A computerized system for loading and discharging oil tankers.

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Abstract.

This thesis takes up the problem with manual tanker cargo operations and the possibilities for creating computer programs to take care of those processes. The main objective is to create a computer program simulating loading and discharging of a VLCC (Very Large Crude-oil Carrier) without any human interference after the initial information about the cargo is entered into the computer. The program is made in VBA (Visual Basic for Applications) for Microsoft Office Excel. This simulation shows that it is fully possible to do this technically, but further research for this thesis around the subject then concentrates on why it is not already done.

The thesis is based on the authors own experience as a ship officer on board tankers from 1979 until 1999, and takes into account that even though others might have different opinions built on their own experiences it should represent a common thought for most tanker officers.

This thesis is trying to show if it is technically possible and also put some light on reasons why it should be done. The intended audience this paper is trying to reach is producers of cargo control systems and also maritime legislators.

The methodology used for this thesis is Autoethnography as this was found to give the best outcome due to restrictions the author faced at the outset of the thesis.

The conclusion of the thesis was that it is fully possible technically to produce a safe and efficient computer controlled system for controlling cargo operation on tankers and that it should also contribute to the safety of both people and environment. In addition it should also save time and money using such a system.

Contents

Chapter 1. Introduction:

The topic of this thesis is about certain problems with automated cargo control systems for loading and discharging crude oil / product tankers. Before this particular challenge is described in detail in the following chapters, the trends in seagoing transportation of oil will be outlined.

The project itself consisted of making an automatic loading/discharging program in Visual Basic for Application (VBA) using Microsoft Office Excel. As the author had never made a larger program before and VBA as a programming language was unknown to him, considerable time was taken to get to understand the basics of the language, and to correct mistakes. More than 500 hours were used reading up on the programming language and to produce the finished software. Another 100 hours went in to study and convert the ship used as a template for the program.

The idea of such a program came after having made several small calculator programs for calculation of cargo amount, ship stability and draft/trim on different ships the author sailed on. The artefact was a program that was to work independently of any outside interference from start to finish. As there were no possibilities for having such a program implemented and tested on a real ship, it had to be set up as a simulation. So the finished product had to simulate opening and closing of valves and pumps, both for cargo and for ballast. The program was then to be evaluated by tanker offices for reliability and ease to use.

To be able to make the program and write this report the author used his own experience of over 20 years on tankers of a variety of sizes and types. He has been chief officer and captain on crude oil, product, chemical, OBO and gas carriers, the smallest tanker being a 3000 dwt product tanker, the largest a 393000 dwt crude oil tanker.

Chapter 1 gives a brief history of transportation of oil cargoes by sea and some of the problems discussed. These problems include fatigue, safety, pollution, economy and education among other things.

Chapter 2, literature review comprises of three main points, namely cargo handling, computer modelling and methodology. The cargo handling part shows that the program mathematics are built on proven and accepted formulae, which is the same as used throughout the shipping industry today. When it came to modelling itself there were a few books that gave insightful information both about how to set up a design for a model, and also about the technology itself. There were also several examples found with references to other industries where the same technology were used, namely petrochemical, pharmaceutical and chemical industries. In the methodology part several articles that back up autoethnography as a valid research method. It shows that there are good reasons for a researcher to choose his/her own experiences as a basis for an artefact of this type.

Chapter 3 goes further into the aspects of autoethnography, and discuss how it was used in the context of this thesis. It also takes up the problems with validity and rigour this method of research brings with it.

In the next chapter, Automatic Loading and Discharging Solution, gives a description of the program itself and how it works. The different sub-programs and the outcome of these are discussed. A comparison with a model of a ship and the ship itself is also in this chapter, together with some data about the ship used as a basis for this simulation, namely the "Golar Patricia".

The Discussion in chapter 5, takes up the problems both with building a real time program for tankers, as well as the simulator. It also takes up problems with implementation of such a program. Both human and technological aspects are discussed, and also what the future might bring when it comes to cargo handling with respect to tankers.

Chapter 6 discuss the evaluation of the program, where 3 ship officers took part. They tested the program for about 2 month, and after that participated in facilitated interviews with the author.

In the last chapter, conclusion, the future of such a program is reviewed, particularly if automation is implemented when it comes to cargo operation on tankers.

Background: Seagoing transport of oil

Oil has been transported, by ship or over land, for thousands of years. After oil production from sub-surface wells started in the United States in 1859 both supply and demand increased dramatically. Part of this increase was due to industrialization in

Europe, and the first shipment of oil across the Atlantic took place in 1861. At that time the petroleum products were carried in barrels in general cargo ships (mostly sailing ships) (Wikipedia, 2010). In 1878 the first ship to use the hull or skin as a container for oil was built and in the years to come transportation of oil in bulk became increasingly common. From 1900 petroleum products started to replace coal as a source of energy in many fields and the demand for oil products showed a steady increase worldwide. Oil exploration and production commenced in many parts of the world and oil refineries were constructed. Transportation of crude oil from production sites to the oil refineries and transportation of refined products from the refineries created a growing market for oil tankers.

Major oil companies were established and the oil industry started to play an important role in world trade. In particular during the years from 1920 to 1940 oil production and consumption increased significantly and the need for transportation by sea increased accordingly. In this period the size of the oil tankers was still relatively small, a vessel of 12000 dwt was regarded as a large ship at that time. During the Second World War the availability of oil products was vital to both the allied and the axis forces and thus the carriage of oil products by sea represented an important factor for the outcome of the war. However, war losses both in human lives and number of oil tankers were substantial.

To replace the war losses, the building of new tankers started on a large scale after the war. From 1945 to 1973 the size of the oil tankers increased immensely, especially after 1960. In 1959 the first tanker in excess of 100000 dwt was launched, in 1968 the first in excess of 300000 dwt. The largest "super tanker" ever built is the "Jahre Viking" with a dwt of 564763, a length of 460 metres and a breadth of 69 metres(2010). An oil tanker in excess of 160000 dwt is commonly referred to as a VLCC (Very Large Crude Carrier), a tanker in excess of 320000 dwt is called an ULCC (Ultra Large Crude Carrier). The vessel used as a template for this thesis, "Golar Patricia", is a typical VLCC of 251245 tonnes displacement.

The sharp increase in oil prices in 1973 caused a major drop in oil consumption worldwide. This "oil crisis" had a devastating effect on the market for oil transportation. The freight rates fell dramatically, a large number of oil tankers were laid up, scrapped or sold and many companies engaged in oil transportation faced bankruptcy.

According to the United Nations (International Maritime Organisation, 2012) over 80% of the global trade by volume and over 70% by value is carried over sea. The same site from the IMO shows that 2752 million tons of oil is transported over the seas every year. A large part of it is crude oil and oil products (petrol, diesel, kerosene and so on). In spite of these huge volumes, sea-going oil transport remains largely unnoticed until oil spills occur. Examples are ships like the Torrey Canyon outside Cornwall, UK, in 1967, with an estimated oil spill of 25 – 36 million gallons of crude oil (BBC Home). Amoco Cadiz outside Portsall, France, spilled around 69 million gallons of crude oil and Atlantic Empress in 1979 outside Trinidad and Tobago, spilling about 90 million gallons of crude oil into the sea (Moss, 2010).

Tanker Trade

Tankers the size of Golar Patricia are usually engaged in worldwide trade. The most common trade routes are from the Persian Gulf towards Asia, Europe and the United States. Other major oil producing areas are the North Sea (mostly shuttle tankers), West Africa, Indonesia/Brunei and Venezuela. In later years Brazil has also become an important oil producer. Figure 1 Tanker routes shows the most important tanker trade routes. The route around Africa has become less important as most tankers today can go through the Suez Canal, but was the main route from the Persian Gulf to Europe and the United States from the beginning of the 1970s and well into the 1980s. Japan has been a major importer of oil from the Gulf for many years, but today China has also become an important oil receiving country.

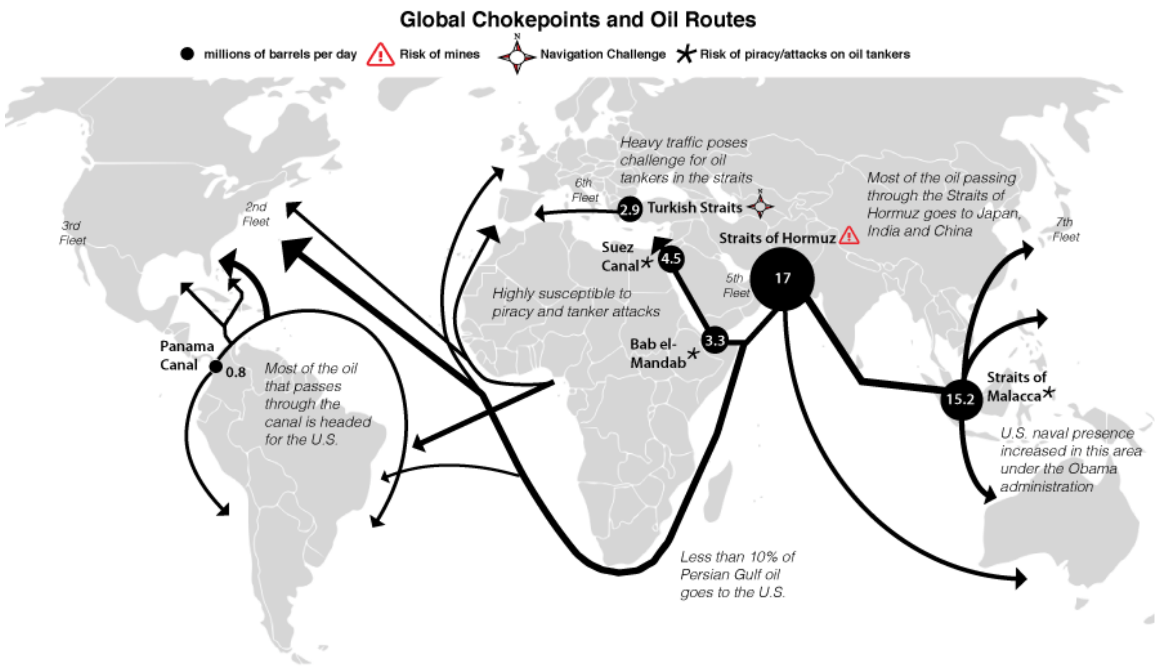


Figure 1 Tanker routes (Anon, 2013)

Modern tankers

Today's tankers differ in several ways from a tanker built in the 1980's. The two most significant differences are that the ships are now by law equipped with a double hull and that the most valves and pumps are remotely operated from a control room.

Double hull means that the ship's cargo area is surrounded with an extra space which is used for ballast. This was done to protect the environment in case a ship should collide or go aground. Before the law came there were quite hefty discussions for and against that, since it also has some disadvantages. Most significant of these is that the ballast area of a ship usually rusts faster than the cargo area and thereby could possibly leave holes in the cargo tank, and oil would penetrate the ballast tanks. The cargo oil protects the steel in the tanks from corrosion by creating a thin film of oil residue that hinders oxygen from reaching the steel. On the other hand, the rust might penetrate the bulkhead from the ballast side. This is due to the difficulties accessing the ballast tanks which on ballast voyages are filled with seawater. When the ballast water was to be pumped out, there might then also be oil pumped into the sea with it. In any case, new tankers are now required to have a double hull.

The double hull is essentially, as mentioned before, to have ballast tanks segregated from the cargo systems. But also on these tankers one may take in ballast in cargo tanks or cargo in the ballast tanks. This is for safety for instance in the case a ship had poor stability during bad weather. More ballast might be needed than the ballast tanks provide capacity for, and a connection can be made by attaching a spool piece between the ballast and cargo lines. This however, is done mostly in the case of extreme danger to the ship and its crew, and on larger ships like the Golar Patricia this should not be necessary at all.

From the cargo operation perspective; however, the change from manual valves and having the convenience of a control room is far more important. It has made the operation much safer as the overview of the operation is now at hand for the officers who can observe what's going on at all times. Also, there are no more people to act in between the orders from the chief officer to the actual procedures that are done. He/She, or the officer on duty, controls the operation and open and close the valves when necessary after having all the different parameters at hand on a console or on a computer. The pumps are also run from the control room, and make it much easier for one man/woman to run all the pumps at the same time. Switches have now replaced big valve wheels and the valves are opened or closed by hydraulic power which works more consistently and more safely than they were when done by the crew.

There has been a big focus on safety the later years, particularly in the maritime industry. Tankers in particular have been noticed because of the environmental disasters they can cause. The M/T Exxon Valdeez is one example of this. There are several factors that play into effect when it comes to safety and how to prevent accidents on board ships, and the next chapter will take up some of them, with the theme of this thesis taking up the main part of the discussion.

Safety issues

Several safety issues arise from the fact that oil is a dangerous cargo to transport and transfer. Several explosions and fires have occurred during cargo operation over the years, but fortunately safer equipment and procedures have made cargo transfer less accident-prone than earlier. This, unfortunately, has made people less observant of the fact that it is still dangerous, and that close control must be maintained during the transfer operations.

Some of my concerns about this stems from the fact that there are, in my and most of my fellow ship officers opinion, too few officers on-board. From this follows the inescapable fatigue that comes from people working too long hours without reasonable sleep intervals, and also from the stressful environment that belongs to the job. Hundreds of millions of dollars are at stake, and also, as this is a dangerous operation, lives of people on-board and at the terminals. Fatigue has been a known cause of accidents in the shipping industry for a number of years, and several maritime and labour organisations, like The Nautical Institute, an organisation for professional maritime workers, and ITF (International Transport workers' Federation) has worked on reducing the problem for a number of years. The Nautical Institute has even a forum on the internet covering the problem of fatigue (The Nautical Institute, 2013), where mariners can send in reports on situations they have encountered regarding fatigue. This forum does not only cover tanker operation, however, but also other type of shipping.

The most dangerous and difficult part of any cargo operation on-board a tanker is at the end of the transfer, being it during loading or discharging. It is also when the officers have to be most alert. Stripping of the tanks requires certain skills and experience, and topping up the tanks is a problem if they should be so unlucky to get an overflow. Millions of dollars might be the result of fines and cleaning up from the spill. A good example of that is the Rena accident, but that was luckily relatively easy to clean up. A worse scenario might be in the middle of a harbour basin, where different shore installations might get damaged. As surveys have shown, 24 hours without sleep is the equivalent to 0.8 per mil. of alcohol in the body, and officers may have periods of 30-40 hours without sleep at these vital times.

Another, and maybe a worse thing, is that many of the officer's on-board ships in general lack experience. This is mainly because the maritime schools have problems educating enough new officers to fill the vacancies. Governments do not invest enough in the education of new ship officers, mainly because they do not see the problems. In Norway the oil industry is one of the major income sources of the country, and as the oil fields are all offshore there is a constant need for new ship officers. There are some countries which are an exemption to this, like the Philippines and some ex-Soviet states that see a large contribution of their national income comes from seafarers, but they can still not fill all the vacancies. In Norway there was a shortage of about 4000 new cadets from schools over the 5 years from 2008 (SkipsMagasinet, 2012)

When the author started at sea in the beginning of the 1970s, at least 3 years sea time as an ordinary crew member was needed to learn the trade, and after a year at mate's school he or she could go on-board as an 3rd mate. After that at least one year sea-time each as 3rd, 2nd and chief mate was needed before he/she could become a captain. Not many had the luck to get up the ranks that fast, and most became captains in their late 30s or early 40s having been sailing for 15-20 years. They also needed two further years at school to become captains.

Today they start at school with no experience at all, making it more difficult to understand the technical aspects of the job. They study for 3 years and obtain a bachelor's degree, which requires more additional studies than the pure nautical subjects, and after those 3 years they go out to sea as cadets. They go through a fixed set of training objectives for one year at sea, and are then promoted to 3rd officers. In the opinion of the author and of most of his fellow officer's having gone through the earlier system, this is not enough, and with the ships being more and more technically advanced it is difficult to get the required knowledge before being promoted to the next position on board the ship. This because, as mentioned before, there is a lack of ship officers.

In one way this is actually what has happened in cycles repeatedly. Relatively young officers have in periods been promoted to captains, and as many of them kept on working until well up in their 60's, they kept younger officers from being promoted. The next cycle were then older chief mates being promoted to captains, and so on. However, during any periods, a newly promoted captain would typically have had 10 – 15 years at sea.

People do not normally think much about ship-bound transportation unless something goes wrong, as with the container ship "Rena" at the Astrolabe Reef outside Tauranga or the "Exon Valdez" in the Puget Sound in Alaska. These accidents were reported mainly because of the oil leakages.

The same holds true for ships that have collided or being grounded, from "Torrey Canyon", outside Cornwall in England, "Amoco Cadiz", the French coast, "Atlantic Empress" and "Aegean Captain" colliding outside Trinidad and Tobago to "Erika", in the Bay of Biscay outside France. The last ship broke in two, however, after having encountered a heavy storm. Most of these accidents have been caused by navigational errors, and the news about what happened has gone around the world. But quite a few accidents have also happened during cargo operation of oil and product tankers, with several lives lost in connection with these accidents. One of the biggest disasters was the French tanker “Betelgeuse” exploding during discharging outside Bantry in Ireland. This accident cost the lives of 50 people, some of them working ashore.

The maritime industry has always been a dangerous workplace. According to United Nation statistics it has one of the 5 highest rates of accidents of any workgroups. The most dangerous British workplace at sea was the fishing industry, followed by merchant shipping (Beacham 2008). Although regulations have been imposed, most of these have to do with the management of the ships, what and how to report matters concerning the running of the ships, but not much has been done when it comes to implementing time-saving equipment on board ships. The result of the new laws and regulations has rather had the opposite effect, more paperwork, and thereby less sleep for the ships officers. To mention an example, the chief officer has the responsibility of the cargo, maintenance on deck and also at sea has to take the 4 to 8 watch. His/her ordinary work-time schedule at sea is from 4am to 8am, and thereafter to lunch taking care of deck maintenance, paper and cargo work. Then he/she has to go on watch again from 4pm to 8pm. This is continuous 7 days a week, 4 to 5 month or more during the time at sea. The IMO stipulates minimum of 8 hours continuous sleep per 24 hours, and already this is impossible for a chief mate. This minimum working time comes up to 84 hours a week, without having the week-end to relax. On top of this comes extra work in his/her ”free time”, and a 90 to 100 hours work week is the norm rather than the exception. A good description of this problem is given in the book “Inviting disaster, Lessons from the edge of technology” by James R. Chiles(Chiles 2002). On top of this, maybe after several months with this working regime, a ship coming to port requires extra work hours, both before, during and after arrival. It is at these times extra vigilance is required, and the people on board most exhausted. See appendix 1 from BBC (2005) for a further explanation of the fatigue problem.

