Underwater Deployment Method

Using a Hull Gateway

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ABSTRACT

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ABSTRACT

This thesis project was completed by Stanislav Abramov and supervised by the Head of the Automation Degree Programme Antti Aimo. After receiving knowledge and experience in offshore operations the author decided to combine this with the knowledge acquired at the university and the idea for this thesis was born.

The purpose of this thesis was to find the optimal solution for an underwater deployment of vehicles in vessels through a hull gateway. Correct maintenance practices and recommendations were studied for this project for it to become more practical. RCM objectives were implemented for a better appliance in the demanding field of offshore operations.

The first encountered source among offshore installation guidelines was International Marine Contractors Association that provides theoretical data and is a globally approved organization setting operational standards in maritime operations. Other sources used here revolved around maintenance and hydraulics.

The final result of this research project was a creation of equipment that made deployment environment safer and usable in weather conditions of increased caution.

For further development a few ideas were conceived including the possibility of implementing building automation to the compartment and creating a prototype of the developed system as it was designed virtually.

Keywords Underwater deployment, moonpool, RCM

Pages 31 p. + appendices 3 p.

Acronyms

DSV – Diving support vessel
ELMAS – Event logic modelling and analysis software
FMEA – failure modes and effects analysis
FTA – Fault tree analysis
HPU – Hydraulic power unit
IMCA – The International Marine Contractors Association
IT – Information technology
LARS – Launch and recovery system
RCM – Reliability centered maintenance
ROV – Remotely operated vehicle
TMS – Tether management system

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1 INTRODUCTION

In 2014, the author of this thesis project took ROV Pilot Technician Grade II courses. This independent coursework included learning about modern subsea robotic interventions, safety and maintenance procedures.
The main goal of this piece of academic work was to synergise the skills gathered from the ROV piloting coursework with the knowledge gathered from HAMK University of Applied Sciences.

The topic choice was taken after a careful consideration about the skills of the author and the possibilities of their implementation. The main inspiration and motive force for the research project was a vision that students of different engineering fields could invest their skills and knowledge into other fields of study to give each other a fresh new look on issues that are routine for the people that are working on them daily.

This research project was divided into two parts. The first one included the creation of the system and the second one was the implementation of RCM methods to the designed equipment.

As mentioned above the author wanted to invest his skills and create a system for offshore operations and if possible to use this like a service that would implement it to vessels or other offshore installations. To achieve this prospects of the system were analysed and a cost assessment was done.

The design process included a familiarization with marine hydraulics and drawing a compartment where all the equipment was situated. In this research project one can find operating process of hydraulics with the description and a related flow diagram.

2 REVIEW ON EXISTING METHODS

Offshore operations require high standards of safety, and in the case of underwater deployment for different underwater intervention instances, a safe environment should be provided. Since research revolves around ROV systems and their installation for frequent and most profitable usage, I will refer to the guidelines given by International Marine Contractors Association (IMCA) not only to pursue the goal of having high standards for the system but also to make this research project applicable to different countries without changes since this association is international.

According to IMCA (2013) there are two methods for deploying ROV to an operational area: Over the Side Deployment and Moon pool/Cursor Deployment.

2.1 Over the Side Deployment

The over the side deployment method is considered to be the most cost-effective one and most frequently used. It gives us a possibility to control a vehicle and its telemetry from the board or a closed compartment with a door system and is normally an A-frame lift which descends payload to the water surface as can be seen in Figure 1. Using a telescopic frame for the same reasons is also an option but it is not as widely used as an A-frame, which became a common option for diving support vessels.

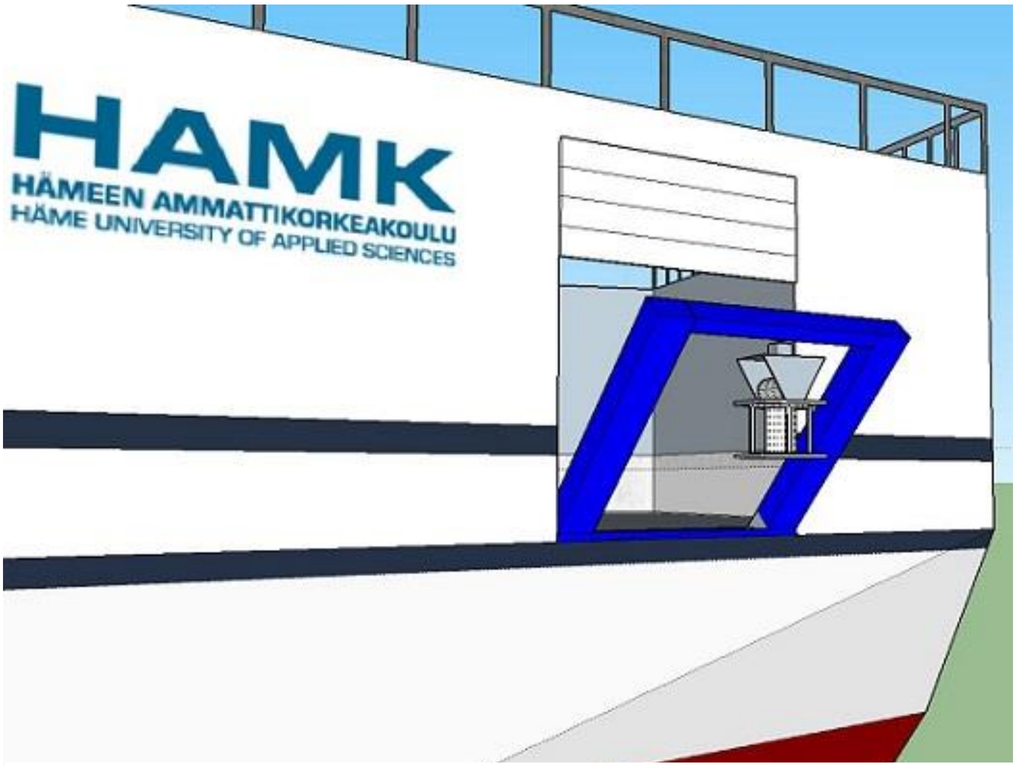

Figure 1 A-frame with payload ready to be deployed (Abramov 2015)

2.2 Moonpool/Cursor Deployment

A moonpool is an opening in the ship or offshore installation hull which provides access from below to different underwater operations.

