes buoyancy, trim and list. Under these extreme conditions a safe and orderly evacuation was nearly impossible [1].

Human Factor

The investigation on this tragic event showed that the most influencing factor was the human factor. A lot of minor discrepancies added up and ended in a catastrophe.
In consideration of compliance of crew members a surprisingly high number of 38 different nationalities are transpired. The company Costa Crociere recruits its personnel via 25 different external agencies spread all over the world. The first disadvantageous is that for the Flag Administration the control of the good quality of recruited personnel is difficult. Moreover, the company should have been aware of language barriers between the crew members itself as well as between crew members and passengers.
The language on board has to be established according to SOLAS requirements. The choice of a widespread, international known language is obvious and would have given many advantages for communication. But the chosen language was Italian.
During the investigation US passengers were surveyed and they testified during emergency several crew members in the muster station were not able to speak English. Furthermore, they were inadequately prepared with the safety procedure.
The analysis of crew certification showed that the training of the crew was not fully responsive to the needs. At 15^{th} October 2011 a training drill for abandoning ship had been carried out. The level of performance of the crew was very low. Consequently, the Master informed and warned the company Costa Crociere about the critical findings.
But also during the incident nobody on the bridge coordinated the emergency with the muster list and the related procedure for abandon ship. And the Damage Control Plan was not used to evaluate the possible actions to be adopted.
In this regard, an explanation for the completely disorganized evacuation during the incident can be found. It is proven that the root cause and progress of the incident is caused and negatively influenced by the human element [1].

2.1.2 Summary

It was a fortunate coincidence that the ship was drifting due to current and wind very close to the coast and grounded in the shallow water. The rescue unit had a very short way between the Costa Concordia and the shore. Probably this saved a lot of lives.
Main influence on the course of the evacuation procedure was the failure of all crew members. The lesson we learn is that adequate crew training is absolutely necessary. Without a well-trained crew no evacuation process will be successful, because crew members are responsible for organisation, guiding, support and controls. Evacuation processes are a very complex issue, which are planned in detail by shipping companies. If only one element in the chain fails, the total process is endangered. Obviously, during the evacuation process on Costa Concordia more than one chain failed.
As it turns out the human factor in an emergency cannot be accurately predicted and evaluated in advance. That is why this thesis will focus on structural modifications for alternative escape routes aiming for a faster and safer evacuation process.

2.2 Star Princess

2.2.1 Description of occurrence

At the 23rd March 2006 the Star Princess was on a passage from Grand Cayman to Montega Bay in Jamaica with a speed of 17.7 kts. It was 03:09 (local time) and wind direction was northeast with force 4, but the sea was calm. On board were 2690 passengers and 1123 crew members.
At 02:50 the security patrol smelled burning on port side and reported this to the officers. Subsequently, the area was checked, but the cause of the smell was not found. Unfortunately, the suspicion of something burning was not unfounded. A few minutes later a fire started on an external stateroom balcony sited on deck ten in the centre of main vertical zone three on port side.
At 03:09 a manual call point alarm was activated by a passenger. At the same time the bridge lookout reported fire as well. The cause of the fire was a discarded cigarette that heated combustible material on a balcony. Before flames developed it smouldered for about 20 minutes. From then on the fire spread very fast along the balconies in fire zones three and four. Within further six minutes the fire spreads up to deck eleven and twelve because of the strong wind. After 24 minutes, also fire zone five was involved.
At 03:13 the crew alert was started and the fire screen doors in fire zone one, two and three were closed. Besides the ventilation was stopped, the speed was decreased and the direction of navigation was changed. Just a few minutes later the passengers were instructed to go to the muster stations.
The ship had four muster stations (A to D), which were public areas on deck seven. The maximum number of passengers at muster stations was between 535 (fire zone: B) and 1064 (fire zone: C). First head counts were made after 1.5 h after the General Emergency Signal. The subsequent roll call took between two to three hours, because it was repeated several times. Since in fire zone C no loudhailer was available huge difficulties to control the passengers occurred.
However, the fire shattered the glass of the balcony doors, but the staterooms were fixed with fire-smothering systems, restricted combustibility of content and thermal boundaries. Nevertheless, large amounts of black, dense smoke developed, which entered the staterooms and alleyways. Of course the smoke influenced the evacuation process of the passengers especially on deck twelve. The visibility was very poor and inhalation of the smoke dangerous. Due to the smoke one passenger died and thirteen additional people were injured.
With water hoses the crew members did the fire fighting. It turned out that it was difficult to reach the balconies due to the construction. 79 staterooms were condemned, 218 were damaged because of fire, smoke or water. The damaged area covered three vertical zones on five decks. Finally, the fire was distinguished at 04:36 [3].

The Department of Maritime Administration of Bermuda investigated the incident in detail. The results of the analysis with regard on the safety processes will be described in the following.

Communication

On the part of the Master the communication and information of the passengers was commendable. The Master kept the passengers fully informed with frequent and comprehensive announcements [3].

Human factor

The crew members were composed of a wide variety on nationalities and professions. The ship officers were British and Italian. The work language on board was English.
All crew members should be able to conduct emergency duties, for example stairway guides or muster personnel. Therefore, the crew received on board training, but according to witness reports, several crew members had no knowledge about the accounting procedure. For instance, a crew member in charge of muster station A had no experience in conduction a roll call, which describes the control of attendance of all passengers allocated to the muster station, although she was engaged since six years in passenger muster duties.
And, apart from the missing experience usual communication problems are added. During roll call difficulties with the language in general, pronouncements of names, identical surnames can occur. But also passengers can hinder the roll call due to restricted hearing ability. Call up 500 names take approximately one hour. Imagine problems occur and the roll call has to be repeated several times. It is obvious that under such conditions no fast evacuation is possible.
Actually the purpose of a muster station is to be a place of safety for the passengers. Whereby the responsible crew member should ensure all passengers are in place and the embarkation into the survival crafts happens in a controlled manner.
All the inconsistencies on board of the Star Princess resulted in the inability to identify the deceased passenger until over six hours after the General Emergency Signal [3].

2.2.2 Summary

This accident showed again the importance of well-prepared and trained crew members. Fortunately, the failure of some crew members had no significant influence. In this incident no full evacuation had to be done, because the fire was brought under control and the ship could drive independently to a safe place. But fires occur quite often on ship accidents and are a danger that should not be underestimated. A fast development and expansion of smoke and gases influence the visibility and health related aspects. On board of the Star Princess one passenger died because of the inhalation of toxic smoke and several others got injured.

The conclusion of both ship accidents is that the human failure occurs because of insufficient emergency training or other reasons. Nevertheless, passengers have to be evacuated in case of an emergency as fast and safe as possible. That is why the concepts of alternative escape routes will not base and rely on assignment of adequately trained crew members, but rather on independence from ship personnel.

3 Research projects

In this chapter different research projects and their findings will be presented to give an overview about the current status, fields of research and development with regard on safety of people on passenger ships.

3.1 Handiami

The Handiami Project was launched in November 1997 and ended in October 1999. The European Commission under the Transport Programme of the 4^{th} Framework Program funded it. The research team considered a wide range in their analyses. Therefore, the team visited high-speed and ro-ro ferries and participated in abandon ship trainings. Moreover, the team attended on conferences on cruise liners, conducted surveys and interviews and participated in workshops focusing on disabled people [4]. The studies and results will be presented in the following.

3.1.1 Disability

The Handiami project was the first one, which investigated on the view of disabled people and tried to integrate the results in the vessel design. Usually adaptions or changes of conditions for disabled people are associated with separate or additional provision of equipment and assistance. The project aimed for a “Design for All” meaning inclusion of special needs in the design. Therefore, all kinds of passengers with their individual properties and claims were taken into account.
Descriptors for identifying the needs of elderly and disabled people were chosen. Those descriptors are: learning difficulties, mental health, hearing impairment, visual impairment, mobility impairment and wheelchair users.
Ships in operation were designed and built many years ago, when the awareness of disability was not up to date. Moreover, no commercial pressure for improvements was exerted. Clearly, the demand for perfect accessibility on old vessels is unrealistic and very cost intensive, but minor improvements with minimal costs and disruption should be intended. The challenge is to work consistently on accessible vessels without designing a financial burden. This requires knowledge about the needs of disabled people. Otherwise, there may be the tendency to focus too much on wheelchair users, which in turn leads to disadvantageous for other disabled people. The demographic of disabled people should not be misunderstood. For example, for people with sensory impairments, simple and inexpensive equipment is already helpful [4].

3.1.2 Ageing Population

It is not surprising what the research team found out about ageing population. The percentage of elderly people is increasing and people living longer today. Consequently, the demographic change has impact on the market share of passenger vessels in travel and tourism [4].

This raises the issue of the extent to which elderly and disabled people are already taken into account by the regulations. MSC/Circ.1238 specifies the passenger population, which is to use to conduct evacuation analyses. Compared to statistics published in 2011 by CLIA an explicit difference is identified. To make the numbers comparable some simplifications are made. The IMO separates people who are older than 50 years depending on the degree of impairment. On the other side CLIA subdivides higher ages in 50-59, 60-74 and >75 years. In diagram 3.1 60-74 years old people are put on level with mobility impaired people (degree 1) and >75 years old people are equal to mobility impaired people (degree 2) [5, 22].

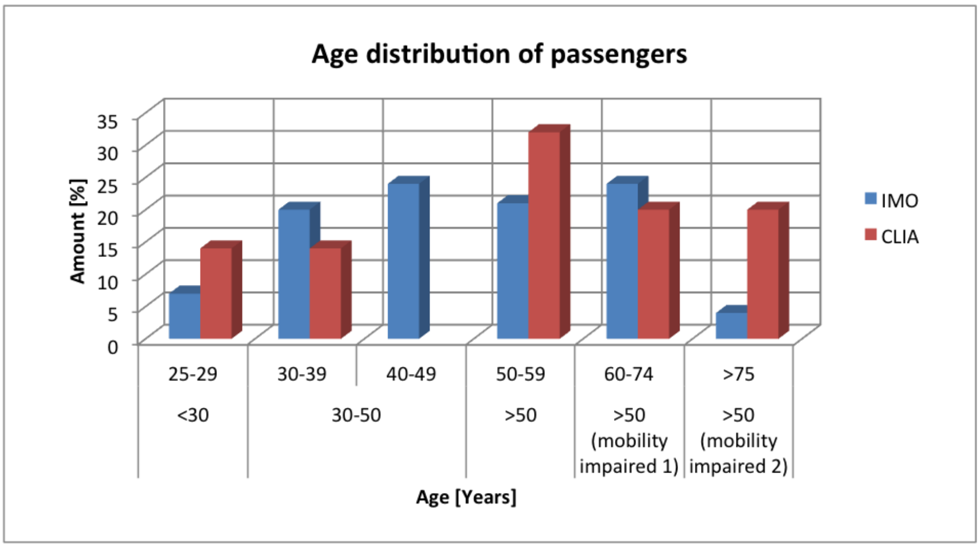

Figure 3.1: Comparison between IMO and CLIA, Source of data: [5, 22]

Obviously, the amount of people with an age >50 years is much higher than stated in the regulation. Whether all people above an age of 60 years are really mobility impaired is questionable. But it can be assumed that elderly people have restrictions of any kind either sensorial impairments or learning difficulties. Consequently, the group of elderly people on passenger ships is growing and has to be considered in terms of safety, especially in rescue- and evacuation processes.

The challenge for the industry is to meet the needs of disabled and elderly people and fulfil the expectations of the market as well. Findings in the maritime industry brought to light the difficulties of tourist in accesses, especially during embarkation and disembarkation. The design of accessible vessels should incorporate the needs of this group providing a high level of customer care [4].

3.1.3 Training

The training level of crew members plays an important role in improving the access and the procedures in emergency situations. Recommendations for training are given by STCW Convention. This convention deals with mandatory minimum requirements for the training and qualification of masters, officers and other personnel on ro-ro passenger ships. Additionally, it refers to training in crowd management, familiarization training, safety training, passenger safety, crisis management, and human behaviour. Within the crowd management a directive on

the evacuation of disabled people and those who need special assistance is included.
The recommendation describes the key issues in safety training, for example the communication with passengers during emergencies. If oral communication is not possible any longer than demonstrations or hand signals are an opportunity to give instructions [4].
The incident on the Star Princess, described in chapter 2.2, gives a negative example. Due to fire, passengers had to go to the muster station. Unfortunately, in fire zone C no loudhailer was available and the responsible person for the roll call had huge difficulties [3].

The findings of the Handimai project showed that the majority of operators do not pay enough attention to the training of their ship crews. Only rudimentary trainings are provided for officers and other personnel. Moreover, in emergency drills and evacuation procedures no representative passenger population was used. A realistic training environment would include elderly and disabled people, but no special trainings on handling with this group of people were conducted. The safety of disabled people means to reconsider the approach so far and adopt fundamentally different emergency procedures. Trainings for crew members shall review the opinions and beliefs regarding disabled people. The transfer of knowledge on disability issues can remove barriers, reduce the fear of communication, and improves work in general. The implementation of training standard in the rules and regulations is inevitable, because disabled people deserve the same quality of service as other passengers.
In conclusion at the present crew training with regard on elderly and disabled people is inadequate and ineffective. Moreover, disability awareness training should also be given to naval architects, designers, and all crew members servicing on a passenger ship [4].

3.1.4 Design

The whole design of a vessel plays the major role in providing an accessible, safe, and comfortable passenger ship. The design issues that are taken into consideration are the vessel design in general, lifesaving equipment, general information, and alarm systems. The aim is one key concept, which improves the effectiveness of all elements. The concept should be usable by all people as far as possible. Benefits are offered not only for elderly people, but also for children, adults with small children, pregnant woman or injured person [4].

One work package of the Handimai project dealt with the topic what we can learn from designers and architects involved in other modes of transport or public spaces? In the maritime transport especially access requirements are important, because this decides whether disabled people travel with passenger vessels. Improvements in accessibility, e.g. obstacle-free passageways, have advantageous for all passengers and crew members due to the increased mobility [4].

As part of the project two case studies on a ro-ro vessel in service and a preliminary design of a car ferry were conducted. In order to achieve full access following design features were addressed: barrier free passage, access to gangways, corridors and passageways, steps and stair lift, handrails, doors, deck and floor surfaces. The challenge is to have barrier free access to the muster stations, safe areas or emergency equipment.
For people with sensory impairments meaning visual, hearing, and mobility impairment, as well adequate information, signage, and alarm systems should be available. For example for deaf and hearing impaired passengers visual warning could be added. Another possibility is issuing passengers with vibrating personnel alarm they carry along during the voyage all the time [4].

Ship personnel needs information before the journey starts about the number of disabled people as well as nature and extent of impairments. Prior to boarding a package of information with detailed information on all assistance devices and safety procedure in order to gain knowledge about the use of support system should be handed out.
The problem with this is the self-identification that has to be done by the passengers. It is to be expected that not all necessary information are given to the operator, because people are not personally conscious [4].

Operators, which were involved in the project, argued that specific evacuation equipment increases the costs and renders the business unviable [4]. Obviously, to achieve ideal standards significant costs and inconvenience occur, but in order to protect passengers it should at least tried to improve accessibility and evacuation procedures as far as possible.

3.1.5 Evacuation

Case studies of vessel emergencies were conducted for the research project. Some findings will be given in the following:

- Wheelchair users were carried during embarkation and disembarkation.
- Crew and officers had no specific emergency evacuation training and no knowledge about the handling of disabled and elderly people.
- Accesses to life rafts have usually a few steps or the passenger have to climb into the life raft [4].

Especially wheelchair users need assistance when the way is not barrier free. Moreover, due to current regulations (SOLAS, Chapter II-2, Rule 13) it is not allowed to use lifts during emergencies. Therefore, wheelchair users are usually carried over the shoulder. That is why proper training of crew members in lifting and carrying techniques to reduce the risk of injuries should be ensured [4].

Preparing the crew to demands in an emergency situation plays a very important role. To gain certification evacuation drills should be performed in strict time constraints. But usually full-scale trials do not reflect the reality. One factor is that passenger population are no representative samples. Sometimes test are carried out with the ships own crew or young and fit people. And, apart from that, tests are not at sea and take the mustering process not into account. This results in a trouble free and unrealistic condition. Of course, such tests do not prepare a crew adequately [4].
Demonstrated is this by the investigation report of the Costa Concordia as well. The inquiry into the accident clarified the untrained status of the crew members. Although the Master noticed that and informed the company, nothing was improved [1].
Equally, the crew on the Star Princess was not prepared appropriate. Six hours after the General Emergency Alarm the crew was not able to identify the deceased passenger [3].
Those examples show how over challenged, helpless, and inexperienced the crew members behave in emergency situations.

3.1.6 Summary

The most important findings which resulted from the Handimai research project are listed in the following:

1. Disabled and elderly people have to be taken into account by the maritime industry thus from naval architects, designers or even lawyers. Those qualified employees should share their knowledge to improve accessibility and evacuation processes on passenger vessels.

2. The market share of disabled and elderly people is high. It is essential to consider their needs in the design and operation to offer a high level of customer care.

3. Training practices are inadequate, ineffective and need to be improved. Moreover, disability awareness training should be obligatory for all crew members.

4. The design of information, signage, and alarm systems should correspond to the needs for people with sensory and mobility impairments.

5. Design, deployment and training must mesh together to achieve a safe evacuation of all passengers [4].

3.2 Sheba

The Ship Evacuation Behaviour Assessment facility enabled the collection of passenger ship evacuation behaviour performance data, which can be used for development of computer simulation software. This facility was designed and constructed in the laboratory of BMT Fleet Technology Limited in Ottawa, Canada. During an operation time of two years a huge amount of data about timing and behaviour of personnel was collected. Those results of initial series of test were incorporated in the software maritimeEXODUS. In particular by implementing speed adjusting factors depending on mobility at certain angles, gender, and age.
The Fire Safety Engineering Group of the University of Greenwich developed maritimeEXODUS with the assistance of BMT Fleet Technology Limited and Transport Canada [6].

Main data of facility

The SHEBA facility consists of a muster room, corridor, steps and staircases leading up to a platform. The dimensions and outfitted spaces are similar to a typical arrangement on passenger vessels. The whole facility is mounted on hydraulic ramps allowing a heel up to 22°. Moreover, it is possible to create smoke and cyclic motions.
Instead of a solid roof, a framework of structural members is on top of the facility. Therefore, it is possible to monitor the behaviour of test personnel with optical sensors and video cameras. During the trails the lights in the main building were dimmed to minimize impact and to keep test personnel focused on marine lighting system and emergency lighting system [6, 7, 8]. The arrangement is shown in figure 12.1 (Annex).

Data collection system

The main objective was the measurement of walking speeds of individuals. Resources available were five optical sensors, which transferred data to computers. The arrangement of the sensors shall avoid the influence of acceleration and deceleration phases of movement.
A certain computer program enabled the calculation of speeds of individuals with data of sensors. Group behaviour was analysed from recorded videos. Six cameras were installed overhead and the exact position of the recorded location was characterized by black lines [6]. The arrangement is shown in figure 12.2 (Annex).

3.2.1 Ship evacuation tests

The test personnel composed of a full range of ages from 8 to 80 years old voluntaries to achieve a well-balanced mix. A test group comprised of 15 people.
The initial studies were conducted in 2001 to determine the flow rate through a typical part of a ship structure. First of all, individuals walked through the facility without test situation to record their fast walk speed. This was done at static angles as well. The focus was moved on the angles 0°, 10° and 20°. To create a sense of urgency during the test periods announcements to abandon the ship, alarm, and bells sounded [6, 7, 9].

Group behaviour

To assess group behaviour and the speed of a group not only single runs, but also group runs were conducted. The people were packed very close at the starting point. During this tests often overtaking and close packing at the stairs occurred.
These tests were also done with static angles. Therefore, people collected in the muster station and only then the facility was tilted to a certain angles. Thus, a surprising effect was generated and avoided to plan a strategy in advance.
At 0° three people walked across the total width and high flow volume was possible. At higher static angles no one walked in the centre of the passageway. Usually people held onto the handrails on the side of inclination. Obviously, this decreased the flow rate.
Furthermore, counterflow was performed with two groups of seven or eight people that were entering at the end of the rig or in the mid of the corridor. This allowed studies on passing behaviour and effects on walking speeds in detail [6].

Results

All the conducted tests were analysed including the development of speed modifying factors as a function on gender and angle.
At the beginning to all test personnel was given a demonstration in donning a lifejacket. Afterwards they were asked to put on the lifejacket on their own and the required time was recorded. This is simple task, but some participants were not able to use the lifejacket adequately in a certain time frame. In a real emergency situation this can have fatal consequences. The required time verified between 8s and 26s, but the mean time was 17s.
The evaluation of individual walking speeds in the passageway showed that there need to be distinctions between males and females. In general, angles up to 10° had little influence on the speeds. And heel angles had less impact on the speeds of males.
As shown in figure 3.2 males were faster between heel angles 0° and 10°. The speed slightly

decreased again between 10° and 20°, but was still faster than at 0°. Whereas the speed of females decreased considerably between 0° and 10° and the steep of the graph increased even more between 10° and 20° [6].

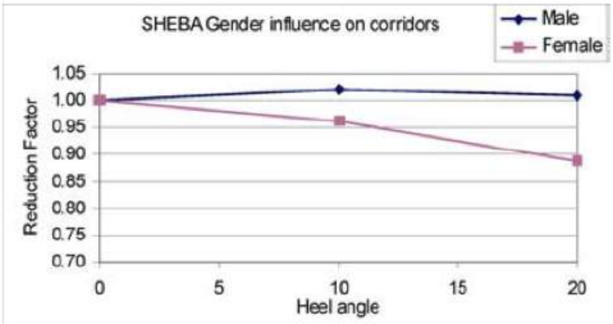

Figure 3.2: Gender influence on speed in corridors, Source: [6]

A significant share on the walking speed had the wearing of lifejackets too. This is shown in figure 3.3. The speeds of those people wearing a lifejacket were slower than the speed of test personnel without lifejacket at 0°. The speeds were the same for both groups at 10°. But at 20° an influence was remarkable. People wearing a lifejacket were faster than those without. This might be due to fewer hesitations to get injuries, because the lifejacket protected the body. In general, at higher angles a more aggressive walking behaviour occurred [6].

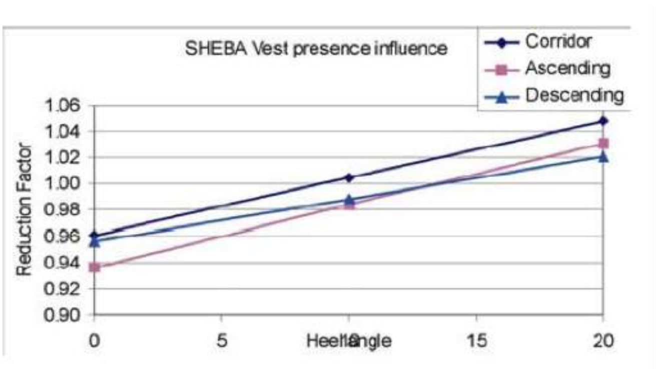

Figure 3.3: Influence of wearing a life vest on speed, Source: [6]

3.2.2 Naval configuration

In 2002 the SHEBA facility was modified and some typical naval elements were included. These elements were: vertical ladders, watertight doors, hatches and steep stairways. A series of tests were conducted with 0° and static heel angles. The arrangement of the naval configuration is shown in figure 12.3 (Annex).
The watertight door and hatch with a sill had single wheels in the middle of the door. Moreover, a vertical ladder and stairs with handrails were implemented. Another stair was used for trim tests on a separate facility. The external facility composed of two stairs back to back with a platform on the top. This facility could be tilted up to 10° fore and aft. For the test with the second stair only experienced shipboard personnel and fit members of public between 18-45 years were chosen. During this tests no lifejacket were worn [6].

Results

Figure 3.4 shows the results of this series of test with the vertical ladder. This is just another example for the necessary distinction between male and female. Females were significantly slower in ascending and descending a vertical ladder [6].

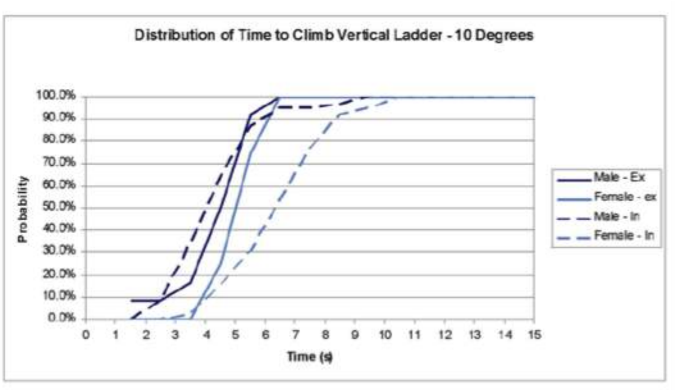

Figure 3.4: Results descending and ascending vertical ladder, Source: [6]

3.2.3 Smoke and cyclic motion

In 2003 and 2004 even more modifications were made to allow cyclic motion and a corridor filled with smoke. The facility was fitted additionally with motion sensors and infra-red cameras [6, 7]. Following variables were captured with each experiment: time through the corridor, time up and down stairs, which side of corridor and stairs were preferred, rate and kind of motion, collision points and congestions. The volunteers for these trials were between 8 and 80 years old.

The smoke density level could be chosen between 0.00 m, 0.50 m, and 1.00 m optical densities and was controlled by optical density sensors. Other dangers of fire and smoke such as noxious gases, reduced oxygen and heat were not simulated.
The cyclic motions was achieved by hydraulic actuators that were controlled by software. There the possibilities to create 5-15 s roll periods overlapping with heel from 0° to 20°. Trails with motion were conducted with a younger group of people. Moreover, hatches and ship doors were avoided to reduce danger of injuries like pinched fingers.

Results

In general, the trails with smoke showed that reduced visibility results in reduction of speed. Only a few people were pushing and causing collisions.
People walking up and down stairs tended to go on the right side. The reason is still unknown but could be because of the motion or right-handed people. As a consequence less congestion developed. Most of the people walking in the corridor tended to keep on one side, only a few were characterized by an aggressive behaviour and used the middle of the floor.

3.2.4 Summary

The data and results from SHEBA evacuation test were submitted to IMO and incorporated to the analysis protocol of MSC/Circ. 1238 [6].
The facility was an important development because it allowed full-scale ship evacuation behaviour tests. Moreover, the effect on mobility due to heel angles could be researched as well as performance of crowds, counterflow, behaviour on stairs, ladders, and doors. Unfortunately, only a few results from the tests trials were published. Due to the amount of tests and different investigations it is assumed that much more data exist on the topic.
In 2005/2006 some efforts were made to validate the results. Therefore, a Mediterranean ferry was chosen and equipped with cameras and timer. The data of conducted trials were compared to SHEBA and showed remarkable similarities.
Nevertheless, some restrictions must be made considering the transferability to reality. Although it was tried to create a real emergency situation with announcements, alarm, bells and dimmed light the behaviour of humans in a real emergency is incalculable. A complex room and escape route arrangement, individual perception of the hazardous situation and panic with impact on the perception, influence the human element in emergencies. Those influencing factors are difficult to reproduce in a test situation. Moreover, voluntaries participated in the tests. It is imaginable that during a real emergency the behaviour of people differs from the test results. On the other hand, test under real condition will not be possible due to moral and ethical reasons.

3.3 Safecrafts

Safecrafts is a EU sponsored project that ran from 2004 to 2009. The development project focused on evacuation systems on passenger ships as well as alternatives of rescue equipment. The main objectives was the assessment of the performance of life saving appliances and the development of two new concepts [15]. The following descriptions will only address novel concepts.

3.3.1 Novel concepts

Self propelled survival craft (SPSC)

This survival craft can carry 400 people and will be stored in the aft of the vessel close to the midship. The ejection is carried out over the stern where the survival craft is sliding down a ramp. The required space is equal to common lifeboats. The advantage is that less valuable space inside the vessel is used instead of deck space [15].

Hard sided life raft (HASLIR)

This kind of liferaft can carry 400 people as well and is fitted with rigid sides that contain propulsion such as small diesel engines or electric motors. Thus HASLIR is a self-propelled life raft, which is located at embarkation deck. The required space is less than for usual lifeboats and only one deck is affected. Moreover, the weight is very low meaning easy launching with a simple crane [15].

ResCube

Not included in the official investigation report is the development of the ResCube within the research project.

Norsafe, a provider of evacuation systems in maritime and offshore industry, launched the ResCube. The field of application will be passenger ferries and cruise ships. The main problem on such vessels is the huge amount of passengers, which have to be evacuated in case of an emergency. Nowadays one deck is provided for the embarkation in lifeboats or rafts resulting in a lack of space, congestions, and crowds. The ResCube allows evacuation from more than one deck at the same time, because it is installed vertical and covers up to six decks. One ResCube can carry 330 people and is launched with a free fall system. According to manufactures specification the ResCube reduces the required deck space compared to ordinary life saving equipment up to 30 %. The disadvantage compared to common lifeboats is a longer travel time to water surface [16, 17]. A principle arrangement on ResCube is shown in figure 3.5. More representations can be found in figure 12.4 and 12.5 (Annex).

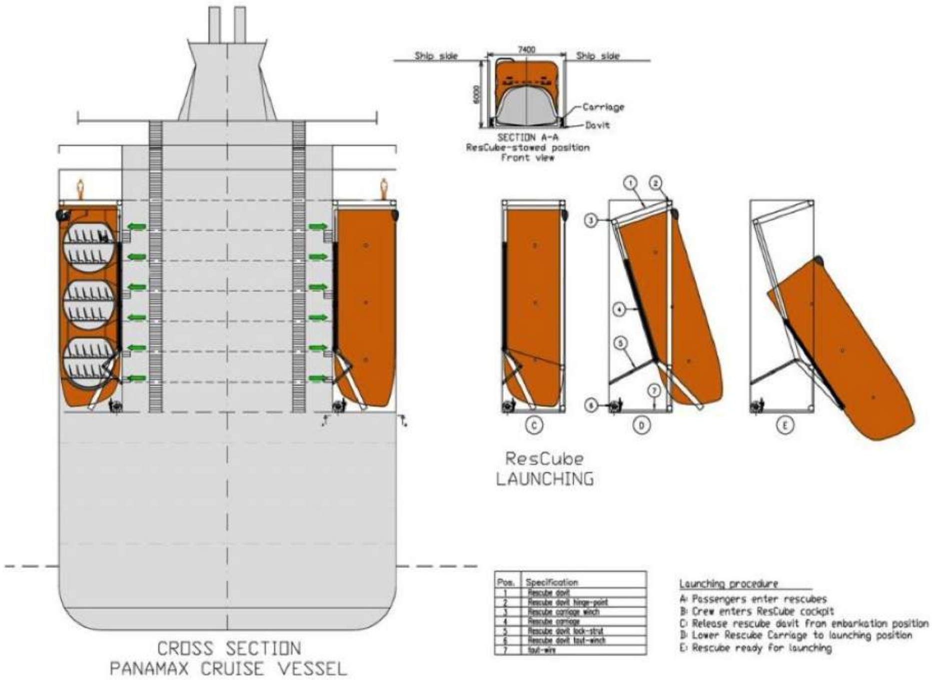

Figure 3.5: Arrangement of ResCube, Source: [17]

3.3.2 Summary

Within this thesis the concept of ResCube will be investigated only. The approach to embark passengers on several decks at the same time is very interesting with regard on a fast evacuation of passengers. That is why the concept will implemented in the model and investigation will be done.

3.4 Safeguard

In the guidelines for evacuation analysis for passenger ships in MSC/Circ.1238 data from the project Fire Exit were established. These response time distribution data relates to the ferry Eurostar Rome, a RO-PAX vessel with cabins, on which two assembly trials were conducted. Only 194 response time data points for day and night case were investigated. Within the Safeguard project this was assessed as few amount of data and little representative. That is why further investigations were done within the research project [10].

Safeguard is a research project funded by the European Commission 7th Framework Programme Sustainable Surface Transport and ran from 2009 to 2012. Main objective was the collection and characterization of data for human performance during evacuation processes with full-scale trials. Especially the response time, meaning the time between alarm and the beginning of movement to assembly stations, was considered. Besides, data about starting locations, arrival time at assembly stations and passenger assembly routes were collected. Therefore, battery-powered cameras, ship own cameras, infrared beacons and IR-tags worn by passengers were used. The full-scale trials were conducted on three different vessels on which in total 2231 response time data points were investigated.
The precise time for the trials was not announced in advance, but because of ethical reason all passengers were informed about the taking place of an assembly trial. Moreover, the trial was conducted at sea [10, 11, 13].

3.4.1 Trials

The first ship was a RO-PAX vessel operated by Color Line. It provides room for 2000 passengers and crew members, and 700 vehicles. Two assembly drills were conducted at 4^{th} and 5^{th} September 2009 each at 8:20, meaning day cases were investigated. On both trails different passengers participated. At the first trial 1431 and at the second 1349 passengers were involved. With 30 cameras a total of 533 and 470 response time data could be collected.
The second ship was a cruise ship operated by Royal Caribbean Cruise Line International. It provides room for 2500 passengers and 842 crew members. One assembly trial was conducted on 31^{th} July 2010 at 9:01 with 2292 passengers. With 106 cameras 1228 response time data points could be collected.
The results of the assembly trails showed significant differences in response time distribution. [10, 13]. The response time distribution describes the probability of a certain period until the evacuee responses to the emergency alarm and begins to move.

Proposed RTD on RO-PAX vessels

The resulting RTD was almost identical with existing day case RTD as shown in figure 3.6. The previous RTD based on 67 RTD data whereas now 1003 RTD were resulting. Accordingly, the more recent results were proposed to IMO as new day case RTDs. Appropriate data for night case was not collected [10].

Proposed RTD on cruise ships

The RTD that derived for public spaces during the full-scale trail represents the proposed new day case. The curve of RTD is limited to 300 s, which is equal to 94.8 %. This distribution bases on 633 points, the current RTD only on 67 data points. A comparison is shown in figure 3.6.
The RTD that derived from cabin areas is proposed as new night case as shown in figure 3.6. If the curve of RTD would be limited to 300 s it includes only 60.3 % of the overall distribution. That is not appropriate and the curve was extended to 700 s, which is equal to 90.3 %. With regard to sleeping passengers at night the curve was shifted to 400 s. This new distribution based on 598 data points, the current RTD only on 127 data points [10].

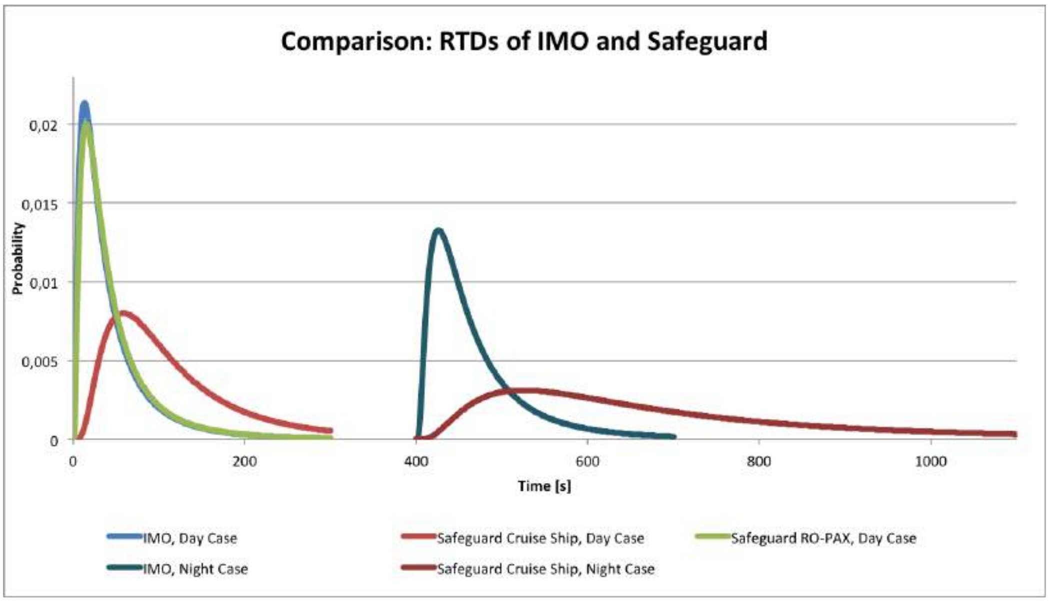

Figure 3.6: Comparison of response time distributions - Day and night cases, Source of data: [10, 21]

3.4.2 Assessing the impact of new RTDs

The impact of the three new proposed RTDs are assessed with the software maritimeEXODUS and two different ship geometries [10].