Figures 2 and 3 show two examples of cargo operations that went wrong. M/T Mega Borg (see Figure 2) exploded outside Galveston, Texas, on June the 8th 1990 during a cargo transfer to a lightering ship. 5 crew members were killed in the blast. As a curiosity it can be mentioned that about a month before the accident, the author was offered the job as a captain on that particular ship.

Figure 2 Mega Borg (IncidentNews, 1990)

Figure 3 M/T Vicuna (Anon, 2004)

Figure 3 shows the M/T Vicuna after an explosion and fire the 15th of November 2004. This happened during a discharge operation in Paranagua, Brazil, and 4 crew members and a surveyor lost their lives.

The foregoing examples are just two of hundreds of accidents that have occurred over the years. The reason for most of these accidents is not usually established, but usually come under the category of human errors. Both accidents here described happened late during the cargo operation, and one must assume that fatigue may be a factor in the cause of the accident.

So, is there any solution to this problem? There are several, but most of them cost money, and that again will increase the transportation cost. Many tankers are old, the average age of tankers in the beginning of 2004 was 17.9 years, and 42.3% of the tanker fleet was over 20 years old (2006)This is of course one of the reasons for many accidents. During the years after 2004 the tanker fleet has been upgraded slowly but steadily. In the late 1990s a price increase of 3 US cents per litre of petrol for a year would be enough to pay for a full renewal of the existing tanker fleet

Another solution is to increase the number of crew on board the ships. From the mid to late 1970s the trend has been instead to reduce the size of the crew to save money. One solution that might work, however, is to computerize some of the tasks the ship officers have to perform, and thereby reduce their workload and also to save time. This will also cost money, but it will be a one-time investment that also will save money. A system that could save several hours during port stay is an automatic distribution and cargo handling program. Several hours before arrival at port, the chief mate has to distribute the cargo and plan for the upcoming operation. This is tedious work, and requires concentration and prudence. Also before, during and after cargo operation is completed, paperwork still has to be completed. If this could be automatically incorporated into the system and done in real time, the port stay could be reduced by several hours.

Cargo Operations

A normal cargo operation begins with the ship receiving a request for a certain cargo to be shipped from A to B. This request consists of weight / volume together with expected temperature and specific gravity of cargo and also if there are any draft restrictions in the loading or the discharge port. The request can also consist of other relevant information such as classification of dangerous cargo etc. The chief mate then makes some calculations based on the given information and then they lay out the cargo on the loading computer. Usually several corrections are needed to get to the final layout of the cargo. In this calculation the dry storage on board the ship, together with the bunkers for the voyage and the freshwater on board must also be taken into consideration. The ship then contacts the charterer and its own office about the result. This usually takes two to three hours, depending on the amount of segregated cargoes the ship has to carry. One has to be aware that both the departure condition from loading port and arrival condition in discharge port have to be calculated, together with possible restrictions during the voyage. This happens for example when the ship passes the Suez Canal. If the cargo is homogenous, the time taken will be maybe an hour. One has to observe here that each tank has to be calculated manually, and only then the result is put into the loading computer to check for stress, trim and draft.

If the cargo is cleared to be taken, the ship steams for the discharge port, and when ready enters the dock. All the necessary valves have then been set up, ready for the loading. This is a job that takes about half a day.

When all the papers are ready, the loading master comes on board and informs the ship about the amount he/she wants to be lifted, the temperature and specific gravity. This will almost certainly differ from the specifications on the charter party, and new calculations have to be made. With small differences, this is done relatively quickly on the loading computer, and the loading starts. With larger differences, a totally new set of calculations have to be made.

A time table for the loading has also been drawn up. This is to see that the ship at all times does not exceed the maximum draft, trim and stress allowed. An incorrect loading sequence could exceed the structural strength of the ship, causing it to fail catastrophically. The time table also includes the times for starting and stopping the de-ballasting and the sequence for the tanks to be filled.

The critical moment for the loading is when the tanks are topped up. Then the officers have to be extremely observant of the ullage (the distance between the cargo and the top of the tank) and the valves position, and ready to change to the next set of tanks to be filled up. This is also in the end of the loading process, when the officers are most tired.

When the loading is completed, an independent surveyor will come on board and check the weight and volume of the cargo. Usually this is done by taking the ullage and temperature of each tank manually and can take an hour or two or even more depending on the size of the ship. New calculations have to be done and the chief officer and the surveyor have to agree on the weight and volume calculated. They use the same figures, but sometimes there are some discrepancies depending on which tables the surveyor and the chief officer use. An important part of the calculation is to ensure that the difference of the shore figures and the ship figures do not exceed a certain percentage, usually up to 5%. This is also the usual difference allowed between the figures stipulated in the charter party and the actual figures calculated.

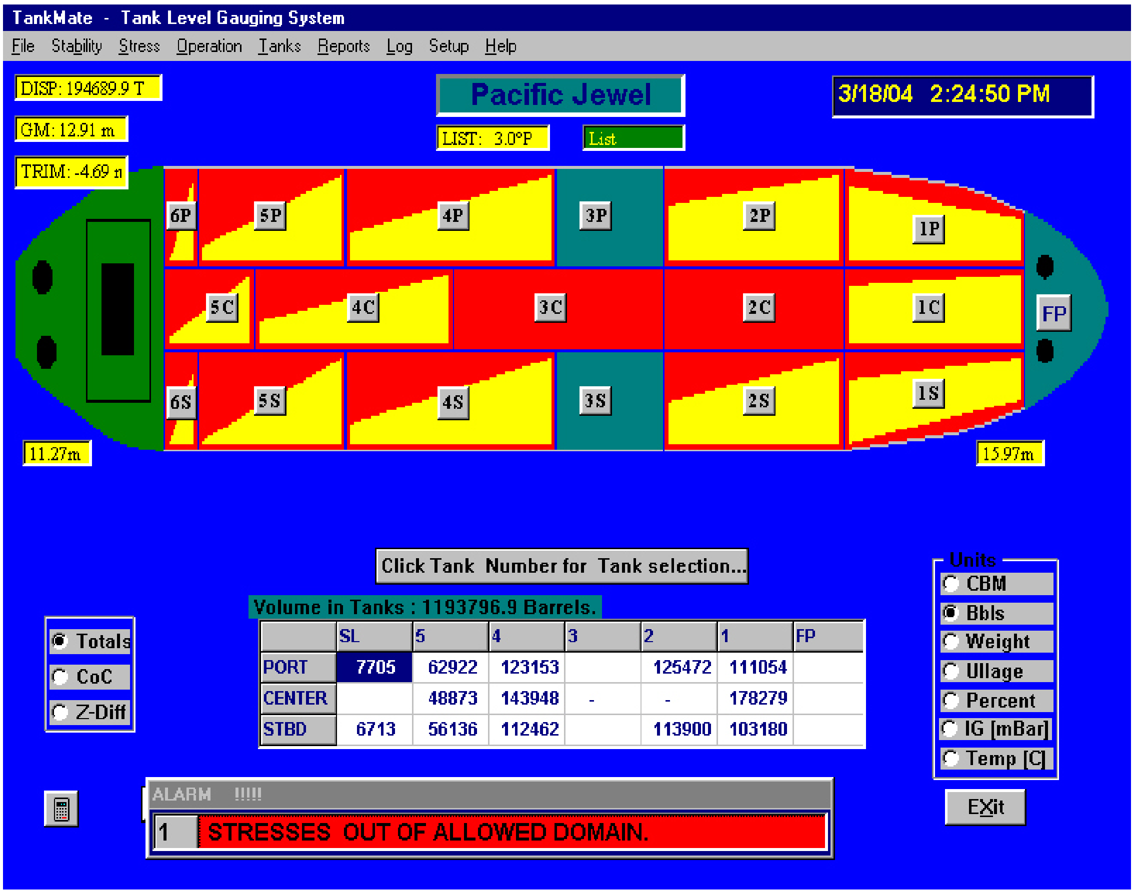
When the calculations and paperwork are completed, the chief officer has to make the ship ready for the sea voyage, and clean up after the loading.

The discharging is in most respects the opposite of the loading, apart from the fact that here the ship has to operate its pumps and have most of the control of the cargo operation. All calculations and checks are the same.

The safety aspect also has to be mentioned with regards to accuracy. An automated system would pick up irregularities much quicker than the officers on watch would, and thereby alarming them by giving advice about how to rectify the situation, or if any danger was detected, shut down the operation. There are today systems that shut down pumps remotely both from ship and shore side, and the computer would be connected to this shutdown system.

A computerized system like this would have to be divided into two separate parts, first a cargo distribution system, and second a cargo operation control system. The first part would take care of the layout of the cargo, i.e. which tank the different grades of cargo go into, and how much of the cargo goes into each tank. Figure 6 and 7 on pages 30 and 31, shows the problem with the cargo layout. Different separations have different pumps, and also different volume. To distribute the cargo so as to carry optimum cargo can in certain cases take hours to do, as trim, stress and maximum draft either at loading port, during sea passage or at discharge port has to be calculated. This program would use the already existing loading computer program to calculate volume, weight and stress of the ship based on specific gravity and temperature of the cargo. Figure 4 shows a loading computer GUI from TotemPlus, which gives the vital information about cargo distribution, weight, volume and stress. The stress is the shear forces between the different sections of the ship, and also the longitudinal bending moment of the ship.

An important piece of information that is also possible to show on the screen is the ullage of the different tanks. The ullage is the distance between the liquid and a fixed point on deck, usually the top of the ullage hatch or the top of the tank entrance hatch. By entering an ullage table (see appendix 2, a modified version of ullage tables for Golar Patricia used at Norwegian maritime schools) with this figure corrected for trim and list, the volume of the tank is determined. The tables are usually given in 5 cm intervals, and interpolation is used for correct volume. This is time consuming and by entering the numbers into a loading computer, quite some time is saved. Modern ships sometimes have remote readings of the ullage, either by pressure sensors or by radar beams. This information goes directly to the loading computer, and thereby offers reading of the ullage and calculation of the weight and volume in real time. Other remote readings are also sometimes connected to the computer, like draft and stress reading from sensors on deck.



	SL	5	4	3	2	1	FP
PORT	7705	62922	123153		125472	111054	
CENTER		48873	143948	-	-	178279	
STBD	6713	56136	112462		113900	103180	

Figure 4 Loading computer GUI for a tanker from Totem Plus (Anon, 2013)

One system for tanker operation planning was designed in the beginning of 1990s in Japan by Ishikawajima-Harima Heavy Industries (Sato, Itoh et al. 1992). This system was for some unknown reason not deployed, and no follow up of the research seems to have occurred. An actual ship was used in the research, and the researchers thereby had the access to a fully working computer. They used an expert system for the distribution part, based on about 150 rules, and used MS-DOS as the operating system. The programming languages were OPS-83 for the knowledge base and its driver, MS-C for graphic display and output, and MS-FORTRAN for calculation of trim, stress and volumes.

The second part of the computer system is the actual operation of the loading/discharging. See figure 10 on page 18 for a schematic layout of such a system.

Attitudes to technological changes in the maritime industry.

Over the years the maritime industry has been slow to introduce new technology on board ships. It took a long time to change from sail driven to steam powered vessels. The first steam ship was built in 1786 (Wikipedia, 2013). One of the last commercial sailing ships, the barque Pamir (Wikipedia, 2013), sank during a storm off the Azores in 1957. Also the change from coal to oil fuel was over several decades, and to the author it seems that seamen and the shipping industry in general are slow to accommodate new innovations, particularly if there is considerable cost involved.

By the end of the 1970's computers had already been introduced in the shipping industry. Mostly it was by introducing computer technology in machine control and in bridge instruments like radars, auto pilots and satellite- and other navigational instruments.

The aversion against new technology was still strong. When the author came on-board his first ship as a 3rd officer he was verbally scolded by the captain and chief officer for using a calculator for astronomical calculation of the ship's position. They both held the opinion that it should be done the old way, by astronomical tables, and not by some newly invented gadget. It had been done for hundreds of years, and so it should done now. Their main argument was this: "What would I do when I ran out of batteries?" I told them that I had spare batteries with me from home, and also, on a ship, there are hundreds of new batteries used for different electrical instruments on-board. I continued to use my calculator, and as they saw that I did my calculations in a third of the time they did theirs, and with a much better accuracy, they finally accepted that it wasn't too bad to use a calculator after all.

This example illustrates the conservative stance in the shipping industry, both ashore and on-board ships. When it comes to seamen the strongest reason for this is that they do not want to see a computer taking over their jobs. In earlier years a seaman was trained in doing a particular job, and did not possess many skills needed ashore. If he had to find work ashore he often had to accept low paid jobs, if he was lucky to get one at all. It was more or less the same with ship officers, the shore based industries did not quite know what to expect from them, and they too had to take whatever jobs that were available to them. What the people ashore did not understand was that a ship officer could be compared to a professional ashore leading a technologically advanced company under sometimes very difficult and dangerous circumstances, and also had more international experience when it came to diplomacy and different cultures than most other professionals based ashore.

Today it has changed a bit, more ship officers, particularly those having a bachelor’s degree from a university, have a better job prospect ashore than ever before. Most of them are now sailing for a few years at sea, and then go to a highly paid job ashore, mainly within the shipping industry, but some also take up positions in governmental agencies. I have therefore seen over the years that the conservative attitude has changed little by little, and most newly educated ship officers accept the new technology without any problems. These young officers have of course been brought up with the computer technology in their own home, and don’t have the aversion many of the older generation of seafarers had to computers.

One of the reasons for the aversion older ship officers have to computers comes from the fact that in the late 1970’s and in the 1980’s the shipping industry wanted to save money. The best way to do that was to reduce the crew to something they called “safety manning” of the ships. it was a minimum of people on-board to take care of the day-to-day work on-board, sailing from A to B, and it did seem that no one took into the consideration that the most crew-intensive work was during cargo operation. On many ships up to half of the crew were sacked, and the rest had to double their workload. To try to rectify this, many shipping companies brought on-board a computer or two, said that the ship were “rationalized”, and sent ashore key personnel. The problem with this was that ship officers, some well over 60 years old, sat with a computer they didn’t know what to do with. One thing was they could hardly use it, and the other was that the only programs installed on them were some word processing and maybe spread-sheet software. This rationalization came down to making watch lists for the crew and some letters to the main offices ashore. So there was no wonder that ship officers had a great aversion towards computers. I myself was not quite one of them and rather saw the benefits they would bring if they could be used properly, and of course also with the right software.

Benefits of a computerized system

There will be some time savings using a system like this, due to the fact that the slowest part of a cargo operation is when starting up/ completing the operation is taking a relatively long time compared with when the processes are up and running. Also the lining up of the valves, which usually takes several hours on a tanker of Golar Patricia's size, will take shorter time, as the computer program can open the relevant valves automatically. Another thing is, that there are a large number of valves involved, and it is easy to make mistakes, even with tight control (see figures 6 and 7 on pages 30 and 31 for simplified drawings of two cargo line systems).

Starting the loading operation is relatively simple; the rate is reduced, to ensure that everything works as wanted. Watchmen go around the deck, to control that there are no leakage, and the same is done in the pump-room. With the right sensors, e.g. flow sensors this would be un-necessary and full cargo rate could be achieved much quicker.

During the final stage of the loading, the topping up of the tanks could continue almost to the end of the operation because the flow is controlled by the computer. There must of course always be someone keeping a close eye on the computers to see that everything functions as intended. The usual way of doing this now is that the chief officer controls the valves and regulates them by reading the ullage and giving the shore orders to reduce their pumping rate to what he/she feels comfortable with. The fewer tanks there are to be filled up, the slower the rate is set to. In other words, it is a time consuming process. A computerized system would be much more able to calculate the necessary flow, based on certain parameters such as how much oil there is in the shore lines, how much time it takes to close the valves and continuously knowing the exact amount of cargo left until completion of the loading operation. There would, therefore, be time savings both in the start and completion of the loading operation.

During the discharging of the cargo, it will also be necessary to line up the valves for the operation. And as with the loading, there is a considerable amount of time involved, and mistakes might happen.

Time is money, and in the shipping industry it means a lot of money. For a tanker of more than 200000 tonnes the port charges for each discharging and loading event can easily come to over 100000 US$, all included, in many ports of the world.

As with all businesses the shipping industry are in it to make money. The capital expenses on a large crude oil tanker are huge (Institute of Shipping Economics and Logistics, 2006), and it is therefore very important to keep the cost down, which is the reason why ships are mostly equipped with only the most necessary equipment regulated by law. A computerized cargo control system would add extra cost to the building price and is therefore not on offer. That such equipment would probably save money in the future might not be considered as the most important part is to get the ship out and running as cheaply as possible.

What is not thought of is that most of the necessary equipment is already on-board. A Cargo Control Console is installed in all tankers today, and have the necessary control switches for pumps and valves needed that would be necessary in a computerized loading/discharging system. The only extra equipment that is needed is the computers, programs and the connection to the equipment already there in the first place.

Figure 5 Cargo Control Console (Anon, 2013)

Figure 5 shows a typical cargo control room console where the main part of the cargo operation is handled. This is the place where the cargo and ballast pumps are controlled, that is, pump revolutions, discharge and suction pressures. Steam to drive the centrifugal pumps is opened by the engineers, and the control of the steam release is then set by the deck officers to regulate the speed. Also most of the valves in use during the cargo operations are controlled from here. Another feature of the control console is usually remote draft readings, to enable the ship officers to read the drafts, and also the trim, of the ship. This is very important when it comes to discharging of the ship, as the suction of the cargo tanks are situated in the aft part of the tanks, and thereby an aft trim is necessary to get as much oil as possible out of the tanks.

Chapter 2. Literature review:

Literature for the thesis has been in three parts; tanker cargo handling, computer modelling and methodology. However, much of the background information that has been used in the introduction chapter has come from internet sources which have been used as supplement and confirmation of the authors own experience and knowledge. Each of the main parts part is discussed below.