With this method the ROV is guided through the splash zone by the means of wires or rails with the conjunction of a cursor. Stability of this technique is better in comparison to over the side deployment, as the ROV is driven through the splash zone and risks of damaging the vehicle are reduced to a minimum. Usually this method is used in offshore installations such as oil rigs, drilling ships and some of the diving support vessels.

In some cases the moonpool is a troublesome asset to the ship. When the ship is traveling in water can create a negative flux of particles in the hull opening and depending on ship structure it can affect the traveling speed.
Hammargren and Törnblom in their thesis project (2012) mention that drillships cannot be implemented with sealing the hatch for their moonpool to prevent negative flux because they are chartered at high daily rates and a failure to open the hatch could lead to huge financial losses. Moving structure solutions are also mentioned in the research but their implementation would bring additional costs with their temporary nature (Hammargren, Törnblom 2012).

2.3 Choice of method

One of the research goals was to centralise ROV operations at one place and to reduce the influence of external interferences. The main working interference offshore is the weather. A closed hall or hangar for deployment is more beneficial if we have to consider the weather. A sudden weather change with a gush of water crushing at the vessel is not going to be very influential compared to an open environment when the crew is aboard during operations. In the case of an open environment you have to narrow your schedule to the point of working only when waters are calm and that affects the overall operational availability.

For vessels that are frequently changing their positions and which during one month involved in several drilling support operations, it is good to have a compartment initially set up as an operations centre for subsea interventions. When all the people involved in underwater work are working at the same place, nobody can interfere with the other crew members responsible for the vessel handling.

Considering provided requirements the moonpool method was chosen in this project. Diving support vessels (DSV), are main underwater intervention vessels, most of them have moonpools in closed compartments. Their usage varies from commercial diving to installation of subsea structures of different kind. When undergoing those procedures, whole crew is working towards the success of those works. Using closed room of DSV is a good way to centralise works so that other crewmembers who are not involved in operations are not interfering.

The system that is developed in the following chapters of this thesis, is expected to be located in the closed compartment, where normally class I or II ROV's are used. This kind of a compartment does not use a lot of space, it would provide a means for isolation of the equipment and simplicity of usage. Maintenance recommendations are given for the chosen method as it can be improved with auxiliary equipment which the workers had not encountered previously.

2.3.1 Prospects of designed system

Prospects of this designed system are blurry, because it has not yet been built. Compartments vary and require adaptation, but as in all of technical research, it gives a foundation for future development even if it failed real implementation. The concept of a ROV handling room or launch room is not entirely new: people use garages daily and cars undergo maintenance exactly there or in the service centres. Adapting garage launch concept to subsea operations would make it easy to be explained to the new personnel. People undergoing training in this area would feel acquainted towards the place, thus training them to keep discipline and order would be easier.

Economic prospects are based on the fact that a launch room would be always ready for vehicle deployment at high chartering rates. A prototype is expected to be based on hydraulics because of its possibility to apply high forces with components of relatively small size. Hydraulics are commonly used in marine technology and them is easy to introduce to an employee who is going to be working with them. Consequently, a system that will be isolating moonpool would be easy to handle. If the weather is calm and the water is still workers can choose not to isolate the deployment area, which would increase the lifetime of the installation. When the ship goes through maintenance procedures, it would be easier to implement equipment preservation solutions. Maintenance recommendation advice was one part of the thesis research, therefore costs for the equipment care could be estimated much easier than spending resources on fault finding and stress testing. The demand for offshore vessels, especially diving support vessels, is frequently changing. At any time of the year different issues can occur and chartering companies or other organizations involved in subsea operations have to keep up with the ongoing situation. If one could provide a standby system to this demanding world of subsea technology, economical benefits for these companies that are using it would be tangible.

The isolation of the deployment area is frequently mentioned in this thesis but its economic value should also be explained. Covering people from influences of weather or unpredictable water gush is main target for the equipment. Providing this isolation surface helps keep compartment dry and if some water sensitive equipment is around because of human factor, probability of damage is greatly decreased.

3 IMPLEMENTATION

The implementation basis of this project was a virtual design. I would like to create a ROV handling room and propose solutions for different issues that could arise in this environment.

Table 1 Companies and their deployment methods. (Abramov 2015)

Company	Vessel	Specifications
Technip	Skandi Arctic	Dive moonpool 2 off 4.2m x 3.6 m
Technip	Skandi Achiever	Moonpool 4.2 m x 4.2 m with aeration
Technip	Olympic Challenger	ROV Moonpool 4.8m x 4.8 m
Fugro	Fugro Symphony	Deployment Locations In enclosed Hangar Area, via hydraulic doors : 1 x Port side, 1 x Starboard side
Fugro	Fugro Pioneer	Rectangular moonpool 1630*883mm
Fugro	Fugro Saltire	Moonpool 7.2m x 7.2m Deployment Locations 1 x Port side, 1 x Starboard side, via hydraulic doors each side of enclosed central ROV Hangar Area
Boskalis	Constructor	1 diving moonpool 4m x 4m
Boskalis	EDT Protea	4.2 m x 4.8 m aft of hangar

According to data, presented in Table one it is clear that most of moonpools are a minimum of four by four meters. Based on this table I chose the same length with an addition of 200 millimetres for further customisation, and 4200 mm to each side is also used as a standard moonpool dimension. Figure 2 shows schematically the area reserved for the moonpool in the drawn compartment.