New day RTD for RO-PAX vessel

For the validation of the new day RTD the same ship geometry was used as in the analysis for MSC/Circ.1238. The hypothetical vessel contains three main vertical zones across ten decks and five decks can be occupied with passengers. The vessel has a capacity of 1650 passengers and 150 crew members.
The calculation showed that both RTDs had almost the same impact, because within 95 % of all cases a difference of 3.2 % occurred. Moreover, there are no significant differences in congestions [10].

Day and night RTD for cruise ships

Again a test geometry of a cruise ship is used for validation of proposed day and night RTDs. It contains twelve passenger decks whereas seven decks are accommodation decks including passenger cabins. The maximum berthing capacity is 3001 passengers.
Four scenarios were calculated including standard day and night cases with specified RTDs and both cases with the new proposed RTD.
In the day case with the new day case RTD, the travel time increased by insignificant 0.1 %. While the travel time in the night case with the new RTD increased by moderate 21.2 % meaning an extent of 1100s [10].

It is conspicuous that the new day case RTD for cruise ships had less influence than the day case RTD for RO-PAX vessel on the total travel time. Considering the curves, as shown in figure 3.6, the curves and the results do not fit together.
The IMO day case RTD is almost similar to the new day case RTD for RO-PAX vessels. But the travel time increases by 3.2 %. On the other hand the IMO day case RTD differs extremely from the new day case RTD for cruise ships and the travel time increases by only 0.1 %. According to Safeguard results the travel time on cruise ships is not influenced significantly, although the curves progression is very different.

3.4.3 Enhanced scenarios

Another aim of the research project was the development of representative scenarios considering fire, trim, and heel to replace the current secondary cases [12].

Heel and Trim

For an investigation on the impact of heel and trim three potential scenarios were identified. Due to a limited research data only one scenario was investigated. This scenario described day and night cases with static heel of 20° and trim of 10° from the start of the assembly process.
Available data was reviewed on the effect of trim and heel on people walking on even ground as well as descending and ascending stairs. Mainly influenced is the change in travel speed. With a simple approach of tables with speed variations, that were developed for the software, were used to implement this effect in the model.
The results of the day case showed that assembly time increased of 24 % in heel case and 13 % in trim case. In the night case the total assembly time increased of 11 % for heel and trim cases [12].

Unfortunately, in releases of Safeguard only increases of percentages were given as a results. More interesting is the influence on the passengers and associated therewith the appropriate approach for improvements in ship design.
Because of this reason the bachelor thesis "Auswirkung statischer Krängungswinkel auf die Evakuierungszeit von Kreuzfahrtschiffen" by J. Gunkel is consulted as additional source.
A main result was the drifting of people to one side when heel occurs meaning no effective use of escape routes was given and congestions build up. This findings were equal to those of SHEBA that are described in chapter 3.2.
Furthermore, investigations showed an exponential evolution of travel time vs. heel angle. But even room arrangement, distribution of people and ship size influence the travel time. Some

proposals for ship designs and evacuation analyses evaluating at 0° heel were made:

1. Public spaces with high personnel capacity should be distributed consistently on the ship.

2. When an evacuation simulation for heel 0° shows an occurrence of areas with high passenger density, these may be critical in heel cases higher than 0°. A generous dimensioning of doors, corridors and stairs and the provision of sufficient landing areas can avoid congestions at higher heel angles.

Moreover, a formula for assessment of travel time depending on the heel angle was provided. This formula has to be taken with caution, because it bases on only two investigations of two different ships. But it enables a calculation of the estimated travel time when heel occurs without an evacuation simulation [14].

3.4.4 Summary

Until now the results of Safeguard are not ready to be implemented into the regulations. The SDC expressed its concerns with regard on the influence of the number of tests, circumstances, chosen time, the number of participants and pre-announcements on the data. Therefore, it is questionable to use such data as basis for statistical data. A reliable data basis needs more realistic data, test and evaluations [32].

In general, this research project seems to be long overdue with regard to the amount of response time data on which MSC/Circ.1238 is based on. But unfortunately, during the Safeguard project only day cases were conducted. One of these day cases was edited to represent a night case, meaning a given period of time shall consider sleeping passengers. Until now no full-scale trial was conducted at night. That means no representative data are given and it is questionable whether a day case can be easily transferred into a night case by adding a time period.
Moreover, it is not comprehensible which age structures participated in the test trials. Within MSC/Circ.1238 a certain age structure is given. Although, it is not clearly stated in the guideline that there is a connection between age and response time distribution, it seems to be obvious that a connections exists. To make the RTDs comparable Safeguard should have published the population on which the new data base.

Within the Safeguard project the influences of the new RTDs were investigated. As mentioned before the curve progressions and curves seem not to fit together. Furthermore, it is stated in the publishments of Safeguard that the new proposed RTDs have no influence on the place of congestion development.
This results are not comprehensible and raise questions, that is why within this thesis the RTDs for cruise ships are investigated as well.

4 Human element

4.1 Human element in general

To understand human behaviour in emergency situations it is necessary to take a closer look to the human element in general. But what means human element? The human element describes human behaviour influenced by psychology factors like resistance to changes, emotionality or rationality [51]. The interaction of people between themselves and others is shaped by different factors, which are explained in the following chapter. It is important to be aware that everything is affected by humans: people design, build and maintain ships. Therefore it is important to consider the influence on decision making and acting of people.
Most of the following general aspects match more to workers on board of passenger ships. But in most cases accidents happen due to human error. This means the crew on a cruise liner caused or was complicit in the emergency. However, the crew is responsible for the passengers, that is why it is regarded as necessary to take their behaviour and the reasons into account.

Make sense of things

The question is: what people are paying attention to and why? Every person makes sense of things in another way due to cultural differences and contrasting interpretations. People usually filter out unconsciously most information whereby they rely on mental filters. Those filters base on our personnel needs, self-concept, past experience, shared goals and need to be practical. Every time people are making sense of things they create a unique situation of their own construction. As a result, it is difficult to share our own situation with others. Empathy and communication is necessary to overcome this situation [51]. The mental filters are explained shortly:

Our personnel needs
Personnel needs mean basic needs, which guarantee our own survival. Ignorance of basic needs is hardly possible, because they tend to develop a dominating behaviour.
There is a hierarchy of needs: First of all physiological needs (e.g. breathing, eating and drinking), secondly safety needs (e.g. personnel or financial safety), thirdly social needs (e.g. family) and followed by self-respect and self-development [51].

Our self-concept
People develop a sense of personal identity with experience of life and contact to other humans. Over time evolves a sense of self, which influences the communication with others, dealing with authorities and teamworking mainly [51].

Our past experience
From past experience, which includes beliefs, rules, procedures or stories, humans generate conclusions and reflections and apply those to the present. The more experience people have, the more familiar people feel in the present with certain tasks.
At this point, a distinction between experience and expertise has to be made. Although someone has much experience doing something, it can result in wrong conclusion and bad practise leading

to overconfidence and inadvertent risk taking. On the contrary an expert is able to assess the situation and act appropriate. [51].
With regard to the two accidents described in chapter 2 the difference in acting of the Masters is shown in exemplary manner. The Master of Star Princess communicated commendable with the passengers and had the emergency situation under control. Whereby the Master of Costa Concordia was unsafe in his behaviour and overwhelmed by the emergency situation. It can be assumed that in first case a Master with expertise and in the second case a Master with experience was on board.

Our shared goals
If people, which are part of a team, work for one goal they support their sense making capabilities. Sharing goals supports people to developed shared methods, a realistic understanding of each others role and their capabilities. Of course, problems occur when goals diverge. This is quite often, when safety considerations meet profit making [51].

Our need to be practical
Usually people tend to be practical, which means the working level is limited to the level of understanding. It is not aimed to search for absolute truth. People stop to decide for a course of action when enough information is available. Then people assume the situation is properly assessed with the given information [51].

In particular in the shipping industry insufficient attention is paid to training in teamworking skills and communication skills, which is shown by several examples. The risk of misunderstanding rises enormously when people have a skill gap. On cruise liner, with thousands of passengers and crew members on board, this can have disastrous consequences.

Taking risks

When sense-making is inadequate, not safe or inefficient then risk develops. The assessment of risk is influenced by the amount of control people think they have, the value something has for people and the extent to which things are familiar to the person. The challenge is for each person to find the weaknesses in its assumptions and manage them [51].

- Perceived control: The more control people think we have, the less risk they believe to take.
- Perceived value: If people support a goal that is regarded highly desirable, it is assumed that less risk appears.
- Perceived familiarity: When certain circumstances seem to be familiar, the less risk seems to occur.
- Complacency: If the surrounding is familiar people feel safe and comfortable. They are in a so called comfort zone [51].

Making decisions

Making decisions is influenced by many factors mentioned below. In the majority of cases a fully rational decision making is not possible.

Available time
The time to think influences majorly the decision making.

Available information
Usually people only use parts of the information that are available. The perception of people searches for information, which seems to be relevant in terms to our mental filters [51].

Efficiency vs. thoroughness
Less time in thinking and high effort in action means efficiency. Whereby much thinking and less action means thoroughness. Subsequently, decisions are always a compromise [51].

Situational awareness
The situational awareness depends on the level of mental activity. The perception picks up all relevant, from subtle to obvious, information. The comprehension integrates the relevant information to form a picture about the situation, taken into account the meaning, significance and priority of the information. Only understanding of the information is not enough, projection has to be done as well. The understandings have to be projected into the future to create the best option in the present [51].

Situational familiarity
For experts it is obvious what to do in a specific situation, whereby for non-experts it is not that easy. Especially, decision making under pressure is influenced by the level of knowledge and experience. Expert search for key elements, combine them with their past experience to make a decision for the current situation. Non-experts may be efficient in their action, but no sufficient thoroughly, which can cause incidents [51].

Making mistakes

Every person, expert or not, is making mistakes. In particular in safety-critical industries, like the cruising industry, mistakes can have serious consequences. Investigations on ship accidents showed that the main reason for maritime causalities is human error. It has to be distinguished between three kind of mistakes:

- Skill-based mistake: Work is done without much thinking, because the task is familiar and well-practised. When a mistake is made, people suddenly forget what to do. This is called memory lapse.

- Rule-based mistake: A certain activity has to apply to given rules and procedures. When a mistake is made, the person fails to apply to the rules.

- Knowledge-based mistake: A certain task is done unconsciously. When a mistakes is made, wrong sense-making is done. The decision bases on wrong interpretations, insufficient experience and training or bad communication [51].

Several factors encourage making mistakes. This can be individual or organisational influences.

Individual influences
First of all, inadequate rest and a high stress level cause fatigue and stress. This influences attention and concentration negatively. Moreover, the response time is increased. Secondly, insufficient training and experience result in doing a task with insufficient knowledge. This

can lead to a poor safety culture. Thirdly, by inadequate communication messages are not transmitted clearly [51].

Organisational influences
If there is a lack of time for doing a task, people tend to work more efficient with negative influence on thoroughness. Furthermore, inadequate design of equipment, user controls or work procedures affect workload, stress level and response times. Another important factor is inadequate staffing meaning less people for too much work. Of course, this increases workload, fatigue and stress level, but also the safety culture. Poor staffing can result in demotivation, low morale and in conclusion to a higher amount of mistakes.
An adequate safety culture requires training, staff investments and safe practises in work processes [51].

Getting tired and stressed

People get tired when they are awake too long. And factors, like workload, affect fatigue as well. But fatigue is hard to define and measure. Some influencing factors are described below.

- Sleep debt: People need enough sleep to recover. If this is not done an absence is built up and can lead to misreading situations, overlooking of key information or momentary nodding.

- Time of day: Everybody has a natural daily rhythm. People are in least alert in the early morning and most alert in the period before midday.

- Environment: The level of fatigue increases with bad levels of noise, vibration, temperature and motion [51].

Other influencing factors of level of fatigue are diets and nutrition, fitness and movement.
The effects of fatigue are various, for example inattention, communication and concentration difficulties, carelessness, slow comprehension and learning, slow information processing, mood changes etc.
The connection between fatigue and stress is quite simple. If the demand on people is exceeded stress develops. Stress changes body, such as the hormone level and blood chemistry. A sign of chronic stress are sleeping difficulties. At the same time sleep debt is a source of stress too.
Other causes of stress, especially for seafarers are: high workload levels, long work hours and shift work, adverse circumstances, social isolation and home leave worries [51]. With regard on crew members on cruise liners also communication difficulties due to different nationalities can develop.

Learning and developing

People are learning things by creating a meaning for new concepts and principles. A distinction has to be made between education and training. Education aims at widening and extending peoples horizon. Training focuses on particular response to achieve a specific performance standard. Nevertheless, in both cases mental and behavioural repertoires of people are increased.
For learning and internalize something basic principles have to be met. Things, which have to be learned, need to be interesting. If people see the point of learning and understand the use, then they make benefit from the information. Furthermore, it is important that people trust the

source of the information. But effective training needs even more than interesting information. It requires learners engagement, knowledge and skill training [51].

Working with others

Working with others means to trade information, evaluate the meaning and effective interaction. The challenge for most people is to cope with difficult conversations. The key object is to understand all perspectives [51].
In the shipping industry often team work is required. Considering this, team work should be as effective as possible. Teams are united with a common goal. Each member has a defined role to achieve. To reach the common goal it requires technical and team skills. Team skills are:

- Team leadership: A good teamleader gives motivation, direction and coordination. In addition, he clarifies team roles and performance expectations.
- Mutual monitoring: This describes the ability to monitor each other's performance including identification of mistakes and provision of adequate feedback.
- Back-up behaviour: If people working a team have the ability to understand each other´s task, problem can be anticipated or avoided.
- Adaptability: Every team should be able to response to changes in environment, which could have effects on the plan.
- Team orientation: Every part of a team should be able to see themselves as a team member with a common goal. A team should be receptive to suggestions of team members [51].

Most important of effective team work is a kind of glue to keep the team members together. This glue composes of similar mental models, mutual trust and communication [51].

Communicating with others

Why does human communication fail so often? During communication people use the signals of others to construct and anticipate the meaning the counterpart might intends.
The construction of the meaning is influenced by the familiarity of non-verbal signs. But also the cultural background and linked with norms and values have significant influence of the communication. Moreover, language and context have impact on the speed and bandwidth of communication. All those things can lead to communication problems and misunderstanding can occur easily.
Unfortunately, misunderstanding often remain undetected. But even when communication difficulties are detected, insufficient dialogues are conducted to solve the differences [51].

Effective communication requires different perspectives and shared means to explore differences. But successful communication cannot be guaranteed, because it bases on individual ambitions, needs and experiences as well [51].

To understand the human element all above mentioned points have to be taken into account. The human element is a complex and hard to predict element. In particular in emergency situation human behaviour differs from normality. That is why the following chapter will tackle this topic.

4.2 Human element in emergency situations

During the emergency situation on the Costa Concordia video recordings were taken. Those show in exemplary manner how people react in a totally unexpected situation. As soon as the ship hit the rock people in public spaces, passengers as well as crew members, were surprised, confused and overburdened. People did not know what to do and tried to orientate on others, but these did not know any better too. After having surpassed the first shock to some extent, some people were still in fear and others made jokes.
But not only passengers felt crushed, also trained staff on the bridge, did not know what to do. On video recordings one sentence is asked again and again: What shall we do?
Due to common sense passengers walked to the lifeboats by themselves. As it was an uncoordinated rescue an overcrowding in areas of lifeboats resulted [2].

4.2.1 Fear and panic

First of all it is very important to distinguish between fear and panic, because it mainly influences the decision-making and physical activity.

Fear mobilized bodily forces and increases due to that productivity and chances to save its life. An extreme form of fear is panic, which is characterized by counterproductive behaviour. Panic paralyses reasonable thinking and social orders tend to collapse. This is coupled with a reduction of social cohesion and the willingness to help others and themselves. In addition, a higher level of egoism, ruthlessness and running from responsibilities occurs [33].
In reality panic as mass phenomenon appears rather seldom. Also under great fear it is unusual that people cause harm to others. Human natural is social and not egoistic. Under extreme conditions often strong social bonds develop. People help their neighbours first before they help and rescue themselves [34].
But when panic develops it is difficult to control. The highest chances to avoid panic are measures before panic arises. That is why training for crew members of panic prevention and detection is reasonable, but at the same time difficult due to unpredictability and variability of emergencies. One important factor is communication, because a lack of information benefits the development of panic [33]. It is assumed that warnings at an early stage and frequent information have positive influence on passenger behaviour, because people can prepare physically and mentally. Moreover, people will be able to make more rational decisions, if they are not surprised and overwhelmed by an unexpected event [27].
The behaviour of people during the accident of Costa Concordia, described in chapter 2.1 and in the introduction of this chapter, showed the consequences of a delayed and inaccurate announcements.
If people are not sure about what to do, there is a tendency to mass behaviour and alternative escape routes are not seen. Due to physical factors people try to evade as fast as possible whereby they follow light. Social contact such as family members or location of people with a strong leadership should not be underestimated.
When the density in a crowd exceeds a certain level people try to move faster than usual. Some may start pushing and interact physically. Especially movements in bottleneck become uncoordinated. Fallen and injured people can easily become obstacles. This would describe an optimum starting point for the development of panic [23]. Disastrous impacts of panic on a crowd are emergent patterns, which are shortly described in the following:

Freezing by heating
People vary their walking speed and direction more than under normal conditions. Subsequently fluent passenger flows break together and blockades and congestions develop [24, 25].

Faster is slower effect
Due to higher walking speeds and impatience people are pressing and pushing. This means people hinder each other and the effect of friction occurs. Several people compete few gaps and plugs formats in such an uncoordinated situation.
Thereby so called "phantom panic" can be caused, for example through counterflow, which is time intensive, delays the evacuation process and increases impatience [24, 25].

High pressures
Through pressing and pushing extreme high forces can develop and impact people. Extremities can be seriously crushed or pinched, people fall down, get trampled, and choked [24, 25]. Pressures up to $4500\,\mathrm{N/m^2}$ can develop [33].

Herding
When people do not know what to do and where to go they orientate on the behaviour of neighbours. This leads to an inefficient and irregular use of escape routes, overcrowded exits and ignorance of available alternative escape routes. Researches showed that the highest chance of survival is given under a certain composition of individual behaviour and crowing [24, 25].

4.2.2 Panic angle

The panic angle is achieved at 9°. If this angle occurs for a longer time and increases slowly it has a frightening effect [26].
Studies on ship accidents have shown that in almost cases heel occurs. In general, heel has a significant physical, as described in chapter 3, and psychical influence on passengers and should be taken into consideration for the development of alternative escape routes.

4.3 Conclusion

The topic about human element in general gives some specific reasons for the fail of the Costa Concordia crew. Two examples are picked up to explain the connection between the human element and the negative influence on the emergency situation.
Obviously, communication difficulties between crew members and passengers and crew members lead to confusion. Crew members did not get sufficient information from the bridge. Because the bridge team, especially the Master, was overwhelmed by the situation as well. Although he had a long-standing professional experience, the Master made a rule- and knowledge-based mistakes. At this point, it should be noted that considerable experience makes not automatically an expert. Due to the bad communication structure, the team work was not adequately and the evacuation procedure delayed enormously.
Moreover, the training level for emergency situation of the crew members was on a very poor level. Certain crew members were not able to speak English. Other were not familiar with safety procedures. The crew members are responsible for the safe and fast evacuation of thousand of passengers, that is why it is not reasonable to have inadequately trained crew on board. The

part of "Learning and Developing" of safety and emergency procedures was definitely not part of the training program for crew members.

The human element is an influencing aspect of rescue- and evacuation processes. The difficulty is to predict the behaviour of individuals in emergency situation. Until now it is infeasible to simulate the real behaviour of people in evacuation models. But the significant influence is uncountable and has to be taken into account in any way.

5 Relevant rules and regulations

All relevant rules and regulations for dimensioning of escape routes and evacuation analysis are presented in this chapter. Further recommendations and regulations considering the topic safety of passengers and alternative escape routes can be found in chapter 12.1 (Annex).

5.1 SOLAS

The International Convention for the Safety of Life at Sea was adopted in 1974 and entered in force 1980. The articles include, among other things, general obligations and information about amendment procedures. Detailed rules about minimum standards for construction, equipment, as well as operation of ships and their compatibility with safety are given in the convention. Flag States have to ensure that ships comply with these requirements. Therefore, the SOLAS is the most important international treaty regarding the safety of merchant ships [18].
The relevant regulations for this thesis are described shortly in the following:

SOLAS Chapter II-2 "Fire protection, fire detection and fire extinction"

SOLAS Chapter II-2/Regulation 9 "Containment of fire"
This regulation ensures the thermal and structural separation of the ship in so called main vertical zones to avoid spreading fo fire from one zone to another. Those zones are defined as fire zones. One fire zone extends over the total breadth, a maximum length of 48 m and an area of 1600 m^2. Escape routes have to be within one fire zone to ensure an evacuation separately in each fire zone [19].

SOLAS Chapter II-2/Regulation 13 "Means of escape"
This regulation gives standards of dimensioning and arrangement of escape routes. The aim of the rule is to ensure safe escape routes in secure and barrier-free conditions. In general, at least two escape routes far apart have to be provided to escape from all rooms. It is not allowed to use lifts as escape route. Doors have to open in direction of the escape route. Moreover, dead-end corridors are forbidden.
Below the bulkhead deck two independent escape routes are required, but at least one escape routes shall not lead through watertight doors. Above the bulkhead deck for each fire zone at least two independent escape routes are necessary. One of them should be a vertical escape route, this means the route leads through a stairway. The required breadth of corridors, doors and stairways is calculated due to the person appearance in the certain areas.
Specified information are described in the FSS-Code, which are explained in Chapter 5.2 [19].

SOLAS Chapter III "Life saving appliances and arrangements"

SOLAS Chapter III/Regulation 11 "Survival craft muster and embarkation arrangements"
In this regulation detailed information about the requirements of muster stations are presented. Muster station have to be located close to lifeboats. Moreover, for each person a space of 0.35 m^2 has to be provided [19].

5.2 FSS-Code

The Maritime Safety Committee adopted the International Code for Fire Safety Systems to provide international standards required by SOLAS Chapter II-2. For dimensioning of escape routes the rules in FSS-Code Chapter 13 apply to achieve an arrangement including stairs, doors, and corridors that can handle the predicted person appearance [20].

FSS Code Chapter 13 "Arrangement of mean escapes"

For the calculation of the width of stairways on passenger ships some basic requirements are made. For example, that stairways have to be greater or equal to 900 mm in clear width. If a certain number of people using the stair is exceeded, the clear width has to be increased. But several more rules must be observed for the calculation of the stairway width. Those rules can be found in Chapter 13, Paragraph 2.1.
The required tread width W between handrails is calculated with a formula, shown in figure 5.1. In this formula $N_{1,2,3,4}$ is defined as the total number of people on decks with the highest maximum occupancy, the second, third and fourth highest occupancy within one stairway.

when joining two decks: $W=(N_1+N_2)$ 10mm;
when joining three decks: $W=(N_1+N_2+0.5N_3)$ 10mm;
when joining four decks: $W=(N_1+N_2+0.5N_3+0.25N_4)$ 10mm;
when joining five decks or more decks, the width of the stairways shall be determined by applying the above formula for four decks to the deck under consideration and to the consecutive deck,

Figure 5.1: Calculation of W, Source of data: [20]

To calculate the total number of people who have to evacuate through the corridors, doors and stairways two cases of occupancy are defined. Every part of the escape route should be dimensioned for the largest occupancy.

- Case 1: 100 % of passengers are in their cabins, 2/3 of the crew are in their cabins and 1/3 of the crew is distributed in service spaces.
- Case 2: 75 % of public spaces are used by passengers and the crew is distributed to 1/3 in service spaces, 1/3 in public spaces and 1/3 in crew spaces.

Therefore, stairway widths base on crew and passenger load on each deck. Maximum capacity of public spaces can be either defined by the number of seats or a required area of 2 m^2 to each person [20].
Moreover, when a landing area is provided at stairways at deck level the calculated value of the required tread can be reduced. Furthermore, it is not allowed to reduce the width of stairways in the direction of evacuation to the assembly station [20].
In general, stairways have to be fitted with handrails on each side that maximum clear width is 1800 mm. The vertical rise of stairways shall not be greater than 3.50 m if no landing area is provided. This landing area shall be between 2-16 m^2 and has to be increased in certain cases. The angle of inclination of a stairway shall not exceed 45° [20].
Doorways and corridors as well as landings are sized in the same manner as stairways. The whole width of stairway exit doors shall not be less than the width of stairways servicing the deck [20].

5.3 MSC/Circ.1238

"Guidelines for a evacuation analysis for new and existing passenger ships"

Until now for cruise liners no evacuation analysis is compulsory. Consequently, it has not to be proven that all passengers can be evacuated in sufficient time in a safe manner from the vessel. Indeed, it is important to recognize that cruise journeys are a growing industry with a high market share. With regard on the growing size of passenger vessels and their increasing capacity it appears to be long overdue to implement a compulsory evacuation analysis. So far, an evacuation analysis can be done according to MSC/Circ.1238.

The Maritime Safety Committee approved this guideline on evacuation analyses for new and existing passenger vessel as well as ro-ro passenger ships in 2007. The aim is to provide a uniform application with typical benchmark scenarios and relevant data. This ensures an assessment of evacuation performances and comparisons between different ships types and designs. It is less important to simulate a real emergency. Due to a shortfall in verification data and practical experience to the current state it would be connected with huge difficulties. The data and parameters given in the guidelines so far are based on data coming from civil building experience. Nevertheless, this approach enables to identify inadequate escape arrangements, congestion points and proves whether the escape arrangement is flexible enough. The information of an evacuation analysis can be used to improve evacuation arrangements and increase safety on board of a passenger vessel [21].

The guideline proposes two methods: a simplified evacuation analysis and an advanced evacuation analysis. Within the simplified method the assumptions are limiting the scope by their nature. That is why for a complex layout the advanced method is recommended [21].
Further explanations of this chapter refer to the advanced method, because it applies to the evacuation simulation program used for this thesis.

Assumptions

For the advanced evacuation analysis several assumptions are made.

- Passengers and crew members are individuals characterized by different abilities and response times.
- Passengers and crew members follow the main escape route.
- Passenger load and initial distribution is based in FSS Code.
- The escape arrangement is fully available, unless it is not stated otherwise.
- Implementation of a safety factor, including crew members, who are immediately ready to assist in case of an emergency, passengers follow the signage system and crew instructions. Fire and its effects do not influence passenger and crew performance. Group behaviour, ship motion, heel and trim are not considered as well [21].

Benchmark Scenarios

Case 1 and 2 are specified in Chapter 13 of FSS-Code. In MSC/Circ.1238 further distinctions considering the distribution of passengers and crew members are done. Case 3 and 4 take into account the reduced escape routes availability.

Case 1: Primary night case
Passenger and crew distribution are according to FSS-Code Chapter 13. Due to supplementation 1/3 of the crew is located in service spaces. Half of them is located in service spaces and behave like passengers. 25 % are located in emergency stations and have not to be modelled. The remaining 25 % are located at assembly stations and move towards the most distant passenger cabin. This leads to counterflow with other evacuees. When the passenger cabin is reached these crew members are not longer considered in the simulation [21].

Case 2: Primary day case
Passenger and crew distribution are according to FSS-Code Chapter 13. Similar supplementations regarding the crew are required. 1/3 is located in the crew cabins and 1/3 works in the public spaces. The remaining 1/3 is distributed as follows: 50 % are located in service spaces, 25 % are at the emergency stations and do not have to be modelled and 25 % are the counterflowing crew like in Case 1 [21].

Case 3: Secondary night case
Passenger and crew distribution are according to Case 1. The fire zone with the longest evacuation time is chosen and further investigated. Two opportunities are given: either the stairway with the highest capacity is unavailable or 50 % of the people in the fire zone with the highest capacity use the adjacent fire zone [21].

Case 4: Secondary day case
Passenger and crew distribution are according to Case 2. One fire zone has to be investigated like in Case 3 [21].

Calculation of evacuation time

The evacuation time is calculated with following formula:

$$1.25 \cdot T + 2/3 \cdot (E + L) \leq n \tag{5.1}$$

$$E + L \leq 30min \tag{5.2}$$

- 1.25 = Safety factor
- T = Travel time
- E + L = Embarkation and launching time
- n = maximum permissible evacuation time
  - n = 60 for ro-ro passenger ships
  - n = 60 passenger ship with no more than 3 main vertical zone

- n = 80 passenger ship with more than 3 main vertical zones

The unknown value in this formula is the total travel time T, which is calculated with the evacuation simulation program. The travel time starts with the announcement of the evacuation and ends when all people reached their destination.
Each person is an individual, this means people have different abilities and response times. The abilities are defined by gender and age. The passenger population composes as shown in figure 5.2.

Population groups - passengers	**Percentage of passengers (%)**
Females younger than 30 years	7
Females 30-50 years old	7
Females older than 50 years	16
Females older than 50, mobility impaired (1)	10
Females older than 50, mobility impaired (2)	10
Males younger than 30 years	7
Males 30-50 years old	7
Males older than 50 years	16
Males older than 50, mobility impaired (1)	10
Males older than 50, mobility impaired (2)	10
Population groups – crew	**Percentage of crew (%)**
Crew females	50
Crew males	50

Figure 5.2: Passenger population, Source: [21]

Each individual has a certain response time to the emergency alarm, which is logarithmic normal distributed. The response times distribution for night cases 1 and 3 differ from day cases 2 and 4. In the following formulas the variable x is the response time in seconds and y is the probability density at response time x.

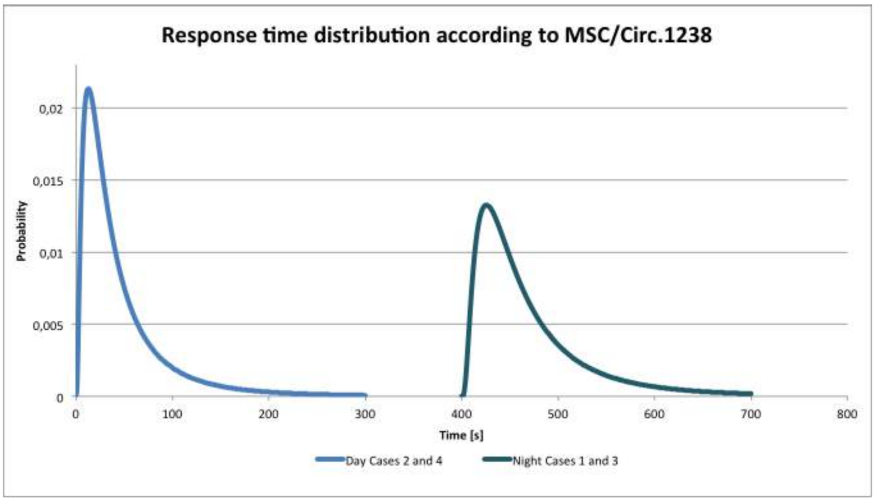

Figure 5.3: Response times, Source of data: [21]

In addition, the maximum travel speeds of males and females are considered with a function of age. This function of maximum walking speed vs. age is shown in figure 5.4. The walking speed for each age and gender group is further defined by a statistical uniform distribution including a minimum and maximum value. It also distinguished between the walking speed on flat terrains, stairs and through doors.

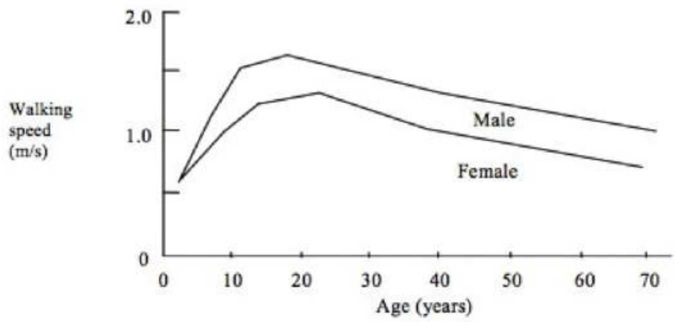

Figure 5.4: Maximum walking speed vs. age, Source: [21]

All this characteristics influence the total travel time. This means for each calculation run another travel time results.
It is recommended to calculated 50 simulations for each case. Out of the results the significant travel time is chosen, which is defined as value higher than 95 % of all calculated values. That means for four cases four different travel times are calculated. The highest travel time is chosen and substituted in the formula (5.1) [21].

6 Devices to improve evacuation processes

This chapter presents ideas about devices which can influence the evacuation process advantageously. This ideas are still in development or are already implemented in evacuation processes of buildings. To current status non of this ideas is provided on passenger vessels. Therefore, no reliable data are available about the influence of such systems or devices. But it can be assumed that all of the presented devices have advantageous influence on the progress and overall time of the evacuation process.
These devices are signage systems as well as interaction of people with signage systems, directional sound evacuation, vibrating alarm, evacuation chairs and tracking systems. Especially for elderly and disabled people some of these devices benefit a fast and safe evacuation.

6.1 Signage system

In MSC/Circ.1238 it is assumed that all passengers follow the signage system and crew instructions. Deviations from this assumption are considered by the safety factor 1.25, as described in chapter 5.3 [21]. For a real emergency case it can be assumed that not all passengers and crew members follow the emergency signs. This has already been proven in experimental studies.
The interaction of people with signage systems is a very complex topic and was investigated in detail by Xie,H. within a dissertation [40]. The main problem of the process of interaction is shown in figure 6.1.

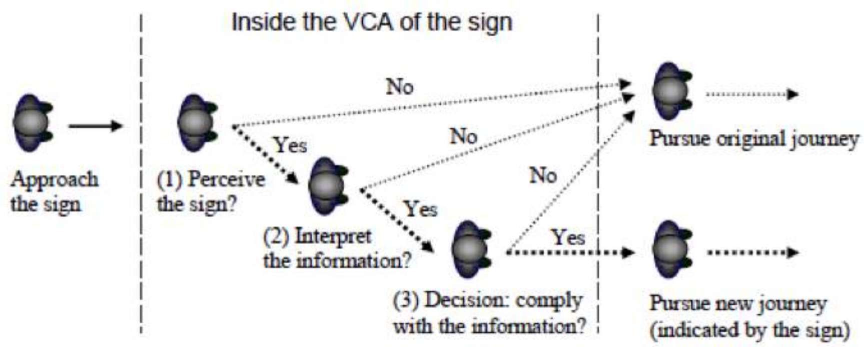

Figure 6.1: The process of the interaction of an occupant with a sign, Source: [40]

Approaching an emergency sign directly does not mean the sign is perceived, interpreted adequately and decision-making is according to information given by the sign.
In general, people who do not detect the emergency sign need twice the time for decision making about the route they follow as those who detect the sign. Another influencing factor is the familiarity of the people with the environment. Furthermore, is has to be distinguished between open and confined spaces. With regard on passenger ships confined spaces comply more with a typical arrangement of a cabin area and open spaces comply with public spaces like restaurants or open decks.