Cargo handling

There is not much literature when it comes to automatic tanker loading and discharging. Most of the information gathered is from the different cargo control equipment, such as the Kockumation Group (Kockumation Group, 2013), Kongsberg Maritime (Kongsberg Maritime, 2013) and TotemPlus (Totem Plus, 2013). There is a large literature on other types of production and processing automation, but not specifically on loading and discharging of crude oil tankers. These books usually discuss the mathematical aspect of the input and output of the processes, and were of no real help to this project.

The cargo calculation methods used in the program were taken from the book "Lasteberegninger og behandling av last: fordypning nautiske fag og fiskerifag" by Inge Tellnes ((Tellnes, 2002). This is a standard text book used in Norwegian nautical schools when it comes to calculation of trim and stability of ships.

Another useful book has, when it comes to explaining the background of trim and cargo calculation, been "Ship Hydrostatic and Stability" by A. B. Biran ((Biran, 2003). This book takes up the mathematical and physical problems of this subject.

Computer Modelling

Most of the books covering computer modelling and also computers controlling processes take up the problems of mathematical computation of parameters for inputs and outputs of real-time systems and would be relevant if a system was developed for a real ship.

Even so, a few books proved to be of value. Karl Johan Åström and Björn Wittenmark (Åström & Wittenmark, 1997) write that “Potentially all control systems that are implemented today are based on computer control”. This was the starting point in the building of this simulation. According to their book earlier use of computer programs to control processes were restricted to larger industrial systems, because of the cost, speed and reliability of the computers at that time. Today computers are available for a relative low price and with a speed and capacity far exceeding that of just 10-15 years ago. One of the benefits with computer controlled systems is that it can continue without human interference if that is preferred. This was the intention of this system, so the program could run until completion with a minimum of human input.

The book “Discrete-time systems” (Cadzow, 1973) also follows Åström & Wittenmark in the way it that it takes up the problem with real world systems and their design. Mathematical formulae in these books show how to moderate inputs to get to an optimal result both when it comes to safety and reliability.

Goodwin, Graebe and Salgado write in their book “Control system design” (Goodwin, Graebe, & Salgado, 2001) that “In particular, improved control is a key enabling technology underpinning

- enhanced product quality
- waste minimization
- environmental protection
- greater throughput for a given installed capacity
- greater yield
- deferring of costly plant upgrades, and
- higher safety margins”

Not all of these points are important when it comes to tanker cargo operations, but in particular higher safety margins, environmental protection and enhanced product quality (in the meaning that a computer will load/unload a tanker faster and with less problems then a ship officer will be able to do) are key elements in the desire for making such a program compulsory on tankers. An example of an ammonia plant is also set up in this book, which would be comparable with a ship when it comes to valves, lines and tanks to be controlled. Other comparable industries would be chemical, medical, power plants and petroleum refineries.

When it came to system modelling Goodwin et al also take up this problem. They write that it is important to remember that a real system is complex, and that it is usually impossible to completely model the real system. Compromises must be made with a cargo system like this, it would take too much time to create the exact mathematical computations, when it comes to cargo flow rates and so on. They mention that the best way to go is usually to make it simple at first, and then add features as solutions evolve. This simulation is a first attempt, and made just to show that it is possible to make a real world system that would work in a safe and economical manner.

In his book “System simulation” (Gordon, 1978) says that “a system is often affected by changes occurring outside the system”. A system like this will for example be affected by what is done by the receiver/deliverer of the cargo. The refinery or crude oil depot that works in conjunction with the ship during the cargo operation will also have their systems that control their setting of valves and pumps. These settings will vary from time to time and it is important to be able for the system to quickly and correctly respond to such variations.

Changes can also come from within the system, such as in this case valves that get stuck, and variation in steam delivery for pumps. It is important that the system can correct such changes, or if necessary close down the operation by itself. Such safety guards will of course be incorporated in a fully working system.

Methodology

The methodology used when collecting data to solve this project has been autoethnography. There are several articles found covering this method of research, but most have been around projects covering the authors of these articles own personal experiences. A useful source is autoethnography: A tool for practice and education (Cunningham & Jones, 2005). This proceeding describes the use of autoethnography in education.

This approach has been used in the IT industry, as described by Ulrike Schultze in an article in the MIS Quarterly (Schultze, 2000). Although this article discusses the use of autoethnography in the field of knowledge management and not systems and programming development several points can be drawn from the conclusion. An important and reassuring factor is that she wrote, “informing practises are situated practical solutions to the balancing subjectivity and objectivity, where subjectivity, tacit knowledge, and the willingness to “” add one’s self”” is associated with being “”value adding””, and objectivity is associated with authority and safety against attacks on one’s personal identity and competence” This reinforced the authors decision on going forward with the autoethnography as the method of choice. On page 32 she has set up a table with requirements for a “High Quality Ethnography and Confession Writing”. She put up 5 criteria in her table: Authenticity, Plausibility, Criticality, Self-revealing writing and Interlacing “actual” and confessional content. It is the author’s belief that this thesis has followed those criteria.

Another book used for the methodology was Design and Development Research (Richey & Klein, 2007). This book emphasizes that developing computer programs is also considered research.

An article in MIS Quarterly, Design Science in Information System research ((Hevner, March, Park, & Ram, 2004, March), outline a set of guidelines for Design-Science Research. They set up 7 guidelines to proper design research.

1. Design as an Artefact
2. Problem Relevance
3. Design Evaluation
4. Research Contribution
5. Research Rigor
6. Design as a Search Process
7. Communication of Research

This thesis has followed those guidelines, but has to be further explained. When it comes to guideline 3, Design Evaluation, it can be argued that it has been weak. The author’s opinion on the other hand is that with a program like this, it is the result that has to be looked into, and as such it has worked to the satisfaction of him and also the 3 colleagues that evaluated it.

Guideline 4 might be more difficult to explain, but it is hoped that a proof that this can be a starting step for further research into the subject.

When it comes to guideline 5 the articles authors mention on page 88 that “rigor is derived from effective use of knowledge base. The knowledgebase in this thesis has been the author’s own experience, and as such been used to its full extent.

The communication of research is not as easy to follow as this thesis is intended for delivery to AUT. What happened to it after that is up to the University, and not up to the author.

Chapter 3. Methodology:

In this chapter the methods used in this thesis will be described and discussed. Autoethnography will be treated first, since it has been the source for much of the material presented, both on the wider context outlined in the introductory chapter and on loading and discharging operations. Thereafter the role of simulators in the maritime industry will be discussed.

Autoethnography

This thesis is basically a product of the author's almost 35 years at sea, mostly on tankers of all kinds, product, crude oil, chemical and gas. I first sailed on a crude oil tanker in 1979, straight out of merchant marine officer's school.

When the author started his thesis he knew it was difficult to collect information about the subject here in New Zealand. Few people here have tanker experience, and he did not know how to get in contact with them. His supervisor then suggested auto-ethnography as an option using my own experience as a resource for collecting data. The author has worked on tankers as an officer for 20 years would probably make him as knowledgeable as most when it comes to tanker operations.

One objection to this kind of research was that the author did not set out to write a thesis when he started working at sea. No notes or plans were made, and it was just the interest in the field that made him discuss the problems around automatic loading and discharging with fellow ship officers. When this comes to make out requirements for the program it would not make much difference though, as the only differences with others making it would be the GUI (Graphical User Interface). Inputs would have been the same, although programming language could have differed.

Another problem which is considered is the possibility of bias. The program itself is probably not much influenced by that, but rather the thesis, as it is built on one man's experiences which would differ from anyone else's. Care is taken to avoid this, by discussing with colleagues both on board ships and ashore, but it will always be a product of one person, and thereby prone to bias.

On a ship you live in a confined space with other seamen for long periods at the time. You get to know your fellow crewmembers very well, and much of the talk concentrates on work. I have since I graduated from the ship officer's school had an interest in computers and automation and discussed that subject at length with my fellow officers. Although I at that time did not intend to write a thesis about it, much of what was discussed is still fresh in my mind. To my surprise many, particularly older officers were against computerization of anything on-board a ship at all. They tended to be conservative, and what was good enough for them was good enough for us, and the next generations to come as long as they could see. Many of the older officers had been at sea from well before the second world, and had sailed on ships without radars for many years. I then asked them if they approved of the radars, the navigation equipment like Decca, Omega and Loran C and they were usually happy with those. When I said that those were to be compared with computerized systems they usually just brushed it off and were happy with that.

Most of those officers are long gone, and new generations of seamen came on-board, most of them more technologically aware and educated. The shipping industry is now high technology and the people educated during the last 20 years are computer literate. Time is now also more important than it was 20-30 years ago, where you often loaded or discharged a ship during daylight hours. Most ships also had 4 deck officers on-board plus captain, so the chief mate worked during day-time, taking care of the cargo and the maintenance of the ship, apart from the engine area, which is the chief engineer's responsibility. The chief mate therefore usually had 3 experienced tanker-men to rely on when it came to cargo handling. He could therefore have some sleep from time to time without really have to worry about what could happened if he was not personally overlooking the cargo operation at all times, and be relatively well rested during the last stages of the operation.

As this thesis is built on experiences it has to be regarded as "Personal Narratives" (Ellis, Adams, & Bochner, 2011), "stories about authors who view themselves as the phenomenon and write evocative narratives specifically focused on their academic, research, and personal lives (e.g., BERRY, 2007; GOODALL, 2006; POULOS, 2008; TILLMANN, 2009). These often are the most controversial forms of autoethnography for traditional social scientists, especially if they are not accompanied by more traditional analysis and/or connections to scholarly literature. Personal narratives propose to understand a self or some aspect of a life as it intersects with a cultural context, connect to other participants as core searchers, and invite readers to enter the author's world and to use what they learn there to reflect on, understand, and cope with their own lives”.

The role of simulators in the maritime industry

Simulators have been used in the maritime industry since the middle of the 1980s. The first ones that were used were used to teach navigators to use ARPA (Automatic Radar Plotting and Acquisition). Later on came simulated ship bridges which included ARPA devices but also incorporated other navigational instruments and visual screens

The requirements for the model developed in this thesis, which is also a simulator, as for a system installed on-board a ship, would be that it is as easy to use, and with as little human interference as possible. It should be an automatic process that sees to that the oil goes safely and efficiently to and from a shore terminal and ship.

Rigour

The rigour of the simulation program is shown in the outcome. There are many programming languages, and also programming methods that could be used to achieve the same outcome as shown here. However, regardless of the tools used to produce the program the same inputs have to be used and the same calculations performed. So the rigor of the simulation could be proved by making a program using another programming language to come to the same result.

When it comes to the writings in the thesis, it is both built on literature about the subject and on the authors own experiences. There will be seafarers with different opinions to those expressed in this paper, and so it should be. Other countries will have different customs, cultures and way of doing things, but it is believed that the essence of what is written will be the same regardless of who would be writing it.

Validity

The program was validated by 3 colleagues at the nautical department at one of the two nautical schools where the author teaches, the University College of Stord/Haugesund. Two of the lecturers had earlier been on crude oil tankers similar to the Golar Patricia, and the third had been on chemical tankers. They received the program for evaluation about two months before a meeting were held where we went through the simulator program.

To validate a program like this it is important to know what the outcome will be. The validators all knew from experience how such a program had to work and they were well aware of the requirements for performance valuation. They had tried the program with various different inputs and found it to work as intended. As there were a close working relationship with the author and the valuators the program was discussed in length, and found to be easy to use, and with necessary inputs and outputs as should be required from such a program.

A questionnaire could be used as documentation to their findings, but as this thesis also builds on numerous discussions with other seafaring colleagues over the years it was considered sufficient to use facilitated interview to get to the same results.

On the question about the importance of such a design and if in the future this would be the way to go they all concluded that research into automation of cargo handling, not only on crude oil tankers, but also on other tankers, and cargo ships in general, was the way to go. This went both for cost effectiveness and for safety. When an accident occurs, both at sea and ashore, people start to find solutions to prevent it from happening again, and one solution to maritime accidents could be to automate the loading and discharging processes on ships. They therefore found it relevant to continue research on problems as were taken up in this thesis.

Another problem was if the development of a program was considered research. The book Design and Development Research (Richey & Klein, 2007) took up this problem and followed the shift over the last few years in thinking when it comes to define developments as design. They also set up rules for rigour and validation of a design to qualify it as research, and steps to follow which has been used during the creation of the simulator program.

Chapter 4. Automatic Loading and Discharging Solution

The purpose of this thesis was to create a computer program to simulate automatic loading/discharging operations on board crude oil tankers. A computerized real world program on a tanker would thereby be proven to be possible, and if implemented on tankers hopefully save time during port stay. Another benefit would be safety as a computer would be able to react faster than a person, probably very tired and with increased reaction time in unexpected situations.

It was decided to use Microsoft Office Excel for making the program as this is readily available to most people, and a spreadsheet lends itself very well to tables using large data sets. The simulation programme did not use much data as such, but a real loading/discharging program would have a huge amount of data that would be used.

VBA (Visual Basic for Applications) is a programming language that is incorporated in the Excel application, and as many people use Microsoft Office it is already easily at hand. It is a Pseudo Object Oriented Language which is important as many subroutines were used to create the simulation. The subroutines were divided into two categories, the first one initializing and updating of the GUI and the second one calculation of the changing ullages, drafts, trim and displacement.

Modelled ship

The ship chosen for this program was the S/T Golar Patricia. There were two reasons for that, firstly that the ship is used for educational purposes in Norway's maritime schools and thereby the necessary hydrostatical measurements were, albeit limited, readily at hand. The second reason was that the author has been working for the same company that owned the ship, sailing on one of its sister ships (the Golar Kanto). This was a ship typical for that area, a VLCC (Very Large Crude-oil Carrier) of 216,326 deadweight tonnes, and built to the specifications normally laid out for such a tanker. It had the superstructure at the aft ship and the pump-room at the aft part of the main deck area, just in front of the engine room and the superstructure. For discharge she had 4 main cargo pumps which also were used for ballasting/de-ballasting the ship. In addition to this there were two cargo tanks, namely the #3 port and starboard wing tanks that were specifically designed to carry ballast water only and were not normally connected to the cargo system, but could, via separate valves and spool pieces, be connected in an emergency situation requiring oil to be filled also in these tanks.

The loading of the ship was conducted via a manifold situated on the amidships area and down to the bottom cargo lines (see figures 6 and 7 for typical cargo lines arrangements) via drop-valves from the deck lines. The discharge was done via the pump-room and up to the deck lines and manifold and then onto the shore facilities. One problem with loading and discharging such a tanker was that ballast had to be taken into a tank after the tank was stripped of oil during the discharge or emptied for ballast water before the tank was loaded with oil during loading operations.

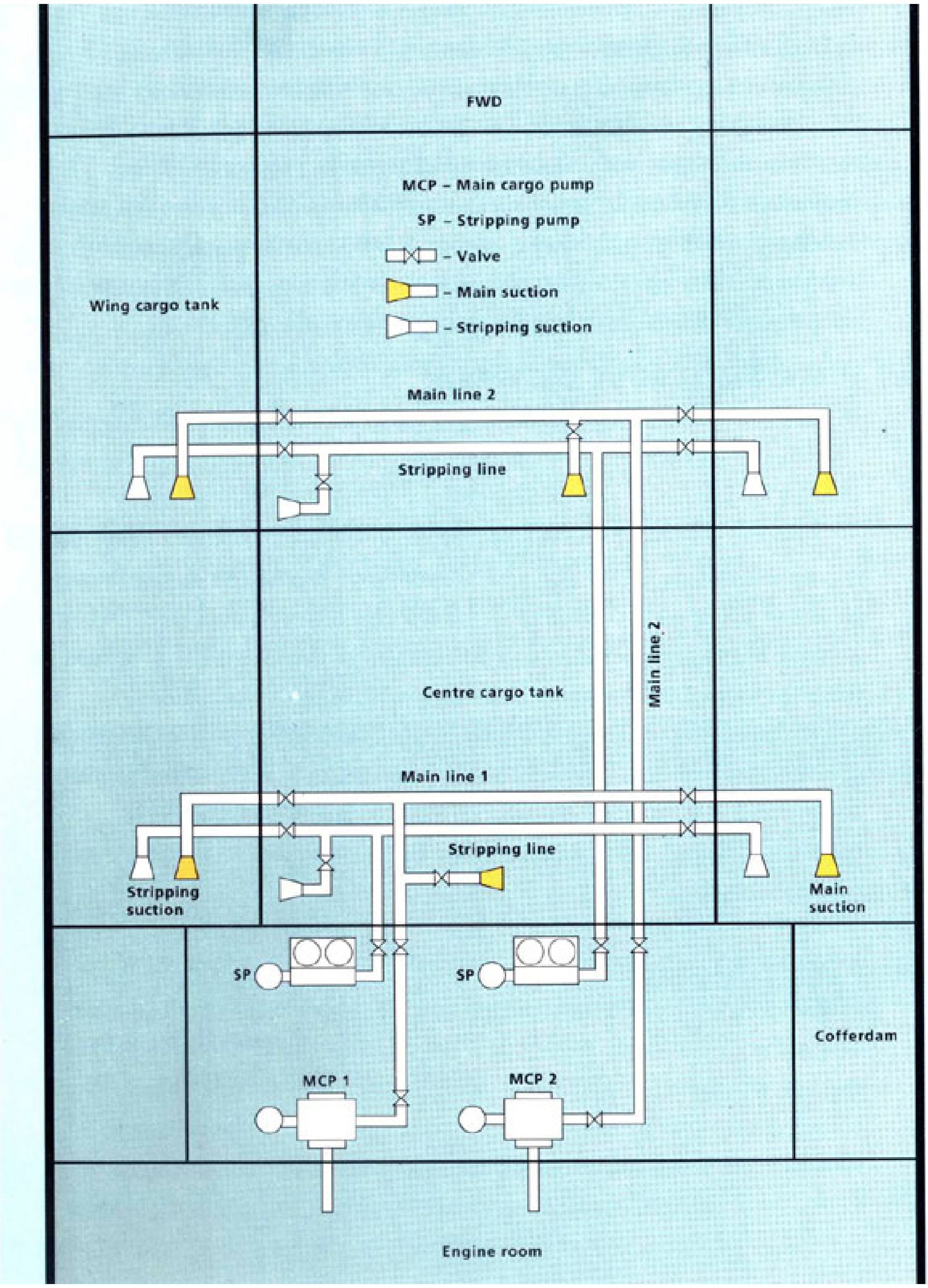


Figure 6 Typical Cargo line and pump room arrangement (Anon, 2013)