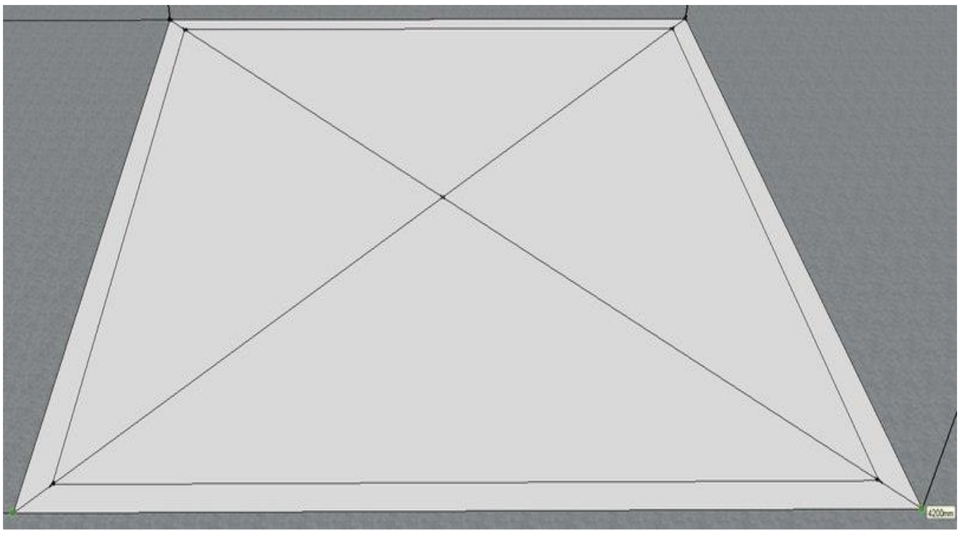

Figure 2 Moonpool illustration 4200mm x 4200mm (Abramov 2015)

3.1 System components

3.1.1 Tether management

After having chosen the dimensions for the moonpool further planning of auxiliary equipment could be made. In this particular case, when ROV would enter water below the ship, the first piece of equipment moving behind the vehicle is its telemetry.

A tether or umbilical is a mean for establishing linkage with a vehicle, and normally a twisted pair or fibre cables are used. Tether management system (TMS), Launch and recovery systems (LARS) are the solutions for a tether deployment. Both solutions imply that target payload is safely driven to the operational area with a desired length of tether following it. Figure 3 illustrates Luffing A-frame LARS with auxiliary systems. With the assistance of an ROV manual (Christ, Wernli 2014), the author defined the equipment that should be taken into account when designing the deployment system:

- Hydraulic power unit (HPU)
- Winch
- TMS

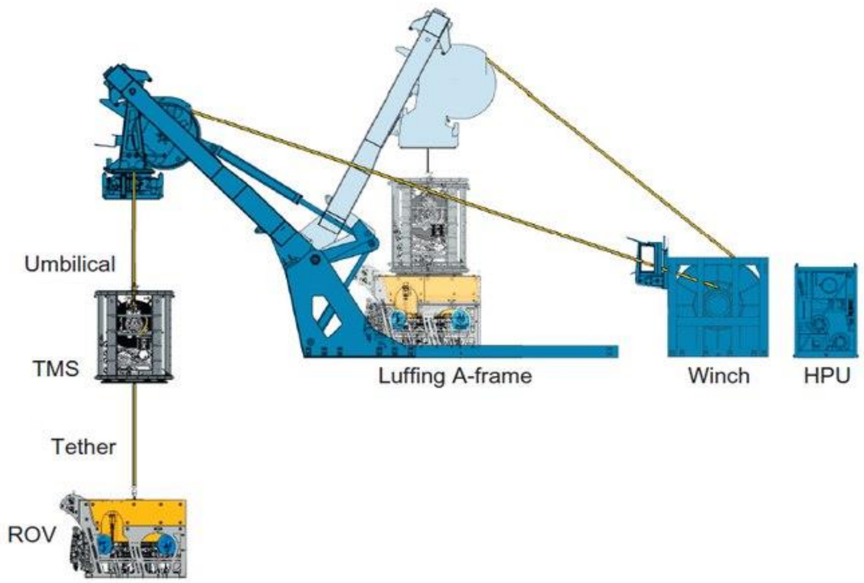

Figure 3 LARS example provided in ROV Manual, Courtesy Schilling Robotics (Christ, Wernli 2014)

According to knowledge mentioned above, the system that was developed by the author included enough space for all of the equipment. Physical obstacles and ease of use also had to be taken into account.
At this point it was possible to draw the interior of the deployment room and based on that continue research with further improvements. Figure four explains the positions for the equipment chosen for the system.