The results of experimental studies in buildings showed following connection between open and confined spaces, familiarity with the building, detection of signs and adequate interpretation:

	Detection of sign		Information used for wayfinding	
	Familiar	Unfamiliar	Familiar	Unfamiliar
Confined space	No data	75 %	No data	94 %
Open space	30 %	38 %	94 %	97 %

Figure 6.2: Results of experimental studies, Source of data: [40]

It is assumed that passengers on cruise liners tend to be unfamiliar with the arrangement on the ship. This means in confined spaces, e.g. cabin areas, 75% of people detect the sign and 94% of them interpret and use the information to find the right way to the exit. Whereas in open spaces, e.g. open decks, only 38% of people detect the emergency sign. But if they detect the sign nearly all people use the information adequately for wayfinding [40].

In accordance with this findings a decisive reason for the detection and interpretation is the visibility of signage. The main issue is that signage systems are usually seen every day, but are not used. In an emergency case people oversee those signs easily. However, nearly all people who see an emergency sign follow them. This means emergency signs are very effective if they are seen by the evacuees. The challenge is to design emergency signs in a way they cannot be overseen. This is one investigation topic within the Getaway project, which was launched 2011 and is still running.

The Getaway (Generating Simulations to enable Testing of alternative Routes to improve Wayfinding in Evacuation of Overground and Underground Terminals) project develops an Intelligent Active Dynamic Signage System to improve the wayfinding. Therefore the implementation of lit, flashing and running signs are investigated. The investigations are based on the amount of only 38 % of people who see the emergency sign, if it is placed in front of their field of view and their vision is not limited [41].
So far the investigation on the new signage system showed that the detectability of evacuation signs increased by 103 %. With standard signs 99 % of people try to evacuate via the nearest exit, whereas with flashing signs this drops to 57 %. The other 43 % follow the exit indicated by the flashing signs even if it is not the nearest exit.

Although this project is not finished and no final results are published some findings are promising. With regard to an evacuation of a passenger ship an intelligent guiding with improved signage systems and distribution of people on the evacuation routes could avoid congestions and decrease the overall evacuation time.

6.2 Directional Sound Evacuation

In particular for people with visual impairments, but also for all other passengers, a directional sound evacuation system can have many advantages.
Visual aids on passenger ships includes lighting, signage and photo-luminescent guidance strips. Those are ineffective when fire and smoke occurs. During the fire on Star Princess, as described in chapter 2.2, large amounts of black, dense, noxious smoke developed. The official investigation report stated that the visibility was not more than 0.5 m. Subsequently, photo-luminescent

lighting fitted to the deck was not seen [3]. Moreover, smoke irritates the eyes and causes reflex closing.
The example shows that emergency signs are not detected easily when smoke occurs, but directional sound enables the identification of the escape routes to the exit. A manufacturer of directional sound beacons is Soundalert, who promises that the human ear can locate accurately the direction from which the sound is caused. According to the information of Soundalert, the evacuation time can be reduced up to 70 % under smoke conditions and up to 35 % under perfect visibility [42]. In 2001 trials on ro-ro ferries were conducted by the University of Strathclyde to investigate on the effectiveness of directional sound beacons. The results showed a clear benefit of the system as an aid to guidance, especially in trials using smoke [46].
In addition, directional sound evacuation systems are independent from language, which makes it suitable for everybody.

6.3 Vibration Alarm

For deaf and hard of hearing people a vibration alarm should be provided. For example, a fire alarm informer system in form of a pager is already provided by the manufacturer Stanley Security Products for buildings. If this system is transferred to passenger ships hard of hearing people can be informed fast and reliable in case of an emergency.
This pager should be carried by passengers who benefit from a vibration alarm during the whole day. The cabins for deaf and hard of hearing people should be equipped with vibrating pillow alarm to ensure that people wake up in case of an emergency during night [43].

6.4 Evacuation Chair

During an emergency also people with mobility impairments have to be evacuate in a safe and fast manner. On passenger ships it is not allowed to use lifts during an emergency case.

Figure 6.3: Evacuation Chair, Source: [44]

Not only wheelchairs users, but also people with an injury or other impairments need assistance during an evacuation process. With an evacuation chair one person can be transported easily along corridors or down stairs, whereas the evacuation chair is sliding like a sleigh on runners.

Only one assistance person is needed for pushing the evacuation chair. In a folded condition it can be arranged space-saving close to stairs [44].

6.5 Tracking

To current status passengers are moving to the muster station when the general emergency alarm is activated. There passengers are counted by crew members, who have a list with names. This procedure is time intensive and susceptible to errors and problem such as communication difficulties.
If people on board of a passenger ships could be localized, tracked and accounted by a tracking system the mustering and evacuation process would been faster for sure. The project LYNCEUS (People Localization for Safe Ship Evacuation during Emergency) works currently on the provision of an evacuation control system with position and health status of passengers and crew members. Moreover, the continuous assessment of the status and development of the emergency and provision of updated information to evacuees should be possible.
A wide network of sensors on the ship ensures the localisation, tracking and accounting of people, equipped with active devices during an emergency on board and after abandoning for SAR operations. These devices are only activated when required without an action by the individuals. The recording process counts disembarking people and concludes to the number of people who are still on board. Deviations from the planned process such as people going to the wrong muster station, duty station, lifeboat or people falling overboard are taken into consideration as well. The data of individuals will include the passenger or crew identification number, name, cabin number and special needs [45].
This project started in 2012 and is still running [45]. Thus, no final results about the practical implementation and the success of the project can be given.

6.6 Conclusion

Different promising methods such as an improved signage system or a directional sound leading system were developed to enhance evacuation processes. Unfortunately, until now on cruise liners such methods do not apply. But it is conceivable that those methods could be developed further for the cruise shipping industry in order to provide improved evacuation systems on passenger ships.
In particular, for disabled and elderly people simple and not cost intensive assistances can be provided. This can be a pager, which gives alarm through vibration or evacuation chairs to transport people, who are not able to evacuate themselves.
To ensure a safe and adapted to the needs evacuation process it seems to be necessary to list all people with impairments and the kind of their impairment before the journey starts. Especially people who have special needs should be informed about the ways they are evacuated and guided in case of an emergency. Moreover, the choice of the cabin should be thought through with regard on the location and equipment.
To provide all this improved methods it requires owners, who are willing to invest money in the safety of passenger ships meaning alarm and guiding methods, adequately equipped cabins for people with special needs and improvements in communication and information structures for and to people with special needs.

7 Software

In this chapter an overview about existing evacuation simulation software and a detailed description about Aeneas is given.

7.1 Overview

Aeneas

This software was developed by TraffGo HT in cooperation with GL and is certificated through BG-Verkehr. Aeneas composed of two main components. The first one is AeneasSed, which allows definition of routes and distribution of people. The second component is AeneasSim, which executes the evacuation simulation. This software is chosen for the investigations on alternative escape routes. A more detailed description of the program is done in chapter 7.2.

MaritimeEXODUS

EXODUS is software developed by the FSEG for the simulation of evacuation behaviours and pedestrian dynamics whereas a large number of people and large complex enclosures can be incorporated. MaritimeEXODUS is the ship version and consists of five sub-models: Occupant, Movement, Behaviour, Toxicity and Hazard. With these tools is it possible to simulate individual people, behaviour, vessel details, interaction between people-people, people-structure and people-environment. And the interaction with fire hazards data and angle of heel can be included. As an output two- and three dimensional graphics are generated [39].

EVI

This program was developed by Safety at Sea to simulate pedestrian movement, evacuation of people from ships and offshore structures and buildings. The evacuation analysis is based on MSC/Circ.1238. Furthermore, an impact assessment of casualty scenarios can be conducted [35].

ODIGO

ODIGO is a crowd motion simulation software, which complies with IMO requirements and was developed by Principia. The simulation engine uses a multi agent model. Within the agent definition features and starting points are distributed in a random way. This software is mainly used for evacuation simulation, but is suitable for simulation of embarkation and disembarkation too. The application areas are shipbuilding, aerospace and civil engineering [36].

Other simulation software

EVAC: Software for simulation of mustering process on passenger vessels.
MonteDEM: Software for the assessment of fire safety of ships.

7.2 Aeneas

For mathematical modelling two different approaches can be made: macroscopic and microscopic. The macroscopic approach compares the flow of a crowd with liquids or gases. Within the simplified method in MSC/Circ.1238 this approach used. The disadvantage of this approach is difficulty to define real world systems and the ability to investigate complex structures.
The simulation within Aeneas is done by adopting a microscopic approach, according to the advanced method in MSC/Circ.1238. The advantage of a microscopic model is that internal (psychological) and external (structural) factors can be taken into account in an appropriate way. Individuals and their movement can be modelled and considers individual behaviour by describing a set of parameters. The so called multi-agent model is based on a cellular automata model [48]. In the following explanations people are described as agents.

Cellular automata model

Two problem occur within an evacuation simulation: the two-dimensional movement of people and complexity of psychological and social influences. The CA model provides a natural approach for this problems. Basic principles for the CA model are defined. First of all, the layout plan is subdivided into square cells. Each accessible cell is occupied by one agent or is empty. Agents are individuals that differ in their abilities. These are defined by a set of parameters. The motion of agents is described by their direction and walking speed [47].

The connection between individual parameters and crowd flow is shown in figure 7.1. In the simulation this is represented by an algorithm based on a single agent [47]:

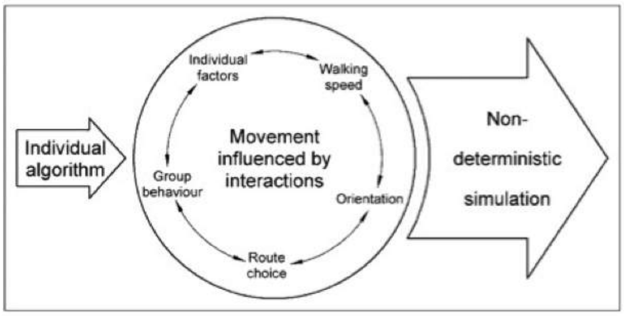

Figure 7.1: The algorithm models of the evacuation sequence on the level of individual persons interacting with each other, Source: [47]

Each agent moves according to its individual set of parameters. Therefore, crowd movement is influenced by individual factors of agents, walking speeds, orientation, route choice as well as group behaviour. Subsequently, due to the stochastic factors the results of the simulations are non-deterministic.

It is desired to choose the direction along the shortest escape route and to aim for the maximum walking speed. If the destination cell is occupied the agent varies its direction and walking speed to search for alternative cells. The agent moves directly, but swerves other agents and obstacles. When a forward motion is no longer possible the agent stops [48].

All agents move and orientate due to the movement algorithm, which is equal to all. The time is subdivided in so called timesteps. One timestep represents one second. At the begin of each timestep the agent determines the direction of movement, while moving towards the goals and swerving obstacles. At higher speeds an agent can move trough more than one cell per timestep [49, 50]. The closeness to reality of the flow-density relation within the model was investigated with different cases and compared to empirical data. Results showed that reality is met very well, when one person occupies all cells passed in one timestep [49].

Parameter

Each agent is characterized by individual parameters, which influence the movements significantly. At the moment it is possible to set person-specific parameters, but psychological decision making processes are not yet included in the model due to a lack of sufficient data [48]. The parameters can be defined according to equal and normal distribution. These are defined with a maximum and minimum value or an average value and standard deviation [37].

Type	Description
Walking speed	Describes the maximum travelled cells in one second.
Patience	Maximum time of stop before person begins to move again.
Sway	Accuracy of following the potential.
Reaction	Time before person reacts to the emergency alarm and begins to move.
Dawdle	Probability of a stop for one timestep to describe breaks for regeneration and orientation.
Inertia	Inertia of keeping the current direction of movement.

Table 7.1: Parameters, Source: [37,38]

The parameters walking speed and reaction time base on the requirements of the regulation MSC/Circ.1238. The walking speed is implemented due to the distribution shown in chapter 5.3 figure 5.4. The formulas shown in 5.3 are implemented in Aeneas to represent the reaction behaviour. With the other parameters, patience, sway, dawdle and inertia, human behaviour is described.

Demographics

The population can be subdivided into passengers and crew members. The percentage distribution is shown in Chapter 5.3, figure 5.2.
These person groups are characterized by individual behaviour due to the defined parameters. The user can set the parameters on its own or he takes the deposited sets of parameters for each person group and case, which are already defined within Aeneas. Those sets represent the requirements according to MSC/Circ.1238. Therefore is it quite easy and not time-intensive to apply the required settings to the population.

Layout

The layout of escape routes is distributed in square cells with an edge-length of 0.4 m. The transformation of a 3D-layout into cells is illustrated in figure 7.2. The resulting floorspace of 0.16 m^2 for each agent represents the required space in a congestion, when no flow is longer

possible. Therefore the highest people density is 6.25 P/m^2.
One agent can occupy one cell and jumps from one accessible cell to the next cell along their escape route toward the exit. If an agent is hindered in his forward movement by another agent he has to adopt his speed to the available space [37, 49].

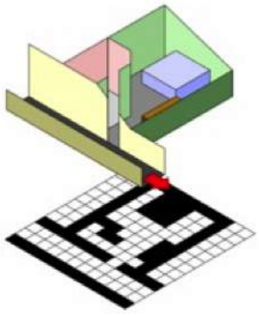

Figure 7.2: Transformation of layout, Source: [37]

Each cell contains different information. First of all, the accessibility of cells is defined. If a cell can be accessed it can take influence on the walking speeds and directions of agents.

Cell types

Free cells
Free cells are characterized by white cells. This cells do not influence the movement.

Walls, fitments, other objects
Those cells cannot be accessed, because they are a physical obstacle.

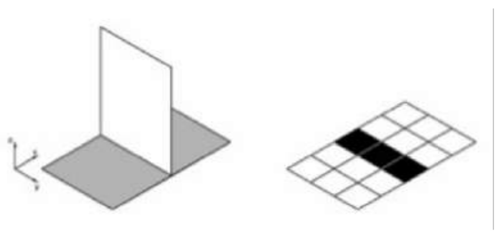

Figure 7.3: Cell type: Wall, Source: [37]

Exits
Agents, which reach the exit are saved. These cells can be assigned with time parameters to influence evacuation behaviour. Those interval or blocking durations can vary. Within this thesis only one possibility is used. With this option an exit can be blocked per agent. This means, the definition of an individual time for each agent, he has to stay on the exit cell until getting rescued [37]. The scope of application is explained in chapter 9.5.4.

Doors
This cells reduce the flow of people and the walking speed is reduced to one fourth.

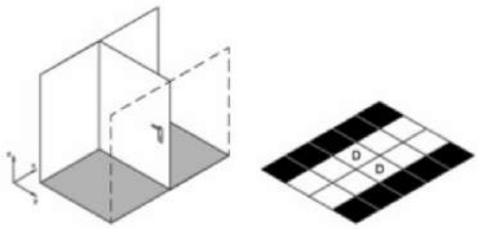

Figure 7.4: Cell type: Door, Source: [37]

Steps
To change the deck level the cell type step is used to move agents down or up stairs. On this cells agents walk with half of their speed. Lateral boundaries have to be walls. Stairs are always illustrated on the upper level and can be accessed in both directions.

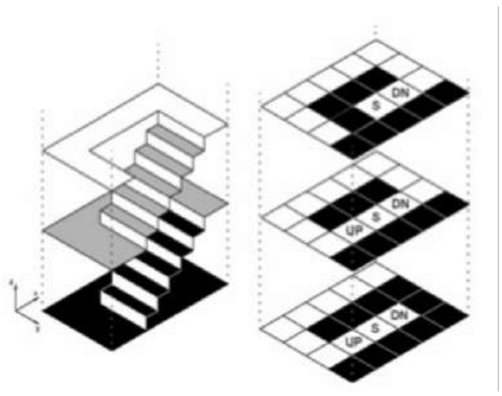

Figure 7.5: Cell type: Stair, Source: [37]

Route choice

Routes for agents are defined by marking way-leading parts of the layout. To each group of agents individual routes can be assigned. At each end of the route an exit has to be defined. When agents reach the exit cell they are saved and not longer considered in the simulation.

Potential

The orientation along the escape route is defined by potentials. Each cell is equipped with a potential giving a value for directional determination. The value of the potential becomes higher the closer the exit gets. If the goal cell is marked the potential spreads from one accessible cell to the next. In this way orientation is given to the agents. A smothering algorithm takes architectural circumstances into account. So agents do not stick to one side of corridor, if they want to bend off on a corner [38, 49]. The determination of direction of movement is shown in exemplary manner in figure 7.6.

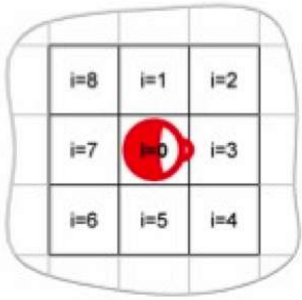

Figure 7.6: Determination of direction of movement, Source: [37]

The agent can choose between eight cells for the next step. The probability p_i for cell i is calculated with following formula:

$$p_i = e^{-\frac{(P_i - P_0)+S}{S}} \tag{7.1}$$

- p_i: Probability for the choice of cell i
- P_i: Potential value of cell i
- P_0: Potential value of cell 0
- S: Parameter sway

When the value S gets higher the influence of the potential gradient decreases and the agent walks undirected. After the probabilities for all eight directions are calculated the resulting value p_i is multiplied with the inertia value Θ. Subsequently, the current walking direction is given more weight.

$$p_i = P_i \cdot \Theta \tag{7.2}$$

Update and movement

An update within Aeneas describes the kind and sequence in which an agent moves. The simulation software uses a random shuffled update. This means one timestep consist of a certain number of sub-updates, which is equal to the maximum speed of the total population. In each sub-update agents move in random order one cell forward as long as enough space is available. When the agent is rescued or the individual maximum amount of steps in one timestep is reached the agent is not longer moved.
The example in figure 7.7 shows the movement of agents during two timesteps. At time = 0 two agent stand in a row. At time = 1 the black agent moved two cells forward, but the white agent could not move, because all cells were occupied. At time = 2 the black agent moved forward again and the white agent could move as well, because now cells were available.

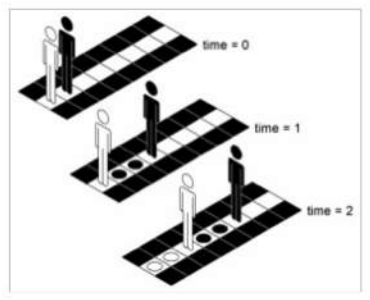

Figure 7.7: Movement during two timesteps, Source: [37]

Ship motion

With Aeneas rolling and pitching movement can be simulated. Therefore, TraffGo HT collected empirical data on walking speed reduction of humans due to ship motions. As the most substantiated regarded were data by TNO, because the test took also secondary effects like visual perception of stationary or vertical reference points into account. The results of TNO about dynamic ship motion and its influence on walking speed were partly similar to those of SHEBA. The investigations on SHEBA are described in detail in chapter 3.2. TNO examined on the effect of sinusoidal pitch and roll motion. The results showed that decreases in walking speed for dynamic motion is less than for static list. During a dynamic motion the floor is horizontal at certain times and enables a faster forward movement. The results for pitch motions had a similar effect like roll motion, but with lesser extent. Roll motion occurs perpendicular to the walking direction. With an increase in frequency of roll motions the lateral forces affecting the body during walking rise and walking speed is reduced even more. When a pitch motion occurs walking is speeded up and down [50].

In Aeneas dynamic motion is not taken into account, because only little data is available. Moreover, damaged vessels do not move very rapid. In most cases a slow increase of list occurs.

The models used in Aeneas to simulate ship motion are described in detail in chapter 12.2 (Annex). This model data describing the walking behaviour when ship motion occurs cannot be changed or adapted by the user.

Calculation

It is suggested to calculated 500 runs by TraffGo, whereby in MSC/Circ.1238 only 50 runs for each of the four scenarios are demanded.
The results of the simulation are statistical data like distribution of evacuation time or curves showing the amount of rescued person vs. time. With the results of the mean value calculation characteristic runs can be repeated to get detailed information. All this data as well as visual results like density plots allow an evaluation of the evacuation process.

7.2.1 Conclusion

To evaluate a ship design with regard on safety and evacuation procedures two opportunities are given: full scale trials or simulations. With simulation software an evacuation analysis can be conducted fast, cheap and at an early stage of design. This offers the opportunity to identify and eliminate weak points before the vessel is build.

The simulation software Aeneas can conduct an evacuation analysis according to MSC/Circ.1238. The sequences of evacuation procedures are visualized. Therefore, crowd movements, influences of changes in evacuation procedures and the geometry of the floorplan can be simulated. The advantage of Aeneas is that complex layouts can be modelled in a simple way. Unfortunately, only square cells with an area of $0.16\,\mathrm{m}^2$ are available to describe the layout. This means the floorplan of a vessel has to be simplified partly if it is necessary.
The human element is described by a set of parameters according to the regulation MSC/Circ.1238. This parameters can be changed by the user. Unfortunately, only normal and equal distribution can be used. This leads to discrepancies when response time distributions differing from the requirements are investigated as explained in chapter 9.6.4. Another example for a limitation is the composition of the population. This cannot be changed, because the distribution of person groups is done in Aeneas internally according to guideline. People with special needs like wheelchair users cannot be modelled by the user manually. Especially wheelchair user would need more space than the provided width of 0.4m within Aeneas.
The aim of this thesis is to investigate on alternative escape routes. This investigation can be conducted with Aeneas. But due to certain limitations of the simulation software not all ideas and approaches can be implemented.

Nevertheless, Aeneas is a simulation software with a clear user interface which is easy to apply. Until now only little data on comparisons of real evacuation drills and simulation results exist. But this data showed a good correlation. However, more data should be collected to calibrate the model and give the possibility to model extraordinary circumstances like panic, darkness, smoke or water in the ship.

8 Evacuation simulation

Description of model

Base for the investigations was the "Evacuation Plan" of a cruise liner newbuilding from the Meyer Werft. The plan described an early stage of design, but this is regarded as sufficient for this kind of investigation. To limit the computing duration and the effort to model modifications two main vertical zones have been chosen. Main vertical zone three and four represent a typical arrangement on a passenger cruise ship with six passenger cabin decks, three crew cabin decks and several public spaces.
The distribution of passengers and crew members as well as the assignment of escape routes is done according to the Evacuation Plan. The Evacuation Plan was designed according the current rules and regulations mentioned in chapter 5. The plan can be found in the Annex (Data CD).
The allocation of people to their muster stations had to be adapted to the chosen main vertical zones. Because in the original plan people located in main vertical zone three or four are mustered in areas outside the chosen zones.
This will influence the evacuation analysis not significantly, because it is ensured that the capacities of each escape route element are not exceeded. Therefore, the evacuation analysis is still according to the rules.

Muster station concept

The original concept cannot be taken over, because necessary muster stations are not arranged within the limits of main vertical zone three and four.
The passengers in cabins and public spaces are allocated as evenly as possible to the nearest muster station. The muster stations for passengers K, I, L and J are located outside and the crew muster station M is located inside as shown in figure 8.1.

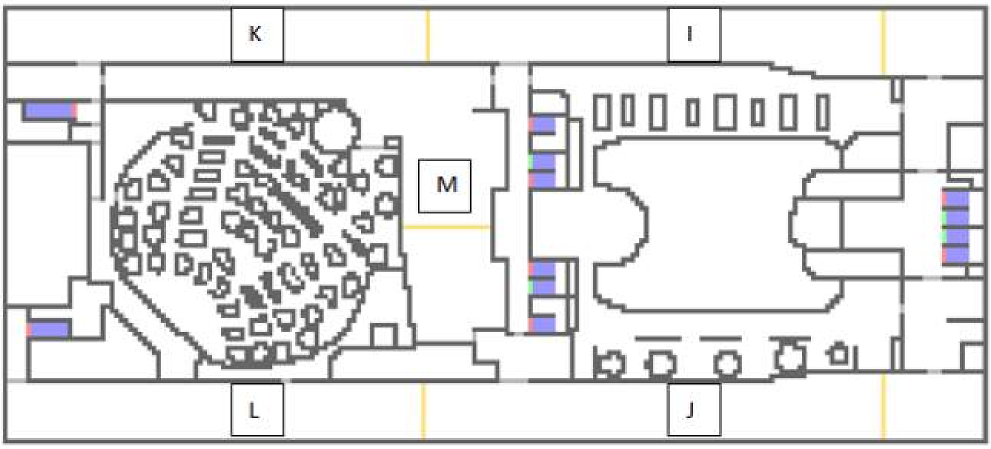

Figure 8.1: Adapted muster station concept

Preparation of model

The main vertical zones three and four were modelled according to the Evacuation Plan (Version A) in AutoCad. Then dxf-files could be imported into Aeneas. Several manual corrections had to be done to achieve a well-prepared model.
In Aeneas the layout is distributed in square cells with an edge-length of 0.4m. When the dxf-file is imported sometimes cells are shifted to a wrong position. That is why manual corrections had to be done.

Settings

The settings within Aeneas are done according to MSC/Circ.1238. This includes the assignment of certain groups and parameters, which define the walking behaviour, to agents.

Scenarios

First of all, it is distinguished between day and night case according to the benchmark scenarios 1 and 2 in MSC/Circ.1238. Furthermore, heel (0°, 10° and 20°) and trim (10°) cases are considered. When heel occurs the ship tilts to starboard side and when trim occurs it tilts forward.

Simulation

The evacuation simulation is done with the program Aeneas, versions 2.5.0.8 and 2.6.0.0. With regard to recommendations of TraffGo HT, the developer of Aeneas, each case is simulated 500 times.

9 Investigations on modifications

To evaluate the modifications initial day and night cases will be investigated. The results and outputs provide a basis for the comparison and assessment of alternative escape routes.
The calculation models and output data for all cases can be found in the Annex (Data CD).

9.1 Initial cases

The basic model used for the calculations for the initial cases can be found in chapter 12.3 (Annex). In figure 12.21 (Annex) the numbering of the stairways according to the Evacuation Plan (Data CD) can be found.

Night Case

In general, in this case only a few critical points occur. When no heel or trim occurs no considerable congestions develop. Under heel conditions (10° and 20°) significant congestions in the corridor, transverse to midship, on the Deck 4 (embarkation deck) develop. As well on stairway nr. 42 from Deck 6 to Deck 4 a congestion develops corresponding to list of the ship. Moreover on stairway nr. 34 on Deck 6 and 7 on the starboard side a significant congestion occurs. Under trim conditions (10°) only a small congestion develops on the corridor on Deck 4.

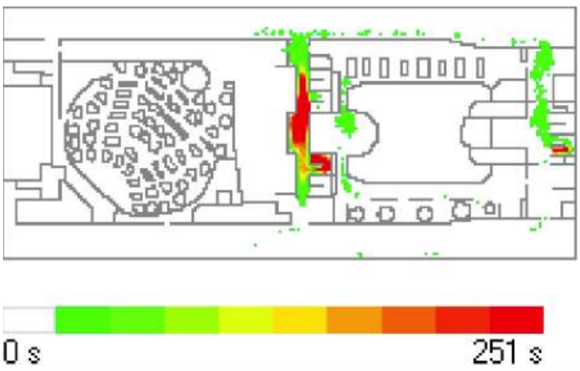

Figure 9.1: Density plot of IC, Heel 20°, Deck 4

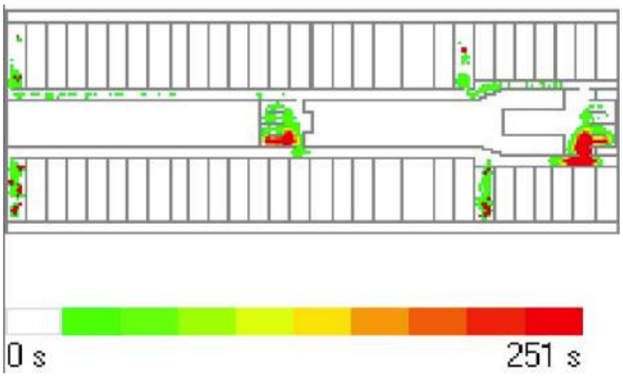

Figure 9.2: Density plot of IC, Heel 20°, Deck 6

The total evacuation time increases in average about 18.5%, when heel of 10° or trim of 10° occurs, but it doubles when heel of 20° occurs compared to the case when no heel or trim is defined.

Day Case

Due to the distribution of people the day cases differs a lot from the night case. During the day case the majority passengers is distributed in public spaces, whereas during the night case all passengers are distributed in their cabins.
Critical points are the restaurant in main vertical zone three on Deck 2, stairway nr. 40 on portside leading from Deck 2 to the embarkation deck and the corridor on Deck 4.

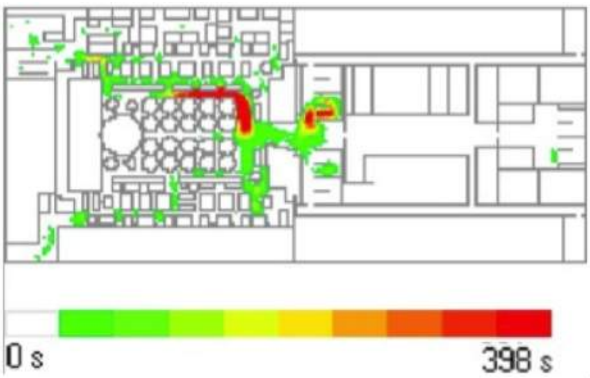

Figure 9.3: Density plot of IC, Heel 20°, Deck 2

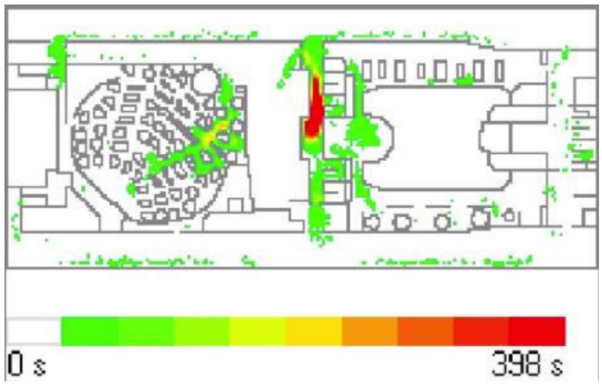

Figure 9.4: Density plot of IC, Heel 20°, Deck 4

The congestions on the critical points develop also under trim and heel condition, but with a different intensity. The total evacuation time increases in average about 24.1%, when heel of 10° or trim of 10° occurs. But when heel of 20° occurs the travel time increases by 118% compared to the case when no heel or trim is defined.

9.1.1 Effects of heel and trim

As explained in chapter 12.2 ship motion, like heel or trim, influences the parameter dawdle probability and the parameter sway, which causes a drifting by slope. Therefore, the walking behaviour of each person changes with different heel or trim angles. Subsequently, the total travel time is increased when the people need more time to reach their goal. In most cases heel causes congestions as the initial cases show.
But in certain cases heel or trim conditions can have positive influences on the overall evacuation situation. An example is the comparison between the 0° and 10° heel initial day case. During the 10° heel case a congestion in the restaurant on Deck 2 dissolves approximately 240s earlier, because the heel pulled apart a certain amount of people and shifted them into another part of the restaurant. This was sufficient to benefit a faster dissolvement of the congestion on the critical point.
Within nearly every day case investigations trim conditions had positive influence on the significant travel time and the overall evacuation process. Trim caused as well a pulling apart of people and congestions dissolved earlier.

The guideline MSC/Circ.1238 does not consider and require investigations on heel or trim cases. But the decision to investigate on heel 10°, 20° and trim 10° results from the preliminary work including ship accidents and research projects. Due to this ship motion will be taken into account, because it is very likely that in case of an ship emergency also trim or heel occurs. Changed environmental conditions influence the walking behaviour and the development of the evacuation process significantly. When modifications are implemented the impact of heel or trim will be taken into account as well. The evaluation of a modification should not based on a case describing only one ambient condition.

9.1.2 Evaluation

For the assessment of the modifications the significant cases are considered. For those cases single runs are conducted and outputs like density plots, screenshots, evacuation curves etc. are produced. Density plots describe significant congestions. Such congestions are defined by MSC/Circ.1238. A congestion is significant, when the population density exceeds 4P/m^2 for longer than 10% of the total travel time. The maximum value in the scale of the density plots is equal to 10% of the total travel time.
Whilst the investigations were evaluated it was noted that the influence of modifications on the overall travel time had less influences than expected. Because of that an additional criterion was introduced to describe a time when most people are rescued. The travel time ends, when the last person arrives at the muster station. Therefore, high values for the travel time resulted due to individuals, which are slow compared to the all other people. The new "95%-rescue criterion" describes the time reduction, when 95% of all people are rescued, compared to the relevant reference case.

At the end of each chapter, which describes one modification, an overview about all important data is attached. This overview includes the minimum, maximum and significant travel times of the initial cases and the modified cases. Those are shown in diagrams as well. A second table describes the 95%-rescue criterion in percentage and seconds. In the following diagrams evacuation curves are shown, which describe the amount of rescued people over time.

9.2 Modification 1: Larger stairway-, corridor- and door widths

With this modification the influences of larger widths of certain escape route elements will be investigated. The escape route arrangements are changed in its dimensions in two steps.

Element	Position	Initial width [mm]	M1.1 [mm]	M1.2 [mm]
Stairs	Stairways nr. 34, 40, 42	1200	1600	2000
Corridor	Deck 4	1200	2000	2800
Doors	Deck 4	800	1200	2800
	Deck 5	800	1600	2800

Table 9.1: Dimension of escape route elements

Due to the increase of stairway widths the size of landing areas are enlarged appropriately as well.

Night Case

The results for the night cases showed that modifications like larger stairway widths can avoid or reduce the intensity of congestions. The overall significant travel time is hardly influenced. When no heel or trim occurs the significant travel time can be reduced by 4% (=52s). But when heel of 20° occurs it rises by 7% (180s). Therefore, larger escape routes sizes can also have negative influences on the evacuation process, because people tend to sway more when the limiting walls have a larger distance.
The 95%-rescue criterion shows that only some individuals are influenced negatively, because the majority of people is rescued at an earlier point in time.
In average of all heel and trim cases 95% of all people are rescued about 11.5% (133s) earlier than in the initial cases without any modifications. The greatest impact occurs at heel of 20°, when the total evacuation time increases by 7%, but 95% of all people are rescued about 192s earlier compared to the initial case with heel of 20°.

Day Case

In the day cases the effects of changed sizes of escape route elements are greater compared to the night cases. After the first step of investigations still room for improvements was given. That is why a second step was investigated as shown in table 9.1.
For example on Deck 4 in the initial case congestions develop in front of the stairways nr. 40 (PS and SB). Investigation M1.1 shows a congestion only on the portside. In figure 9.6 the first step of modifications is shown. In this step all escape route elements were enlarged in size. Many people reached the corridor on Deck 4 at the same time, but the door leading to the muster station on portside was not large enough in size. Due to this a congestion developed in the corridor on Deck 4 in front of the door on portside. However, the congestion in the initial case on stairway nr. 40 (SB) on Deck 4 could already been avoided in Modification 1.1.
In M1.2 the escape route elements are enlarged in size again. As shown in the figures below no congestions develop. Through adapted door widths on Deck 4 an uniform outflow of people can be achieved.