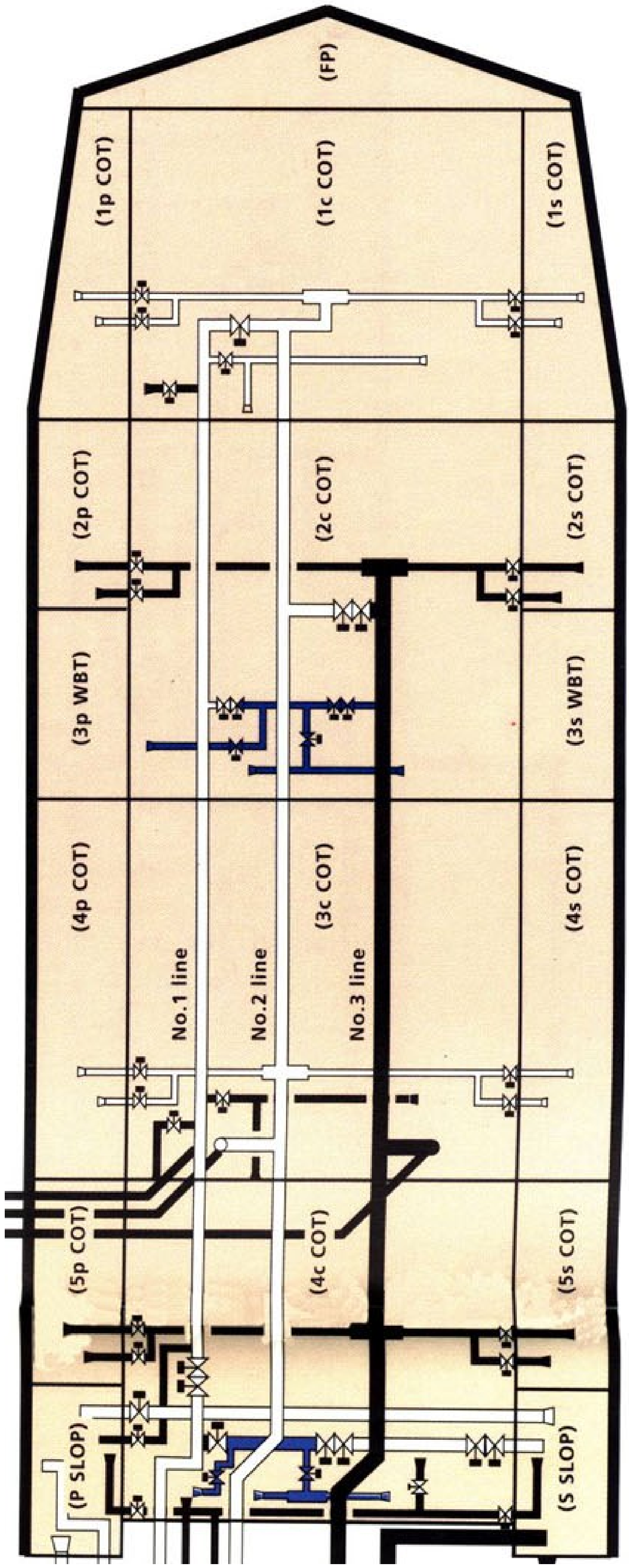


Figure 7 Cargo Lines arrangement (Anon, 2013)

The loading process

The loading process today often starts several days before the ship reaches loading port. The ship's master receive an e-mail or phone call where its asked if the ship can load a certain amount of cargo, either from the ships main office or from a charterer if the ship is on time chart. He/she, together with the chief officer, second officer and the chief engineer then calculate how much the ship needs for bunkers and other consumption, and he/she will then agree or deny the loading proposal depending on whether the ship can take the proposed amount of cargo or not. If it can, the cargo has to be laid out and calculated according to the required draft and trim. If the ship is to lift more than one type of oil, these types have to be segregated, and the possibilities for pumping in or out more than one cargo at the time has to be considered for timesaving during both loading and discharging.

The ship will now sail for the loading port to lift the intended cargo. If it has been gas freed beforehand, i.e. the ship's cargo tanks have a normal atmosphere containing about 21% oxygen, inerting has to be started. This means that the exhaust gas from the engine or steam boiler, also known as flue gas, has to be inserted into the cargo tanks. These tanks are now closed, and the pressure regulated with the use of so called P/V (pressure/vacuum) valves. The valves open, or close, at certain pre-set pressure or vacuum parameters. Inerting of the tanks usually takes several days, but is a very important safety issue, and if COW-ing (Crude Oil Washing) is to take place during the discharge operation, the tanks have to be inerted according to the rules and regulations from IMO. Most shipping companies and shore facilities also do not allow cargo operations at all without the tanks having been inerted.

About a day before the ship reaches loading port, the chief officer and the pump-man/woman goes through the cargo line drawings to prepare for the loading. They open the valves necessary for the operation, except manifold and tank valves, to prepare the ship and to avoid time delays in port. The manifold and tank valves would be opened just prior to the commencing of loading.

The chief officer presents a written request for de-ballasting to the shore personnel as soon as possible, so that he/she can start de-ballasting before the paperwork is finished. As there are quite a lot of official business to take care of before the ship is cleared for discharging, 2-3 or even 4 hours might go before this is finished. Customs and immigration officials come on board and they might require each crew member and the ships officer to check their passport and personal belongings. Provision and spare parts have to be arranged, and also a crew change might be scheduled. Finally, vetting agents and port state or flag state officials might come on board to control the ship. These people have to be accommodated as best as possible to be able to get the ship through the often very strict controls required by the IMO, ILO and different classification societies.

During the time the various inspectors are on board the cargo operation will proceed. The inspectors want to be shown around, and a ship officer has to follow them around. Also ship crew will be asked to do different tasks the inspectors want to check out if they can perform. All the checks, the handling of provision, crew changes and so on take time, and the ship officers alertness may be diverted from their main task, namely to load the vessel. It is also during the starting-up period and during the final completion of the operation that the highest level of alertness is demanded from the officers and most accidents may occur.

After the loading has started, the 2nd and 3rd officers go 6 hours on watch, and 6 hours off. They control the valves, look after the ullages, trim, list and write up the rate and pump-logs for each hour. The pump-man/woman and chief officer might get a couple of hours sleep, but usually they are occupied with some other work, mostly paperwork or inspections. Because of that the chief officer is starting to get tired when the ship is ready for topping up the cargo tanks. It might have been 25 to 30 hours since he/she had some sleep, and now he/she is in the middle of the most critical phase of the loading operation. It is critical that the tanks are not overflowing and causing an oil spill as this can cause millions of dollars in fines and clean-up costs. In addition, substantial jail sentences might be given to both the captain, chief officer and other crew members being directly involved in the oil spill. It is enough to remember the containership Rena that went aground on the Astrolabe reef outside Mount Maunganui (Wikipedia, 2013) 5^{th} of October 2011. According to Wikipedia the oil spill was up to 2,500 barrels of fuel oil, but this is dwarfed by the comparison with a ship of Golar Patricia’s size that can have more than 40,000 barrels of fuel together with a cargo of more than 1,300,000 barrels. The Wikipedia website regarding the Rena oil spill (Wikipedia, 2013) states that the maximum jail sentence for spilling oil into the sea in New Zealand waters is 2 years, and with fines of up to NZ$ 300,000. However, there are several countries in the world that deal a lot harsher with people causing an oil spill than New Zealand does.

The author personally knows of a Polish captain that got 3 years jail time Venezuela in 1988 for spilling some small quantities of dirty ballast into the river at Maracaibo.

Another problem is, apart from that the chief mate is most possibly now extremely tired, is that at the completion of the cargo operation there is a lot of paperwork to do. There are now several people from shore on board, agents, cargo owner's representatives, shore facility representatives, cargo surveyors, government and port officials, agents and so on, and all need help from the chief officer. When taken into account that a shipload of 300000 m3 of Brent crude oil (which is approximately the amount of oil the real Golar Patricia carried) easily comes up to a price of over 200 million US$ (Oil-Price.net, 2013).This comes in addition to the price of a new tanker of over 100 million US dollars (Xun, 2013). And this is all in the hands of usually very tired ship officers.

When the ship arrives at the discharge port many of the same procedures are repeated. The valves have to be opened and the inert gas system has to be started up and running. Most of the inert gas operation is run by the engineers, but it had to be monitored and regulated by the ship's officers. It is extremely important during the discharge operation when most probably the shore side demands COW (Crude Oil Washing). This is done by redirecting cargo oil from being taken to shore to being run through the washing machines for the cargo tanks. If the tank atmosphere has an oxygen content of over 11% in volume and the hydrocarbon content is between about 1% (Lower Explosive Limit) to 10% (Upper Explosive Limit) in volume, it is a danger of explosion in the tank. This is particularly important during COW-ing operation when the oil is pushed through a small nozzle to make a pressure of at least 9 bars, usually 10 to 12 bars, to wash off sludge and sediments on the tanks sides, bottom and top. It has therefore a great potential to create static electricity and thereby an explosion in the tank should the atmosphere be outside the safety limits for oxygen and hydrocarbon levels.

Another important function of the inerting of the tanks is that it during discharging it is upholding a positive pressure and thereby hindering tank from imploding if there should be any complications with the ventilation system of that tanks, i.e. that the P/V valve(Pressure/Vacuum valve) should malfunction.

Inerting of the tanks are also important because of the dangers of sparks due to static electricity in the tanks caused by the pressure (9 bars and above) of the washing oil during COW-ing operations. Several tankers, among them Golar Patricia, have exploded and sunk due to this phenomenon, either when washing the tanks by water or crude oil.

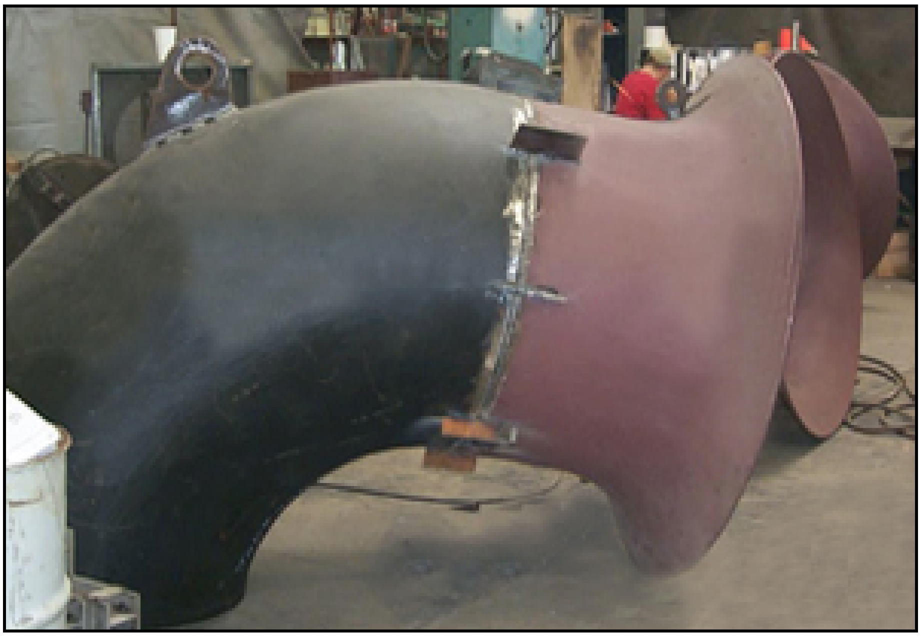


Figure 8 Bellmouth (Anon, 2013)

A tank will never be completely empty from oil after a discharge operation, as the Bellmouth (figure 8) will always be some centimetres above the bottom of the tank. Stripping pumps, with stripping lines also ending with a Bellmouth in the tank will start to suck air if the suction pressure is too high, and a centrifugal pump pumping air will just trip. There are several techniques to avoid this problem; one is to have a so-called Vacuum tank filled with oil to feed the pump when it is sucking air. Another is to have automatic controls of the of the pumps revolutions combined with the suction and pressure valves on the pump to reduce the valve setting and thereby limiting the amount of air coming into the pump. This is called an automatic anti-surge system and in most cases works quite well.

At the time the cargo operation is about to be completed, the officers are usually very tired, and possibilities for an accident have increased dramatically. A leak could create an overflow of a tank and result in pollution of the sea, with dire consequences for ship officers and company. To take the vessel Rena's oil spill outside Mount Maunganui as an example and compare that with a tanker of Golar Patricia's size, it will illustrate the seriousness of such a situation. According to Wikipedia (Wikipedia, 2013) the oil spill was around 400m3 of oil. A short calculation shows that Golar Patricia with full speed on all four pumps would have used about one and a half minute to pump that amount into the sea. Another example would be British Petroleum chartered oil rig Deepwater Horizon’s oil spill in the Gulf of Mexico on April the 10th 2010. Again according to Wikipedia (Wikipedia, 2013) the oil spill totalled about 780000m3 ± 10% of crude oil and covered a great part of the coasts of Louisiana, Alabama and also a smaller part of Florida. The extent of this oil spill is shown on figure 9.

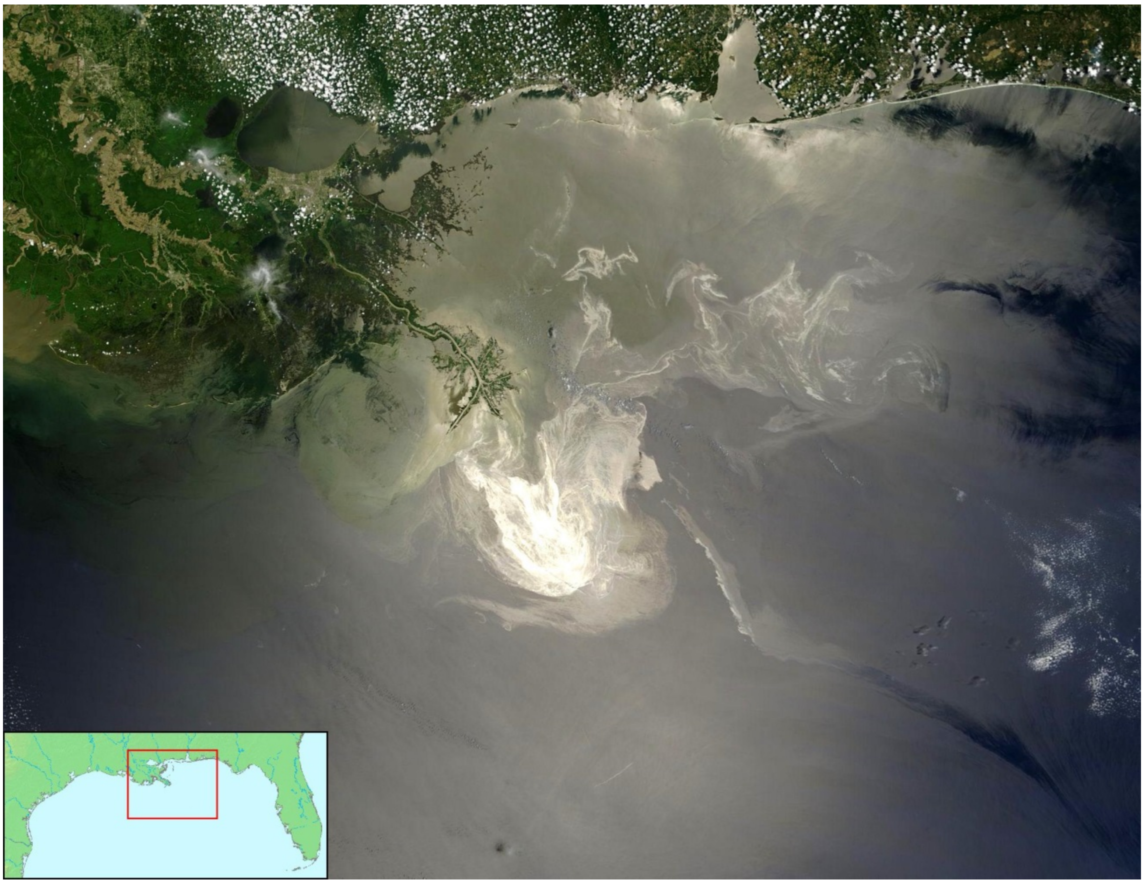


Figure 9 Deepwater Horizon oil spill (Michon Scott NASA's Earth Observatory, 2010)

The largest ship ever built, the super-tanker Seawise Giant, could carry about 706000m3 of oil and would have created an oil spill of just a little bit under this. According to the Wikipedia site on the oil spill: “The spill had a strong economic impact to BP as also the Gulf Coast's economy sectors such as offshore drilling, fishing and tourism. On BP's expenditures on the spill included the cost of the spill response, containment, relief well drilling, grants to the Gulf States, claims paid, and federal costs, including fines and penalties. As of March 2012, BP estimated the company's total spill-related expenses do not exceed $37.2 billion. However, by some estimation penalties that BP may be required to pay have reached as high as $90 billion. In addition, in November 2012 the EPA announced that BP will be temporarily banned from seeking new contracts with the US government. Due to the loss of the market value, BP had dropped from the second to the fourth largest of the four major oil companies by 2013. During the crisis, BP gas stations in the United States reported sales off between 10 and 40% due to backlash against the company.

Local officials in Louisiana expressed concern that the offshore drilling moratorium imposed in response to the spill would further harm the economies of coastal communities as the oil industry employs about 58,000 Louisiana residents and has created another 260,000 oil-related jobs, accounting for about 17% of all Louisiana jobs. NOAA had closed 86,985 square miles (225,290 km2), or approximately 36% of Federal waters in the Gulf of Mexico, for commercial fishing causing $2.5 billion cost for the fishing industry. The U.S. Travel Association estimated that the economic impact of the oil spill on tourism across the Gulf Coast over a three-year period could exceed approximately $23 billion, in a region that supports over 400,000 travel industry jobs generating $34 billion in revenue annually".

As shown, the consequences of an oil spill can be enormous, and great care should be taken to prevent such an accident. The problem with a computer program and bugs has been taken up by several people I have talked to during the years, particularly some years ago when computers were less reliable then today. But today's computers control more and more of our lives, and most people seems to have accepted that.

Of more importance is the fact that the more tired people are, the less observant they are. Several website articles write about this problem, among them eHow health (eHow, 2012), Diseaseproof (Ferreri, 2012) and others. Most conclude that 24 hours lack of sleep correspond to about 0.8 per mill. blood alcohol level when it comes to eye-hands co-ordination and reaction time.