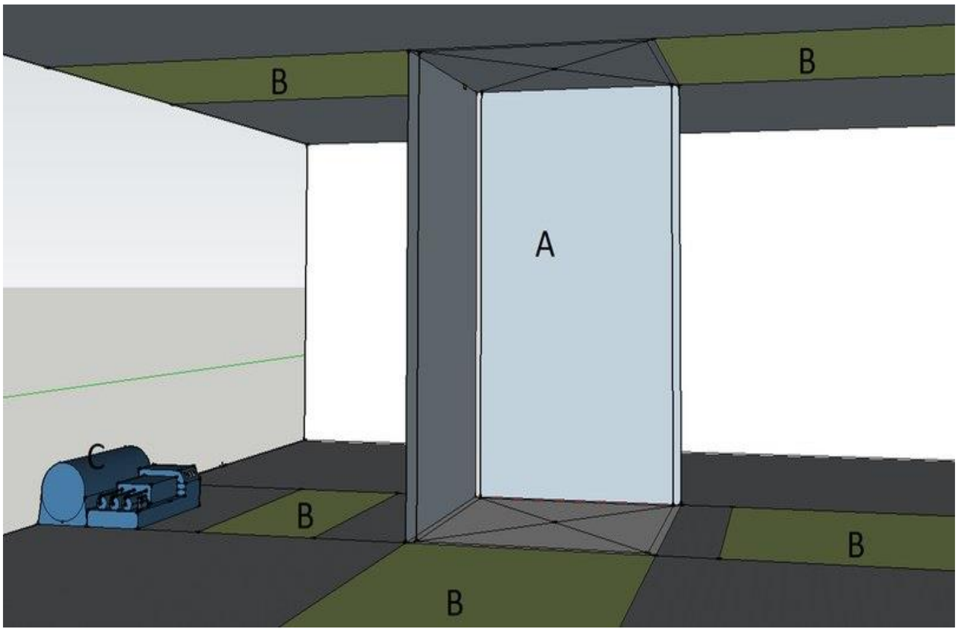

Figure 4 Example of possible equipment positioning, A – space for TMS and means of isolation, B – winch systems for cable handling or heave compensation, C – Hydraulic power unit (Abramov 2015)

3.1.2 Lifting equipment

Area “A” in the Figure 4 illustrates space above the moonpool. The deployment of an ROV through this area, should be made by lifting systems. During ROV pilot technician courses the author noticed that if a moonpool was used, the safest way to guide the equipment through was to use frames that would keep the system stable until the payload reached a desired depth. With the help of round shaped snubbers and TMS tightly attached to the vehicle, it is possible to achieve a safe deployment through the hull area. However, if weather conditions affect stability, ship roll can cause damage. The installation could swing like a pendulum and hit the equipment by the vessel walls. To reduce the possibility of this kind of damage the installation could be strengthened by metallic frames.

Since this research project aimed at developing compartment for frequent use in different weather conditions, preference was given to the most reliable option. Stabilizing cursor with rails is widely used to negate the effects of weather conditions and for a safe handling of ROV through the moonpool. Isolated deployment area with a sliding cursor mechanism inside was the chosen option here. Isolating A-frame mechanism would have been more troublesome since it travels some distance from the initial position to the position above deployment area adding more installation costs.

3.1.3 Hydraulic Power Unit

The hydraulic power unit is an essential asset to the installation where lifting of equipment takes place. In the developed system, it was wise to have hydraulics for lifting because hydraulics have a proven record of reliability. If failure of the system happened, hand control could be used with steering solutions or lever action like a car jack.

Figure four illustrates the position and schematic representation of the HPU unit. The close location to the operational area was chosen because it was essential to monitor the readings and have visual observation for working hydraulic machines. Readings can indicate troubles in systems and if was needed some maintenance, it could be brought to a stop. In IMCA guidelines for installing ROV systems it is mentioned that exhausts and vents should be positioned so that they remain clear and not located where they could pose a risk to personnel (IMCA R 018, 6). This requirement is fulfilled simply by locating hydraulics into different areas of the ship or using specific means of ventilation but in the case of our setup, it was left in the proposed place for demonstrational purposes.

3.1.4 HPU operating process

When the HPU begins functioning, hydraulic liquid is moved out of the tank into the accumulator by the gear pump. Process is continued until pressure in the accumulator reaches predefined level, at this point begins circulation of fluid, to achieve that charging valve is switching pumping action into circulation. This causes the pump to discharge liquid through charging valve once again into the tank at minimal pressure. One-way valve prevents fluid from flowing out of the accumulator. Charging valve activates once again if the pressure drops. (Thomasnet 2015)

3.2 Details of drawn system

It was mentioned before that moonpool was 4200 by 4200 millimetres wide.
The system was designed according to provided dimensions. The project provided safe and relatively dry handling of the system. To achieve that, the system was divided into two states “Operational” and “Preparatory”. The operational state means that the system undergoes deployment operations or the vehicle is in use and the Preparatory state is for maintenance and ROV system preparations. By preparation, it is meant that the ROV personnel is undergoing checklist routines, maintenance or having toolbox talk and the system is not yet operated. Further development is provided to the two state division in the next chapters.

3.2.1 Hydraulics

The two state divided system was planned to be piston like. Marine industry is rich in various hydraulic systems that have proven record of reliability. With the help of "The Hydraulic Trainer" (Volume three) which is a training manual for planning and design of hydraulic power systems, operating pressure of up to 300 bars was estimated and a diagram was drawn according to the data presented in the manual (Drexler, Faatz, Feicht, Geis & Morlok 1988, 21). The system is handled by a hydraulic piston of compatible size. In Figure 5 it is presented how the hydraulic part of the system would look like with its flow diagram drawn in Festo Didactic FluidSIM software.