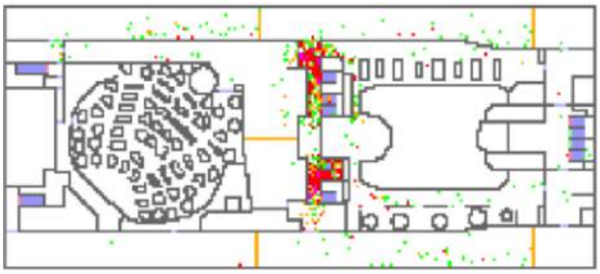

Figure 9.5: Screenshot of IC, heel 10°, t=420s

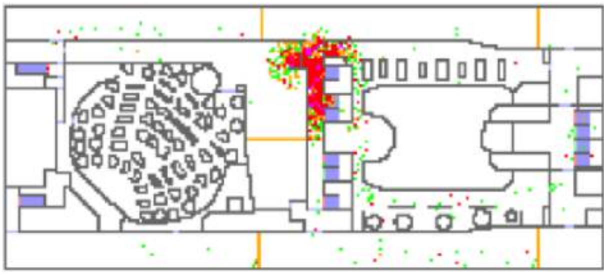

Figure 9.6: Screenshot of M1.1, heel 10°, t=420s

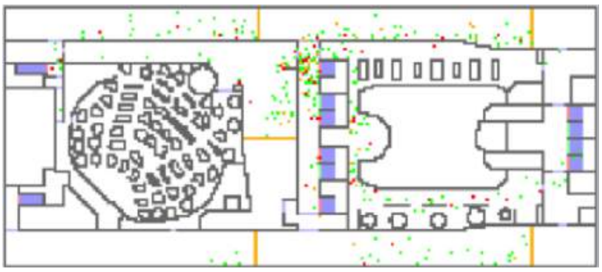

Figure 9.7: Screenshot of M1.2, heel 10°, t=420s

The significant travel time decreases between 39%-50% depending on the trim or heel. When no heel occurs and trim of 10° 95% of all people reach their muster station approximately 65% (=1150s) earlier compared to the initial cases. And at heel of 10° and 20° 95% of all people reach their aim 43% (=813s) earlier.

9.2.1 Evaluation of modification

In general, the modification has much more influence in the day case. In the night case a higher amount of people is rescued at an earlier point in time, but the total, maximum and minimum travel time change only within a small range. Moreover, the night case has only limited potential for further improvements, because the initial night case has only few critical areas.
In the day case the larger stairway-, corridor- and door widths can avoid or dissolve congestions much earlier. As a result the total, minimum and maximum travel time can be reduced compared to the initial cases.
The stepwise modification and investigation showed that it is not sufficient to change only the dimension of selected escape route elements. It is necessary to consider the total escape routes to avoid backlog or shifting congestions.
Nevertheless, larger dimensions of escape route elements can also influence the walking behaviour negatively. In heel and trim cases people tend to sway. When more space is provided people may need more time to reach their goal.

During this Modification 1.2 the stairs have a width of 2000mm. With regard to FSS-Code, Chapter 13, Rule 2.2.1 this would not be permitted. According to the rule the clear width between handrails on stairways is limited to 1800mm. To implement the higher width of 2000mm alternative design has to apply.

9.2.2 Overview of data

Initial Cases					M1.2: Larger stairway-, corridor-, and door widths				
Night Cases								ΔSign. T [%]	ΔSign. T [s]
Heel	Trim	Min. T [s]	Max. T [s]	Sign. T [s]	Min. T [s]	Max. T [s]	Sign. T [s]		
0	-	989	1627	1264	951	1289	1212	-4,11	-52
10	-	1241	1622	1514	1157	1673	1533	1,25	19
20	-	1771	2835	2512	1724	2994	2692	7,17	180
	0	989	1627	1264	951	1289	1212	-4,11	-52
-	10	1210	1578	1482	1148	1590	1483	0,07	1
							average	1,09	37
Day Cases								ΔSign. T [%]	ΔSign. T [s]
Heel	Trim	Min. T [s]	Max. T [s]	Sign. T [s]	Min. T [s]	Max. T [s]	Sign. T [s]		
0	-	1157	12647	2514	670	1449	1245	-50,48	-1269
10	-	1502	2708	2341	925	1677	1426	-39,09	-915
20	-	2291	4628	3938	1602	2783	2349	-40,35	-1589
	0	1157	12647	2514	670	1449	1245	-50,48	-1269
-	10	937	2167	1860	827	1158	1104	-40,65	-756
							average	-42,64	-1132

Figure 9.8: Overview time data

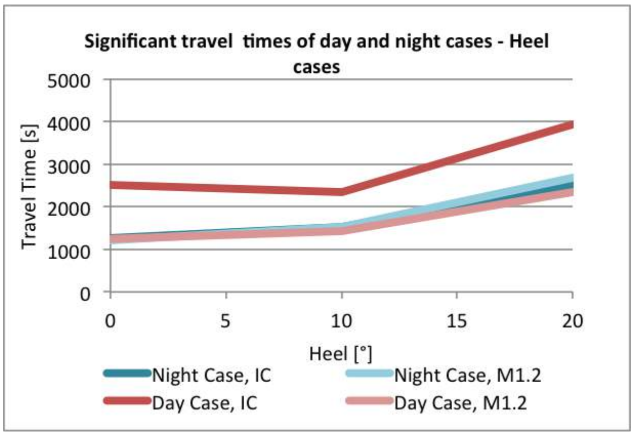

Figure 9.9: Significant time data curves, Heel cases

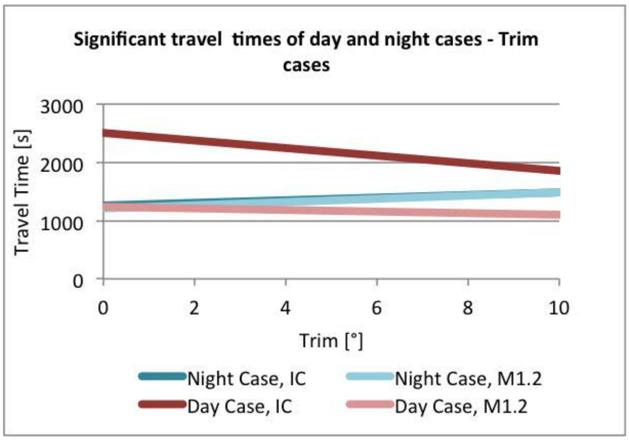

Figure 9.10: Significant time data curves, Trim Cases

Night Case			
	Time [s] Rescue of 95%	Δt [%]	Δt [s]
M1.2 Heel = 0	816	-10,03	-91
IC Heel = 0	907		
M1.2 Heel = 10	943	-12,03	-129
IC Heel = 10	1072		
M1.2 Heel = 20	1346	-12,48	-192
IC Heel = 20	1538		
M1.2 Trim = 10	936	-11,36	-120
IC Trim = 10	1056		
	average	-11,48	-133
Day Case			
	Time [s] Rescue of 95%	Δt [%]	Δt [s]
M1.2 Heel = 0	665	-65,84	-1282
IC Heel = 0	1947		
M1.2 Heel = 10	958	-46,24	-824
IC Heel = 10	1782		
M1.2 Heel = 20	1192	-40,25	-803
IC Heel = 20	1995		
M1.2 Trim = 10	553	-64,62	-1010
IC Trim = 10	1563		
	average	-54,24	-980

Figure 9.11: Overview 95%-rescue criterion data

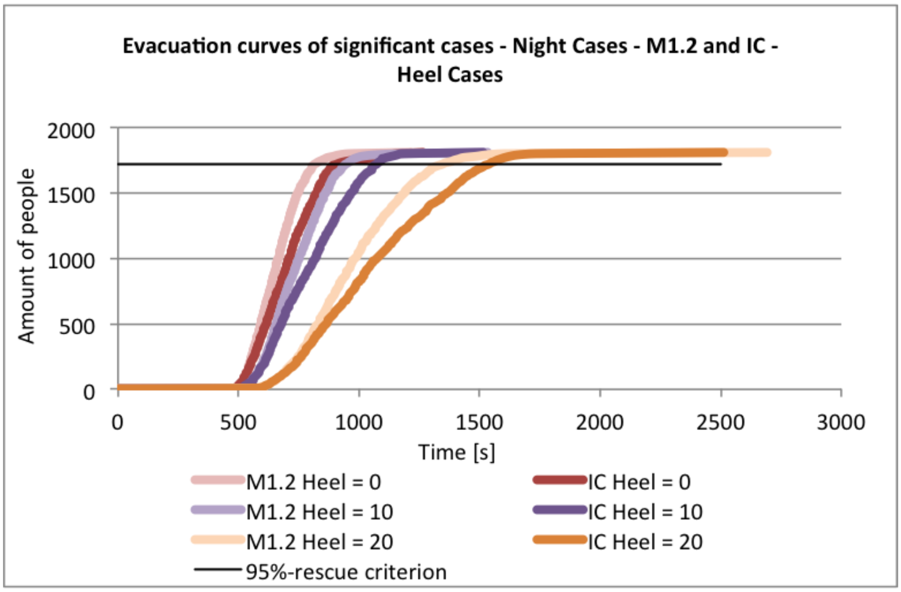

Figure 9.12: Evacuation curves, Heel cases, Night cases

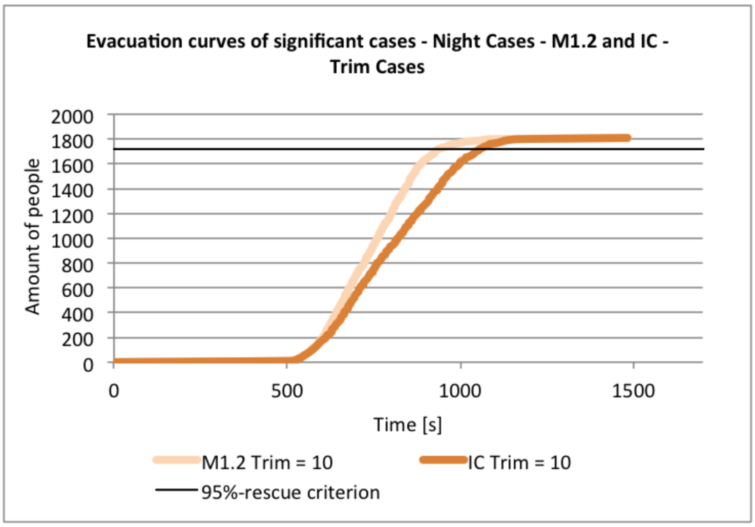

Figure 9.13: Evacuation curves, Trim cases, Night cases

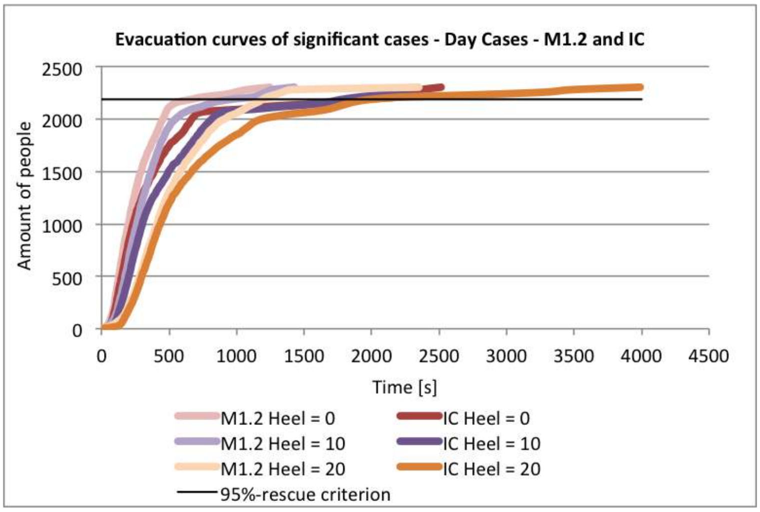

Figure 9.14: Evacuation curves, Heel cases, Day cases

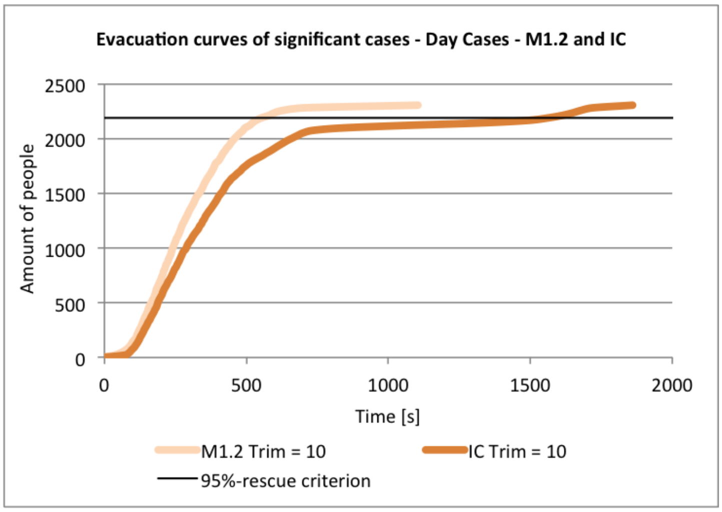

Figure 9.15: Evacuation curves, Trim cases, Day cases

9.3 Modification 2: Heel support systems

Research projects on human behaviour during emergencies found out, that people do not use the total width of escape routes when heel occurs. That is why the modification of a heel support system intends to support people by additional handrails to move straight towards their goal. Due to limitations within Aeneas it is not possible to model handrails. As an alternative walls are included.

9.3.1 Simulations with certain parts of the arrangement

To illustrate the human walking behaviour, effects of heel and support systems in an empty room are investigated. The empty room has a length of 35 m and a breadth of 37 m. In the aft part of the room 300 people are distributed.

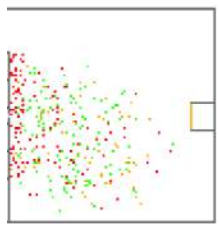

Figure 9.16: Screenshot of empty room, Heel 20°, t=60s

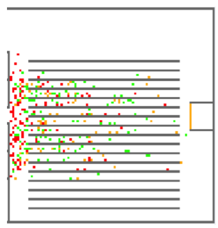

Figure 9.17: Screenshot of empty room with heel support system, Heel 20°, t=60s

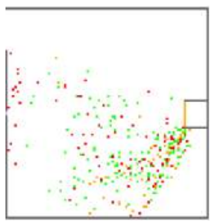

Figure 9.18: Screenshot of empty room, Heel 20°, t=90s

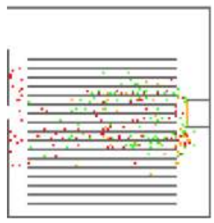

Figure 9.19: Screenshot of empty room with heel support system, Heel 20°, t=90s

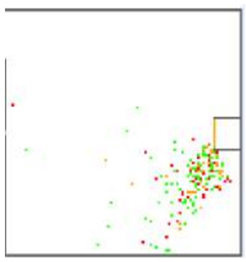

Figure 9.20: Screenshot of empty room, Heel 20°, t=210s

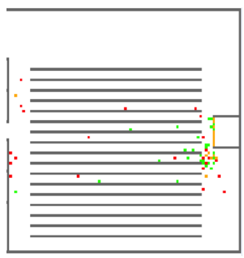

Figure 9.21: Screenshot of empty room with heel support system, Heel 20°, t=210s

The figures above shows the walking behaviour plotted over time at heel of 20°. Obviously, people sway to the heeling side. With a support system this effect is reduced and people reach their goal much earlier. People can hold their direction more easily and the total travel time can be reduced by 22.5 % at a heel angle of 20°.

First of all, simulations on certain parts of the model arrangement are investigated. It is assumed that a heel support system does not effect the overall evacuation time, but benefits the faster evacuation of areas equipped with such devices. In following areas of the arrangement heel support systems are implemented and considered independently.

- Test 1: Deck 5, MVZ 3, public space
- Test 2: Deck 4, MVZ 3 and 4, muster stations
- Test 3: Deck 3, MVZ 4, public space

For all test a certain number of people is distributed in the aft part of the areas and walk towards their goal in the forward part.
Between 0° to 10° no positive effect of the support system results. On the contrary, the support system can be an obstacle and increase the travel time when small heeling angles occur. The most advantageous situation for a heel support system occurs at heel of 20°, because people are guided straight to their goal by the support system and travel time is decreased. The effect of swaying is reduced significantly.
Moreover, the simulations one and two were done with many short (length=1.60 m) and continuous support systems. The findings clearly showed that short support systems do not fulfil their purpose. When a short support systems ends, people drift towards the ship´s list again until they reach the next support system. Is the support system continuous as long as possible people can keep their direction over a long period of time.
Furthermore, a support system is recommendable only when an area has a great width. This was proved with the investigations on the muster stations. There are no obstacles arranged and the goal is directly in the walking direction. Therefore, in such areas people do not sway much, because walls leading to the goal decrease this effect. The same also applies to corridors, which are usually characterized by narrow distances between walls.

9.3.2 Investigation on model

To prove the influence on the total model the day and night cases are investigated on a model equipped with heel support systems.
Base for the evaluation is the model resulting from Modification 1.2 with larger stairway-, corridor-, and door widths. In Modification 1.2 all congestions, which influence the evacuation process mainly, are avoided or reduced. That is why this model seems to be the best option to investigate on the impact of a heel support system.
On this model the heel support systems are implemented on corridors on passenger cabin decks. The heel support systems are continuous as long as the arrangement allows it. For example, in front of doors no support systems are provided. In the centre of the corridors a wall is implemented in the model. The distances from the devices to the corridor walls are 800 mm on each side. This allows people overtaking each other.

Moreover, in the public spaces, mentioned within the simulations on certain parts of the arrangements, support systems are implemented as well.

Night Case

It is expected that during the night cases no significant advantages occur, because most people are distributed in their cabins. This means their escape routes lead mainly through narrow corridors and stairways. Public space with great widths are only used as escape routes by some crew members, which are distributed in service spaces.
When no heel or trim of 10° occurs the heel support system seem to be an obstacle, because the total travel time increases by up to 5% (=62s). At heel 10° and 20° the total travel time decreases, but less than 1%. Considering the 95%-rescue criterion shows a similar tendency. In average the time, when 95% of people are rescued is increased by approximately 1% (=10s).
The minimum travel time values are similar to the initial case, whereas the maximum travel time values are higher when no heel, heel of 20° or trim of 10° occurs.

Day Case

During the day cases most people are distributed in public spaces. In case of heel and trim it is expected that the heel support systems have positive influences on the evacuation process.
The total evacuation time increases by 3% (=38s), when no heel occurs. But when heel of 10° and 20° occurs, the total evacuation increases by 5% (=126s) as well. The most significant increase occurs at trim 10° with 43% (=479s). When a closer look is taken to the evacuation process, it become clear that this high travel time depends on one single person only.
Considering the 95%-rescue criterion is very interesting, because when heel of 20° and trim of 10° occurs, the time when 95% of all people are rescued decreases by 11% (=130s) and 20% (=135s). When no heel occurs the 95%-rescue criterion rises by 28%. This confirms the assumption that a heel support system is an obstacle under this condition.
The minimum travel time values are similar to the initial case, whereas the maximum travel time values are higher in all cases.

9.3.3 Evaluation of modification

The investigations showed that a precondition for a successful and appropriate implementation of a heel support system is heel greater than 10° and areas with a great width. Moreover, the heel support systems should be continuous as long as possible.
If those conditions are not fulfilled the positive effects cannot be achieved and the heel support system is an obstacle, which influences the evacuation time and process negatively.
On the overall evacuation process few influences occur. The minimum, maximum and significant travel time values show that for some individuals a heel support system can be an obstacle. The advantage of the concept is that certain areas can be evacuated faster and people are supported when heel angles higher than 10° occurs.

9.3.4 Overview of data

M1.2: Larger element widths					M2: Heel support systems				
Night Case								ΔSign.	ΔSign.
Heel	Trim	Min. T [s]	Max. T [s]	Sign. T [s]	Min. T [s]	Max. T [s]	Sign. T [s]	T [%]	T [s]
0	-	951	1289	1212	958	1742	1274	5,12	62
10	-	1157	1673	1533	1159	1646	1522	-0,72	-11
20	-	1724	2994	2692	1734	3330	2684	-0,30	-8
	0	951	1289	1212	958	1742	1274	5,12	62
-	10	1148	1590	1483	1173	1734	1498	1,01	15
							average	1,28	15
Day Case								ΔSign.	ΔSign.
Heel	Trim	Min. T [s]	Max. T [s]	Sign. T [s]	Min. T [s]	Max. T [s]	Sign. T [s]		
0	-	670	1449	1245	650	1485	1283	3,05	38
10	-	925	1677	1426	932	1986	1505	5,54	79
20	-	1602	2783	2349	1612	3470	2475	5,36	126
	0	670	1449	1245	650	1485	1283	3,05	38
-	10	827	1158	1104	878	2093	1583	43,39	479
							average	4,25	70

Figure 9.22: Overview time data

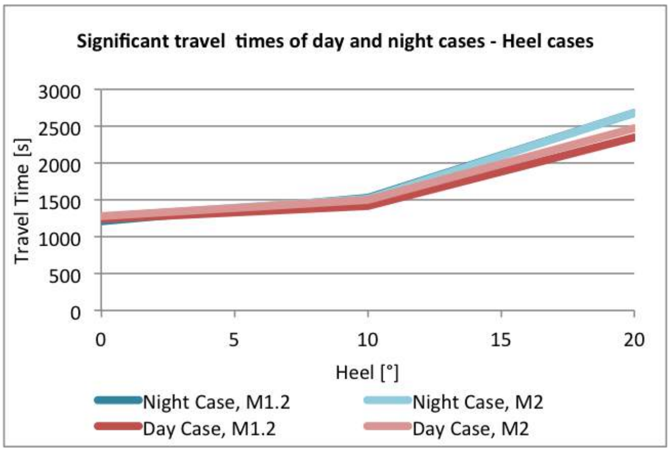

Figure 9.23: Significant time data curves, Heel cases

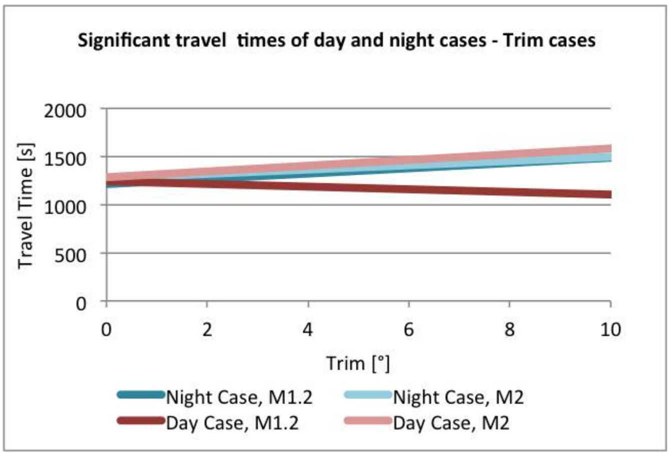

Figure 9.24: Significant time data curves, Trim cases

Night Case			
	Time [s] Rescue of 95%	Δt [%]	Δt [s]
M2 Heel = 0	810	-0,74	-6
M1.2 Heel = 0	816		
M2 Heel = 10	968	2,65	25
M1.2 Heel = 10	943		
M2 Heel = 20	1346	0,00	0
M1.2 Heel = 20	1346		
M2 Trim = 10	958	2,35	22
M1.2 Trim = 10	936		
average		1,07	10
Day Case			
	Time [s] Rescue of 95%	Δt [%]	Δt [s]
M2 Heel = 0	850	27,82	185
M1.2 Heel = 0	665		
M2 Heel = 10	976	1,88	18
M1.2 Heel = 10	958		
M2 Heel = 20	1062	-10,91	-130
M1.2 Heel = 20	1192		
M2 Trim = 10	553	-19,62	-135
M1.2 Trim = 10	688		
average		-0,21	-16

Figure 9.25: Overview 95%-rescue criterion data

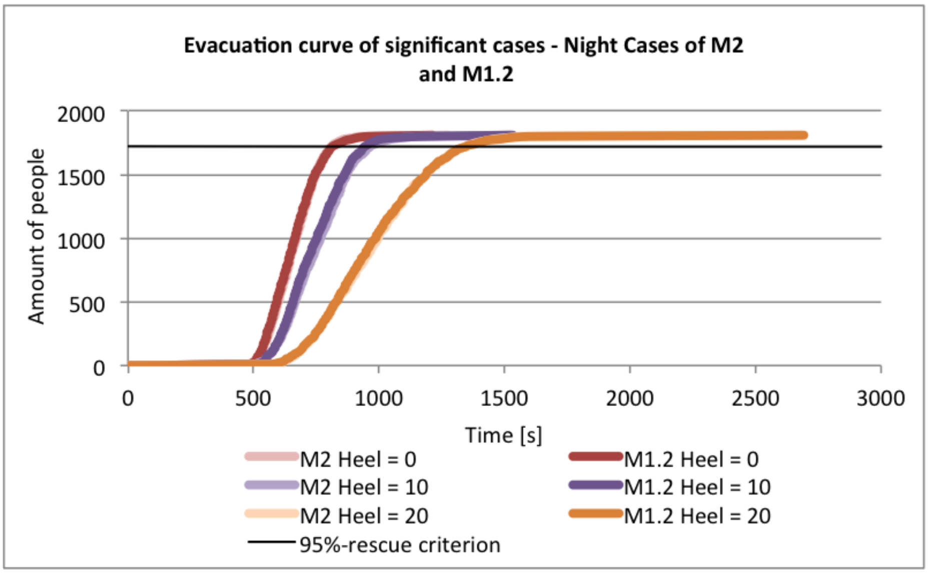

Figure 9.26: Evacuation curves, Heel cases, Night cases

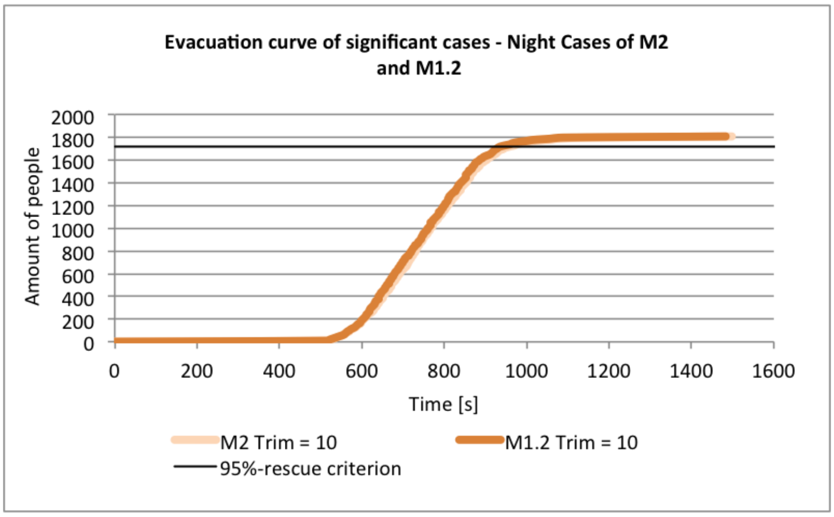

Figure 9.27: Evacuation curves, Trim cases, Night cases

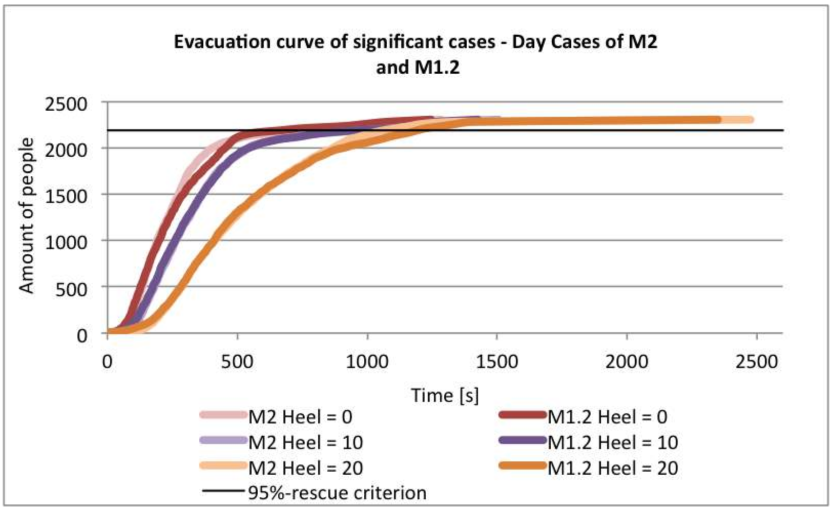

Figure 9.28: Evacuation curves, Heel cases, Day cases

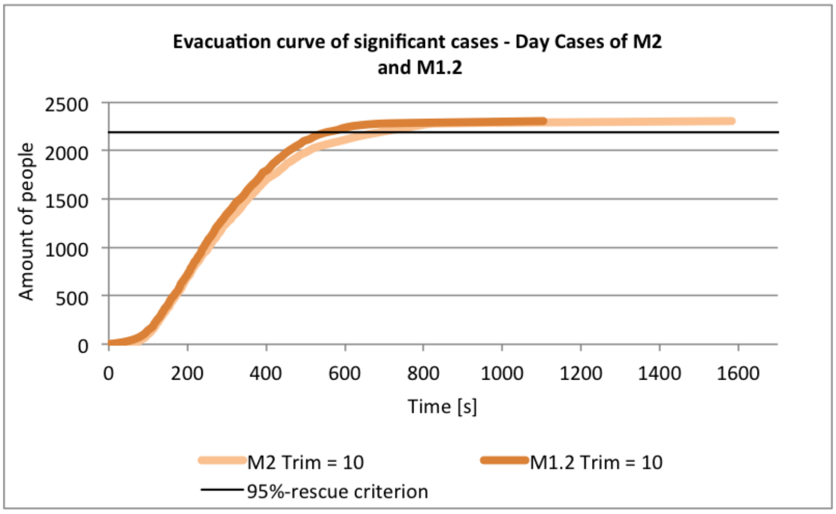

Figure 9.29: Evacuation curves, Trim cases, Day cases

9.4 Modification 3: Additional escape route components

The initial cases showed a high load on the escape route elements on the embarkation deck. In this chapter the focus will be one additional escape route elements to decrease the load and influence the overall evacuation procedure positive.
The embarkation deck is highly frequented especially during the day case. Because of this reason only the day case will be investigated.

9.4.1 Modification 3.1 Additional doors and alternative escape routes

Critical points in the initial day cases were the corridor, doors and stairways on Deck 4 leading to the muster stations. In the first step on the embarkation deck additional doors from the public spaces to the muster stations have been added. The idea is to redirect people from the public spaces directly to their muster station. In the initial cases people from public spaces on Deck 4 use the main corridor, where congestions developed. To minimize the load on the corridor people who are located in the public spaces on Deck 4 use additional doors to reach the muster stations. These doors need not to be active during normal operations, but only when an evacuation is necessary.
Furthermore, in the middle of the corridor on midship two additional doors (breadth=800 mm) for crew members are being added. In the initial cases crew members reach the embarkation deck by stairway nr. 42. By passing the public space in main vertical zone four and the corridor, they reach their muster station in main vertical zone three. This leads to a counter flow effect on the corridor in front of the exits towards the muster station. To avoid this the crew is redirected to the additional doors on midship. These doors should only be active when an emergency occurs.

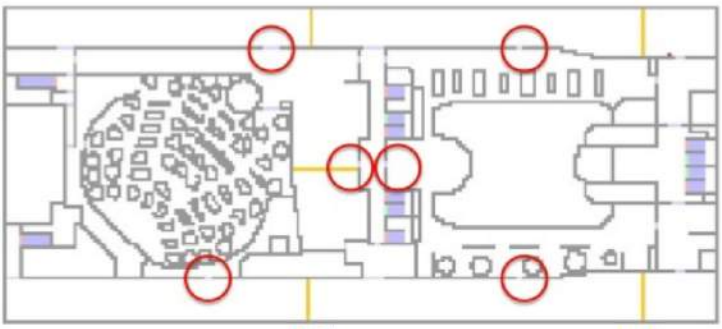

Figure 9.30: Additional doors on embarkation deck

Moreover, from Deck 2, main vertical zone three, many people use stairway nr. 40 to reach the embarkation deck. To reduce the load on these main escape routes 196 passengers from Deck 2 are redirected to stairway nr. 42. This stairway is a crew stairway only. Previous investigations showed that stairway nr. 42 is no critical escape route element, because no significant congestions develop there. In the following figure is shown with yellow arrows the initial escape routes for passengers from the restaurant in main vertical tone three. The red arrows show the alternative escape route.

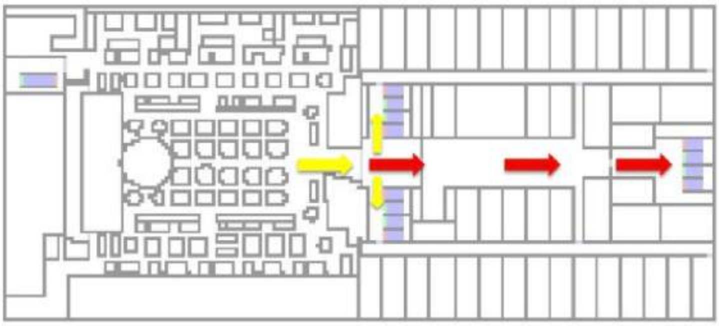

Figure 9.31: Alternative escape route on Deck 2

Day case

Due to additional elements and allocation of alternative escape routes congestions can be reduced significantly. In the restaurant on Deck 2, stairway nr. 40 SB and on the corridor in front of stairway nr. 40 SB still congestions develop, but these have less extents than in the initial cases. The figures below shows the densities on the embarkation deck.
The effect of additional doors for crew members in Deck 4 midship is visible as well. On the corridor in front of the new doors leading to the crew muster station a congestion develops. This is assessed an an uncritical development, because the congestion is small and located in area which is not heavily frequented.

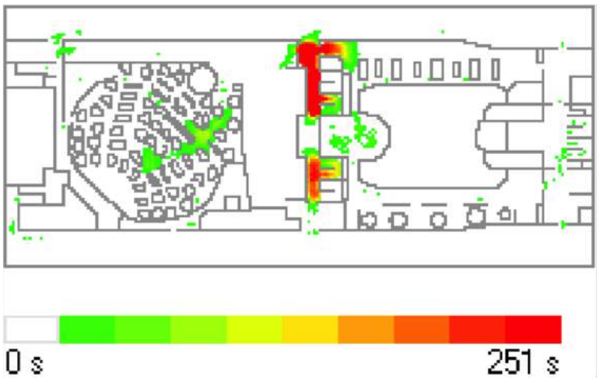

Figure 9.32: Density plot of initial case, Deck 4, Heel = 0°

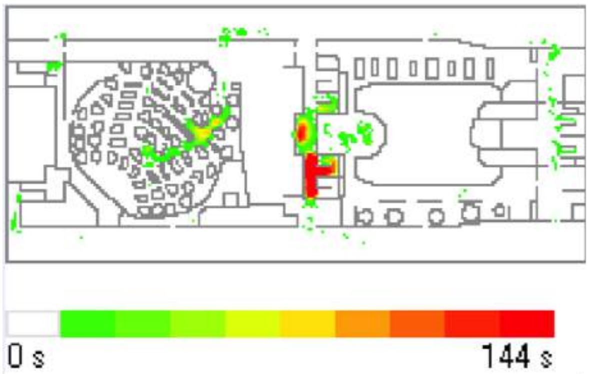

Figure 9.33: Density plot of M3.1, Deck 4, Heel = 0°

In all other heel and trim cases similar influences of the modifications are being noted. Congestions developed at the same areas, but with lesser extents. Stairway nr. 42 is used now by much more passengers to reach the muster stations. Nevertheless, no congestions developed on this alternative escape route. When a heel of 20° occurs it is visible that the person density is much higher than in the initial case. This is shown in the following figures.

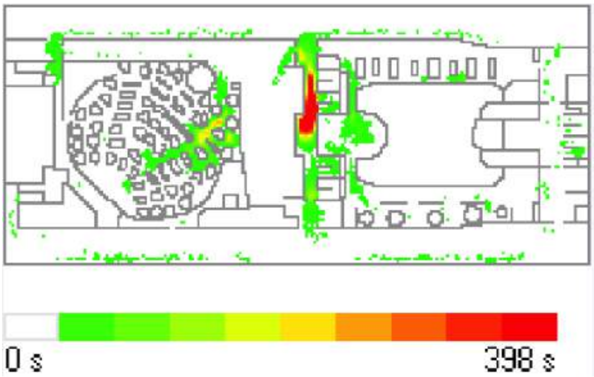

Figure 9.34: Density plot of initial case, Deck 4, Heel = 20°

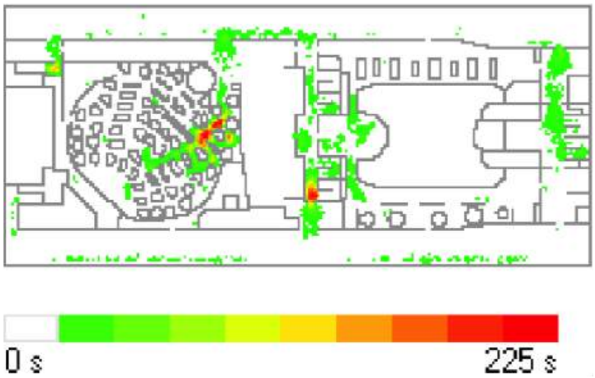

Figure 9.35: Density plot of M3.1, Deck 4, Heel = 20°

The total evacuation time in average can be reduced by approximately 37% (=1009s). The maximum and minimum values are reduced in all cases as well.
Considering the 95%-rescue criterion, it is shown that the time can be reduced by 55% (=1071s) when no heel or trim occurs. When heel and trim of 10° occurs, the time when 95% of all people reached their muster stations can be reduced by approximately 39% (=695s). The worst case occurs with heel of 20°, when the 95%-rescue criterion can only be decreased by 34% (=672s).