Progressive effects of alcohol

BAC (% by vol.)	Behavior	Impairment
0.010–0.029	• Average individual appears normal	• Subtle effects that can be detected with special tests
0.030–0.059	• Mild euphoria • Relaxation • Joyousness • Talkativeness • Decreased inhibition	• Concentration
0.06–0.09	• Blunted feelings • Disinhibition • Extroversion	• Reasoning • Depth perception • Peripheral vision • Glare recovery
0.10–0.19	• Over-expression • Emotional swings • Anger or sadness • Boisterousness • Decreased libido	• Reflexes • Reaction time • Gross motor control • Staggering • Slurred speech • Temporary erectile dysfunction • Possibility of temporary alcohol poisoning
0.20–0.29	• Stupor • Loss of understanding • Impaired sensations • Possibility of falling unconscious	• Severe motor impairment • Loss of consciousness • Memory blackout
0.30–0.39	• Severe central nervous system depression • Unconsciousness • Possibility of death	• Bladder function • Breathing • Dysequilibrium • Heart rate
0.40–0.50	• General lack of behaviour • Unconsciousness • Possibility of death	• Breathing • Heart rate • Positional Alcohol Nystagmus
>0.50	• High risk of poisoning • Possibility of death	

Table 1 How Alcohol affects the body (Salazar, Guillermo J. and. Antuñano Melchor J, 1994)

The above table (Table 1) show the effect of alcohol from a Blood Alcohol Level of 0.10 to 0.19 vol. %, which should indicate a lack of sleep of 24 hours and more. This is at least twice the amount of Blood Alcohol Level a driver of a car is allowed to have on New Zealand Roads.

An article in the “Accident Analysis and Prevention” journal ((Gander, et al., 2011) takes up another problem, namely the laws that regulate how many hours work and sleep that is allowed. One of the topics mention there is that regulation in itself regarding work/rest time is not always sufficient to make a person feel refreshed. The biological clock also inflicts on a person. Ship officers works both night and day, every day of the week, and this can be compared with shift work ashore. The article says that “Performance capacity is systematically affected by a range of factors that need to be considered in a comprehensive approach to fatigue risk management”. It is thereafter listed up some factors:

- It fluctuates across the daily cycle of the circadian biological clock, so the risk of fatigue is greater when performance capacity is reduced during biological night.
- It is reduced in a cumulative, dose-dependent manner by restricted sleep.
- It decreases as continuous time awake increases.
- It decreases as continuous time on a task increases, and the rate of decline is influenced by the intensity of work demands (workload).

This shows that there are several reasons for fatigue related accidents on board ships, and the author likes to add that due to the global nature of shipping a ship often travels through several times-zones during a voyage, and thereby add to the confusion of the biological clock.

New laws regarding work/ rest times on ships have been implemented. The International Labour Organization (ILO) has a convention, Maritime Labour Convention, 2006 (MLC, 2006) with amendments in 2012, that now regulates working conditions at sea. On paper this works fine, but in practice it does not. A ship goes to port 24 hours a day, and work continues until it is loaded/discharged. There is a clause in the convention that says that necessary work has to be done regardless of time spent on the job, so up until now the convention, which is put into law in most seafaring countries has not worked totally as intended, but it is a step in the right direction.

Most often a chief officer is awake for more than 30 hours, many times even 40, and considering the consequences that can result from a wrong or late decision it would in the opinion of the author outweigh the possibility for a computer malfunction. However, the intention of installing a computer to load and discharge the cargo from a tanker is not to relieve the officers on duty of their responsibilities, but to be a tool for a safer and more efficient cargo handling.

Computerized systems

A modern crude oil or product tanker is normally equipped with a cargo control room (see figure 5). This is where the officers on watch and the chief officer usually spend most of their time during the cargo operation. From here the valves used during cargo operation can be opened or closed remotely, pumps started and stopped and their rotation rate adjusted. They can also from here read drafts, ullages both in cargo and ballast tanks, and in some instances also in bunker oil, lube oil and fresh water tanks.

All tankers over 65 metres in length are also by law equipped with a cargo computer which the officers can use to calculate the bending moments, shear forces, drafts and ullages. This computer calculates the draft, trim and stability of the ship but also the stress on the ship’s hull i.e. share forces and bending moments. Draft, trim and stability can easily be calculated, but the stress calculation is cumbersome and takes some time to do. Several larger ships have broken in half during loading or discharging operations so the IMO now demands that ships have an instrument which can perform this calculation in a relatively short time.

The first of these devices came already in the 1960s but was then restricted to stress calculations. Later on, in the 1980s computers were introduced to do the calculations, and stability was also included into the programs.

Schematic Information Flow

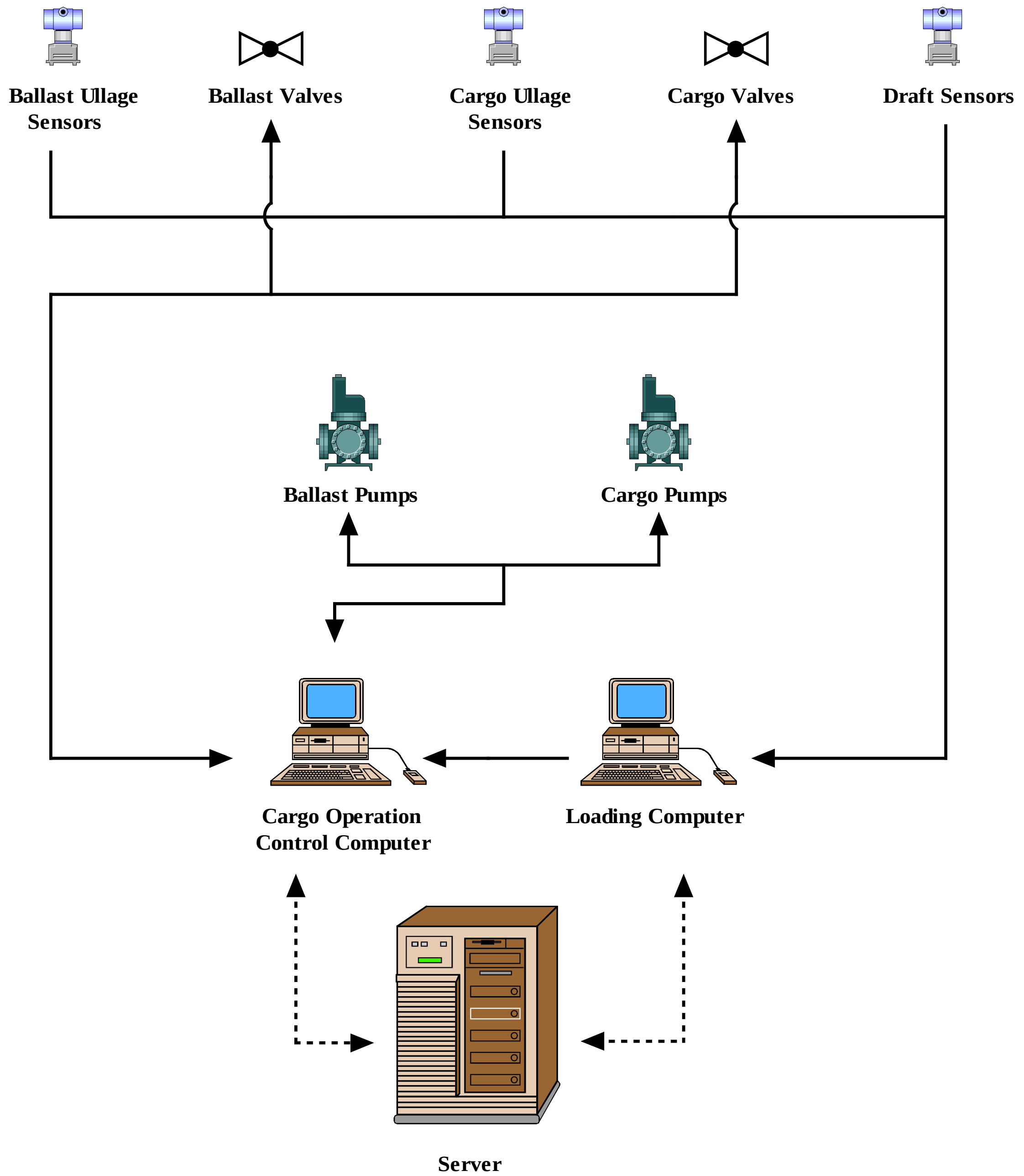


Figure 10 Real Life Schematic Diagram of a Loading/Discharging System (Author, 2006)

A tanker operation program for a real tanker would mostly use inputs from sources already installed on a ship, as draft sensors, cargo tanks ullage and temperature sensors, different valve indicators and pump indicators for steam pressure and revolutions. This information would then be compared with parameters set by either the ship officers, that being density of the cargo, stop ullages, pump revolutions, stripping speed, topping off rates and any other information needed by the particular ship to be able to perform the necessary loading or discharging operation.

It will also need to constantly monitor the inputs from the ships different sensors to be able to set pump speed and valve openings to the right level of openings to satisfy a correct loading procedure. This will be done by a Cargo Operation Control Computer which will use the input needed to perform the operation itself, but also send some information like draft and ullages to a Loading Computer which will then also as a check calculate the draft and ullages to compare and confirm that the Cargo Operation Control Computer’s information is correct. This would be done to have a safety control built into the system.

Another and very important control that would have been done by the Loading Computer would be the check of the ship hull’s bending moments and shear forces. Several ships have broken in two because of these problems, and there has to be a constant surveillance in this area to prevent such an accident happening again. Even though a ship today must have a loading/discharging plan where ship deflection is taken into account, and agreed on by both ship and shore officials before any cargo operation commence, IMO regulations demand that a constant check on bending moment and shear forces must be kept throughout the whole operation.

For a program on a real ship to work it has to be properly it has to be able to take decisions according to rules set up by the makers of the program working together with experienced ship officers. On new built tankers there are relatively few problems with cargo operations as soon as the first few loading and discharging operations have been completed. This is because there usually are a few initial problems that have to be worked out to get the best performance out of the loading/discharging system. On older tankers however, there is a tendency for there to be more problems, particularly with valves and pumps. Most common are valve problems, they tend to stick in a set position, mostly closed or open, but also sometimes in between, and then there has to be a solution to solve this.

A system that changes variables over time is said to be “time-varying”, dependent on a discreet time constant *k* (Cadzow, 1973) and (Åström & Wittenmark, 1997). This means that there will be a constant time interval between checks of the different variables of the system. This will be governed by a delay unit that operates in a manner of reading constant inputs at a specific time. On the simulation the constant *k* is set to 5 seconds.

Åström & Wittenmark (Åström & Wittenmark, 1997) also stress the importance of reliability when it comes to analysing a dynamic system, and comes up with different formulae for solving the problems. As this is not necessary for a simulation it will not be gone further into, but it has to be mentioned that reliability is of outmost importance when it comes to designing a real time system for cargo contlolled operations on board tankers.

A computer system on board a ship will have to be very robust. The environmental factors, like hot or cold weather, always humid, will require high quality equipment to be able to work reliably. Again according to Åström & Wittenmark the system will be sensitive for pertubations, not only from the loading/discharging side, but also from the outside sensors that send inputs to it. This would have to be thoroughly investigated before it is installed on board a tanker.

Adjusted ship design

A modern crude oil or product tanker is normally equipped with a cargo control room (see figure 5). This is where the officers on watch and the chief officer usually spend most of their time during the cargo operation. From here the valves used during cargo operation can be opened or closed remotely, pumps started and stopped and their rotation rate adjusted. They can also from here read drafts, ullages both in cargo and ballast tanks, and in some instances also in bunker oil, lube oil and fresh water tanks.

All tankers over 65 metres in length are also by law equipped with a cargo computer which the officers can use to calculate the bending moments, share forces, drafts and ullages.

Not all of the valves are shown on the control console. There are hundreds of valves around a ship, and most of them have special functions not needed during ordinary cargo operations. These valves, from small drain-cocks on lines and pumps to large cross-over valves from the cargo to ballast systems are usually either permanently open or closed. These need not be controlled from a computer system.

The design ship had to be changed quite significantly in order to make the computer program work. Most information regarding the tanks, cargo lines, valves and pumps were not available. Furthermore, the ship was not built according to rules and regulations of today. Still another reason for the changes was that there was not sufficient time or resources for making a full computer model of a real ship. I talked to some people working at Kongsberg Maritime, which are making control systems for engine room, bridge and cargo controls, but also are one of the world leaders when it comes to bridge, engine and cargo simulators, how long time it took to make their cargo simulators for tankers, and they told me three men took over three years to make it. This in itself made me realize that there had to be made compromises to be able to do this thesis on 90 points.

The first change made was to make the ship modern, that is, convert the cargo oil wing tanks to ballast tanks. This because the original ship had only two small segregated water ballast tanks and was without a double hull which is obligatory today. It was therefore also necessary to create ballast lines, tank valves and a ballast pump for that purpose. Usually the ballast systems on ships are fairly straight forward and do not require a lot of valves to be able to work.

The cargo system, on the other hand, consist of a fair amount of valves, crossover lines etc., and even on a sophisticated loading simulator as the one from Kongsberg Maritime do not show all of valves for the different models. As I did not have the complete system drawings of the ship's cargo system there were no way to show all valves and lines, and also not enough time to build that into the simulator, I had to create a simplified system that would work in real life, but has never been implemented on a ship. In all fairness, many of the extra valves on board a tanker are either always closed or always open, and not used apart for in special circumstances, so they were not really necessary for the simulator to work.

The second change was that the number of cargo pumps and line systems were reduced from four to two. For 5 cargo tanks and two slop tanks, and the size of this ship, that would be a reasonable number of pumps. A larger ship would probably require more pumps, as the usual requirement for a tanker is to be discharged in 20 hours with full speed on the pumps, and disregarding the extra time for starting up and stripping. These operations are usually done with the pumps on reduced speed.

The simulator itself is programmed in Excel VBA. A number of other programming languages could be used, such as C, C++ , C# and Visual Basic, all of which I am familiar with. VBA was chosen because of the ability to manipulate and store large amounts of numbers. Other programming languages, like Simula I or Simula 67, could also be used, but although these languages influenced the development of C and C++, it would probably take too much time to learn such a language, and it was therefore better to stay with a relatively known programming language.

Simulation Program

As the hydrostatic and ullage tables can easily be used in a spreadsheet program, and Microsoft Office Excel is used by many shipping companies on board their ships, it was decided to use this program for the development. It fit the criteria for being (Pseudo) Object Oriented, and to transform data to create graphs used by the GUI (see figures 12 to 16 on pages 51 to 55). Much of the ship's data could be used directly from the spreadsheet cells, but it was finally chosen to use arrays to represent the tables, and use cells in Excel to hold the intermediate calculation results and to represent information on the GUI. All tables are duplicated in Excel sheets, and a sheet is also showing the calculation method used to calculate draft and trim.

The GUI shows the information needed to assert that valves are open or closed, pumps are running or stopped and graphs of filling ratios. Drafts, trim and displacement are also shown together with a drawing of the cargo/ballast tank area of the ship and line arrangement.

The program itself starts by the user pressing the button "Input Controls" to initiate the program, and also input the variables Cargo Density, Cargo Temperature and Cargo rate, see Figure 11 Input Windows. Please note that the part covering the cargo and ballast pump controls only illustrates how it might look if this was a working program installed on a tanker. Such a program would have possibilities for the cargo officers to intervene if any problem should occur which the program itself could not fix by itself. While the variables are stored into cells on Excel, the Input button also checks the valves by setting them in a closed position and the pumps stopped. The density ranges from 0.810 tonnes/m^3 to 0.830 tonnes/m^3, temperature from 10 deg. C to 27.75 deg. C. These ranges are chosen due to the limited tables used at Norwegian Maritime Schools are also used for the program, and the fact that if it is possible to calculate within a limited range of the tables it is also possible to use the whole tables for the calculations. The loading/discharging rate would at maximum speed on a ship like this about 10,000 m^3 per hour, but can in the simulation be set to much higher rate to speed up the program. The author usually uses a rate of 200,000 m^3 per hour, but the larger the rate is, the larger the differences in filling ratios and ullages become due to the larger amount of volume used in each round of calculation.

During the initialization the different tables, i.e. hydrostatic tables, ullage tables and so on are created into arrays. The figures in these tables are used to calculate the displacement, draft and trim of the ship. Initial stores, bunkers etc. are put into cells in the “Test Cargo Calculation Form” table to calculate trimming moments and to find the displacement, reference draft and drafts forward and aft. Longitudinal centre of Gravity for each tank and weight are also set into these tables. The IMO-recommended BG-method is used to calculate the trim. This table is also used during the loading/discharging sequences for updating the draft, trim and displacement.

One thing to notice is that the hydrostatic and ullage tables are not divided into centimetres so there has to be an interpolation done by the programme to find intermediate values. This also comes to the VCF (Volume Correction Factor) when calculating the correct density of the oil. Ullage and hydrostatic data also have to be interpolated to get the correct values.