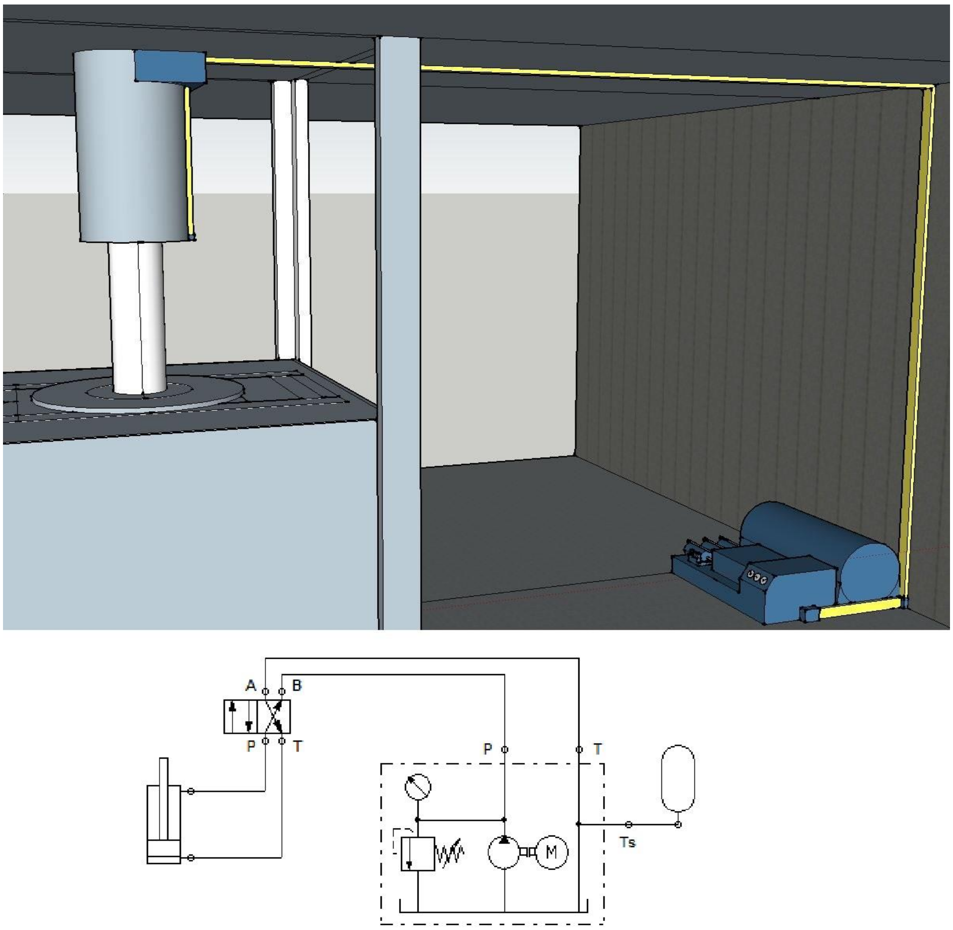

Figure 5 Hydraulic design with flow diagram. Yellow square tube demonstrates hydraulic piping. Blue colour stands chosen for hydraulics and related auxiliary components. (Abramov 2015)

3.2.2 Covering structure.

In this chapter, the mechanical moving parts and frames are examined. Amongst mechanical installations, there were parts in the ROV system that took some space and should be delivered along with it. Amongst that equipment there was a heave compensation unit that provided safety for deployed tools. Therefore, if ROV of any class is delivered, we have to take into account that actual size of system may vary. For example, Saab Seaeye Company produces vehicles called Tiger with specific sizes of TMS. As the author had simulator experience with this vehicle, it was used here as the vehicle of choice for examination and modelling.

Table 2 Saab Seaeye TMS type 2 specifications and dimensions (Saab Seaeye, 2015)

TMS 2 Specifications**:**	
ROV model	Seaeye Tiger
Construction	Galvanized steel
Bailing System	Polypropylene construction with hard-anodized aluminium central boss. Seaeye SM4 motor drive with hard rubber universal coupling to bale arm gearbox.
Electronics Pod	Hard-anodised aluminium cylinder. Seaeye metal shell connectors.
Tether capacity	140m of 17mm tether
TMS 2 Dimensions:	
Length	1200 mm
Width	1200 mm
Height to lift eye	1640 mm
Total Weight in air	Approx. 460 kg
Depth Rating	1000 metres

Data given in Table 2 provides the dimensions for the estimating area that was to be isolated. Width should be no less than 1200 mm with an addition of at least 500 mm for the crew to reach equipment between bars that guide the moving structure. The length is approximated around 3000mm, 1200mm - the length of the TMS cage with an addition of 1640 mm clearance for lifting purposes. Figure 6 demonstrates the drawing, made according to required lengths with respect to 4200 by 4200 mm moonpool. The structure itself was a square-shaped metallic box reinforced by frames on the edges. To simplify the description author proposed calling it a metallic carcass padded with metallic sheets.