9.4.2 Evaluation of modification

This modification is assessed as very successful because the maximum and minimum values as well as the significant travel times, the 95%-rescue criterion and the development of congestions could be decreased.
Simple solutions, like additional doors for certain person groups, which are guiding the people more straight to their goal, can reduce congestions. And thus, crossing escape routes in heavily frequented areas should be avoided to prevent counterflow effects.
If strong congestions and backlog develop in certain areas it should be taken into account to use alternative escape routes, which are no critical areas. Although this might be not the direct route and causes a detour. Therefore, also alternative escape routes like crew escape routes should be considered to pull congestions apart and reduce the load on the main escape route.

Within this modification stairway nr. 42 is used by crew members and passengers. In the initial cases this stairway was only used by crew members. For a practical implementation also the requirements explained in Chapter 5 need to be considered.
The allocation of alternative escape routes influences the calculation of stairway widths according to FSS-Code, Chapter 13. This regulation gives a calculation method to define the widths of stairways depending on the amount of people using this stairway.
When alternative escape routes are needed for a safe evacuation, certain escape route elements are used by a higher amount of people than planned. Therefore, the calculated capacity of an escape route element should be taken into account, when alternative escape routes will be in use.

9.4.3 Modification 3.2: Additional stairway

Another idea is to provide an additional escape route element, which is not active during normal operations. For example pull-out stairways could be implemented, which are extended and used for evacuation procedures only.
The additional stairway is implemented in main vertical zone three from Deck 2 to Deck 4 to minimize the load on the main escape route. A certain amount of passengers from Deck 2 and Deck 3 are redirected via this additional stairway with an breadth of 1200 mm.

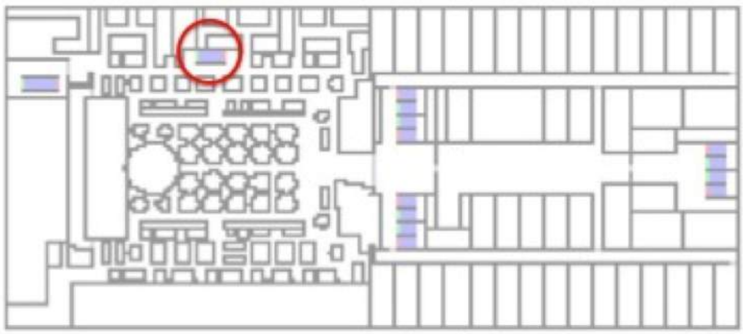

Figure 9.36: Additional stairway on Deck 2

This modification was investigated for the day case only, because the additional stairway is located in a public space which is not in use during the night case.

Day case

On the embarkation deck within the initial cases and M3.2 congestions developed. But during the initial case on Deck 3 also backlog occurred. This backlog is reduced, when a certain amount of people uses an alternative escape route element. The differences are shown in the density plots below.

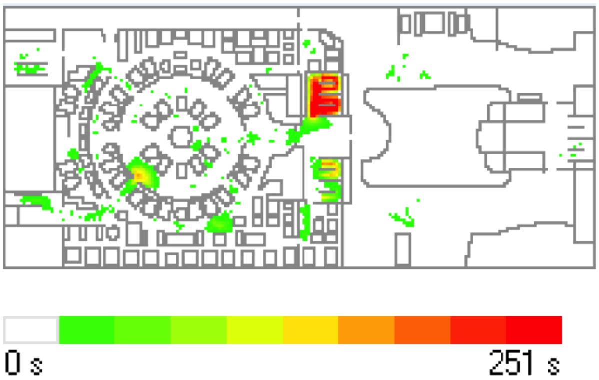

Figure 9.37: Density plot of initial case, Deck 3, Heel = 0°

Figure 9.38: Density plot of M3.1, Deck 3, Heel = 0°

In all other heel and trim cases the same effect appeared. When heel of 20° occurs the backlog on Deck 3 can be avoided completely. Only a high person density is visible on the density plots of M3.2. The total evacuation time is reduced by 24% (=595s) when no heel or trim occurs, 7% (159s) at heel 10°, 9% (=358s) at heel 20° and 17% (323s) at trim 10°. The maximum and minimum travel time values are reduced in all cases as well. The 95%-rescue criterion is on average reduced by 33% (=599s).

9.4.4 Evaluation of modification

This modification is very successful too, because congestions are reduced, the minimum, maximum and significant travel times and the 95%-rescue criterion are lowered significantly compared to the initial cases. Thus, the results of modification 3.1 and 3.2 are quite similar.
To add additional escape route elements, which are only used in case of an emergency for evacuation procedures, turned out as very effective concept. Another promising approach is the redirecting of people to alternative escape routes.
For the practise this would require an intelligent guiding system. The development of evacuation procedures depends decisively on the distribution of people and the environmental conditions. Those are hard to predict and differ from case to case.
To achieve a safer and faster evacuation process an intelligent guiding system seem to be necessary to guide people on proper evacuation routes depending on the situation. An intelligent guiding system should be able to identify the location of people and identify hazards and their impact on the accessibility on the evacuation route. Moreover, a system is necessary which is able to predict the location and intensity of congestion development in the current situation. In case of using an alternative escape routes like in Modification 3.1 it should be calculable how many people can use the alternative route without overloading it. Considering all this points an intelligent guiding should be able to guide the people to their muster station on the safest way.

9.4.5 Overview of data

Initial Cases					M3.1: Additional doors & alternative escape routes				
Day Case								ΔSign. T	ΔSign. T
Heel	Trim	Min. T [s]	Max. T [s]	Sign. T [s]	Min. T [s]	Max. T [s]	Sign. T [s]	[%]	[s]
0	-	1157	12647	2514	744	1680	1449	-42,36	-1065
10	-	1502	2708	2341	837	2031	1641	-29,90	-700
20	-	2291	4628	3938	1443	3137	2257	-42,69	-1681
	0	1157	12647	2514	744	1680	1449	-42,36	-1065
-	10	937	2167	1860	824	1524	1272	-31,61	-588
							average	-36,64	-1009
Initial Cases					**M3.2: Additional stairway**				
Day Case								ΔSign. T	ΔSign. T
Heel	Trim	Min. T [s]	Max. T [s]	Sign. T [s]	Min. T [s]	Max. T [s]	Sign. T [s]		
0	-	1157	12647	2514	921	2181	1919	-23,67	-595
10	-	1502	2708	2341	1068	2690	2182	-6,79	-159
20	-	2291	4628	3938	1775	4281	3580	-9,09	-358
	0	1157	12647	2514	921	2181	1919	-23,67	-595
-	10	937	2167	1860	880	1840	1537	-17,37	-323
							average	-14,23	-359

Figure 9.39: Overview time data

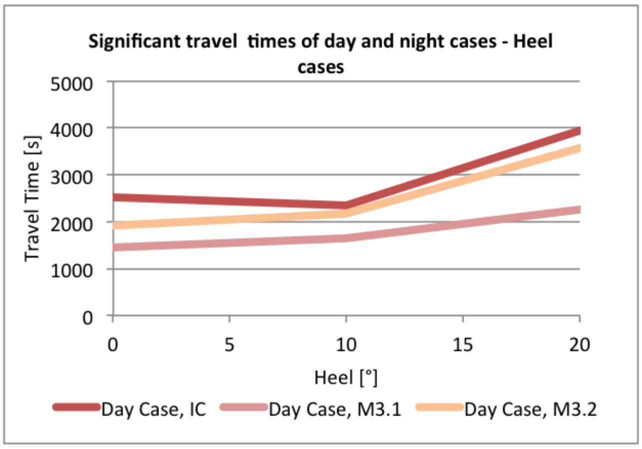

Figure 9.40: Significant time data curves, Heel cases

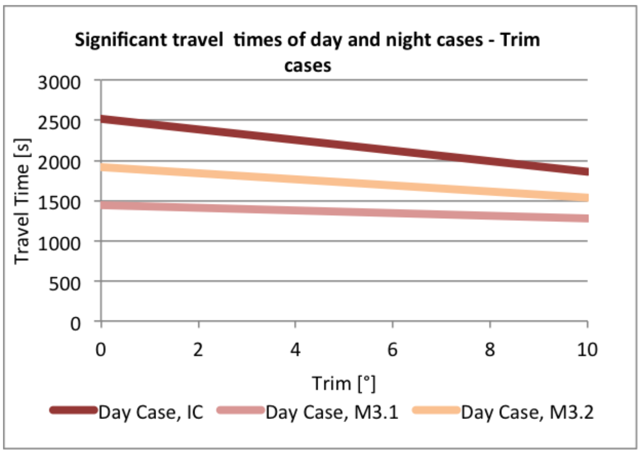

Figure 9.41: Significant time data curves, Trim cases

M3.1: Day Case			
	Time [s] Rescue of 95%	Δt [%]	Δt [s]
M3.1 Heel = 0	876	-55,01	-1071
IC Heel = 0	1947		
M3.1 Heel = 10	1116	-37,37	-666
IC Heel = 10	1782		
M3.1 Heel = 20	1323	-33,68	-672
IC Heel = 20	1995		
M3.1 Trim = 10	935	-40,18	-628
IC Trim = 10	1563		
average		-41,56	-759
M3.2: Day Case			
	Time [s] Rescue of 95%	Δt [%]	Δt [s]
M3.2 Heel = 0	1151	-40,88	-796
IC Heel = 0	1947		
M3.2 Heel = 10	1498	-15,94	-284
IC Heel = 10	1782		
M3.2 Heel = 20	1219	-38,90	-776
IC Heel = 20	1995		
M3.2 Trim = 10	1025	-34,42	-538
IC Trim = 10	1563		
average		-32,53	-599

Figure 9.42: Overview 95%-rescue criterion data

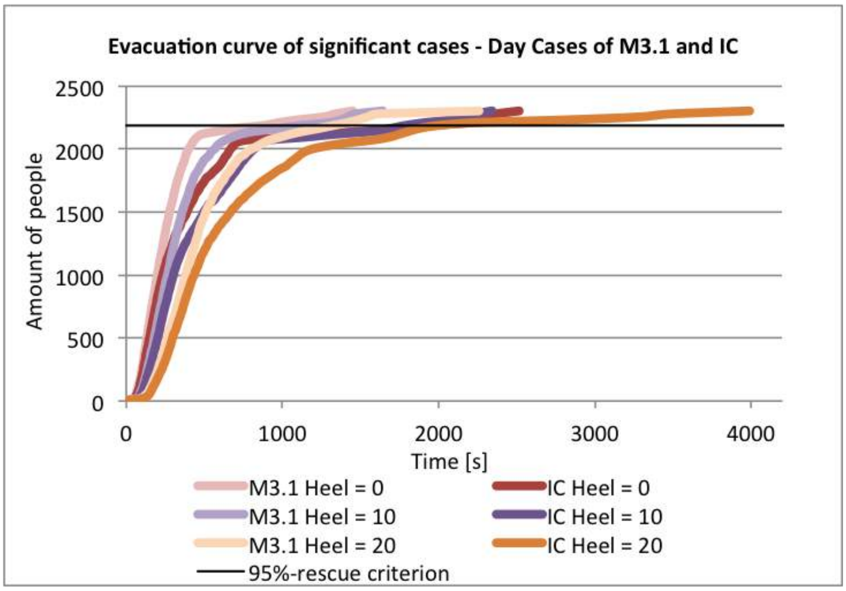

Figure 9.43: Evacuation curves, Heel cases, Day cases, M3.1

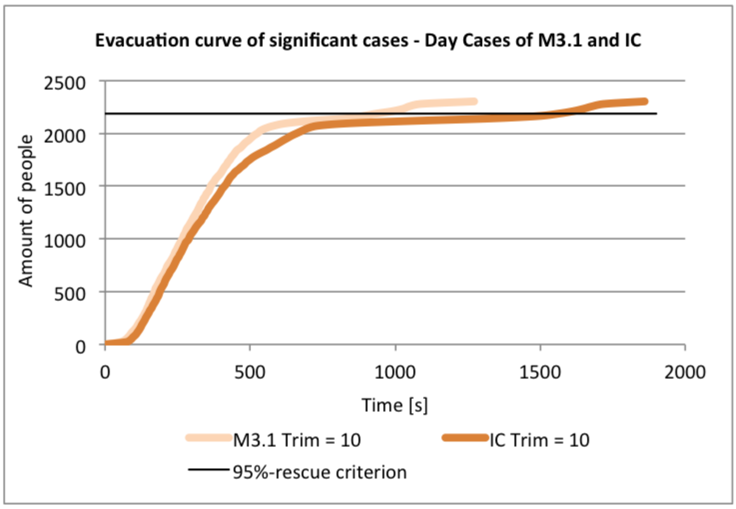

Figure 9.44: Evacuation curves, Trim cases, Day cases, M3.1

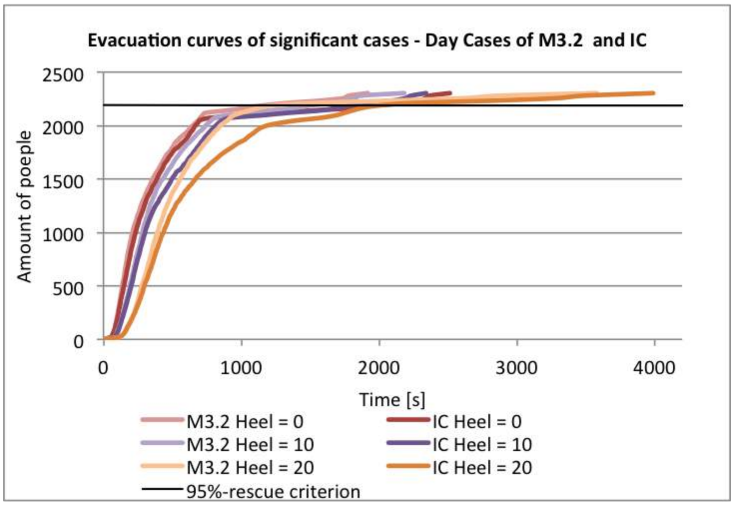

Figure 9.45: Evacuation curves, Heel cases, Day cases, M3.2

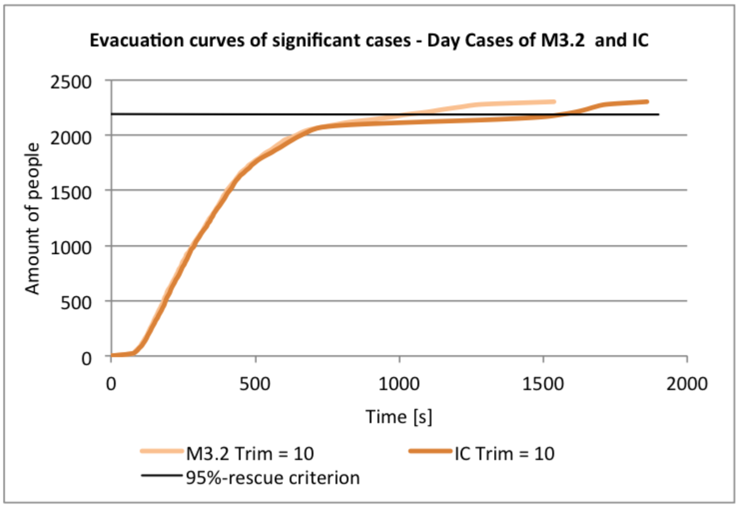

Figure 9.46: Evacuation curves, Trim cases, Day cases, M3.2

9.5 Modification 4: Alternative rescue systems

9.5.1 Modification 4.1: ResCube

The concept of a ResCube is already described in chapter 3.3. In the model four ResCubes with an capacity of 1320 seats are implemented. In the aft part of each fire zone one element is arranged on starboard and portside. In front of the entrances to the ResCube small muster stations with a size of $34m^2$ are provided.
On the passenger cabin Decks 6 to 10 one ResCube needs the space for two cabins as shown in figure 9.47. In two fire zones now 40 cabins less can be provided, because of this new rescue system. The room arrangement on Deck 4 and 5 has to be adapted as well.
Each ResCube can take 55 per persons and deck. Therefore, in the night case all passengers can follow the main corridor towards their muster station without changing the deck level. But in the day case most people are located in the public spaces, that means they have to move up to get to their muster stations.

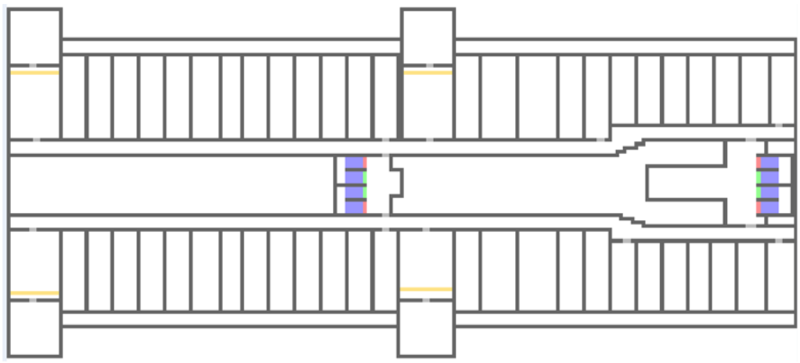

Figure 9.47: Arrangement of ResCube on passenger cabin decks

Night Case

In the night case the capacity of the ResCubes is sufficient to evacuate all passengers via this rescue system. The crew members are still mustered on Deck 4.
The embarkation deck is used by the crew members only, but still congestions on the corridor in front of the portside entrance to the crew muster station develop. Those congestions are under all heel and trim conditions less intensive compared to the initial cases, because the total amount of people using Deck 4 is lowered. The densities on the embarkation deck are shown in the figures 9.48 and 9.49.
Congestions on the passengers cabins decks are avoided completely, because the stairways are not in use. On Deck 33, a crew cabin deck, a congestion in front of the stairway leading to the upper decks developed.
The total evacuation time is lowered by approximately 6% (=107s) when no heel, heel of 10° and 20° occurs. Under trim condition the time can be reduced by only 4% (=63s). The maximum and minimum travel time values are lowered in all cases as well.
But the significant influence of the new rescue system is shown in the evacuation curves. The majority of people can be rescued at earlier point in time. Considering the 95%-rescue criterion is indicative, because in average 95% of all people are rescued 17% (=210s) earlier. The most positive effect occurs at heel 20°, when the 95%-criterion is decreased by 28% (=430s).

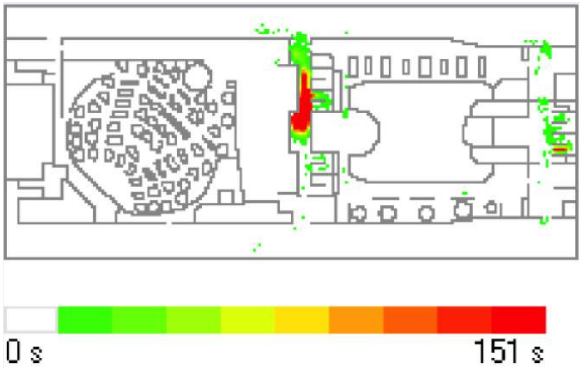

Figure 9.48: Density plot of initial case, Deck 4, Heel = 10°

Figure 9.49: Density plot of M4.1, Deck 4, Heel = 10°

Day Case

Due to a totally different distribution of people during the day case now four ResCubes are not sufficient to evacuate all passengers via this new rescue system. The surplus amount of people is directed to the usual muster stations on Deck 4. In practise, they would be evacuated in neighbouring fire zones. The allocation of passengers to the muster station is as follows:

Initial position	Target position
Deck 5	Deck 10
Deck 4	Deck 9 and 8
Deck 3	Deck 8, 7 and 4
Deck 2	Deck 6, 5 and 4

Table 9.2: New allocation of muster stations in M4.1

The new allocation of escape routes to the passengers results in long distances to muster stations and congestion development. Especially on Deck 3 and 4 congestions and backlog occurred, because all people had to move upward to the passenger cabin decks. The intensity of the congestion compared to the initial case is shown in the figures below.

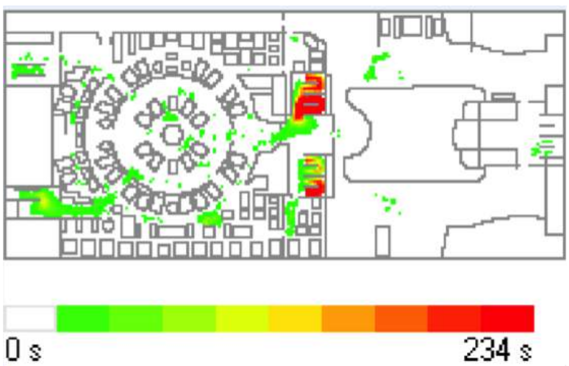

Figure 9.50: Density plot of initial case, Deck 4, Heel = 0°

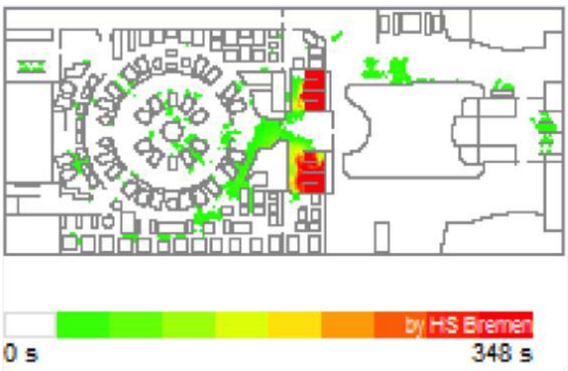

Figure 9.51: Density plot of M4.1, Deck 4, Heel = 0°

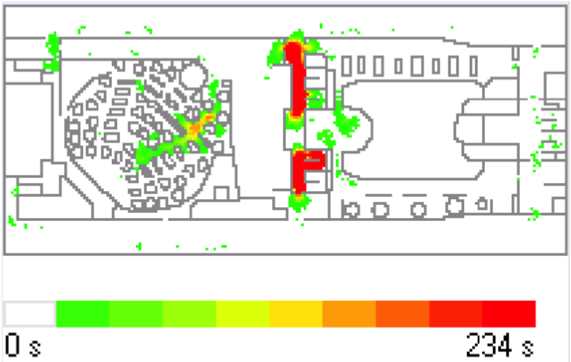

Figure 9.52: Density plot of initial case, Deck 4, Heel = 0°

Figure 9.53: Density plot of M4.1, Deck 4, Heel = 0°

The total evacuation time increases significantly in all heel and trim cases. The greatest increase occurs at trim 10° when the total evacuation time increases by 118% (=2207s). On average the significant travel time rises by 69% (=1613s). The maximum and minimum travel time values increase significantly compared to the initial cases.
Taken into account the 95%-rescue criterion shows an average increase of 88% (=1584s). Therefore all day cases exceed the allowed travel time to fulfil MSC/Circ.1238. Consequently, this design would not be permitted with regard to evacuation processes.

The initial day case with heel of 20° exceeds the limit as well. This is permissible because MSC/Circ.1238 requires no evacuation simulation at heel or trim conditions. At heel of 0° the limit is not exceeded and therefore the design would be valid.

9.5.2 Evaluation of modification

The ResCube is an innovative system with an interesting approach to evacuate people from a passenger vessel. For the night case this system is a good option, because the walking distance can be reduced. Moreover, the people on passenger cabin decks do not have to change the deck level which results in less congestion development.
On the other side, the day case had to be considered as well. Usually only one rescue system is provided on a passenger vessel. This means if an emergency occurs during the day all passengers would have to walk to their muster station according to the location of their cabin. It is assumed that in most cases many deck levels are between the current and target position. Therefore, the travel distances become very long. The investigations on the day case proved the suspicion. The output data showed congestion development with great extents on the stairways and extremely increasing evacuation times.
In conclusion the ResCube can not be recommended as an alternative rescue system under consideration of MSC/Circ.1238, because during the day case too much disadvantages occur.
Alternative rescue systems should provide advantages for several possible cases. For the night case the ResCube is an effective approach to evacuate people faster from the vessel. But during the day the evacuation process is worse compared to the initial cases.

9.5.3 Overview of data

Initial Cases					M4.1: ResCube				
Night Case								ΔSign. T [%]	ΔSign. T [s]
Heel	Trim	Min. T [s]	Max. T [s]	Sign. T [s]	Min. T [s]	Max. T [s]	Sign. T [s]		
0	-	989	1627	1264	927	1280	1187	-6,09	-77
10	-	1241	1622	1514	1030	1537	1422	-6,08	-92
20	-	1771	2835	2512	1397	2747	2360	-6,05	-152
	0	989	1627	1264	927	1280	1187	-6,09	-77
-	10	1210	1578	1482	1093	1555	1419	-4,25	-63
							average	-5,62	-96
Day Case								ΔSign.	ΔSign.
Heel	Trim	Min. T [s]	Max. T [s]	Sign. T [s]	Min. T [s]	Max. T [s]	Sign. T [s]		
0	-	1157	12647	2514	3433	4950	4674	85,92	2160
10	-	1502	2708	2341	2440	3842	3485	48,87	1144
20	-	2291	4628	3938	2890	5639	4877	23,84	939
	0	1157	12647	2514	3433	4950	4674	85,92	2160
-	10	937	2167	1860	2384	4478	4067	118,66	2207
							average	69,32	1613

Figure 9.54: Overview time data

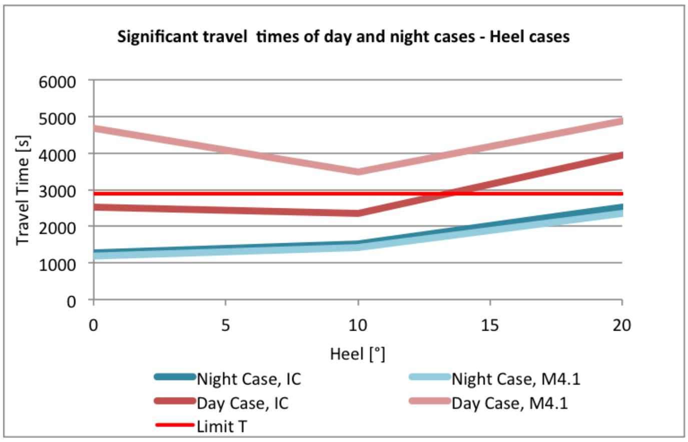

Figure 9.55: Significant time data curves, Heel cases

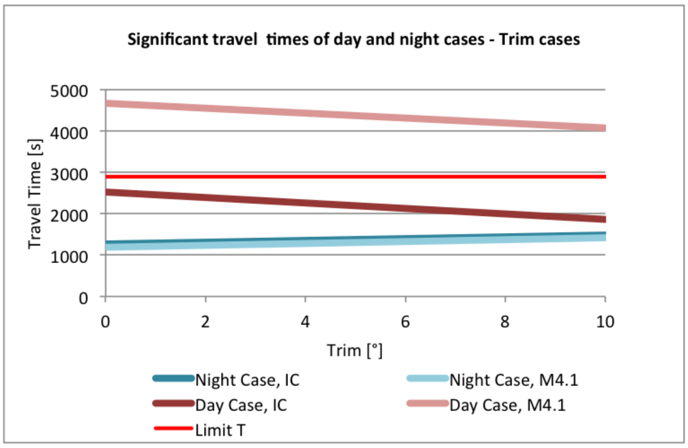

Figure 9.56: Significant time data curves, Trim cases

Night Case			
	Time [s] Rescue of 95%	Δt [%]	Δt [s]
M4.1 Heel = 0	795	-12,35	-112
IC Heel = 0	907		
M4.1 Heel = 10	884	-17,54	-188
IC Heel = 10	1072		
M4.1 Heel = 20	1108	-27,96	-430
IC Heel = 20	1538		
M4.1 Trim = 10	949	-10,13	-107
IC Trim = 10	1056		
average		-16,99	-209
Day Case			
	Time [s] Rescue of 95%	Δt [%]	Δt [s]
M4.1 Heel = 0	4279	119,77	2332
IC Heel = 0	1947		
M4.1 Heel = 10	3120	75,08	1338
IC Heel = 10	1782		
M4.1 Heel = 20	2710	35,84	715
IC Heel = 20	1995		
M4.1 Trim = 10	3514	124,82	1951
IC Trim = 10	1563		
average		88,88	1584

Figure 9.57: Overview 95%-rescue criterion data

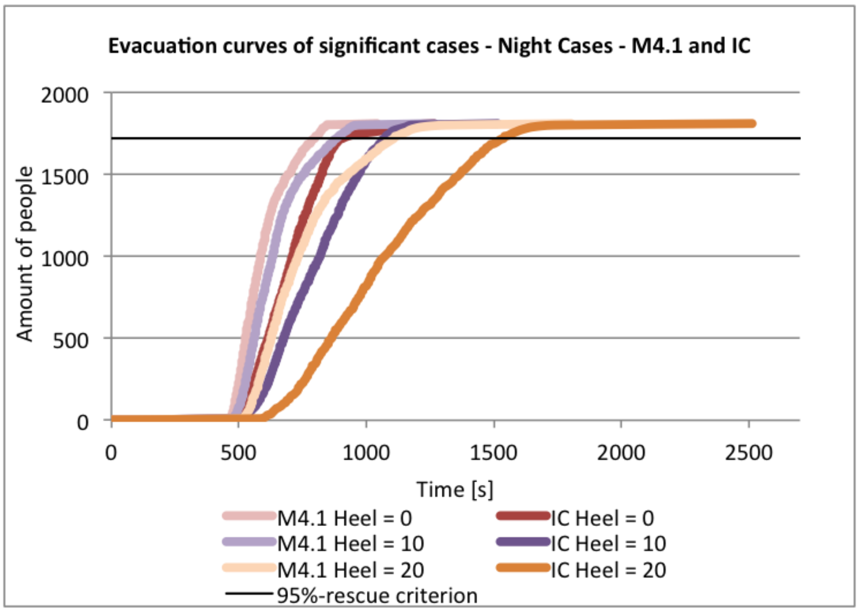

Figure 9.58: Evacuation curves, Heel cases, Night cases

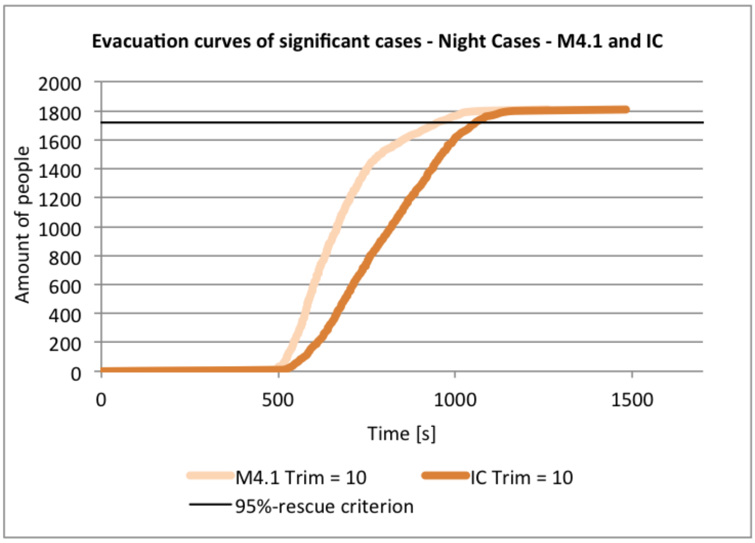

Figure 9.59: Evacuation curves, Trim cases, Night cases

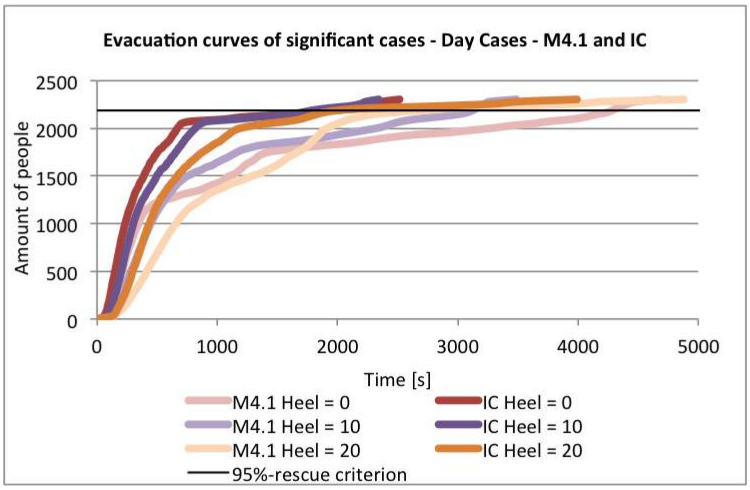

Figure 9.60: Evacuation curves, Heel cases, Day cases

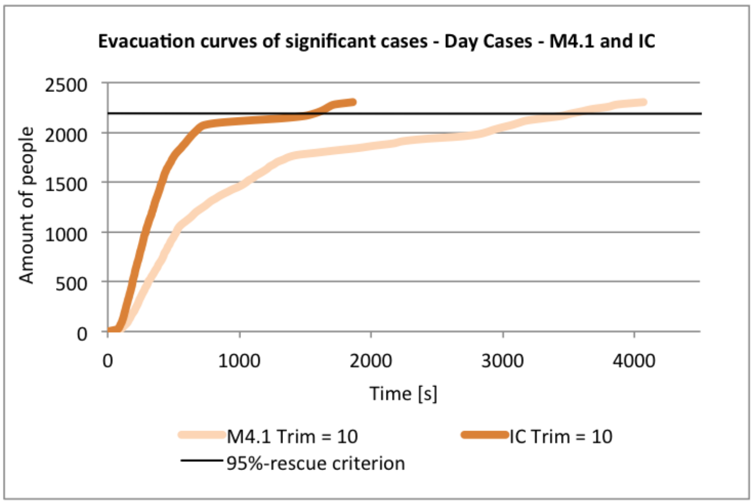

Figure 9.61: Evacuation curves, Trim cases, Day cases

9.5.4 Modification 4.2: Evacuation slides

Marine evacuation systems compose of an inflatable slide or escape chute, which allow a direct evacuation from the vessel into the liferaft. With slides and chutes people can be evacuated very fast, that is why this concept is implemented in the model.
Within this thesis only evacuation processes are investigated and no rescue processes like embarkation and launching. Therefore, the scope of application of evacuation slides is adapted to the initial conditions.
During the night cases all passengers are distributed on the passenger cabin decks. Now from each deck and fire zone two evacuation slides are implemented to evacuate the people directly from their cabin deck to the muster stations where lifeboats are ready for embarkation.
Until now no evacuation slides for this scope of application transporting passengers fast from high decks to the embarkation decks exist. Therefore, no manufacturer and reliable data can be presented. As an approach for the evacuation times with evacuation slides different slide and chute systems are compared. The results showed a range for evacuation times between 2,73 and 3,18 s/person. For this investigation a time of 4 s/person is chosen.
The implementation in the model is shown in the figure below. The red circles show the entrances to the evacuation slide. Within Aeneas this entrances are modelled with one exit cells which is blocked for four seconds, when one person entered the cell.