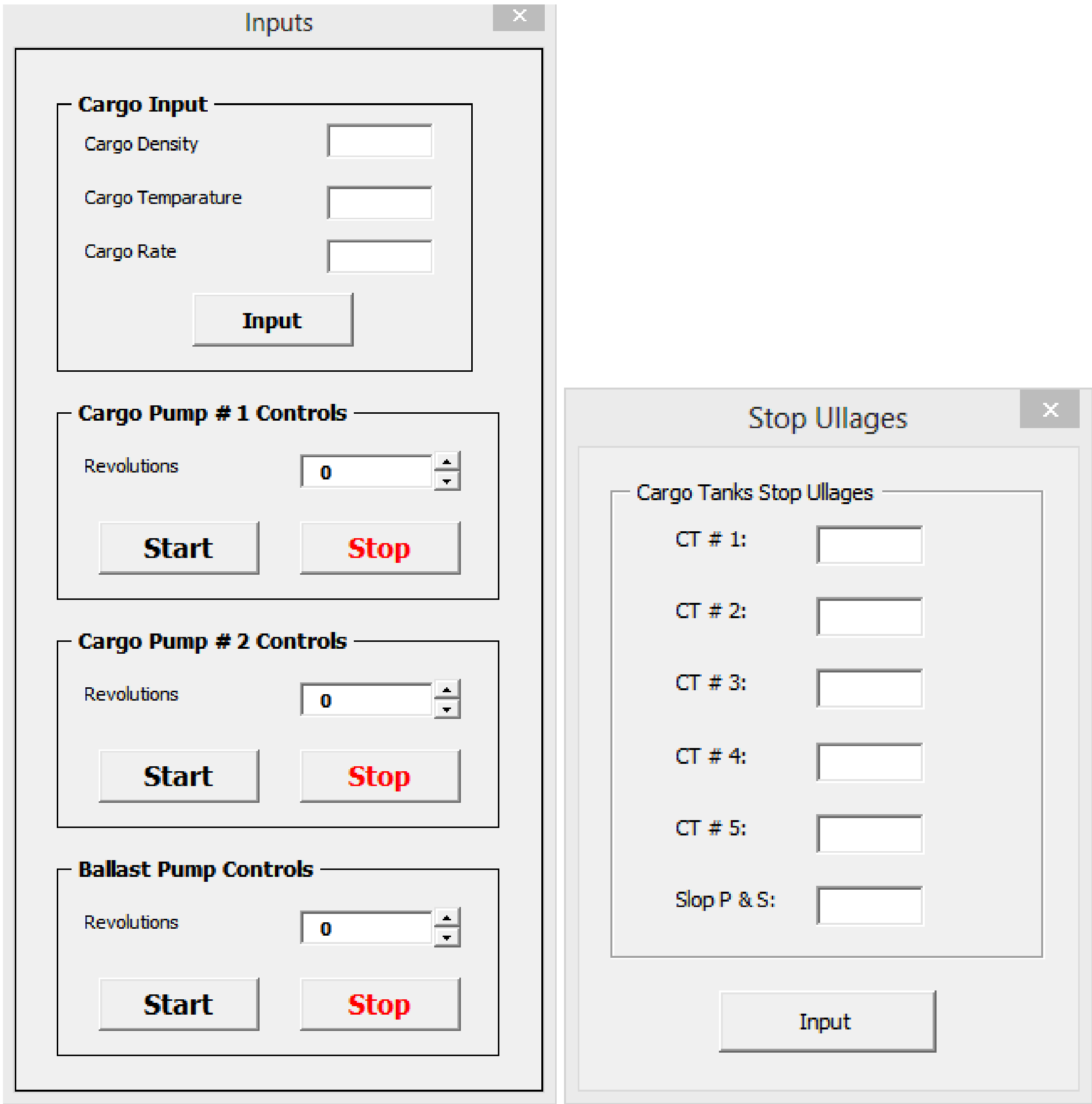


Figure 11 Input Windows (Screenshot)

The next procedure would be to start the loading or discharging process. This is done by clicking on the Loading or Discharging button on the GUI. The valves are from the beginning set in Closed position by the initialization of the program, as they would be on a real tanker before their lining up (setting of the position, closed/open). To concentrate on the loading first (see Figure 9 GUI after Initialization, ready for loading), the ullage have to be set for each tank and the ship's draft, trim and displacement is calculated. This is done by the subroutines ShowHydrostatics which calculate the reference draft and displacement, and TestTrimAftForward calculating the trim. In the simulation program this is done by the subroutine InitiateLoading, which open the valves in the tanks, and also the drop-valves on the lines from deck lines to bottom lines. The oil will then be simulated to flow freely into the tanks.

The process then continues in the subroutine LoadingProcess that takes the values from the test Cargo Calculation Form and set them as variables for the calculations. After this is done, the process calls the subroutine CalculateNewVolumeLoading (ratePer5seconds) that uses the rate per hour and transforms that into a rate per 5 seconds. The 5 second rate is used as the program goes through the process of calculation of new ullage, draft, trim and displacement every 5 seconds, and thereby controls the time it takes for the loading to be completed. It also has to calculate the same rate for the ballast, as this is to be completed a short time before the loading.

CalculateNewVolumeLoading(ratePer5seconds) is the working subroutine of the program. It goes through it's cycles every 5 seconds, calling the subroutines for the hydrostatic calculations and ullages. For each cycle it checks that the ullages in each tank is within the limit set up by the operator of the program during the initiation, and if any tank has its set ullage limit exceeded it closes the valve to the tank, and continues with the other tanks until they are full. then the loading stops, all valves are closed, and the program ends. See Figure 10 GUI during loadingfor a screenshot taken during the loading process. Note that the ballast pump is running, and that both the graphs for the ballast tanks and cargo tanks are decreasing/increasing. Also note that the valves are showing in their correct position (Open/Closed) and that the the percentage of the tanks ullages shows on the graphs.

When each tank reaches it's pre-set ullage the program calls the CloseValve subroutine for that valve. This subroutine changes the white closed valve icon to an open black one, and indicates it is open. The tables for the respective cargo or ballast valve changes to closed, and the ullage and filling ratio for the closed tank is no longer updated. As the last two tanks have less then 2 m of ullage to go to the final stop ullage the loading rate is reduced by a factor of 6 to simulate the final topping off of the tanks, which is always done at a reduced speed.

To discharge the ship the initiation is done in the same way. The displacement, draft and trim is calculated on the basis that the ship is fully loaded. Other loading conditions can be simulated by putting in other cargo volumes in the tanks on the Test Cargo Calculation Form. The discharging differs from loading in the way that this times the cargo pumps on board the ship have to be started, the drop-valves have to be closed while the discharge valves on the deck line and sucktion and discharge valves before and after the pumps have to be opened. When the discharge operation starts the pumps automatically starts. During the operation the valves close when the tank is empty, or close to empty, as it will on a real tanker. When the two last tanks to be emptied have less then 2 meters of oil left, the stripping pumps start, and strip the rest of the tanks empty. This is in reality usually a piston pump, and work regardless of sucking air instead of oil, in contrast to the centrifugal cargo and ballast pumps that will stop if they do that. The rate is reduced by a factor of 4 to simulate this as the stripping pump has a lower capacity then the cargo pumps. Note that the factor of 4 is used here instead of 6 when it comes to loading, as it is always more critical to top off a tank than stripping it due to the danger of overloading and thereby the possibility of pollution.

The program used several subroutines to perform whole loading/discharging operations. The subroutine Initializing called other subroutines to set up arrays for the hydrostatic and data and ullages. It also called up the subroutines for creating each of the valves and pumps. The draft, trim and displament was then calculated for the last loading condition as the figures conserning the deadweight would still be saved in their respective cells in the spreadsheet. The calculation was done using IMO recommended formulae and set-up. Table 2 Shows the set-up for calculation of the BG-arm in the Excel sheet Test Cargo Calculation Form. Numbers are taken from a random calculation (see next page).

LCG Moment Calculation:
Calculation

Item	Weight	Lcg	Longitudinal moment
Light Ship	32900	145.5	4786950
Stores forward	2000	300.2	600400
Stores aft	300	22.5	6750
Fuel oil tank (S)	1500	32.87	49305
Fuel oil tank (P)	1500	32.87	49305
F/O Settling tank (S)	80	46.07	3685.6
F/O Settling tank (P)	80	46.07	3685.6
F/W tank (S)	120	12.23	1467.6
F/W tank (P)	60	14.02	841.2
F/W tank (S)	230	16.14	3712.2
F/W tank (P)	230	16.14	3712.2
After-peak tank	120	5.73	687.6
Stern tube tank	75	8.57	642.75
Lub. oil tank	56	20.3	1136.8
C/T # 1	27740.447	260.65	7230547.523
C/T # 2	24935.814	207	5161713.431
C/T # 3	12506.647	168.75	2110496.698
C/T # 4	24935.814	130.52	3254622.401
C/T # 5	26394.223	78.01	2059013.339
Slop tank P	2518.117	57.05	143658.5672
Slop Tank S	2518.117	57.05	143658.5672
W/T # 1 (P&S)	-197.83	258.71	-51179.30575
W/T # 2 (P&S)	-64.58	207.00	-13367.025
W/T # 3 (P&S)	32652.81	130.52	4261844.761
W/T # 4 (P&S)	31924.65	130.52	4166805.318
W/T # 5 (P&S)	23224.25	85.42	1983815.008
Total	248339.48		35963910.83

LCG = Moment / Weight: 144.82

BG=> LCB - LCG = 20.668869

Table 2 Excel spreadsheet calculation of the BG-arm (Author, 2013)

Draft forward TF = m

Draft aft + TA = m □ Trim = TF - TA = m (by stern or by bow)

Mean draft TM = m /2 = m

Draft amidships (starboard) T□ (S/B) = m

Draft amidships (port) + T□ (Port) = m

Average draft amidships T□ = m / 2 = m

TF = TA indicates no trim/even keel

TM = T□ indicates no sag or hog

TF = TA = T□ = TM indicates no trim/no sag or hog/even keel

T□ > TM indicates sag

T□ < TM indicates hog

TM = m

\+ Total sag / − total hog = m

T□ = m

□ Correction due to sag or hog: = m

Correction due to trim : = m

TR (Reference draft) = m

The displacement corresponding to TR :

TR = m □ □ Tonnes (From loading table

Correction Form No. 2

Planning of a loading requires that the displacement and the trim are calculated first. Then the mean draft (TM) must be found in order to distribute the trim about this draft.

If the displacement is known, the corresponding reference draft (TR) can be extracted from the loading table:

☐ Tonnes ☐ TR m (from loading table)

If the ship has a trim, or a sag or hog is expected, the following corrections will have to be made in order to find the mean draft (TM):

TR (Reference draft)	=	m
☐ Correction due to trim :	=	m
☐ Correction due to sag or hog :	=	m
T☐	=	m
− Total sag / + Total hog	=	m
TM (Mean draft)	=	m

The trim is distributed about the mean draft (TM) to find TF and TA :

TF = TM ☐ (+ if trim occurs by the bow, and − if trim by the stern)

TA = TM ☐ (+ if trim occurs by the stern, and − if trim by the bow)

Table 3 Calculation of Draft, Displacement and Trim (Author, 2013)

These forms are used to update the ship's condition every 5 seconds, according to the rate used for calculation. Subroutines for finding the correct ullage are now used, the cargo weight calculated on the basis of volumes in the tanks, and again the new ship condition put into the respective cells of the GUI. This is done automatically until the ullages are either at the set distances, for loading, or the ship is empty, for discharging. One important setting when it comes to the discharging of the tanks is that they will never be completely empty during the operation. There will always be some sets of oil (or ballast) in the tanks, and this is also simulated.

When the cargo operation is completed, the program closes all tank valves that remained open, and also shut down the program. If the ship was loading, the cargo will remain in the tanks if the program is saved, and it will be the starting point for a discharge operation. If it isn't saved, the initiation of the program will see to that the tanks are loaded to 98% of full capacity. The program itself then ends, and it is up to the user to decide want he will do next, either start from scratch or go from the earlier condition.

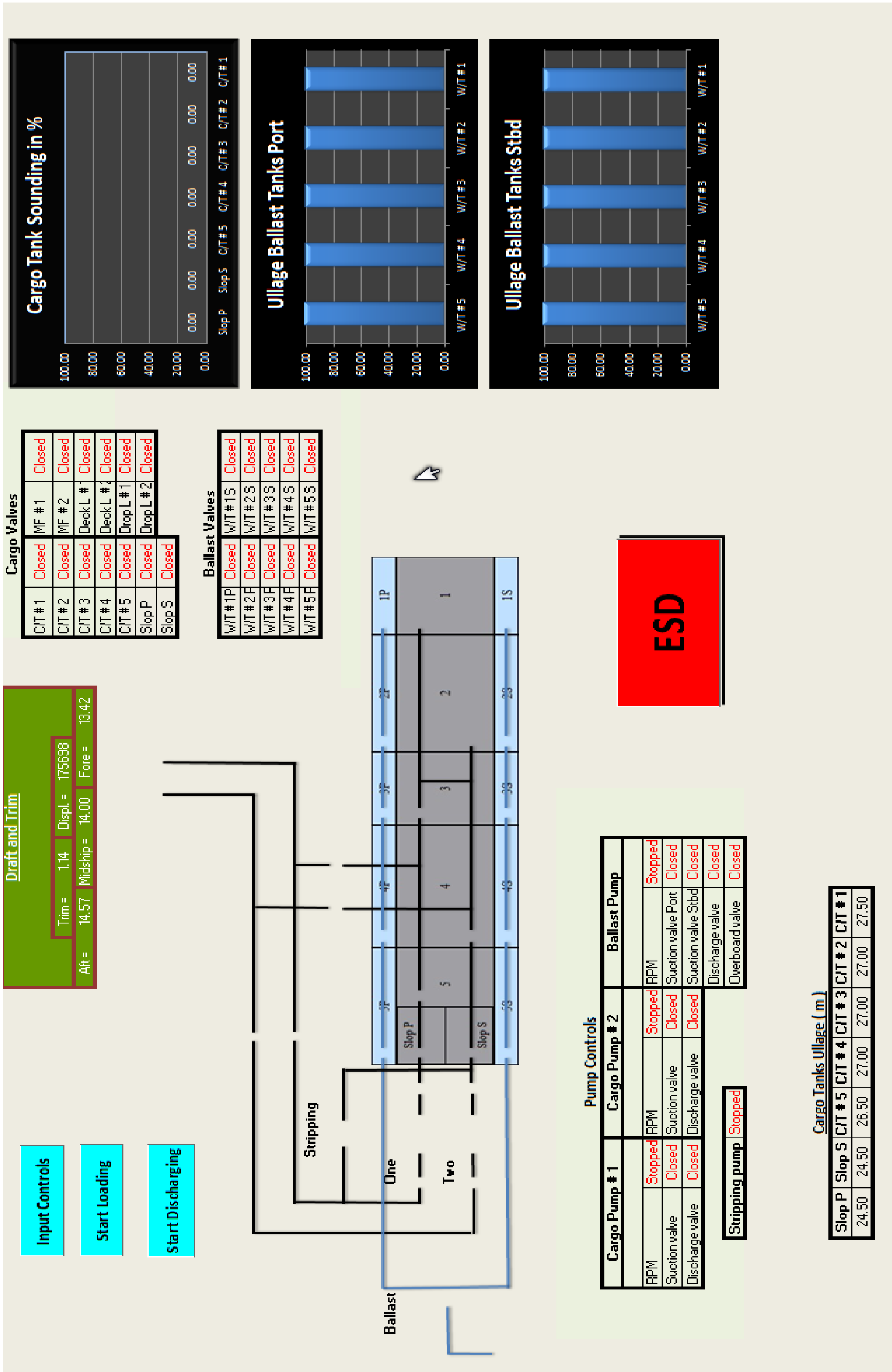


Figure 8 GUI before initialization (Screenshot)

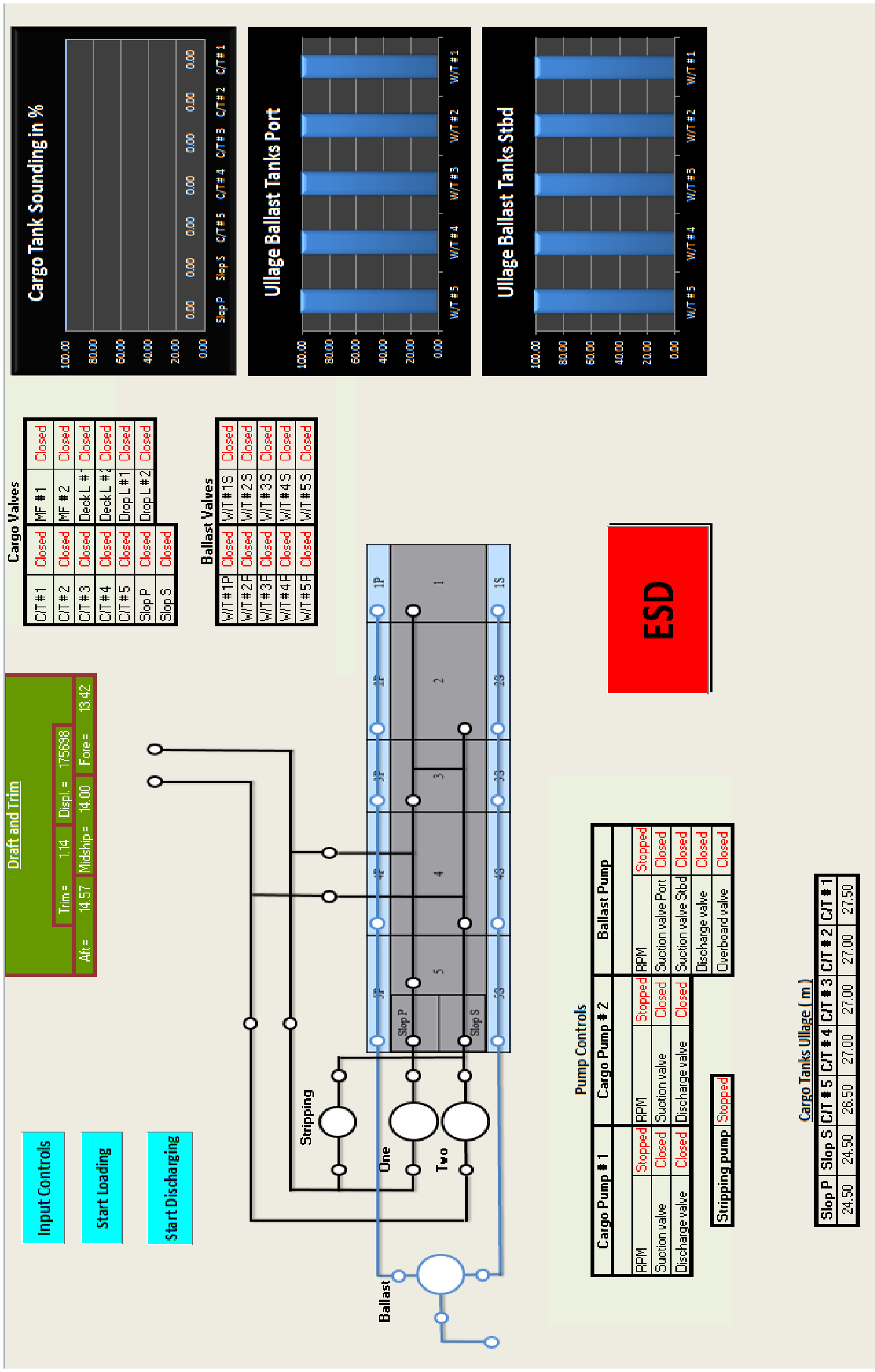


Figure 9 GUI after Initialization, ready for loading (Screenshot)