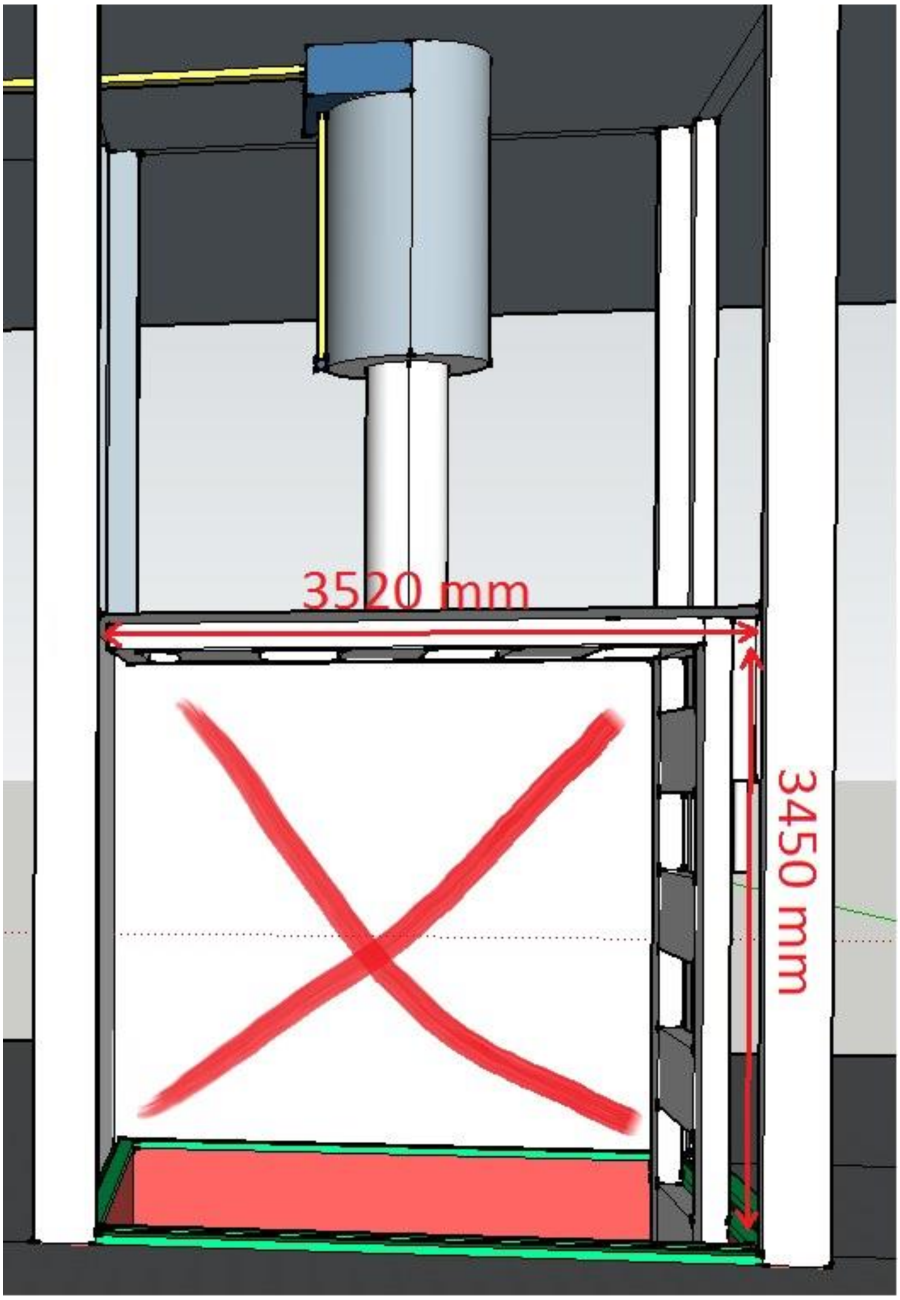

Figure 6 Area marked with X is reserved for TMS installation and its dimensions. (Abramov 2015)

3.2.3 Isolation

Isolation of the deployment system is made by making top-down moving structure. Structure is moving from above to cover deployment area with equipment prepared to launch. Box-like structure is moved by hydraulic piston and is isolated by means of applying pressure to the rubber installed into input notches. Figure 7 visually explains moving direction of covering structure and demonstrates position of input notches.