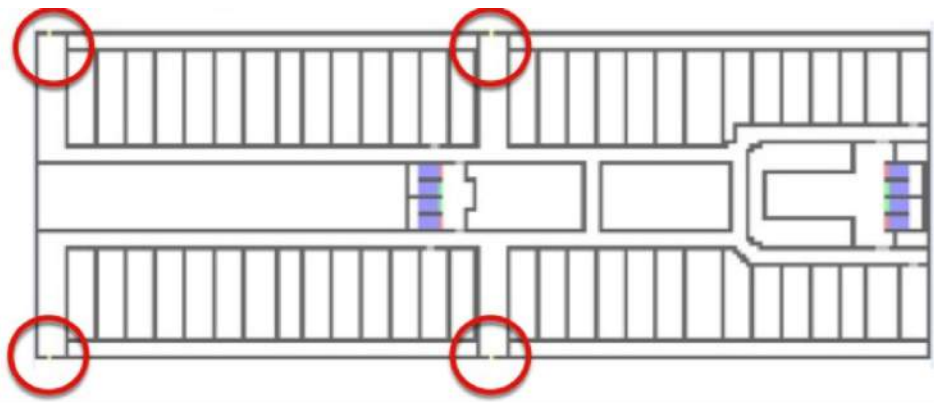

Figure 9.62: Arrangement of evacuation slides on passenger cabin decks

This modification is only investigated for the night case, because the evacuation slides would only be used under this conditions.

Night Case

Congestions which are caused by crew members, for example on Deck 33 occurred as well. The stairways leading from the passenger cabin decks to the embarkation deck are not used. Accordingly, no congestion developed there. Due to the time of 4 s each person needs to be evacuated via the evacuation slide small congestions developed on the passengers cabin decks in front of the evacuation slide entrances. In the figures below the effects of the use of evacuation slides are shown. In the initial cases on Deck 9 a congestion developed on the stairways. This congestion is avoided in the modified case.

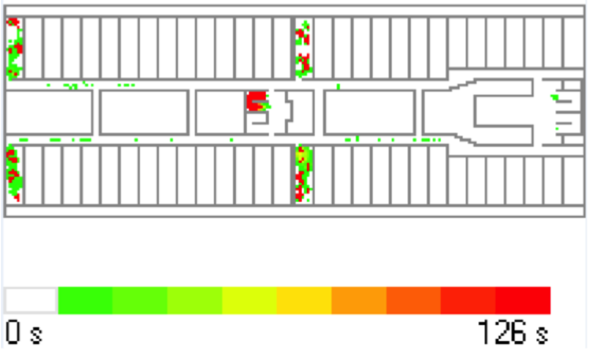

Figure 9.63: Density plot of initial case, Deck 9, Heel = 0°

Figure 9.64: Density plot of M4.2, Deck 9, Heel = 0°

In all other trim and heel cases similar effect occurred. Another positive effect is the minimized load on the embarkation deck. The development of congestions is reduced significantly as shown in the figures below.

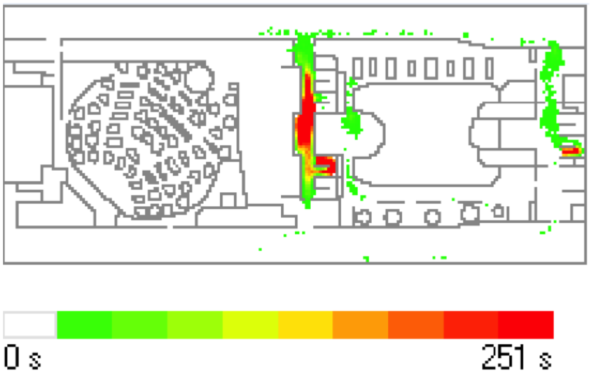

Figure 9.65: Density plot of initial case, Deck 4, Heel = 20°

Figure 9.66: Density plot of M4.2, Deck 4, Heel = 20°

The total evacuation time changed not significantly, because crew members are considered in the modification case as well. The highest reduction of approximately 4% (=45s) is achieved when no heel occurs. The minimum travel time values were lowered as well, but the maximum travel time values increased in all cases, excepted for the case without heel or trim.
More interesting is the consideration of the 95%-rescue criterion. It is expected that much more people are rescued at an earlier point in time, because the passengers have a short travel distance to the evacuation slide entrances. The values show that when heel of 0° and trim of 10° occurs, 95% of all people are rescued 14% (=138s) earlier. When heel of 20° occurs the value rises up to 26% (=398s). This proves the effectiveness of an evacuation slide to evacuate passengers faster during an emergency.

9.5.5 Evaluation of modification

In general, the concept of evacuation slides from high decks to the embarkation deck give the opportunity to evacuate certain person groups faster. The length of escape routes is reduced and influences the evacuation time of passengers. The total travel time is not reduced significantly, because also crew members have to be considered within an evacuation process.
An advantage compared to the ResCube system is the scope of application. The evacuation slides are only an additional escape route element which can be used during the night case. Whereas the ResCube is a rescue system, which has to be used during the day case as well.
The disadvantage of evacuation slides is that no such system for this scope of application is available on the market. And it is not verified whether people can use slides or chutes during heel or trim conditions. Moreover, it is questionable if people would use an evacuation slide voluntarily.

9.5.6 Overview of data

Initial Cases					M4.2: Evacuation slides				
Night Case								ΔSign. T [%]	ΔSign. T [s]
Heel	Trim	Min. T [s]	Max. T [s]	Sign. T [s]	Min. T [s]	Max. T [s]	Sign. T [s]		
0	-	989	1627	1264	903	1315	1219	-3,56	-45
10	-	1241	1622	1514	1111	1630	1508	-0,396	-6
20	-	1771	2835	2512	1640	3052	2533	0,836	21
	0	989	1627	1264	903	1315	1219	-3,56	-45
-	10	1210	1578	1482	1100	1592	1485	0,2024	3
							average	-0,73	-7

Figure 9.67: Overview time data

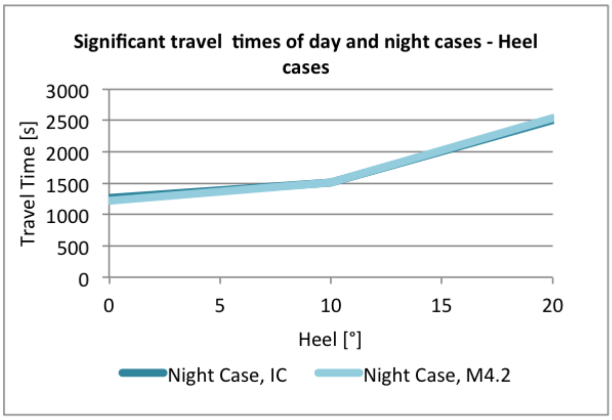

Figure 9.68: Significant time data curves, Heel cases

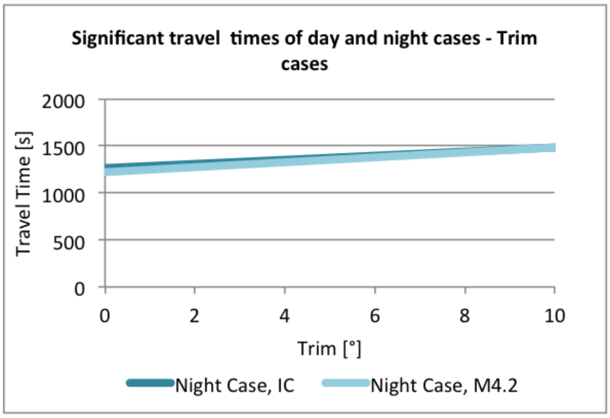

Figure 9.69: Significant time data curves, Trim cases

Night Case			
	Time [s] Rescue of 95%	Δt [%]	Δt [s]
M4.2 Heel = 0	784	-13,56	-123,00
IC Heel = 0	907		
M4.2 Heel = 10	864	-19,40	-208,00
IC Heel = 10	1072		
M4.2 Heel = 20	1140	-25,88	-398,00
IC Heel = 20	1538		
M4.2 Trim = 10	904	-14,39	-152,00
IC Trim = 10	1056		
average		-18,31	-220

Figure 9.70: Overview 95%-rescue criterion data

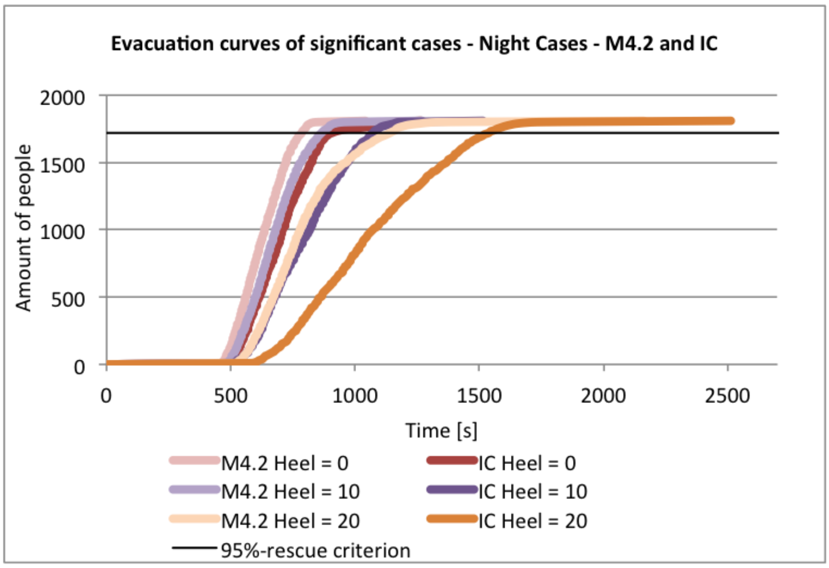

Figure 9.71: Evacuation curves, Heel cases, Night cases

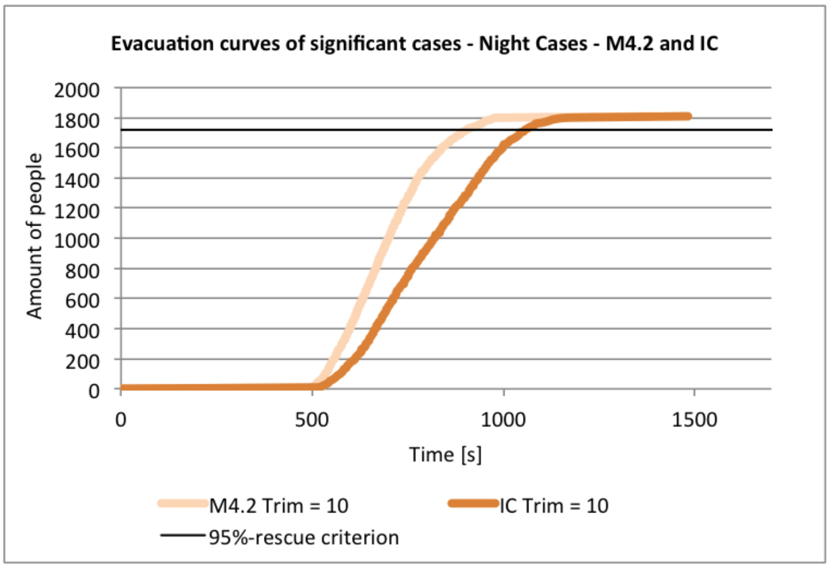

Figure 9.72: Evacuation curves, Trim cases, Night cases

9.6 Modification 5: Individual parameters

9.6.1 Modification 5.1: Distribution of passengers on cabins decks according to age

Investigations within this thesis and former research studies showed that the weakest point in the chain has to be considered. The weak points on passenger vessels are slow people, who have a long distance from their current position to the muster station. Because of this reason a new approach for the distribution of passengers on the cabin decks is made to investigate on the age depended distribution and the impact on the overall evacuation process.
Therefore, only the night case is investigated and a new initial case without crew members is defined to achieve a better basis for evaluation.

According to MSC/Circ.1238 the walking speeds of passengers and crew members depends on the age, the kind of escape route elements (flat terrain, stair up/down, door) and influences of trim or heel.
A manual allocation of walking speeds to certain person groups can be done as well. But different escape route elements cannot be taken into account. Because of that, for this modification the values, as shown in the figure below, for walking speeds on flat terrain are considered. Crew members are not taken into account within the initial and modified version.

Table 3.4 – Walking speed on flat terrain (e.g., corridors)

Population groups – passengers	Walking speed on flat terrain (e.g., corridors)	
	Minimum (m/s)	Maximum (m/s)
Females younger than 30 years	0.93	1.55
Females 30-50 years old	0.71	1.19
Females older than 50 years	0.56	0.94
Females older than 50, mobility impaired (1)	0.43	0.71
Females older than 50, mobility impaired (2)	0.37	0.61
Males younger than 30 years	1.11	1.85
Males 30-50 years old	0.97	1.62
Males older than 50 years	0.84	1.4
Males older than 50, mobility impaired (1)	0.64	1.06
Males older than 50, mobility impaired (2)	0.55	0.91
Population groups – crew	**Walking speed on flat terrain (e.g., corridors)**	
	Minimum (m/s)	**Maximum (m/s)**
Crew females	0.93	1.55
Crew males	1.11	1.85

Figure 9.73: Walking speed of certain groups according to MSC/Circ.1238

The passengers are distributed in ten groups and the allocation of speeds is done manually with the given minimum and maximum values. The young and fast passengers are distributed on Deck 10 and Deck 2. The old and slow people are distributed on the Deck 6 and 7, because the distances to the muster stations are very short.
Deck 2 is located close to the muster station as well. But during an evacuation people from this deck have to walk upstairs. In heel or trim cases this influences the walking speed negatively. That is why on Deck 2 only young and fit people are distributed.

	Capacity	Distribution	Group
Deck 10	195	30	F1, M1
		165	F2, M2
Deck 9	243	1	F2, M2
		242	F3, M3
Deck 8	216	138	F3, M3
		78	F4, M4
Deck 7	203	160	F4, M4
		43	F5, M5
Deck 6	195	195	F5, M5
MUSTER STATION			
Deck 2	136	136	F1, M1

Figure 9.74: Passenger distribution on cabin decks according to age

Night case

When no heel or trim occurs no congestions developed within the initial case and the modified case. For the heel cases of 10° and 20°, and trim case of 10° following finding results: Congestions developed on the same points. This congestions developed due to the heel and trim conditions and the influences on the walking speed.
The total travel time is reduced significantly by 9.4% (=180s) when heel of 20° occurs. In all other cases no significant changes are achieved. The minimum travel time values are reduced, but the maximum travel times diverge minimally from the initial case values.
All evacuation curves show that more people are rescued at an earlier point in time. The 95%-rescue criterion is decreased on average by 4.8% (=37s).

9.6.2 Evaluation of modification

The individual distribution of passengers had less influence on the evacuation process as expected. The overall travel time can only be reduced significantly when heel of 20° occurs. The 95%-rescue criterion is lowered as well, but the reduction of time is quite small.
The results show that an age dependent distribution has not much influence on the overall evacuation process. Moreover, the assumption does not meet the requirements of MSC/Circ.1238 completely. Different escape route element influence the walking speed. This was not taken into account within this modification due to limited possibilities in Aeneas. This influences the resulting values as well. Moreover, a practical implementation of such an idea is not realistic because of moral and social principles.

A critical point is the description of mobility impaired people within MSC/Circ.1238. Mobility impaired people are subdivided into two different groups. Unfortunately, no presentation of the characteristics of this groups is given. Those people are only taken into account by slow walking speeds. But mobility impaired people, like wheelchair users, seem not to be considered.
Moreover, the simulation software does not provide any option to model wheelchair users. The only possibility is to adapt the walking speeds, which limits the opportunities for more investigation on this topic.

9.6.3 Overview of data

Initial Cases					M5.1: Passenger distribution according to age				
Night Case								ΔSign.	ΔSign.
Heel	Trim	Min. T [s]	Max. T [s]	Sign. T [s]	Min. T [s]	Max. T [s]	Sign. T [s]	T [%]	T [s]
0	-	943	1178	1125	913	1180	1120	-0,44	5
10	-	1132	1342	1283	1098	1348	1274	-0,70	9
20	-	1570	2096	1909	1494	1920	1729	-9,43	180
	0	943	1178	1125	913	1180	1120	-0,44	5
-	10	1135	1409	1304	1112	1388	1286	-1,38	18
							average	-2,99	53

Figure 9.75: Overview time data

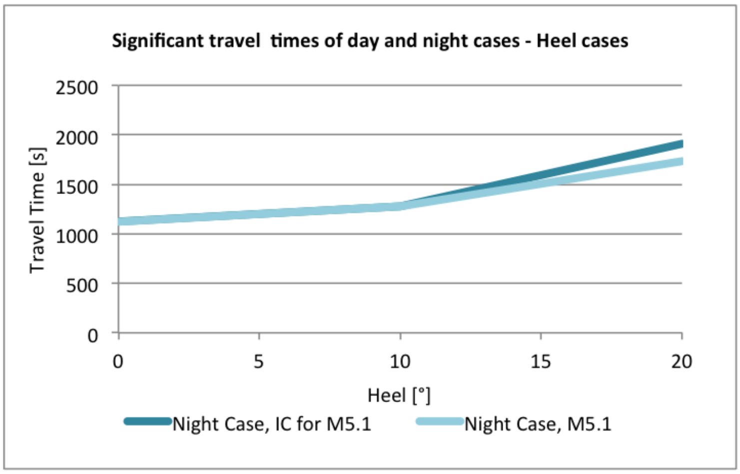

Figure 9.76: Significant time data curves, Heel cases

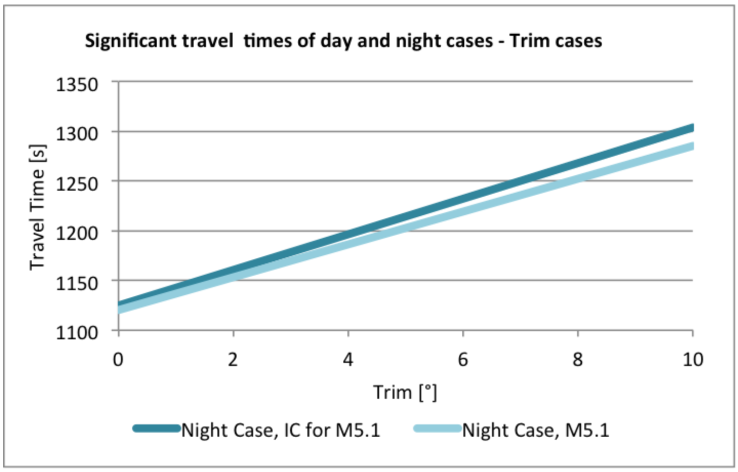

Figure 9.77: Significant time data curves, Trim cases

Night Case			
	Time [s] Rescue of 95%	Δt [%]	Δt [s]
M5.1 Heel = 0	782	-5,44	-45
IC(M5.1) Heel = 0	827		
M5.1 Heel = 10	931	-5,96	-59
IC(M5.1) Heel = 10	990		
M5.1 Heel = 20	1373	-3,04	-43
IC(M5.1) Heel = 20	1416		
M5.1 Trim = 10	925	-4,84	-47
IC(M5.1) Trim = 10	972		
average		-4,82	-37

Figure 9.78: Overview 95%-rescue criterion data

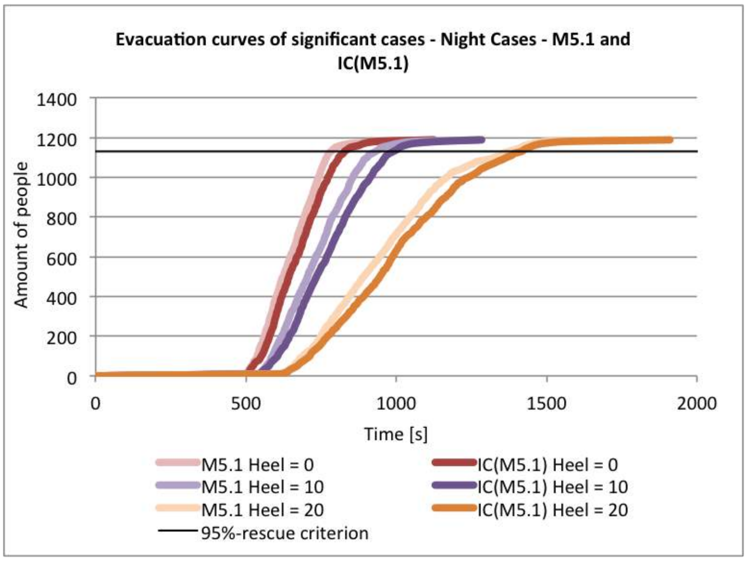

Figure 9.79: Evacuation curves, Heel cases, Night cases

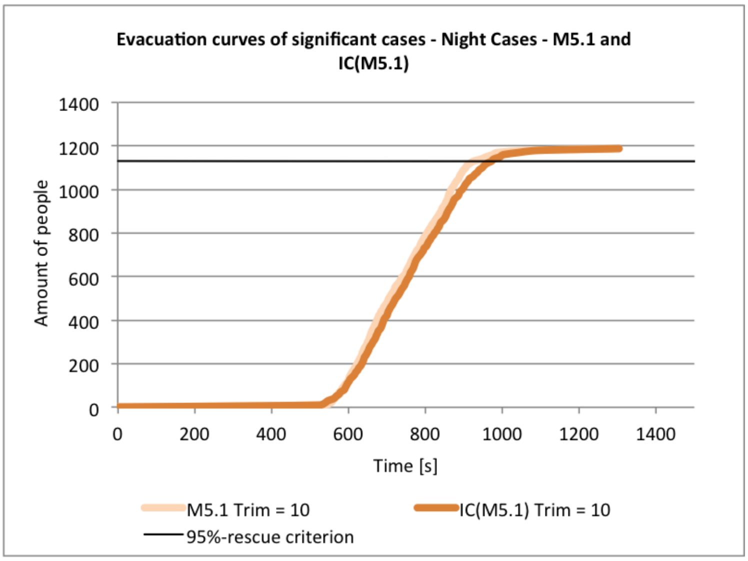

Figure 9.80: Evacuation curves, Trim cases, Night cases

9.6.4 Modification 5.2: Response time distribution according to Safeguard

Research projects like Safeguard and Fire Exit showed that analyses on the same issue can result in different findings. In the guideline MSC/Circ.1238 the resulting response time distributions of the research project Fire Exit were implemented. Within the project Safeguard different response time distributions resulted and a counter-proposal to the IMO and guidelines were published. More detailed information about Safeguard can be found in chapter 3.4.
The influence of different response time distributions is presented in this chapter. The simulation software Aeneas offers the opportunity to implement an individual response time distribution. But only equal or normal distributions can be created. The response time distribution according to Safeguard is a logarithmic normal distribution. Due to the limited possibilities of Aeneas the Safeguard distributions are approximated with a normal distributed curve as shown in the figures below. Pay attention to the axis scale for the night case, because it starts with 400s.

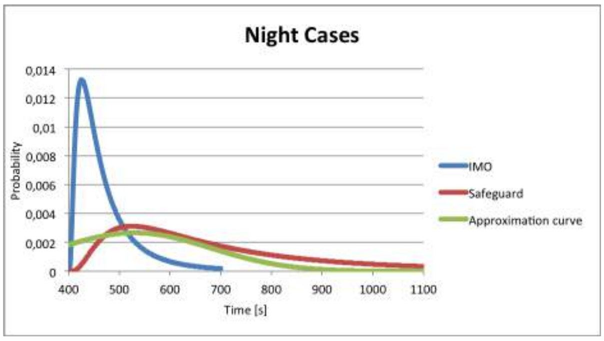

Figure 9.81: Comparison night case curves

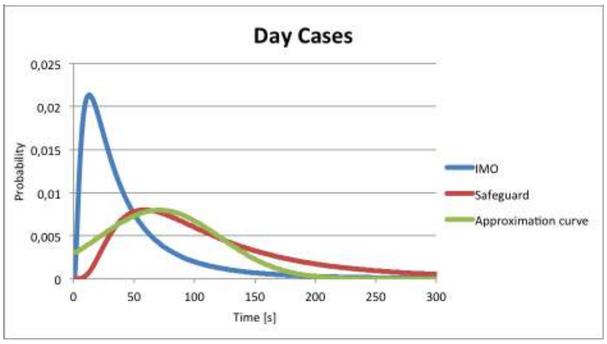

Figure 9.82: Comparison day case curves

The approximation curves do not completely match the Safeguard curves. Between 400-500 s in the night case and between 0-50 s for the day case discrepancies occur. In the evacuation analysis this leads to lower response times for a certain amount of people. Because the probabilities that people start moving between 400-500 s in the night case and between 0-50 s for the day case is higher when the approximation curve is used.
When the approximation curves are flattening discrepancies occur too. For the night case between 700-1100 s and for the day case between 170-300 s the probabilities for high response times are lower compared to the Safeguard curve.

Night case

In the initial case, when no heel occurs, especially on the embarkation deck a congestion developed. When calculating with the new RTD according to Safeguard no congestion on Deck 4 developed anymore. The congestion can be avoided by simply changing the response time distribution. The same effect occurred in the heel case of 10°. An example of Deck 7 is shown in the following figures.

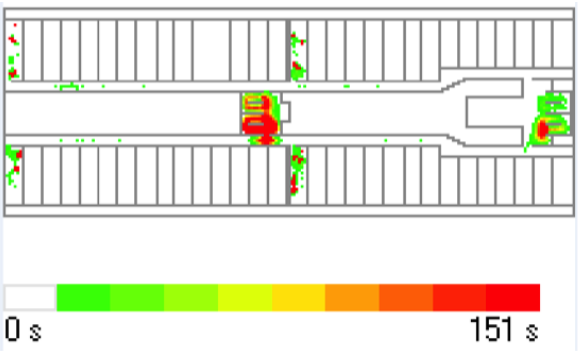

Figure 9.83: Initial case, Deck 7, Heel = 10°

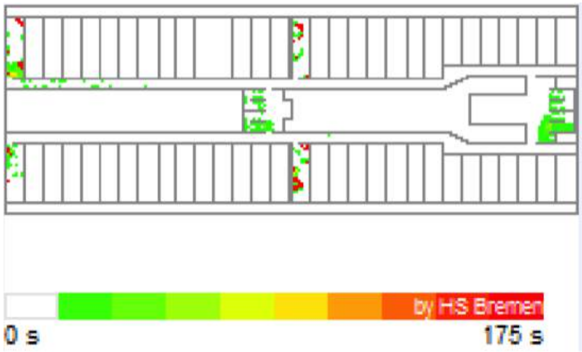

Figure 9.84: Modification 5.2, Deck 7, Heel = 10°

Within the 10° trim case and 20° heel case congestions cannot be avoided due to the influence of heel and trim on the walking behaviour. Nevertheless, the new RTD influences place and extent of congestion development. The figures below shows an example for influences on the place where congestions occurred. In the initial cases the congestion on the embarkation deck developed on the main corridor in front of the exit toward the muster station on the starboard side, whereas in the modified case a congestion developed on stairways nr. 40 on portside. The place which is critical in the initial case is still characterized by a high person density, but the congestion is shifted to another escape route element.

Figure 9.85: Initial case, Deck 4, Trim = 10°

Figure 9.86: Modification 5.2, Deck 4, Trim = 10°

On average the significant travel time increased by 14% (=217s). The maximum and minimum travel time values increased in all cases as well.
Compared to the IMO RTD curve, the Safeguard RTD curve is quite flat and the maximum limitation is shifted from 700 to 1100 s. Because of that is expected that the 95%-rescue criterion increases. More people have a higher reaction time and subsequently the individual travel time rises as well. In average 95% of all people are rescued about 7% (=74s) later compared to the initial cases.

Day case

The comparison of the initial and modified day cases showed effects similar to the night cases. The RTD according to Safeguard influenced the place and extent of congestion development. Especially in trim cases the new RTD distribution influenced significantly the place of congestion as shown in the figures below.

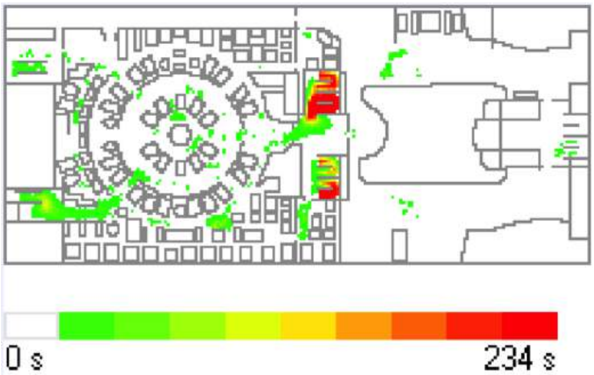

Figure 9.87: Initial case, Deck 3, Heel = 10°

Figure 9.88: Modification 5.2, Deck 3, Heel = 10°

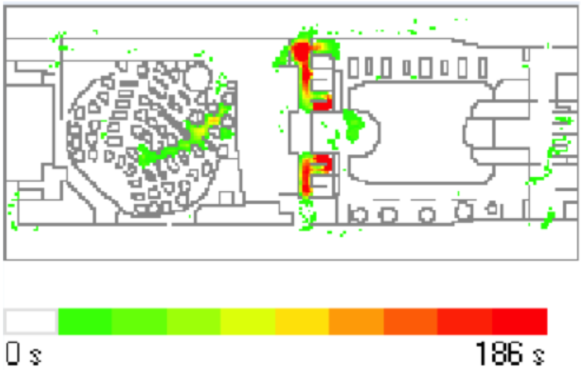

Figure 9.89: Initial case, Deck 4, Trim = 10°

Figure 9.90: Modification 5.2, Deck 4, Trim = 10°

The significant travel time increases on average by 4% (=90s). The highest increase occurred at trim case 10° with 8% (=147s). Between the initial and new maximum and minimum travel time values only slight differences occurred.
The curves of IMO and Safeguard for the day case differ in their form, but the extent from 0s to 300s remains. That is why it is expected that the 95%-criterion rises, but less than within the night cases.
When no heel and heel of 10° occurs it increased by approximately 12% (=232s). Surprisingly, when heel of 20° occurs 95% of all people are rescued 3% (=54s) earlier. Within the 10° trim case the 95%-rescue criterion rised again by 6% (=90s).

9.6.5 Evaluation of modification

The modification and the results showed how much influence the parameters have on the overall evacuation situation. The changes in the response time distribution influenced the place and extent of congestions in certain cases significantly.
Although the intent of MSC/Circ.1238 is to make different designs comparable and not to reflect reality, the investigation showed the impact of varied parameters. Moreover, the guideline aims for identifying potential critical points to give the opportunity to adapt the design and avoid those critical points. As the investigation showed the places of critical points can be influenced by the response time distribution. Therefore it is possible that different approaches can result in different designs.

The response time distributions according to Safeguard were investigated within the research project as well. These results differ from the results within this thesis as shown in the table below. The values take only cases without trim or heel into account.
According to Safeguard no differences in congestion development occurs, when the initial and new RTDs are investigated. It is stated that the RTDs have the same impact on the simulation [10]. This cannot be confirmed, because the investigations within this thesis showed differences in place and extent of congestion development when two different response time distributions are used.

Case	Increase of T [%] - Safeguard	Increase of T [%] - M5.2
Day	0.1	2.4
Night	21.2	14.7

Table 9.3: Percentage increase of travel time

But differences between the investigations have to be considered. Within the Safeguard investigations only 50 runs were conducted. This is sufficient to meet the requirements of MSC/Circ.1238. But within this thesis the proposal of the TraffGO, the manufacturer of the simulation software, is followed and 500 runs were conducted.
Besides, the time of data measurement during Safeguard trials is called into question. The day case proposal derived from the response times, which were collected in public spaces. The night case proposal derived from response times, which were collected in cabin areas. But the night full scale-trial was conducted during the morning, that is why the resulting new response time distribution was shifted by a certain time range. It is questionable whether those data represent the night case appropriately.
Furthermore, it is not published which populations participated on the full-scale trails of Safeguard. The guideline MSC/Circ.1238 defines a certain population. Of course, a population influences the response time distribution significantly. It is regarded as essential that the population and response time distribution fit together. Whether that is the case during the Safeguard project is incomprehensible.

The IMO has also concerns about the Safeguard results. The findings are called into question due to the chosen time of trails, pre-announcements, number of people on board, number and circumstances of tests. The IMO evaluates the data as questionable and not sufficient to use as basis of statistical data [32].