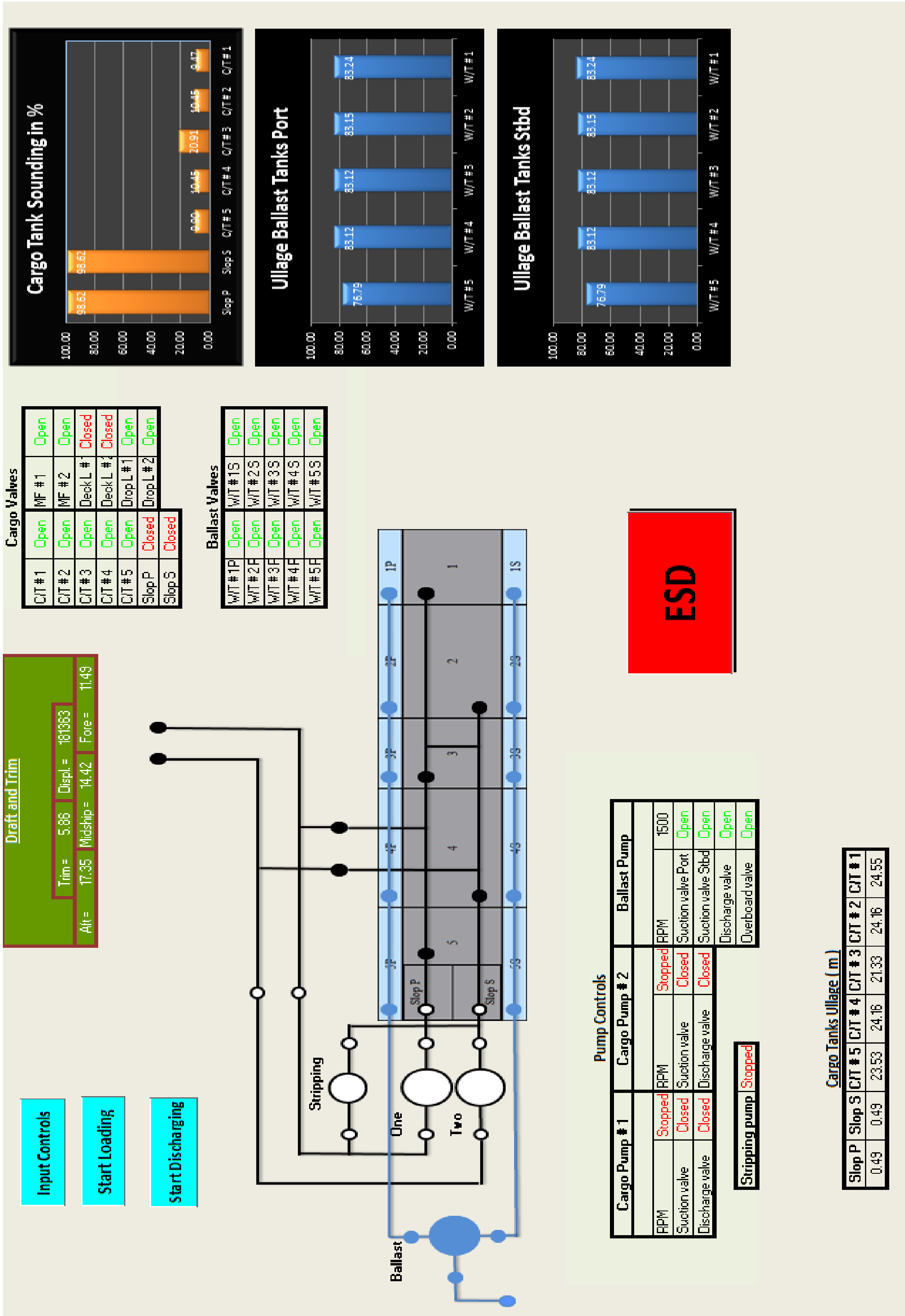


Figure 10 GUI during loading (Screenshot)

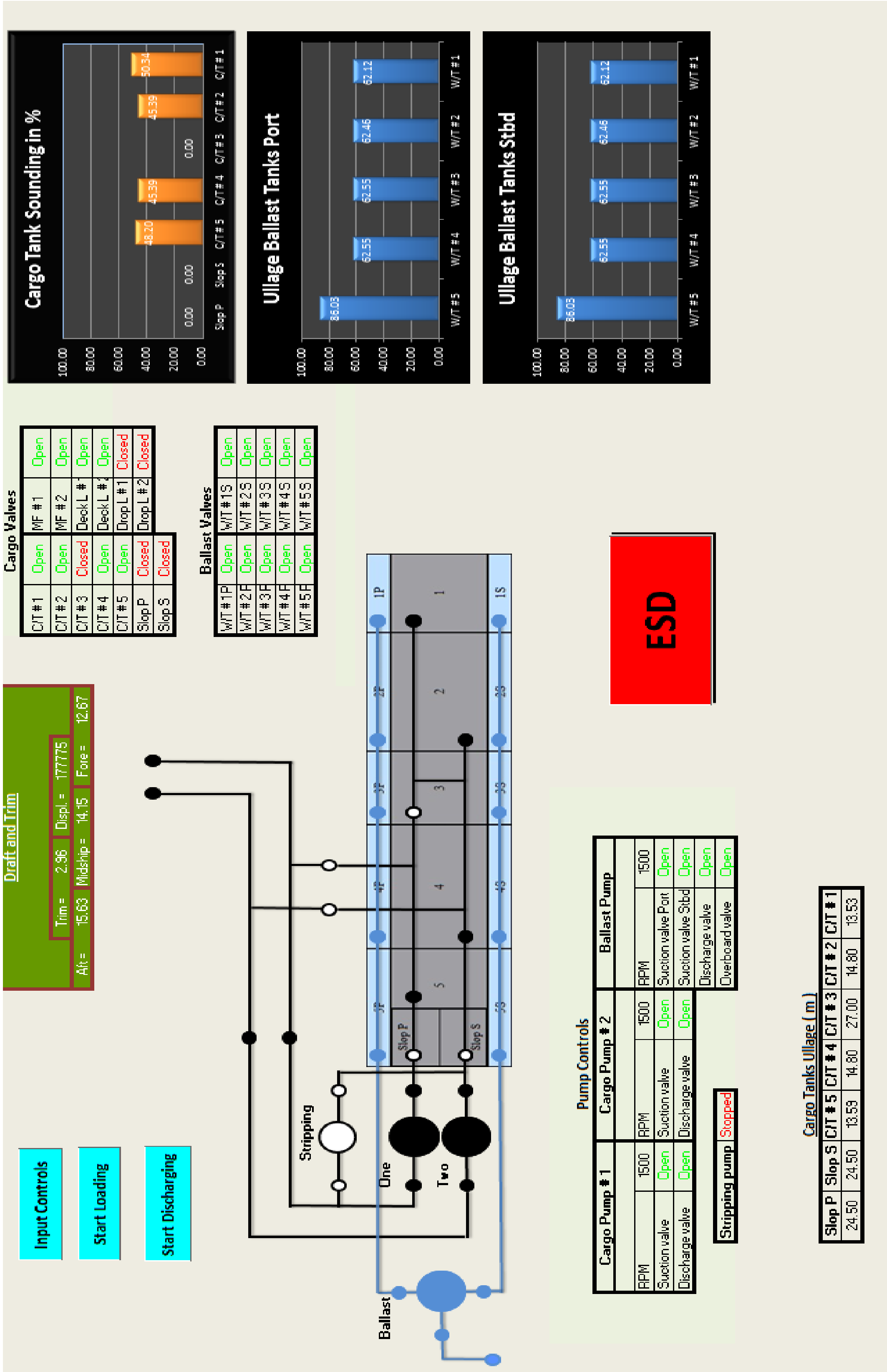


Figure 11 GUI during discharging (Screenshot)

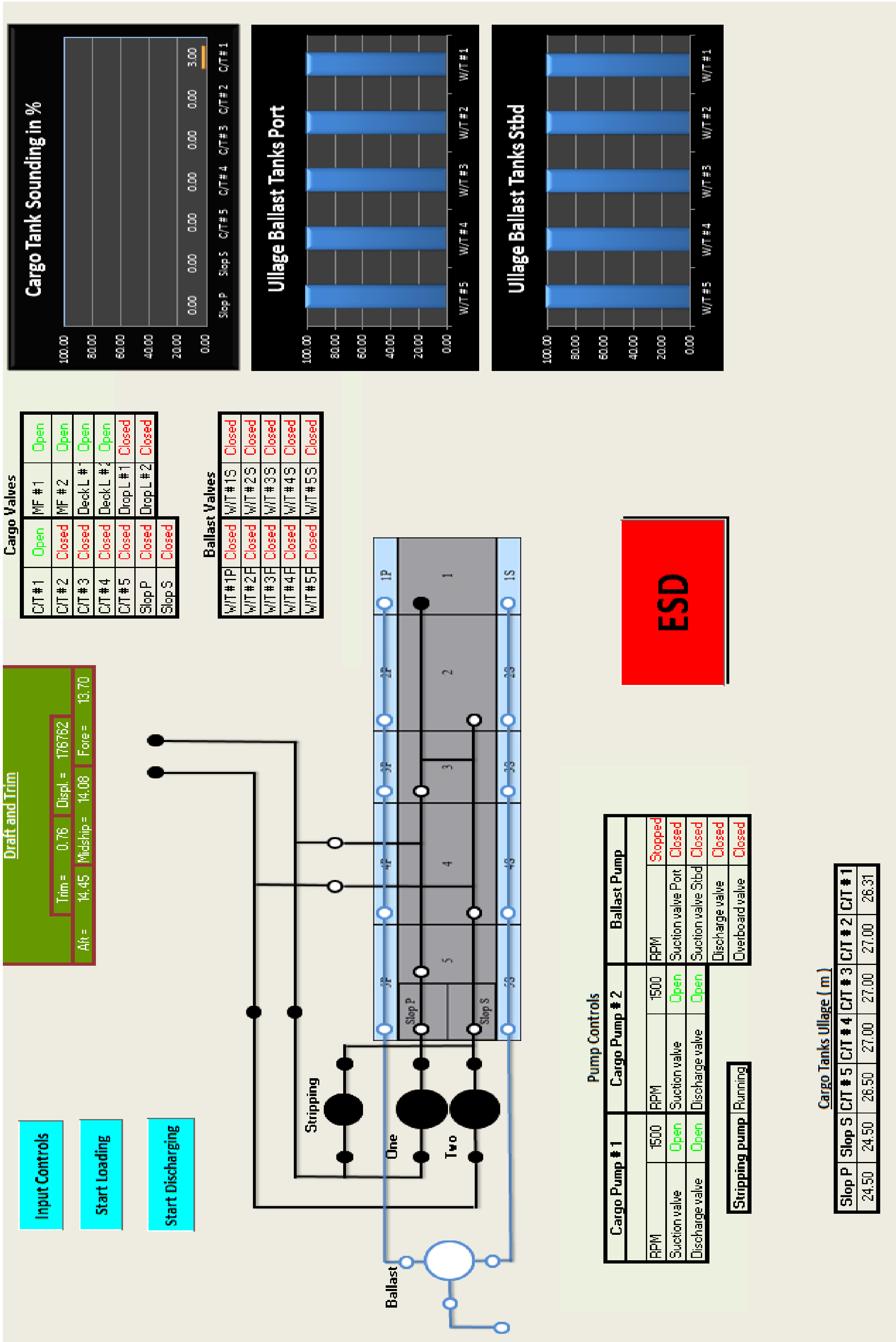


Figure 12 GUI during stripping (Screenshot)

System demands

A computer program is based on a specific set of required outcomes. These outcomes are set by the users, and discussed with the producer of the software. In this case both the producer of the software and the user was the same person. The only way for this project to proceed was that the user, in this case the author, set the parameters to be used and the outcome. This was due to the difficulties to get informed information and feedback from with hands-on experience on relevant tankers. Therefore, the authors experience formed the basis for defining the outcome and parameters.

The requirements for the program were that it should first accurately calculate the specific cargo information for use in further calculations. When this was done, the ship’s displacement had to be calculated together with trim and draft. When this was done the valves had to be opened to the required positions depending on whether it was loading or discharging cargo.

If in loading mode the pumps would not be used, and the cargo will flow freely into the tanks providing the valves were opened all the way into the tanks. The cargo would go into the tanks with a rate specified by the user of the program when the valves had been opened. This flow should be calculated every five seconds, and according to that the ullage should be calculated. A slower rate than specified by the user would be used in the start-up phase as done in real life, to check if everything works as it supposed to. After that the normal rate would be used until the tanks start to fill up. When there is about one metre left before stop ullage is reached the rate will again slow down. When the program starts the ballast valves will also be opened, and the ballast will be emptied using the ballast pumps to pump it out. The rate of de-ballasting would be calculated according to the rate of loading as this has to be synchronized.

When it comes to discharging the same steps have to be performed, apart from this time the ship’s pumps has to be used for cargo transfer. There would be some different valves to be opened, but the calculation methods will be the same. The slower rate will also this time be used for starting up and completing the operation. Also there will be used a sub program for the stripping pump to complete the discharge operation, as this would be used in real life to empty tanks and also the ship lines.

The main problem to solve was that the program should simulate an actual cargo operation without any input from the user after the initial values of the cargo property, rate and, in the case of loading, also the ullages for the individual tanks were set. A working GUI were also needed and the design of that was based on the Cargo Control Console where information about draft, trim, ullages, pumps and valves positions were shown. Three graphs showing the cargo and ballast tanks filling in percent were also wanted. For a real loading and discharging program it would be advisable to use two or 3 screens for this, but as a simulator for the same one screen was deemed sufficient.

Chapter 5. Discussion:

Comparison to other compatible processes

Refineries for example have systems that are monitored by computers, and to a certain degree controlled in such a way that valves and other production machinery, pumps etc., can be manipulated directly from the computers. Also parameter values from the production line can be read from computers. But they are not fully automated, and have to be set and adjusted by the operators. Valves for the loading/discharging operation of the tankers are usually operated by hydraulics or by hand. It could be possible to have a similar system for a refinery as for a tanker and this thought is followed in the discussion for the chapter, as the systems for filling and emptying of the tanks are similar.

Simulator versus reality

A simulator will always be just that, a simulator. In this case it is built on mathematical inputs and not real sensor, as would be the case on a real ship. In this case a simulator program mimicking a real loading or discharging situation would be too complicated to make in the relatively short time available for a master's thesis and with the reduced information available for this particular ship. There has therefore been made a few short-cuts to save time. The program itself is made as a way to show what is possible, with relatively simple programming tools, to make a program that could be expanded upon to make it work on a real ship. The basic functions, like starting and stopping the pumps, opening and closing valves and calculating the cargo and draft is there, so it would be relatively simple to build on that and convert the calculations to reading the inputs from sensors around the ship, like ullage and draft information. These are already installed on every tanker according to rules and regulations from IMO and flag-states and there would not be any additional cost regarding the sensors. They even have a read-out in the cargo control room, and it should be relatively easy to connect these outputs to a computer for using as inputs in a program.

The largest difference between the simulator and a real world system is that on a ship there will be more and different situations to control and that when the ship is getting older, systems like pumps and valves might malfunction. A real cargo control system has to be able to act when things go wrong, either by opening other available valves, starting or stopping the right pumps for the situation, redirecting the cargo via another system and so on. On a simulator these malfunctions have to be programmed, and there would be the same response to the same problems, depending on the programmer's choice. The real program on a ship would have to be able to consider several critical situations at the same time, but, also be able to shut itself down if no solution is found. Fuzzy logic would probably be a good solution to solving difficult situations, but also an expert system with rules concerning how to deal with problems occurring during loading and discharging should be available.

S/T Golar Patricia

The ship, built in 1969, was a conventional tanker for that era, with 15 cargo tanks, two cargo slop tanks and no permanent ballast tanks (made into regulation from 1996? It was 327 metres long, 48.2 metres wide and had a maximum summer draft of 19.52 metres. It had an aft pump-room with 4 centrifugal cargo pumps and one cargo stripping pump. As it was usual for a ship of that size, with 4 cargo pumps, it also had 4 line systems which could, via crossover lines and valves, be connected to each other. The reason for this was that the ship, if necessary could carry 4 segregated grades of cargo.

Figure 13 Golar Patricia under way (Lettens Jan, Retrieved 2013)

Figure 17 shows the Golar Patricia laden and under way. A typical tanker from the 1970s with the cargo lines abaft the manifold area amidships and the superstructure aft. The pump room is situated under the main deck, in front of the superstructure. Note the lines going from the manifold aft to the pump room. All cargo flow through these lines, either down the drop-lines or up through the lines from the pump room. The distribution of the cargo to the respective tanks goes though the bottom lines.

Figure 14 Golar Patricia during docking operation ready for discharging (Anon, retrieved 2013)

In figure 18 the Golar Patricia is approaching the terminal assisted by tugboats. This is the usual way ships of this size are docking due to the fact that most of them do not have a bow thruster to assist them in mooring and unmooring. The tugboats pull the ship close to the dock, and then push it alongside. When the ship leaves the tugboats pull her away from the dock and as far as needed to let the ship get her own manoeuvring space. The docking can take 2-3 or even more hours, depending on the port's layout and also the pilot's and the tugboats captains' skills.

As a curiosity it might be mentioned that Golar Patricia actually sank (Wikipedia, 2009) outside the Canary Islands in 1973 after an explosion in the cargo tanks during tank cleaning operation, with the loss of one life. Figure 19 shows the ship final moments.

Figure 1519 Golar Patricia sinking (Anon, retrieved 2013)

At the time these tankers were built most, if not all of the valves, both on deck, at the bottom lines and in the pump room were manual, and the crew had to open and close them manually. That was demanding work since many of the valves were connected to lines with a diameter up to 3 metres, and on top of that they could get stuck and thereby not possible to move at all. This was of course a safety risk as the crew were also doing other tasks during the cargo operation, and sometimes there were considerable oil spills around the different oil terminals. There were many valves on board, and the cargo operation therefore took time and a larger crew than today was needed. Many of these tankers did not have a control room at all, but pumps were run from the pump room. These pumps were, and still are, mostly steam driven centrifugal pumps, with rotation rates regulated by the steam volume delivered to the turbines that propels the pumps.