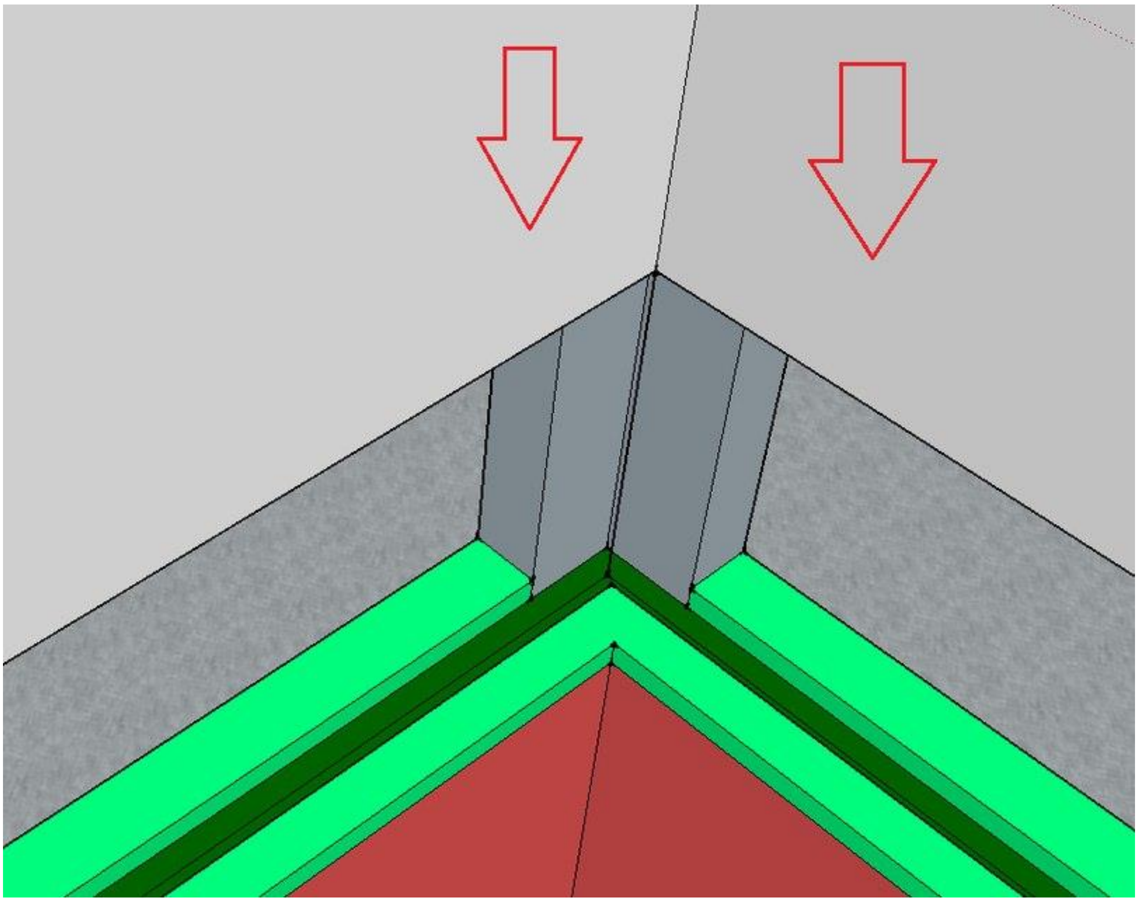

Figure 7 Movement direction of covering structure (arrows), Input notches (Light Green), Rubber isolation pad (Dark Green). (Abramov 2015)

As mentioned above in the method choice and prospects section, this piece of equipment is crucial part of the research as its functionality provides system availability in harsh weather environment. Choice of material that is going to be used in isolation structure is slightly abstract since different clients could have dissimilar to each other requirements of quality. But it is still clear that main parts that are in contact with water, are in danger of corrosion, they require certain protection. If elasticity of the covering structure does not matter to the client, then rubber materials could be used. From authors perspective highest quality is achieved through using materials that are, conceivably, steel alloys which have been treated with galvanic protection. Input notches could be metallic but then it is wise to add rubber pads to the parts that are in physical contact frequently to negate damage from pressure applied. As could be seen on Figure 7, author proposed rubber isolation pad fixed between input notches. Shape of the input notches would fix rubber pad in position when pressure would be applied from above.

3.2.4 Final compartment drawing

Previous chapters have defined necessary equipment that is needed to be in the ROV deployment compartment and it became possible to draw it with correct positioning of the equipment. Figure 8 demonstrates final sketch drawing of the compartment with developed isolation cover system. It is suggested by the author that ROV operations would be centralised in one place, so that other vessel crew would not be interfered. As an addition it is possible to use developed compartment as the control room. Because of the water isolation provided, client can install more environmental sensitive equipment. If there is enough space, empty area could be used as a ROV maintenance or repair workshop, where personnel would prepare equipment for subsea intervention and as mentioned above, they would not bother other crew members of the vessel.

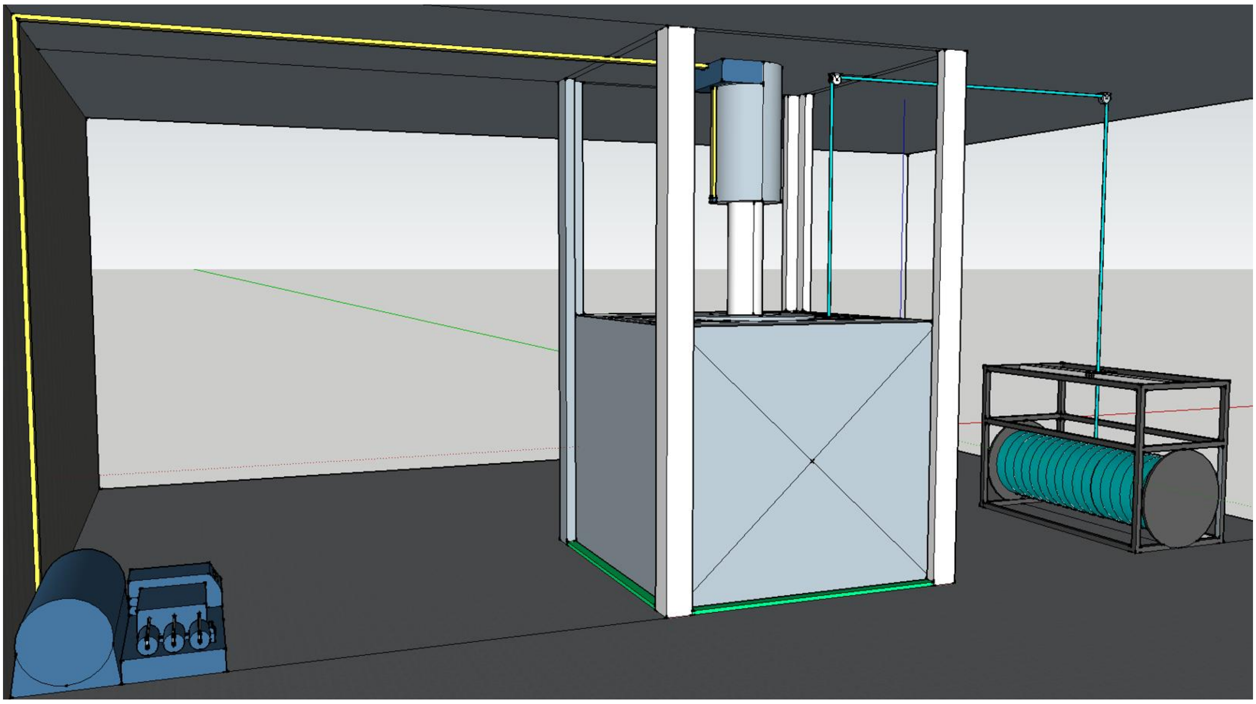

Figure 8 Final drawing of the compartment (Abramov 2015)

In sketch drawing of the system it is seen that main pieces of the equipment are placed in a way that operating one would not interfere with operation of another. Winch has cyan cable coming to the system of pulleys that are guiding cable to the top-down covering structure. This is schematic demonstration of heave compensation system that could be placed in vicinity of the moonpool area. Covering structure is moving up or down with the stroke of the hydraulic piston, its direction is both guided and reinforced with the support beams on the edge of each side of square structure.