9.6.6 Overview of data

Initial Cases					M5.2: RTD according to Safeguard				
Night Case								ΔSign. T	ΔSign.
Heel	Trim	Min. T [s]	Max. T [s]	Sign. T [s]	Min. T [s]	Max. T [s]	Sign. T [s]	[%]	T [s]
0	-	989	1627	1264	1157	1600	1450	14,72	186
10	-	1241	1622	1514	1304	1964	1751	15,65	237
20	-	1771	2835	2512	1845	3077	2730	8,68	218
	0	989	1627	1264	1157	1600	1450	14,72	186
-	10	1210	1578	1482	1302	1888	1709	15,32	227
							average	13,59	217
Day Case								ΔSign. T	ΔSign.
Heel	Trim	Min. T [s]	Max. T [s]	Sign. T [s]	Min. T [s]	Max. T [s]	Sign. T [s]		
0	-	1157	12647	2514	1074	3020	2574	2,39	60
10	-	1502	2708	2341	1373	2908	2392	2,18	51
20	-	2291	4628	3938	2336	4499	4038	2,54	100
	0	1157	12647	2514	1074	3020	2574	2,39	60
-	10	937	2167	1860	939	2562	2007	7,90	147
							average	3,75	90

Figure 9.91: Overview time data

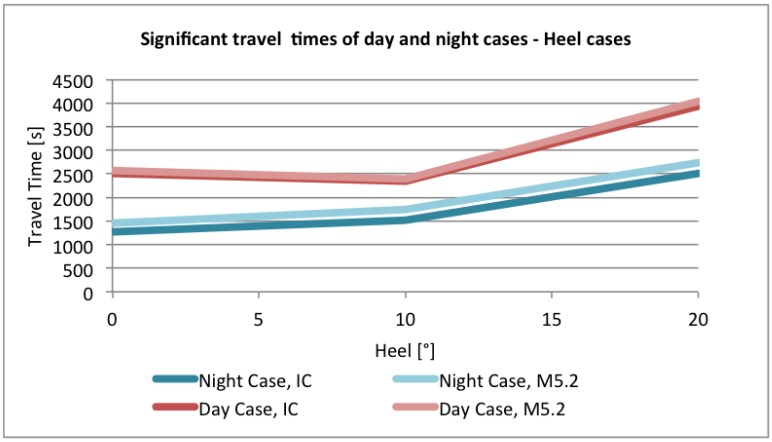

Figure 9.92: Significant time data curves, Heel cases

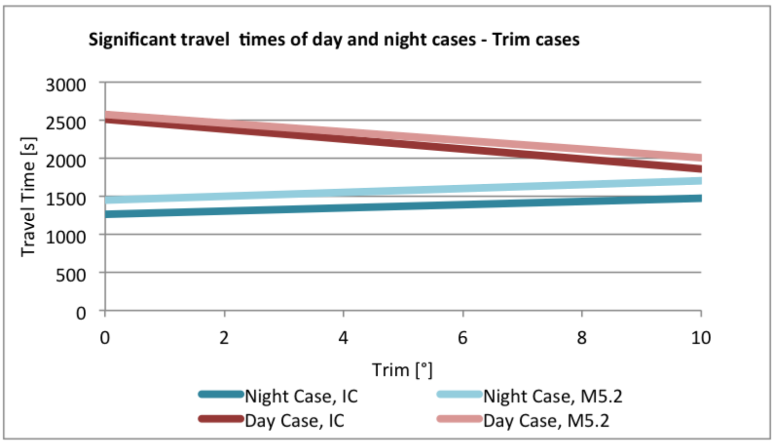

Figure 9.93: Significant time data curves, Trim cases

Night Case			
	Time [s] Rescue of 95%	Δt [%]	Δt [s]
M5.2 Heel = 0	976	7,61	69
IC Heel = 0	907		
M5.2 Heel = 10	1122	4,66	50
IC Heel = 10	1072		
M5.2 Heel = 20	1618	5,20	80
IC Heel = 20	1538		
M5.2 Trim = 10	1154	9,28	98
IC Trim = 10	1056		
average		6,69	74
Day Case			
	Time [s] Rescue of 95%	Δt [%]	Δt [s]
M5.2 Heel = 0	2176	11,76	229
IC Heel = 0	1947		
M5.2 Heel = 10	2017	13,19	235
IC Heel = 10	1782		
M5.2 Heel = 20	1941	-2,71	-54
IC Heel = 20	1995		
M5.2 Trim = 10	1653	5,76	90
IC Trim = 10	1563		
average		7,00	125

Figure 9.94: Overview 95%-rescue criterion data

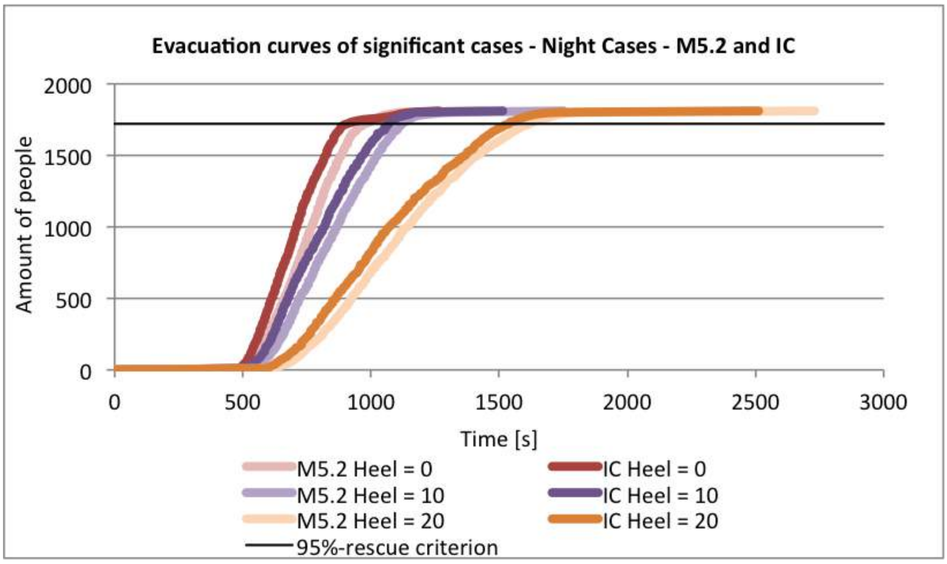

Figure 9.95: Evacuation curves, Heel cases, Night cases

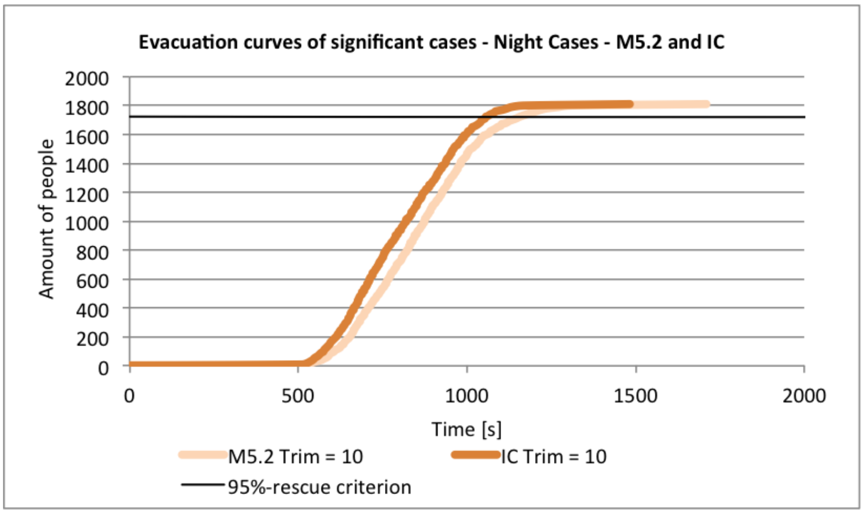

Figure 9.96: Evacuation curves, Trim cases, Night cases

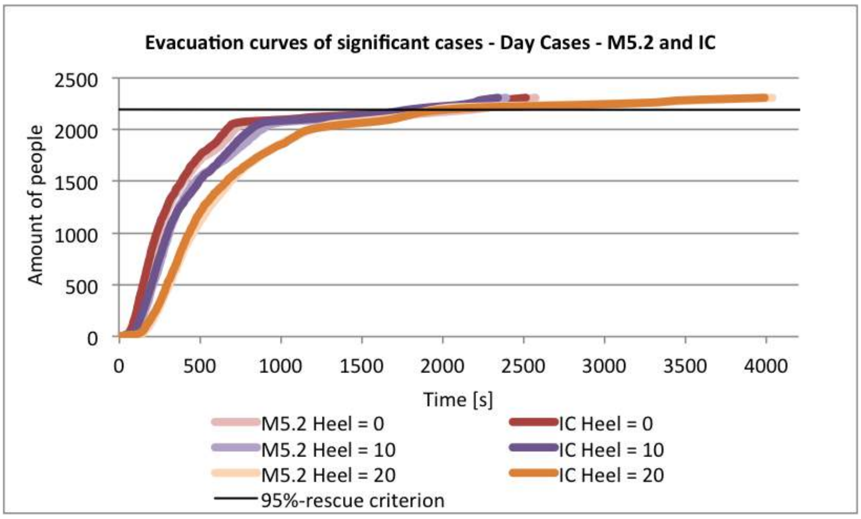

Figure 9.97: Evacuation curves, Heel cases, Day cases

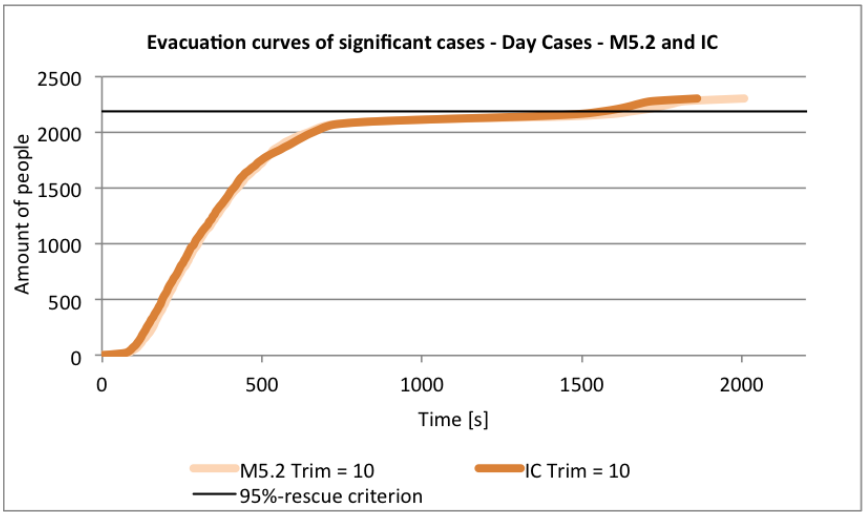

Figure 9.98: Evacuation curves, Trim cases, Day cases

9.7 Influence of modifications on the arrangement

Usually on passengers ships space is a precious commodity. The room arrangement is well thought through and focuses on an efficient use of the available space. But alternative escape route concepts require much space depending on the concept. This is proved by the investigations presented in this thesis.
Within the first investigation the dimensions of escape route elements was increased. Thereby, less space for cabins and public spaces could be provided.
The second modification proposed a heel support system. This system should be hidden and inactive during normal operations. Only when circumstance require it, the heel support system is activated. The advantage of such a system is, that no additional space is needed.
Another modification focused on additional escape route elements, like doors and stairways. This elements do not require additional space as well, because the idea behind this it to active this elements only when the situation requires it. But modifications like this influence the strength of the ships significantly and need to be investigated. Strength calculations has to be done for all modifications, which influence the arrangement of the vessel.
Alternative rescue systems, like the ResCube or evacuation slides, require much space on the passenger cabin decks. The ResCube needs the space of four cabins per deck and fire zone. In this model in one fire zone the space for 20 cabins is used for the implementation of the ResCube concept. On the other hand, evacuation slides need only the space for two cabins per deck and fire zone. In the model for one fire zone the space for only 10 cabins is required.
The most space saving modification was done within investigation 3, when alternative escape routes were allocated. Such an allocation requires no additional space, does not influences the room arrangement and strength calculations.

9.8 Recommendations

In this thesis five different approaches were investigated to aim for a faster and safer evacuation on passenger ships. Due to this, following recommendations for new vessel designs and escape route arrangements can be done:

- Larger corridor,- doors- and stairway widths should be taken into account to pull apart or avoid development of congestions. If one escape route element is increased in size the evacuation process has to be investigated again to avoid backlog or a shift of congestions.

- When heel greater than 10° occurs, in areas with great widths heel support systems should be implemented. Those support system should be continuous as long as possible. Within the normal operation or cases with heel less than 10° no support systems are necessary. On the contrary, those can be obstacles. That is why heel support system should only be active during particular situations.

- Additional escape route elements should be taken into account to minimize the load on certain escape routes, reduce backlog or avoid congestions.

- The use of alternative escape route elements, like crew stairways, should be considered to avoid congestions and minimize the load on the main escape route.

- Alternative rescue system should be beneficial during the day and night case. An alternative approach, like the ResCube system, can not be recommended, because of disadvantages during the day case. Alternative rescue systems which are only an additional device, like evacuation slides, have the advantage to minimize the load on the main escape route and evacuate certain person groups faster.

- The adaptation of escape route arrangements according to the results of evacuation simulation should be done with caution, because reality is usually not met by an evacuation analysis according to MSC/Circ.1238.

9.9 Conclusion

All investigations were done according to MSC/Circ.1238. The point is that this guideline aims not for a description of reality, but for a base to compare different vessel designs. When vessel designs are changed due to the results of the simulation it is questionable whether those changes are successful in reality as well.

With an evacuation analysis the place and extent of congestions can be predicted. The development of congestions depends on the person distribution during the day or night case, room and escape route arrangement, dimensions of escape route elements and parameters, which define the human behaviour. But the assumed parameters may differ in reality. In MSC/Circ.1238 the passenger population composes of certain amounts of different age groups. But are those data up-to-date? The CLIA collected data on passenger ages as well and published results which differ from the IMO assumptions. The comparison is shown in chapter 3, figure 3.1. The CLIA counted much more older and very young people, but middle-aged people are less represented.
The human element is a very complex topic and the behaviour of people during emergency situation is hard to predict. Due to few available data of human behaviour on passenger ships in MSC/Circ.1238 almost all data and parameters base on data from civil building experiences. Only the response time distribution bases on a research project (Fire Exit), which collected appropriate data derived from sea trials.
Moreover, the definition of benchmark scenarios does not met reality. For example during a real day case emergency passengers are guided first to their cabins to take the lifevest. Afterwards people move to their muster stations. This process is not regarded by the guideline. Of course, each shipping company has its own evacuation processes. But why not implementing a requirement to use individual evacuation processes on the model to be examined to achieve a more realistic result?
Furthermore, group behaviour has not be considered according to MSC/Circ.1238. But is this assumption acceptable with regard to passengers on a cruise liner which usually travelling in a group?
Therefore, it is concluded that the data and assumptions used in MSC/Circ.1238 cannot be transferred easily to all kinds of passenger ships, their passengers and individual safety procedures.

Nevertheless, an evacuation simulation is definitely necessary to identify weak points in a design and to prove whether all passengers can be evacuated in a proper time range. Until now only the guideline MSC/Circ.1238 exists to conduct such a simulation. Although the transferability and applicability to different kinds of passenger vessel is questionable, an evacuation simulation should become necessary. It would be strongly advisable to reconsidered certain assumptions and parameters in order to cover different ship types and ship specific characteristics.

The conducted modifications showed that some simple methods like larger escape route element sizes can have positive effects on the overall evacuation process. Another investigation on the ResCube concept resulted in a very negative influence on the evacuation situation. The most successful modification included the allocation of alternative escape routes to a certain amount of people.
Furthermore, in most cases the significant travel time was reduced less than expected. This was due to slow individuals. But the 95%-rescue criterion showed that there are possibilities to evacuate the majority of all passengers faster.
Modification 1, 2 and 4 focused on changes in the ship arrangement. The problem is that incidents and behaviour of humans will never be predictable. Solutions, which influence the arrangement of the vessel, cannot guarantee positive influences in all cases. To be prepared for different incidents solutions for a faster and safer evacuation should be flexible and individually adaptable. Modification 3 investigated on this idea and the results were very successful.
An intelligent evacuation system is regarded as the best opportunity to evacuate people faster and safer during an emergency. This system should be able to identify the locations of passengers. Furthermore, the development of the incident over time and impact on the evacuation process should be predictable. With those information people should be guided situation-dependent and individually to their muster station. The allocation of alternative escape routes could be done by crew members. Another possibility would be improved and individually controlled direction signs, which can be activated when circumstances require it, to support the process of an intelligent guiding.
A practical implementation of an intelligent guiding system is certainly feasible. But more research on the technical realization is necessary.

10 Conclusion and prospect

This thesis aimed for investigations on alternative escape routes to evacuate passengers and crew members in a safe and fast manner. Therefore, different research projects with the topic safety of passengers during evacuation processes were considered. The presented research projects addressed different important aspects and alternative points of view. This should be pursued in the future as well, because there is much potential for improvements on passengers safety.
Some findings of the research projects were used to investigate on alternative escape routes. To assess the new concepts a passenger ship model was used and the modifications were investigated with an evacuation simulation software. The evacuation analyses complied with the guideline MSC/Circ.1238.
The modifications focused mainly on structural modifications to improve the evacuation processes. Nevertheless, one investigation called into question the assumptions of MSC/Circ.1238. One investigation on parameters and their influence on an evacuation process is not sufficient to make generalisations. But subsequent studies on varying parameters and the effect on the evacuation situation seem to be necessary.
The investigations on structural modifications were partly very successful. But the disadvantage of structural solutions is, that it will never be possible to cover all possible eventualities. An evacuation process is influenced by many factors, which can hardly be predicted. Incidents are unpredictable, as well as the behaviour of humans. Because of this reason an intelligent guiding system is regarded as the best option to guarantee a safe and fast evacuation procedure in all possible cases. An intelligent guiding system should be able to identify the locations of people. Moreover, this system should be able to predict the development of hazards and its influences on the evacuation situation. Due to this an individual and situation-dependent guiding of passengers is achieved.
In chapter 9.4.1 alternative escape routes were allocated to a certain amount of people. This method corresponds to the idea of an intelligent guiding system. When heel of 0° occurs the significant travel time can be reduced by 42%. In the specific case this is equal to 17.45 minutes, which can be saved. When heel of 20° occurs the significant travel time is increased by the same percentage. But in this case the saved time is equal to 28 minutes.
The results show that considerable time savings are achieved. In case of an damaging event such a time range can decide about the success of an evacuation process.

To conduct an evacuation process according to MSC/Circ.1238 some assumptions, which differ from reality, are made. Although the aim of the guideline is not to predict reality, the question of the transferability of assumptions to certain ship types and their characteristics arised. In this guideline only recommendations for passenger ships in general are given, but special characteristics of certain ship types are not considered. Within this thesis several aspects had to be simplified to meet the requirements of MSC/Circ.1238, although a real evacuation procedure on a cruise liner differs extremely from the assumptions. It is suggested to take special characteristics for certain ship types into account, when an evacuation simulation is conducted.
Moreover, until now for non-ro-ro passenger ships no evacuation simulation is compulsory. In the last years passengers ships increased in size steadily and carry thousand of passengers during a voyage. Therefore, it is no longer acceptable to have no compulsory regulation to prove whether all passengers can be evacuation in a proper time range.
This opinion is represented by the Maritime Safety Committee in MSC 93/20/4 as well. This paper justifies changes of the assumptions and scenarios within MSC/Circ.1238 to reflect the

differences between ro-ro and non-ro-ro passenger ship evacuation safety. When the exiting guidelines are expanded appropriately, an evacuation analysis for all passenger ships should become mandatory [52].

The investigations within this thesis showed that an evacuation simulation is necessary to identify weak points in the design and avoid congestions. The result of the investigations is that structural modifications cannot cover all possible eventualities. As already stated, an intelligent guiding system is regarded as necessary. Such a system should be able to guide passengers and crew members safe and situation-dependent to the muster stations.
Current research projects focus on the practical implementation of an intelligent guiding system. The research project LYNCEUS develops a wireless sensor network system to locate each passenger onboard as well as overboard for SAR processes [45]. The second research project SIREVA aims for a fast and safe evacuation of passengers as well. Especially elderly and mobility impaired people are taken into account. New technologies and strategies are developed to improve the safety on passenger ships while personal rights are considered. A new evacuation concept including a decision support system and a shore-based situation centre is developed. Both research projects are still running, because of this reason no final result can be presented.

The key issue for a successful evacuation process is and remains the humans. But the human element is a very complex issue. It turned out that a well-trained crew is the key to success, when an emergency on a passenger ship occurs. But at the same time, it is human to make mistakes, which can lead to problems during an evacuation as well.
As presented in previous chapters the human behaviour has significant influence on the procedure of an evacuation. But not only crew members, also all other people, which are involved in the design and construction of a passenger ship should focus on improvements in evacuation processes. A good safety concept takes all kinds of passengers into account including very young, middle-aged people, old people and disabled and mobility impaired people. A design and safety concept for all should be achieved.

11 Bibliography

[1] **Ministry of Infrastructures and Transport:** Main Casualties Investigative Body - Cruise Ship Costa Concordia, 2012

[2] **Youtube video:** Sinking of the Costa Concordia caught on camera, http://www.youtube.com/watch?v=4MtWxnRBVvg

[3] **Department for Transport:** Report on the Investigation of the Fire onboard Star Princess, 10/2006

[4] **Pourzanjani, M./ Young, G./ Aziz ,M.:** HANDIAMI Final Report for Publication, 10/2003

[5] **Cruise Line International Association, Inc.:** 2011 Cruise Market Profile Study, 06/2011

[6] **Glen, I. F./ Iglolliorte, G./ Galea, E.R., Prof./ Gautier, C.:** Experimental Determination of Passenger Behaviour in Ship Evacuation in Support of Advanced Evacuation Simulation

[7] **BMT Fleet Technology Limited:** Evacuation Research for Commercial Applications

[8] **Rina:** SHEBA Facility, http://www.rina.org.uk/sheba-facility.html

[9] **Rina:** SHEBA Ship Evacuation Tests, http://www.rina.org.uk/sheba-ship-evacuation-tests.html

[10] **Brown, R./ Galea, E.R./ Deere, S./ Filippidis, L.:** IMO Inf Paper Summary – Response Time Data for large Passenger Ferries and Cruise Ships, 2012

[11] **Galea, E.R./ Filippidis, L./ Deere,S. / Brown, R./ Nicholls, I./ Hifi, Y./ Besnard, N.:** IMO Inf Paper Summary – The SAFEGUARD Validation Data-Set and Recommendations to IMO Update MSC.1/Circ.1238

[12] **Galea, E.R./ Grandison, A./ Blackshields, D./ Sharp, G./ Filippidis, L./ Deere, S./ Nicholls, I./ Hifi, Y./ Breuillard, A./ Cassez, A.:** IMO Inf Paper Summary – The Enhanced Scenario Paper

[13] **Rina:** Ship Evacuation Trails, http://www.rina.org.uk/ship-evacuation-trials.html

[14] **Gunkel, J.:** Die Auswirkung statischer Krängungswinkel auf die Evakuierungszeit von Kreuzfahrtschiffen, 21.12.12

[15] **TNO:** Safecraft Project, Executive Report, 20.05.2009

[16] **Marinetalk:** Innovative Evacuation System, http://www.marinetalk.com/articles-marine-companies/art/Innovative-Evacuation-System-NOR058112725TU.html

[17] **Business Q4:** Norsafe med nytt livbatsystem, http://bq4.no/2005/03/norsafe-med-nytt-livbtsystem/

[18] **International Maritime Organization:** International Convention for the Saftey of Life at Sea, http://www.imo.org/About/Conventions/ListOfConventions/Pages/International-Convention-for-the-Safety-of-Life-at-Sea-(SOLAS),-1974.aspx

[19] **International Maritime Organization:** SOLAS, 2009

[20] **International Maritime Organization:** International Code for Fire Safety Systems, 2007

[21] **International Maritime Organization:** MSC/Circ.1238 "Guidelines for Evacuation Analysis for New and Existing Passenger Ships", 2007

[22] **International Maritime Organization:** MSC.1/Circ.1212 "Guidelines on Alternative Design and Arrangements for SOLAS Chapters II-I and III", 2006

[23] **Lee, D./ Kim, H./ Park, J.H./ Park, B.-J.:** Current status and future issues in human evacuation, 2003

[24] **Helbig, D./ Werner, T.:** Simulation einer Schiffsevakuierung auf der Basis des sozialen Kräftemodells, 18.04.2002

[25] **Helbig, D./ Johansson, A.:** Pedestrian, Crowd and Evacuation Dynamics

[26] **Quadvlieg, F./ Coevorden, P. van:** Manoeuvering Criteria: More than IMO A751 Requirements alone, 2003

[27] **Ockerby, P.:** Evacuation of a Passenger Phip - Is Panic a major Factor?, 08/2001

[28] **Lloyd´s Register Fairplay:** World Fleet Statistics 2000-2010, 2010

[29] **International Maritime Organization:** MSC/Circ.735 "Recommendation on the design and operation of passenger ships to respond to elderly and disabled persons needs", 24.06.1996

[30] **International Maritime Organization:** MSC 93/6/5 ”Passenger Ship Safety - Recommendations arising from the Costa Concordia casualty", 07.03.2014

[31] **International Maritime Organization:** FP 56/6 ”Review of the recommendation on evacuation analysis for new and existing passenger ships – Problematic layouts being compliant with the guidelines", 02.11.2012

[32] **International Maritime Organization:** SDC 1/13 "Review of the recommendation on evacuation analysis for new and existing passenger ships – Mandatory application of

evacuation analysis to non-ro-ro-passenger ships and priorities for further development", 15.11.2013

[33] **Pajonk, F.G., Dombrowsky, W.R.:** Panik bei Großschadensereignissen, 13.04.2006

[34] **Clarke, L.:** Panic: myth or reality?, 2002

[35] **Safety at Sea:** EVI, http://www.safety-at-sea.co.uk/software/evi/

[36] **Principia, Software Datasheet:** ODIGO, http://www.principia.fr/upload/image/pdf/187_ODIGO-in-Brief.pdf

[37] **TraffGo HT GmbH:** Benutzerhandbuch AENEASed ANEASsim ANEASview, Version 2.5.0, 2008

[38] **Meyer-König, T. /Klüpfel, H. /Schreckenberg, M.:** A microscopic model for simulating mustering and evacuation procedures onboard passenger ships, 2001

[39] **Prof Ed Galea FSEG** The University of Greenwich: Datasheet maritimeEXODUS, 01.06.2013

[40] **Xie, H.:**Investigation into the interaction of people with signage systems and its implementation within evacuation models, 2011

[41] **Getaway:** http://www.getaway-project.eu/

[42] **Sound Alert:** http://soundalert.com/way-finding.htm

[43] **Stanley Security:** Saffire Brochure, http://www.stanleysecurityproducts.co.uk

[44] **Evac Chair** http://www.evac-chair.co.uk/our-products.aspx?p=1

[45] **LYNCEUS:** People localization for safe ship evacuation during emergency, http://www.lynceus-project.eu/easyconsole.cfm/id/1

[46] **Sub-Committee in Fire Protection:** FP 46/INF.9 “Large Passenger Ship Safety: Results of Analysis carried out by the University of Strathclyde”, 30.11.2001

[47] **Klüpfel, H. /Meyer-König, T./ Wahle, J. /Schreckenberg, M.:** Microscopic Simulation of Evacuation Processes on Passenger Ships, 2000

[48] **Meyer-König, T.:** Mikroskopische Simulation von Evakuierungsprozessen, 2002

[49] **Meyer-König, T./ Klüpfel, H./Schreckenberg,M.:** Assessment and Analysis of Evacuation Processes on Passenger Ships by Microscopic Simulation, 2002

[50] **Hamburgische Schiffbau-Versuchsanstalt:** Time-Dependent Survival Probability of a Damaged Ship II - Evacuation in Seaway and Capsizing, 05/2006

[51] **Maritime and Coastguard Agency:** The Human Element – A Guide to Human Behaviour in the Shipping Industry, 04/2012

[52] **Maritime Safety Committee** MSC 93/20/4: Justification to expand the existing output to include development of amendments to SOLAS and other mandatory instruments to make the application of evacuation analysis to passenger ships mandatory, 12.02.2014

12 Annex

Name	Costa Concordia
Flag	Italy
Ship Type	International Passenger
Ownership	Costa Crociere Spa
Details of construction	Year 2006, Fincantieri Boatyards Spa
Length	247.37 m
Length between pp.	247.4 m
Width	35.5 m
Height	11.2 m
Draft	14.18 m
Tonnage	114,147 t
Passenger Capacity	3780
Propulsion Type	Fixed Pitch Propeller
Main Engines	2
Electricity Generation	Diesel Electric
Thruster	aft: 3 x 1720 kW - bow: 3 x 1720 kW
Maximum Speed	21.5 kts

Table 12.1: Fact sheet: Costa Concordia, Source of data: [1]

Name	Star Princess
Flag	Bermuda
Ship Type	Passenger Cruise Ship
Ownership	Prince Cruise Lines Ltd
Details of Construction	Year 2002, Fincantieri-Cantieri Navali Italiani Spa
Length	289.6 m
Width	36.0 m
Draft	8.45 m
Tonnage	108,977 t
Passenger Capacity	2600
Propulsion Type	Fixed Pitch Propeller
Thruster	Fwd and Aft
Maximum Speed	21.5 kts

Table 12.2: Fact sheet: Star Princess, Source of data: [3]

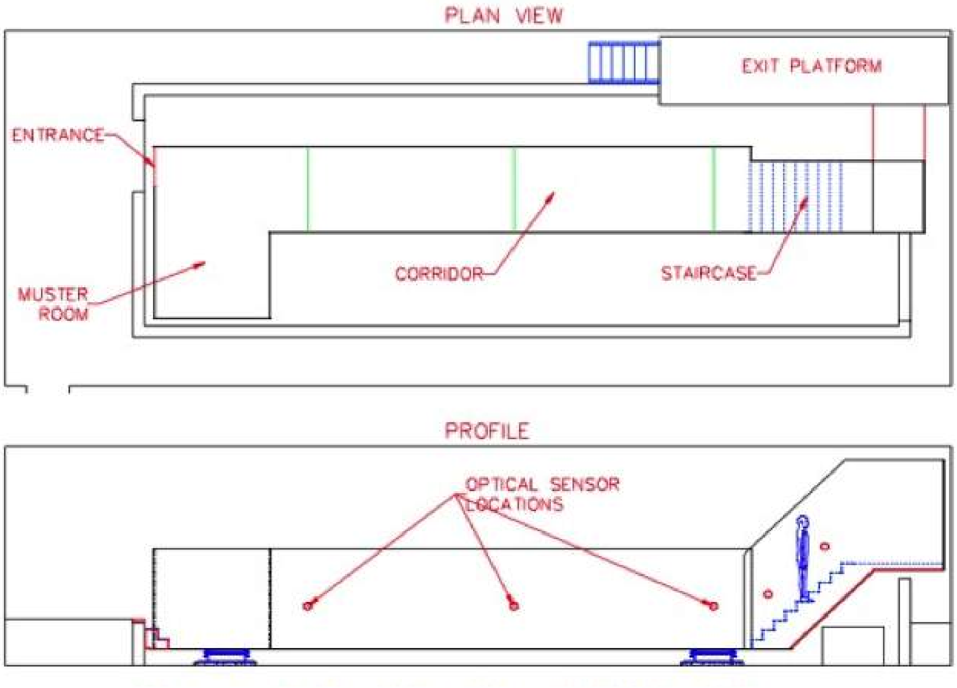

Figure 12.1: Arrangement of facility, Source: [6]

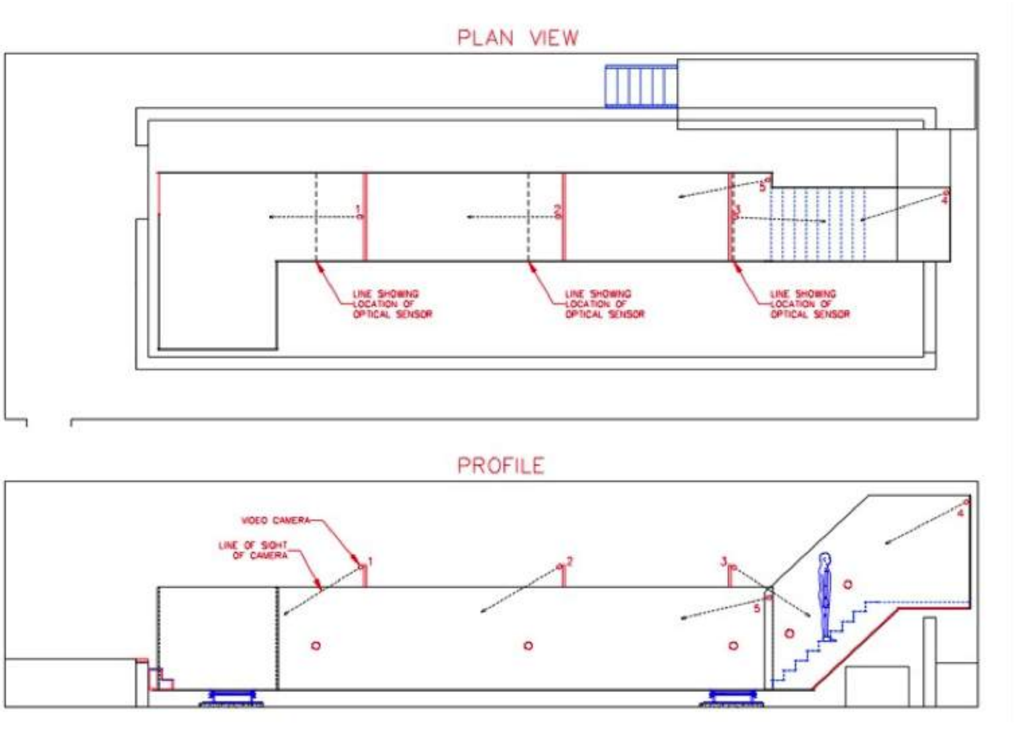

Figure 12.2: Arrangement of measurements, Source: [6]

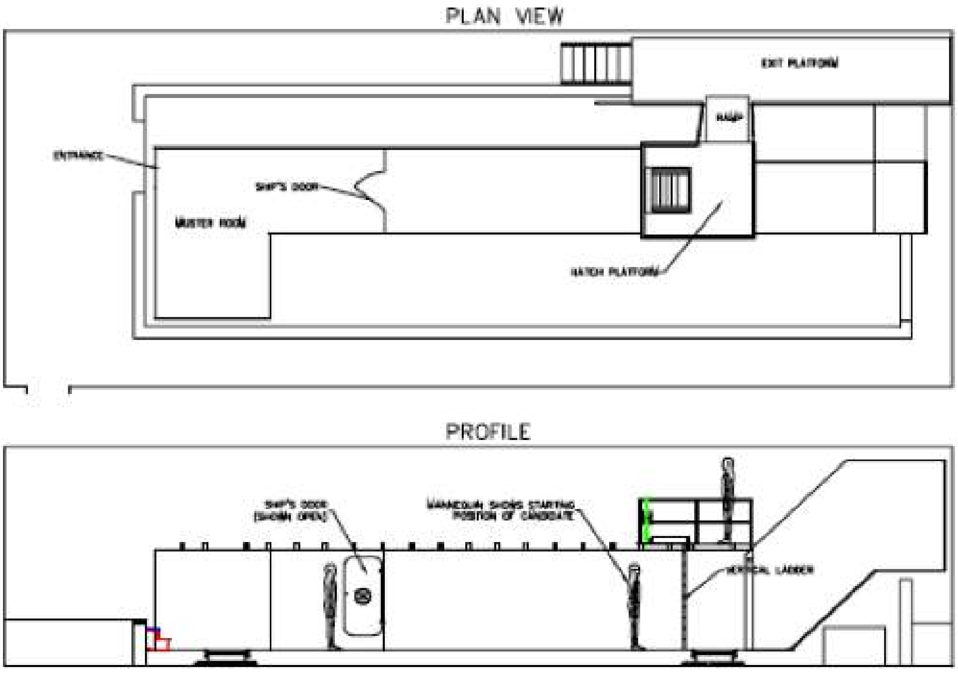

Figure 12.3: Arrangement of naval configuration, Source: [6]

Figure 12.4: ResCube - external view, Source: [17]

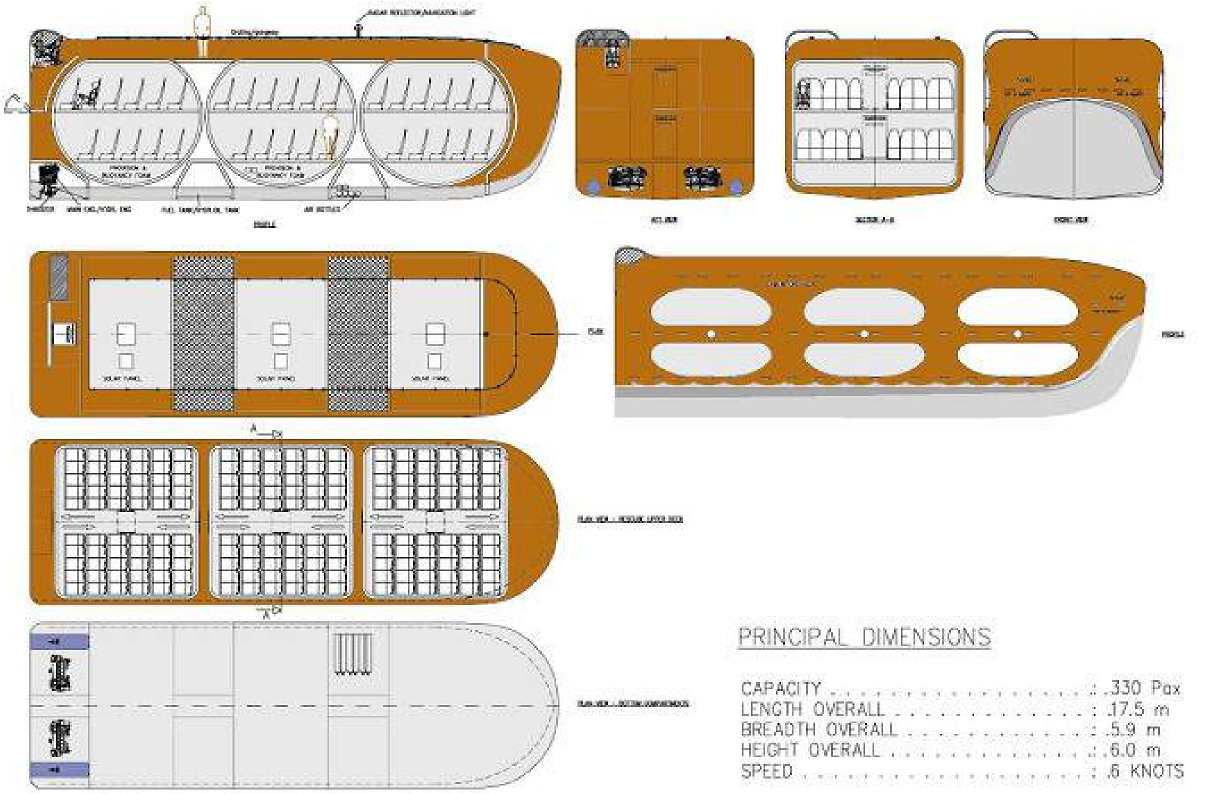

Figure 12.5: ResCube - cross section, Source: [17]

12.1 Further recommendations and rules

12.1.1 FP 56/6

Review of the recommendation on evacuation analysis for new and existing passenger ships – Problematic layouts being compliant with the guidelines

Within FP 56/INF.10 seven examples were conducted to show that current guidelines on evacuation analysis are not sufficient to provide a safe evacuation. In FP 56/6 problematic weakness of MSC/Circ.1238 and FSS Code Chapter 13 are described.
In general, the guidelines allow escape route arrangements with the potential for development of congestions. Moreover, intensive help by the crew is assumed. But escape route and evacuation procedures should be designed easy, understandable for all and work without crew instructions [31].