Today's tankers are built differently in that it now is compulsory with a double hull. The reason for this is that the outside hull is supposed to act as a barrier between the cargo oil and the sea in case of a collision or grounding. The extra space this leave is normally used as ballast tanks (Figure 16 Tanker cross-section).

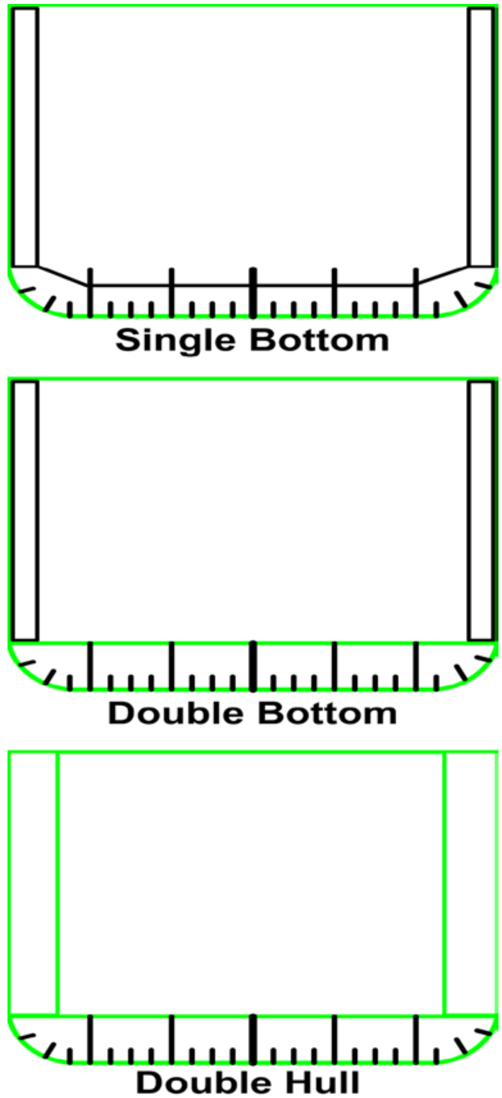


Figure 16 Tanker cross-section (Herbert George W. , 2006)

The cargo tank area is on modern tankers now surrounded by ballast tanks, both on the sides and under the bottom. This was because of the danger of collisions and groundings which could end in an oil-spill. When this was put into law in 1996 there were some strong opinions against the move. The opponents meant that there would be rust damage in the bulkheads between the water ballast tanks and cargo tanks which would result in oil leaking into the ballast water and then again out to the sea while the ship de-ballasted. As far as I know that has not happened yet, but as some tankers with double hull are now getting old, there might be incidents with this result.

Cargo operation of a tanker is usually conducted from a Cargo Control Room. This room is equipped with a control console where a mimic of the line system, pumps and valves etc. are imprinted. There are also installed remote readings of ullages and drafts, and switches which controls the pumps and valves. Some, on modern tankers most, of these valves are controlled from the console, but a few are still manually opened or closed and only depicted on the console by some kind of indicator.

A normal cargo operation consist of calculating the amount to load or discharge, inert the tanks with inert gas, prepare the tanks (loading), setting the valves to the right position and the actual transfer of the cargo. This simulation only takes care of the valve settings and transfer of the cargo.

The person in charge of the cargo operation is the chief officer, and he/she is assisted by the second and third officer together with a pump-man. The rest of the deck crew takes care of the mooring lines and check for any irregularities that could come up, particularly oil leakage. They also operate the manual valves when necessary. The deck crew, and the second and third officers, go 6 hours watches with 6 hours off, while the chief officer and the pump-man are working from start to finish of the cargo operation. This operation usually takes around 24 to 30 hours, but can in extreme cases go up to at least 50 hours, depending on if there are problems while loading or discharging. Mostly these problems are valves that get stuck, slow stripping and pumping problems.

Model

To make a complete and correct model of Golar Patricia is far beyond the scope of this thesis. The purpose with the model presented below is to show that with relatively simple programming it is possible to make a program that could work on a tanker.

Golar Patricia had all the hydrostatic and tank information needed to calculate the cargo. However, as she was a 1970's conventional tanker, she did not have a double hull, or segregated ballast tanks as today's ships, the wing tanks to ballast tanks, and t the centre tanks kept as cargo tanks. Also, because of the reduced number of cargo tanks the segregations and thereby the cargo pumps were reduced to two, with one ballast pump for the ballast. Every second cargo tank was thereby used for each segregation, a system to keep different types of cargo from co-mingling, as is often the norm on tankers with only centre cargo tanks.

The tank valves represent a minimum of what is needed to have a tanker function. There are a plethora of valves all over the ship to facilitate different operations, but most of them are either permanently opened or closed, and therefore not necessary to model. On a real tanker with a working cargo operation program these have to be taken into consideration, however, as the simulation works for a simple tanker model, it would also work on a real ship with more pumps and valves. It would be a more complicated program, but the same principles would apply.

Due to the fact that the wing tanks have been used as ballast tanks the cargo capacity of the ship has been reduced. This does not have any impact on the program itself, and the calculation of draft and trim will be the same.

Shear forces and bending moments on the ship are not calculated here, as, like on a real ship this would be done by the ship's loading computer. The sequence of the loading/discharging operation, that is, which tanks to open and close at pre-arranged intervals, would be set beforehand as would stop ullages for each tank.

Human and environmental aspects of an automatic cargo handling system

The focus on the safety aspect of a work process has in later years become more and more important. Much time is spent on developing safe methods to perform work tasks, but as the author sees it much of that time is used to produce safe routines and checklists to see that routines are followed. An automated loading/discharge process would circumvent this by the fact that the computer program takes care the safety. The development of such a program has to be done under strict rules and regulations when it comes to quality control, but will by that have the safety systems incorporated. Quite some time will thereby be saved for other tasks, and probably and hopefully the officers will be less tired when they take care of the cargo handling.

One aspect of it would be though if the monitoring of a computer screen will be more tiring then the monitoring of a cargo control console. The author believes that even if it would be a computer program would react faster than a tired officer would be able to notice something wrong on the console. The program would also be able to make direct correction to some of the faults that might occur, and thereby save the officer of thinking about different solutions to the problem. As many of the shipping accidents occurs due to human errors, and quite many of them again is a result of fatigue, where reaction time and problem solving skills are reduced, a computer system would be a good way to try to prevent accidents happening.

Are there only positive results from a computer system running a cargo operation? The author thinks it is not. One of the main objections to this would be that it is extremely difficult to produce an error free program. Another important thing is that it would also be extremely difficult to cover every possible problems and solutions to these in a computer program. Such a program is not thought to be a replacement for the officers conducting the cargo operations, but solely a help for them to conduct these operations in a safer way. For some situations a human being would be better to judge the problem than a computer.

Would it be easy to implement such a system on board tankers? The first problem, and probably the most difficult one, would be to convince the shipping industry that it is cost and safety efficient. Then there could many cases be the inherent conservative thinking within the maritime industry in. There could also be people outside the maritime community objecting to such system being implemented on ships. Environmentalists might possible be negative to having a computer running a cargo operation, and the legal society would look into who would be responsible if something went wrong, the ship’s owner/crew or the manufacturer of the program. The ship’s classification society might also possibly be accused for an accident, as it is the organisation responsible for control and acceptance of the program being used.

Chapter 6. Evaluation

The simulator program was evaluated against the requirements set out in the subchapter System Demands. The main evaluation point was that it could run smoothly and continuously without interruption from the loading/discharging started until the tanks were topped up or stripped. No problems were simulated, i.e. pumps stopped or valves stuck in a certain position. With a real life program actual problem that could have dire consequences for crew, ship and the environment would have been taken into account. That could most probably be an expert system, fuzzy logic or even the simple solution that the loading or discharging stopped if something went wrong.

The program was evaluated and tested by 3 of the author's colleagues who all had been on tankers as ship officers. Together they have more than 50 years of seagoing experience, most of that time on tankers. They were given the program for evaluation two month before a facilitated interview was held and the simulation discussed. During the facilitated interview a usability test was conducted. Phil Carters paper on usability testing, "Liberating Usability Testing" ((Carter, 2007, March-April) gave some insightful references to how it should be carried out. The evaluators were "thinking aloud" and expressed their viewpoints with no signs of having problems using the program. It was found to be easy to use, and that the expected outcomes were met.

When it came to reliability the evaluators had put in different variables when it came to rate, density, temperatures and in the case of loading, also ullages. Even with these parameters varying quite significantly from test to test the result had always been the same, and the program showed the expected result each time it was tested.

One important point taken up during the interview was the importance of such a program. Taken into consideration the conservative mind of a seafarer it was positive to hear that they all meant that this was an important and inevitable way forward both when it comes to safety and economy. They saw the problems of convincing the maritime industry and also the maritime authorities that this was the future way to go, but thought that over time when younger people, used to computers in everyday life, took over the top jobs in the maritime industry the attitude would probably change. Also if it could be shown that a computerized loading/discharging system proved economical and reliable it would be implemented on most tankers.

One of the evaluators who had been a captain on gas tankers added that he had heard that Shell Shipping, which has one of the largest tanker fleet in the world, was now working on the same concept of computerized loading and discharging when it comes to their gas tankers. As those ships are different in layout and how they load and discharge, this is not taken into account here.

When asked about when they saw such a systems made compulsory the time diffed from 5 to 10 years. One evaluator said it first had to be proven to show it was safe, reliable and cost efficient first.

One problem with a computer program that simulates a process over time is that it has to be a function that can shorten the time it takes to run. This simulation used the rate function to shorten the runtime. An expected unwanted result of this way to solve the problem was that as the program used five seconds between the calculations the limits on the ullages and filling ration of the tanks were largely exceeded. If the program were run as it would on a real tanker it would take about 20 hours to run, and the problem would be ignorable. There could be some extra programming solving the problem, but to take this, and many other real life problems into account when making a computer simulator like this would have taken too long for a 90 point thesis, and was therefore outside the scope this time.

When it comes to the GUI it would be better if two screens were used, but this was decided against as the author only had one screen at his disposal. If a laptop computer is used to run the program the screen will be rather cluttered with information, but with a 24 inch screen the visuals work well. However, using one screen can have its advantages as all the information is easily accessed without having to watch several screens at the time.

Using a spreadsheet program for making a simulation might have been a good idea, but a more robust and versatile programming language would probably be needed to be able to cope with the large amount of information needed to be processed in real time. Also there would be programs better suited for creating an expert system rules database, but this would be up to the programing companies to decide together with the classification societies.

Chapter 7 Conclusion

In the last 40 years there have been enormous changes in the way people live. Many, if not most, of the changes have been results of the electronic “revolution”. Computers have been introduced in everything from cars and household appliances, television sets to airplanes. The shipping industry has also been greatly affected. New radar sets, computer controlled, electronic charts, DP (Dynamic Positioning) of ships, global positioning systems (GPS), engine controls and radio communication to mention a few. One of the things that seems to have been kept outside this revolution is the cargo handling of tankers. Computers for calculating stress on the hull and stability calculation were introduced many years ago, but further development then seems to have stopped. What the reason or reasons are is difficult to say, but probably a mixture of the fact that it would be an additional expense, conservatisms in the maritime industry. There might also be a fear many older people in the industry, the people that have the deciding power when it comes to order and install such systems, have when it comes to computers.

Whatever the reasons are, the author believe that automation is the way to go, in the case of loading/discharging of tankers and indeed in every other aspect of shipping, as well as in most other industries. There would be many problems to solve before the first system of the kind covered here will be fully operational on board a ship, but further research should to start as soon as possible. The first out should be the producers of cargo control and computer systems for stability and stress calculations together with the ship owners. The author believe the advantages of such a system are large enough to outweigh the disadvantages, and as soon as that agreed on by the ship owners the interest will come for making and implementing it. Another part that has to be involved is the IMO, who will set out conditions and regulations for the programs and their implementation. It is the authors hope and believe that within a few years’ time all tankers will be equipped with automatic loading and discharging systems.

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Figure Index:

Appendices:

Appendix 1

Fatigue factor in ship accidents

Fatigue among sailors on merchant ships caused a "worrying number" of collisions or near misses in 2004, the chief maritime investigator says.

Poor judgement by staff contributed to many accidents, MAIB said

Poor judgement or anticipation by officers on watch - "classic symptoms on fatigue" - also contributed, said Stephen Meyer in his annual report.

Maritime union Numast agreed with Mr Meyer, adding it was "a miracle that there had not been a major accident".

It described the continuing level of fatigue as "scandalous".

'Depressing'

Mr Meyer said that while the details of the accidents varied, "the fundamentals remain depressingly consistent".

In 2004, the Maritime Accident Investigation Branch (MAIB) conducted a safety study covering 1,600 accidents over the last 10 years, 66 of which were examined in detail.

The main concern was the lack of staff on certain cargo vessels plying the short sea trade, leading many to falsify their timesheets.

“ Sooner or later, there'll be a really big accident involving a ship carrying passengers or nuclear waste or some other dangerous cargo ”

Andrew Linington
Numast spokesman

"With only two watchkeepers, even if they did nothing but their bridge watches, they would work an 84-hour week," Mr Meyer said.

"But with routine paperwork, cargo work, maintenance, entering and leaving harbours, inspections, loading/unloading, passage planning etc., their actual working hours are much longer.

"It is an anachronism in the 21st Century, that seafarers are falsifying their timesheets to prove that they are working *only* a 98-hour week."

No enforcement

Numast spokesman Andrew Linington said research underway showed half of shipmasters did not get the required amount of rest.

Half felt this lack of rest was a potential threat to their own safety, and one-third felt it was a risk to the ship's safety.

"Although we have had working time limits for the past four years, the situation has actually got worse, but essentially there is no decent enforcement of the rules," Mr Linington said.

He highlighted the case of an officer who fell asleep on watch, and was awoken when the ship ran aground 30 minutes later.

The officer had had five hours sleep in the preceding 24 hours, but if he had complained to union or management, he would have been sacked under the terms of his contract, the union said.

Fishing vessels lost

"Sooner or later, there'll be a really big accident involving a ship carrying passengers or nuclear waste or some other dangerous cargo," he said.

"The potential for catastrophe is huge."

Of 1,500 cases referred to the Maritime Accident Investigation Branch, there were 31 full investigations, 34 preliminary examinations and 697 administrative enquiries.

Mr Meyer was also concerned about the loss of 24 fishing vessels during 2004.

The percentage of the UK fishing fleet lost each year had remained broadly steady for the past 10 years - a "disappointing" statistic for Mr Meyer.

Appendix 2

ULLAGE TABLE − CENTER TANKS

Ullage (cm)	Volume (m^3)				
	C/T # 1	C/T # 2	C/T # 3	C/T # 4	C/T # 5
0	34717.0	31449.5	15724.8	31449.5	33221.7
5	34676.1	31418.7	15709.3	31418.7	33190.4
10	34629.7	31377.6	15688.8	31377.6	33145.8
15	34577.1	31325.2	15662.6	31325.2	33086.5
20	34513.7	31264.3	15632.2	31264.3	33019.8
25	34448.1	31203.0	15601.5	31203.0	32952.7
30	34380.3	31141.7	15570.8	31141.7	32885.4
35	34312.8	31080.4	15540.2	31080.4	32818.5
40	34245.4	31019.0	15509.5	31019.0	32751.6
45	34177.9	30957.7	15478.9	30957.7	32684.7
50	34110.5	30896.4	15448.7	30896.4	32617.8
52	34083.5	30871.9	15435.9	30871.9	32591.1
54	34056.5	30847.4	15423.7	30847.4	32564.3
56	34029.5	30822.8	15411.4	30822.8	32537.5
58	34002.6	30798.3	15399.2	30798.3	32510.8
60	33975.6	30773.8	15386.9	30773.8	32484.0
61	33962.1	30761.4	15380.8	30761.4	32470.7
62	33948.6	30748.6	15374.6	30748.6	32457.3
63	33935.1	30737.0	15368.5	30737.0	32443.9
64	33921.6	30724.7	15362.4	30724.7	32430.5
65	33908.1	30712.5	15356.2	30712.5	32417.1
66	33894.6	30700.2	15350.1	30700.2	32403.8
67	33881.1	30687.9	15344.0	30687.9	32390.4
68	33867.6	30675.7	15337.8	30675.7	32377.0
69	33854.2	30663.4	15331.7	30663.4	32363.6
70	33840.7	30651.1	15326.0	30651.1	32350.3
71	33827.2	30638.9	15319.8	30638.9	32336.9
72	33813.5	30626.4	15313.2	30626.4	32323.3
73	33800.2	30614.3	15307.2	30614.3	32310.1
74	33786.7	30602.1	15301.0	30602.1	32296.7
75	33773.2	30589.8	15294.9	30589.8	32283.4
76	33759.7	30577.6	15288.8	30577.6	32270.0
77	33746.2	30565.3	15282.6	30565.3	32256.6
78	33732.8	30553.0	15276.5	30553.0	32243.2
79	33719.3	30540.8	15270.4	30540.8	32229.9

80	33705.8	30528.5	15264.5	30528.5	32216.5
81	33692.3	30516.3	15258.1	30516.3	32203.1
82	33678.8	30504.0	15252.0	30504.0	32189.7
83	33665.3	30491.7	15245.9	30491.7	32176.3
84	33651.8	30478.7	15239.7	30478.7	32163.0
85	33638.3	30466.8	15233.6	30466.8	32149.6
86	33624.8	30454.9	15227.5	30454.9	32136.2
87	33611.6	30442.7	15221.3	30442.7	32122.8
88	33598.1	30430.4	15215.2	30430.4	32109.5
89	33584.7	30418.1	15209.1	30418.1	32096.1
90	33571.2	30405.9	15202.9	30405.9	32082.7
92	33544.2	30381.4	15190.7	30381.4	32055.9
94	33517.2	30356.8	15178.4	30356.8	32029.2
96	33490.2	30332.3	15166.2	30332.3	32002.4
98	33463.3	30307.8	15153.9	30307.8	31975.7
100	33436.3	30283.3	15141.6	30283.3	31948.9
105	33368.8	30221.9	15111.0	30221.9	31882.0
110	33301.4	30160.6	15080.3	30160.6	31815.1
115	33233.9	30099.3	15049.7	30099.3	31748.3
120	33166.5	30038.0	15019.0	30038.0	31681.4
v	13.49	12.26	6.13	12.26	13.38
v : Approximate volume reduction per centimetre from ullage 120 cm					