In day cases most of the passengers are located in the public spaces, but the escape route distribution is designed according to the night case. The time the people need to reach an assembly station during day cases differs often from the planned concept. In such a case large numbers of passengers have to be exchanged between the assembly stations which can result in large congestions. A flexible exchange between assembly stations would be beneficial.
In addition, until now open decks are not considered, but usually during the day more than the half of passengers is located on open decks. It is suggested to take open decks into account when dimensioning of escape routes and evacuation analysis.
Modern evacuation concepts, e.g. of AIDA, depend on the support of the crew. But such concepts can fail when crew works not as expected. Investigation on the embarkation process without crew support showed that the procedures suffered less from inoperable crew members. That is why also evacuation processes should address the intuitive behaviour of passengers [31].

Moreover, within FP 56/6 it is claimed that crew counterflow hinders the flow of passengers [31]. In principle I fully agree with this statement, but with regard to modern evacuation concept this is only partly accurate. During evacuation procedures on AIDA crew members are ready to assist on their assigned position before the General Emergency Alarm is activated. Moreover, crew members do not use the passenger escape routes, but crew escape routes. That means only a few amount of crew members, which maybe search for missing passengers, cause counterflow. It should be noticed that modern evacuation procedures try to avoid counterflow as far as possible.

12.1.2 MSC/Circ.1212

“Guidelines on alternative design and arrangements for SOLAS Chapters II-1 and III”

This guideline applies to SOLAS Chapter II-1 part C - "Suppression of fire", D – "Escape" and E – "Operational requirements" as well as to Chapter III. Part F – "Alternative design and arrangements" and provides a methodology for approving alternative designs and arrangements for fire safety. It includes the application on specific engineering, alternative shipboard structures (e.g. life-saving systems) or traditional systems installed in alternative configuration.

The alternative design can deviate from prescriptive requirements, but it has to comply with the intent of the guidelines [22].

The guideline is important for this thesis because in case of a practical implementation of the project findings, it is possible that alternative design would apply. MSC/Circ.1212 gives the opportunity to develop ideas, which differ from common approaches and improve the vessels design and arrangements. The purpose is not to develop a fail-safe system, but the level of safety of an alternative design should be equivalent or better than those according to prescriptive rules [22].

12.1.3 MSC/Circ.735

"Recommendation on the design and operation of passenger ships to respond to elderly and disabled people needs"

Usually passengers are expected to be able to evacuate themselves to the embarkation deck. Within this recommendation especially elderly and disables people are considered. This includes infirm, very young, elderly and disabled people with limited mobility. In general terms it is suggested to design public spaces and escape routes barrier-free and provide adequate assistance by well-trained crew members [29].
The most important aspects of the guideline will be mentioned in the following.

Access to ship:
For wheelchair users and disabled people an easy way of access should be provided. Either unassisted or by ramps, elevators or lifts. Therefore, for example, the maximum slope of a ramp is 1:20. A passenger vessel should be equipped with at least one such access [29].

Elevators:
The elevator floor should be 110 cm wide and 140 cm deep. The doors should be automatic and provide a free opening of 90cm. Handrails should be mounted 90-100 cm above the floor. The area in front of the area should be 150 cm x 150 cm.
Moreover, in the elevators a foldable seats should be provided and the control panel should be built adequately [29].

Accommodation:
The free openings of doors to public spaces should be at least 80 cm. Stairways should not be steep and designed with close steps. For people with reduced vision the front edge of each step should be equipped with contrasting light colour. Handrails should be provided on both sides of the corridor, round in section with a certain diameter, easy to grip and coloured in difference to the background.
For each 100 passengers suitable seats for disabled people should be provided meaning sufficient space and suitable handholds. Furthermore, these seats should be arranged close to evacuation routes [29].

Corridors, doors and handrails:
Especially during a longer voyage sufficient space for elderly and disabled people should be provided on the passenger vessel.
Handrails in corridors should be arranged at height 90 cm above the floor, on both sides, without

edges, coloured in contrast to the background and with tactile markings for visual impaired people. In general, corridors should be wide enough to allow wheelchair users to pass other people [29].

Allocation of cabins:
Cabins for elderly and disabled people who need assistance during an emergency should be arranged close to the embarkation deck. In case of an evacuation these people can be assisted quick and with minimal effort to the muster station.
To realize such a procedure it is necessary to prepare in advance for each voyage a list identifying the cabins with people who need assistance [29].

Crew training:
Within the crew training the crew members should receive clear instruction about the handling of elderly and disables people in emergency situations [29].

Moreover, MSC/Circ.735 gives recommendations for cabins, lavatories, measures for allergic people, information and service.
This recommendation was also analysed in a work package within the Handiami project and evaluated as effective. It is commended to make this rule obligatory and supplement detailed technical papers [4].

12.2 Models for ship motion

Reduction factor slope

The reduction of maximum walking speed due to static inclination is modelled by reduction factors. At an angle of 45° the geometry of a ship would changes significantly, because of that the movement of agent stops at this angle at latest.
Those reduction factors for certain parts of an escape route are described in the following.

Laterally tilted corridor

Empirical data showed that normal movement of people stops, when the angle of a literally tilted corridor exceeds 35°. In Aeneas agents move with 5 % of their maximum speed between 35° and 45°. The reduction factor is named r_{trans}.

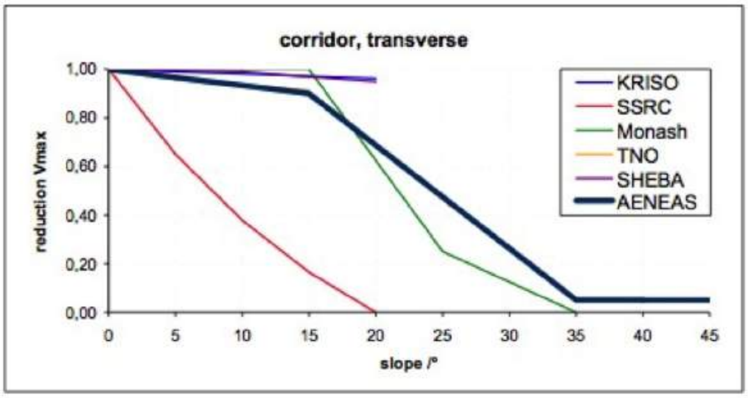

Figure 12.6: Laterally tilted corridor, Source: [50]

Corridor with a longitudinal slope

Empirical data ended at +/- 20°. But in Aeneas it is assumed that upward movement in a corridor with a longitudinal slope is only possible up to 30°. Downward movement is also possible up to 30°, but at higher inclination angles up to 45° only very slow movement is possible. The reduction factor is named r_{long}.

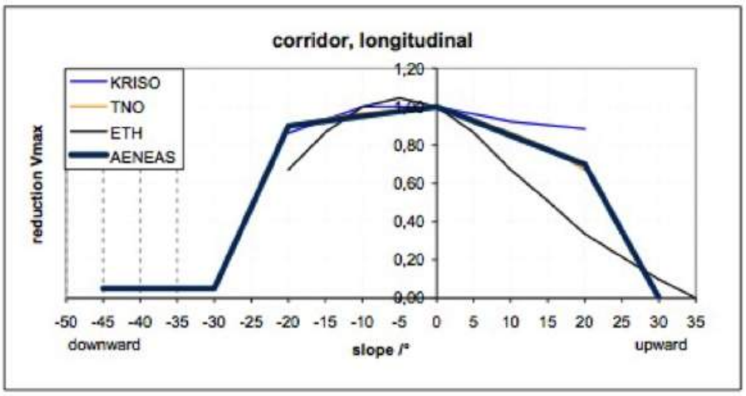

Figure 12.7: Corridor with longitudinal slope, Source: [50]

Laterally tilted stair

The speed reduction factor r_{trans} is quite similar to the reduction factor for laterally tilted corridor.

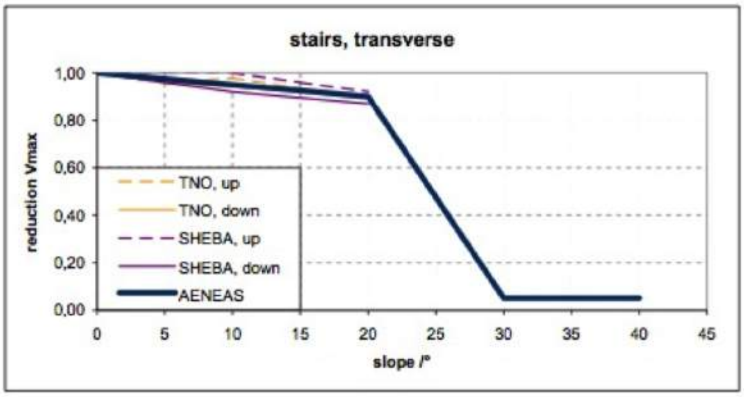

Figure 12.8: Laterally tilted stair, Source: [50]

Longitudinal tilted stair

The upward movement curve in Aeneas ends at a slope of 30°. It is assumed that the average population can not move up such a slope. The curve continues up to 45° due to modelling reasons and to achieve a consistent orientation of agents. The downward movement curve is identical at negative slope.

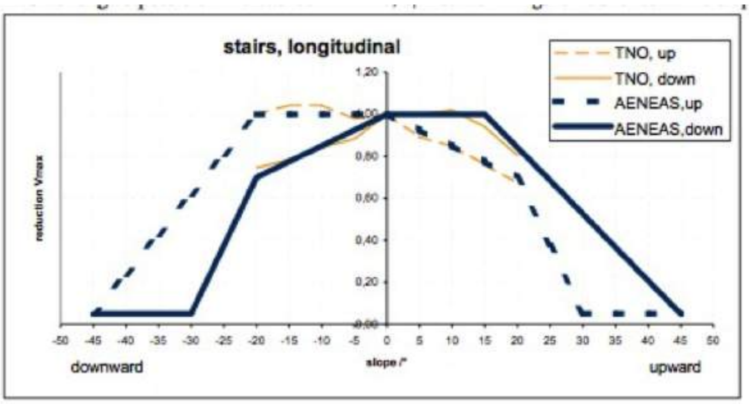

Figure 12.9: Longitudinal tilted stair, Source: [50]

Ship angular motion and felt slope

Usually the true slop is not identical with the felt slope. The horizontal acceleration due to ship motion affects a person and influences the true slope angle.

$$\phi_{\text{feel}} = \phi_{\text{real}} - arctan\frac{\ddot{\phi} \cdot h}{g} \tag{12.1}$$

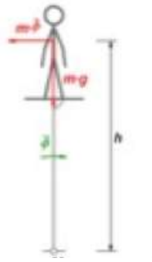

Figure 12.10: Felt angle depending on ship motion, Source: [50]

The felt angles are determined for the walking direction and transverse to it. Then the corresponding reduction factors, r_{trans} and r_{long}, are assessed using the two felt angles. The smaller reduction factor r is chosen for further calculation.
The reduction factor influences the increase of the parameter dawdle probability tr. Therefore, the dawdle probability has to be calculated due to slope.

$$tr_{\phi} = 1 - r \tag{12.2}$$

The overall dawdle probability is calculated due to the individual dawdle probability and due to ship motion.

$$tr = (1 - tr_i) \cdot tr_{\phi} + tr_i \tag{12.3}$$

Drifted cause by slope

Slope increases the space required by each agent. That is why a slope dependent drift is added, which increases the probability for downhill movement. The transition probability p_{i} is calculated differently for the lowest cell and their neighbouring cells according to slope.

$$p_{\text{i}} = p_{\text{i-1}} = p_{\text{i+1}} = d \cdot p_{\text{i,max}} > p_{\text{i}}, p_{\text{i-1}}, p_{\text{i+1}} \tag{12.4}$$

The drift factor d is calculated with following formula:

$$d = 0.02 \cdot \phi_f eel \tag{12.5}$$

12.3 Simulation model

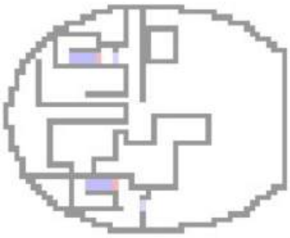

Figure 12.11: Deck 14

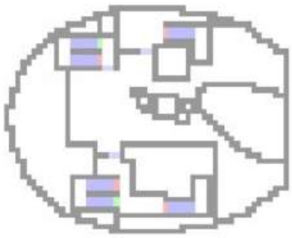

Figure 12.12: Deck 13

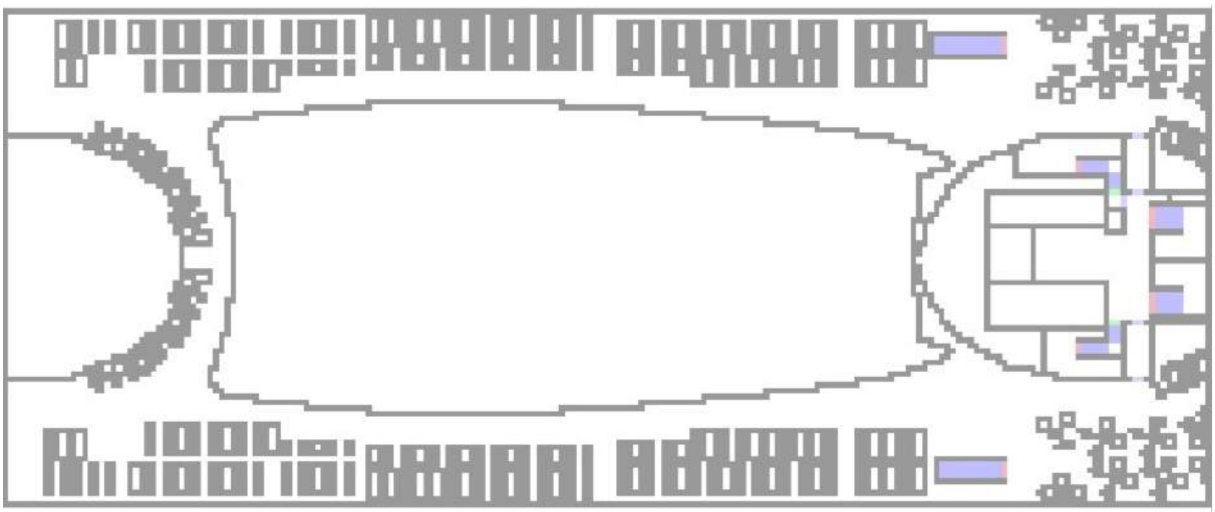

Figure 12.13: Deck 12

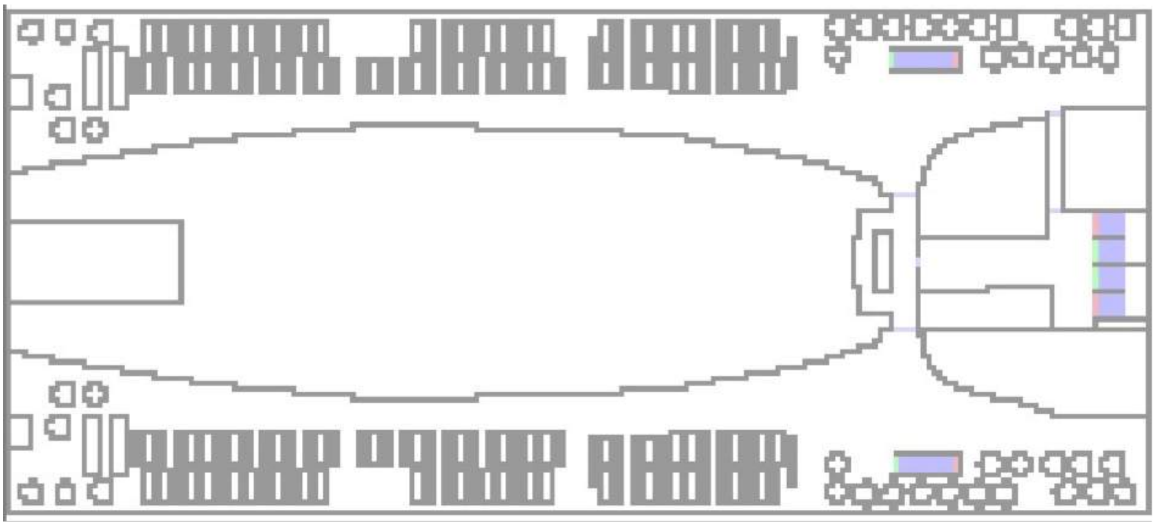

Figure 12.14: Deck 11

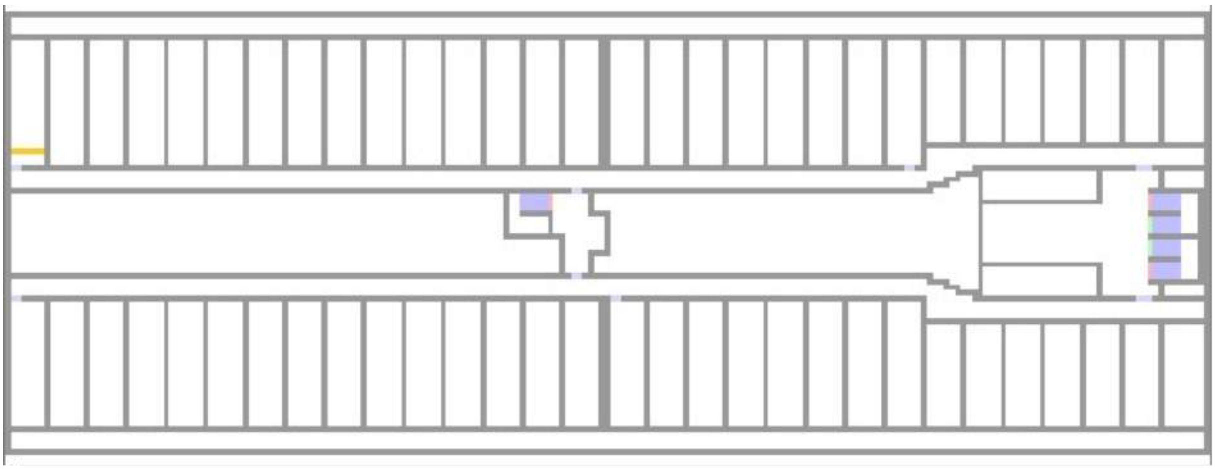

Figure 12.15: Deck 10

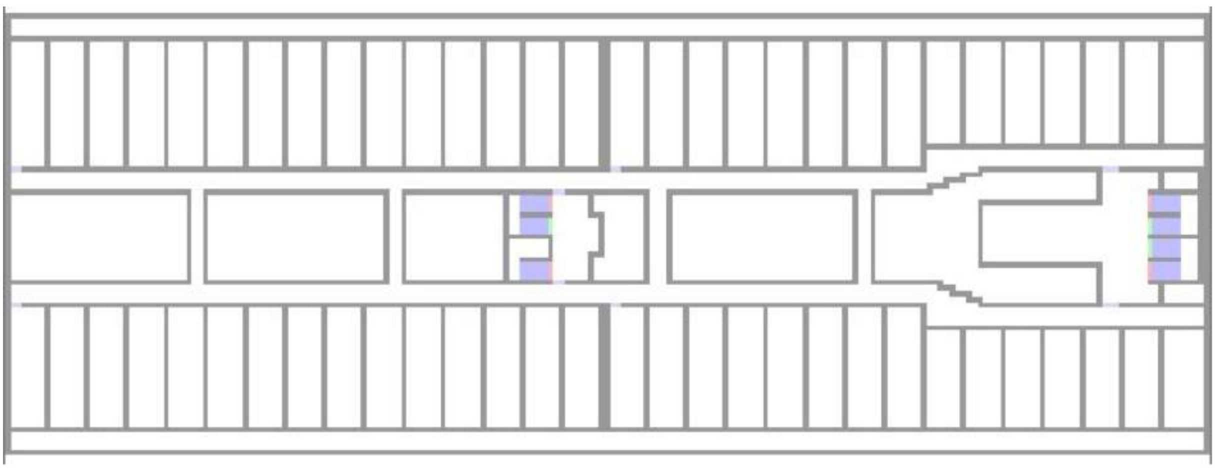

Figure 12.16: Deck 9

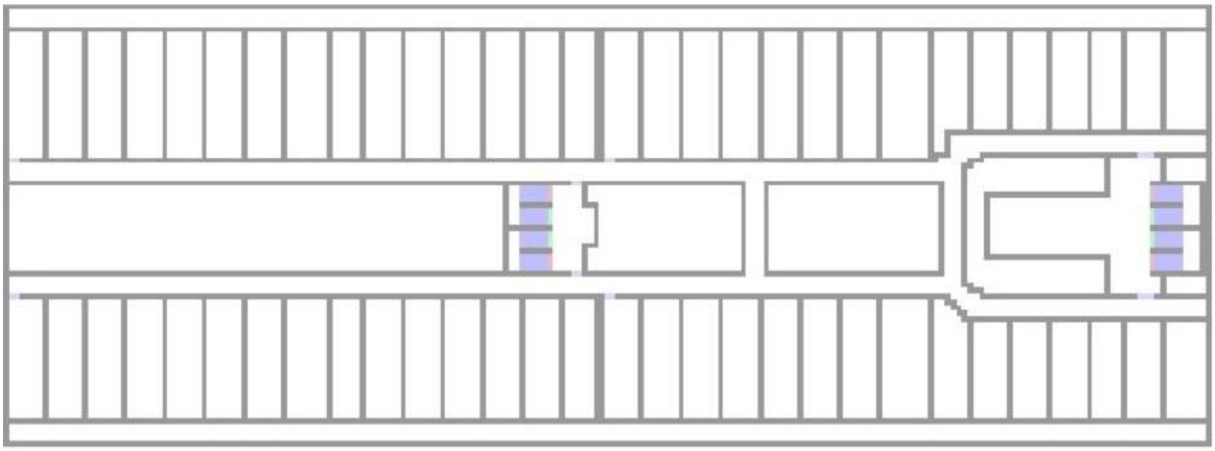

Figure 12.17: Deck 8

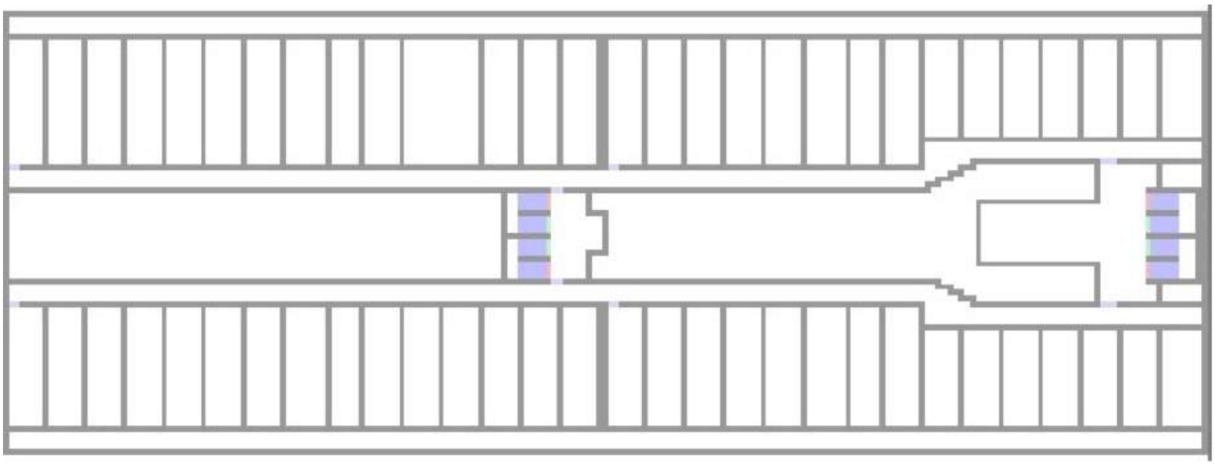

Figure 12.18: Deck 7

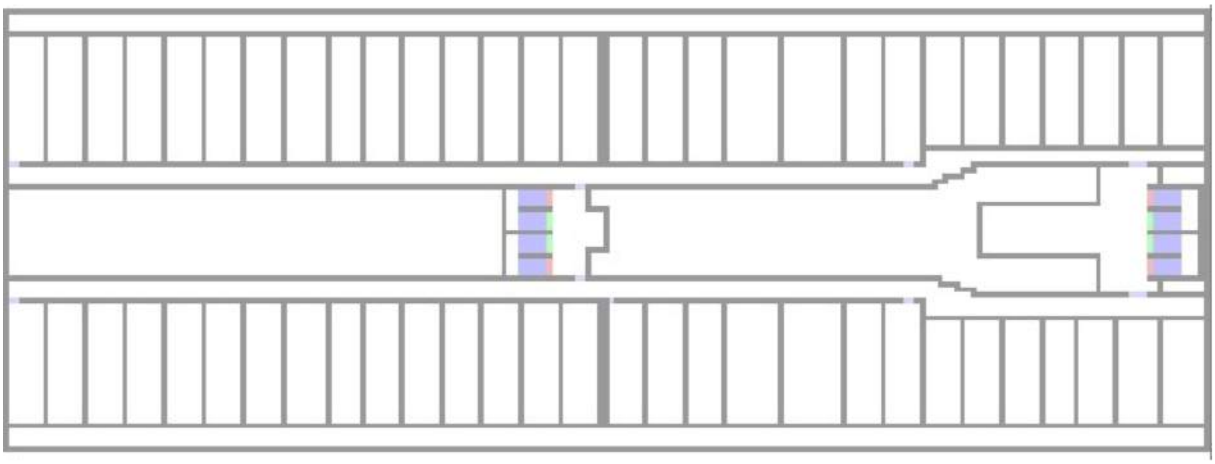

Figure 12.19: Deck 6

Figure 12.20: Deck 5

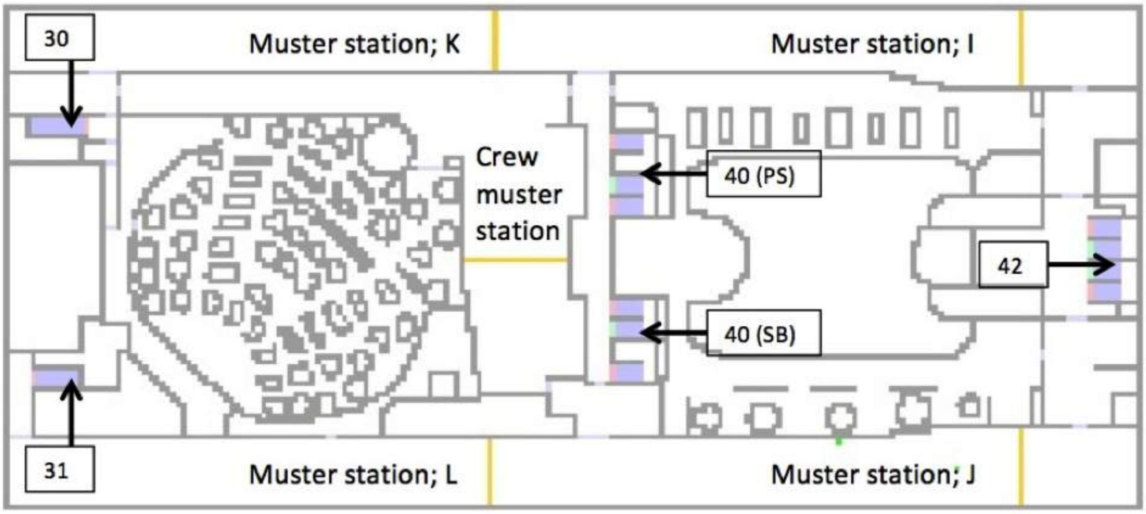

Figure 12.21: Deck 4

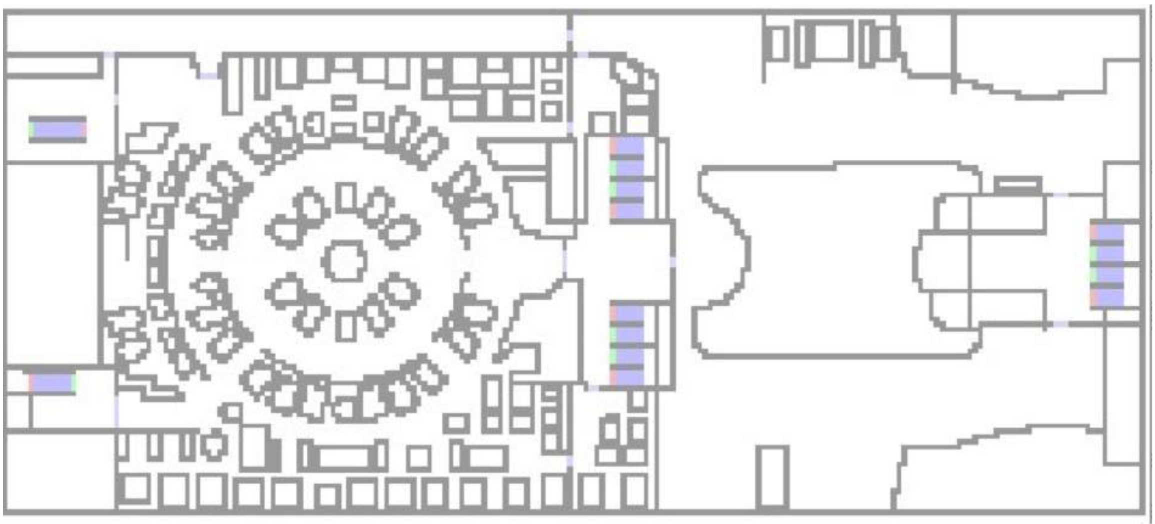

Figure 12.22: Deck 3

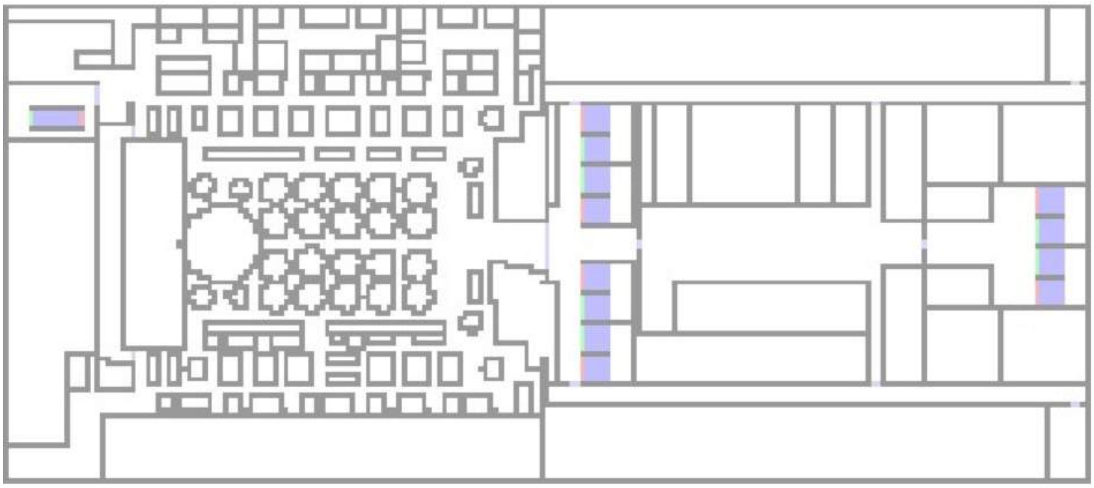

Figure 12.23: Deck 2

Figure 12.24: Deck 1

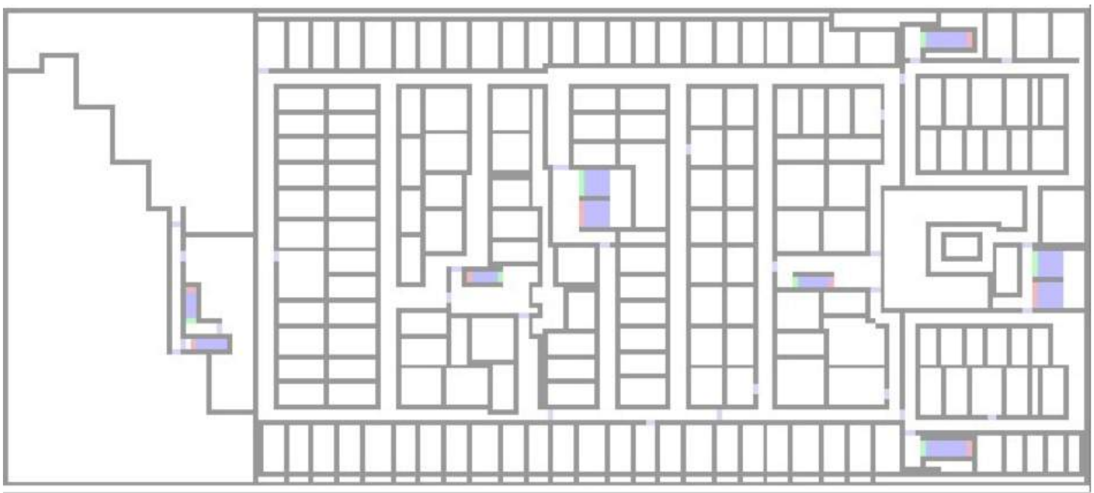

Figure 12.25: Deck 33

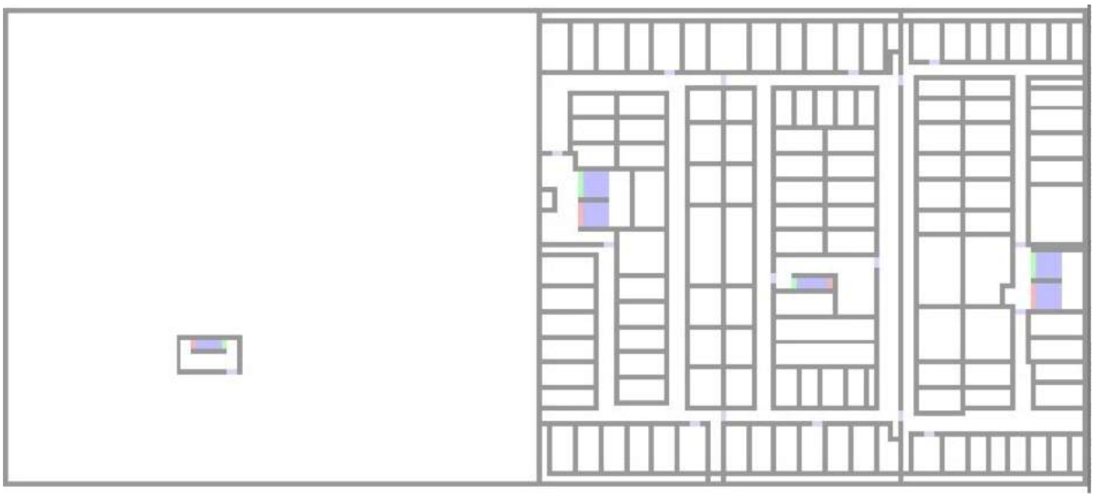

Figure 12.26: Deck 32

Figure 12.27: Deck 31

Colour Code

In the simulation software Aeneas cell types are defined by different colours. The colours can be matched by the user individually. In this thesis following colour code will be used:

Cell type	Colour
Free cell	White
Walls	Black
Doors	Yellow
Steps	Magenta
Steps up	Red
Steps down	Blue

Table 12.3: Colour code