4 MAINTENANCE

4.1 RCM

From engineering point of view, management of any physical asset is divided in two elements. It must be maintained and may need modification from time to time. Reliability centered maintenance (RCM) is focused on determination of what must be done in order to ensure that physical asset continues to do what its user want it to do in its present operating context. (Moubray, J 1997 6-7)

4.1.1 Seven basic RCM questions

To ensure sustainability and long-term operability of equipment, I have decided to use RCM method. RCM process is made from answering to seven basic questions.

What are the functions and associated performance standards of the asset in its present operating context?

Virtual nature of examined system cripples possibility to get firsthand experience from users of the asset, which could be very valuable information. Despite virtual nature, it is still possible to describe functions and define performance standards. Intentional simplicity of the system implies that it is limited to two states and only function is to transit from one state to another. Other possible function is isolation of system during unfavorable weather conditions.

In what way does it fail to fulfil its functions?

Table 3 Failure functions. (Abramov 2015)

Function	Functional failure
To move piston up or down.	Not enough pressure from HPU. Directional valve not switching liquid flow direction. Piston components worn out. Pressure liquid leakage.
System isolation.	Physical obstruction. Sealing components worn out.

	Structural integrity impaired. Input notches damage.

What causes each functional failure?

Table 4 Functional failures and causes. (Abramov S.2015)

Functional Failure (modes)	**Cause**
Piston movement	
Not Enough pressure from HPU.	One of the HPU components failed.
Directional valve not switching liquid flow direction.	Component break or control system failure.
Piston components worn out.	Fracture or wear of moving components.
Isolation structure	
Physical obstruction.	Some object gets in the way of moving parts.
Sealing components worn out.	Rubber seal worn out and small cracks leak water.
Structural integrity impaired.	Bend of the structure due to constant pressure applied.
Input notches compromised.	Physical damage of notches made them incapable to insert related structure.

What happens when each failure occurs?

The case system is based on hydraulics and its operability; therefore, it has direct relation with HPU availability. Even though HPU could consist from many different components, main ones are in an almost every hydraulic power unit. Failure of any of the HPU components can lead to inability of system operation. Considering the severity of possible failures inside auxiliary hydraulic units, their failure effects are examined along with mentioned failure causes in Table 5 down below.

Table 5 Failure Effects. (Abramov S.2015)

Failure	Failure mode
	Piston movement (And HPU Components failure)
Accumulator failure	Failure of the accumulator can be traced by overall pressure loss in hydraulic system and fluid leakage. The pool of liquid could be noticed near the faulty system. This could lead to a formation of a slippery surface that can potentially harm personnel. Pressure loss results in a slow operation of the system and inadequate control response. Accumulators have certain degree of isolation with precisely calculated characteristics. To avoid defection of set characteristics it is wise to replace faulty piece of equipment with the new one.
Motor Pump failure	Pumps serve as a motive force that is driving liquid to the accumulators or through valves. Failure of this component can be noticed by emitting of unusual noise, increase of noise loudness, heating of related components or hydraulic liquid, cavitation, slow operation. To prevent most of those issues it is recommended to schedule preventive maintenance according to documentation provided by supplier.
Tank failure	Being a storage unit for the liquid, tank can build up unwanted sludge if some liquid other than operating liquid would enter hydraulic system. Leakage of tank can lead to a slippery surfaces near equipment that can damage personnel and overall system pressure loss. Tanks are not always pressurized and it is possible to repair them on cite without component replacement.
Filter failure	Failure of filter unit can lead to the change in operating liquid properties or build up unwanted sludge. Theoretically, it is possible to operate system without or with faulty filter unit and because most of them are self-contained, they can often be replaced even when HPU is being operated.
Power Unit Controllers failure	Broken control interface causes inability to operate hydraulic system. It could be noticed instantly as the system will not respond to operation commands. Causes vary from software bugs and crashes to related mechanisms damage. Main hazard of this event is jamming of the system. Nature of the failure could be based on software issues and normally it is the case for the information technology specialist. Other failure cases could be found with electrical testing equipment as modern control systems are based on electrical signal handling.
Directional valve is not switching liquid flow direction	Most descriptive evidence that event of failure has occurred would be movement of piston to only one direction. Leakage of fluid if that is the case, could be seen nearby the directional valve. To repair this part of

	equipment, operating liquid should be drained to the storage tank and broken component should be replaced.
Piston components worn out.	Unusual noises while the system is in motion, could indicate that components are in danger of breaking. If piston is broken whole lifting system would become unavailable. To repair this system operating liquid should be drained to storage tank and then components could be replaced. Liquid leakage could be noticed by observing unusual amounts of liquid around the moving parts that are obviously exceeding allowable amounts.
	Isolation structure
Physical obstruction.	System is not isolated and that could be noticed visually, some object is in the way. To fix this issue, system should be lifted up and obstructing object removed from traveling path. If the system is bent it still could potentially isolate environment, only severe bending and damage to structural integrity can lead to failure in isolation. Some minor bending could be fixed by straightening with rubber hammer for instance. Severe damages should be fixed by component change.
Sealing components worn out.	Sealing components below sealing structure leak water that could be noticed visually. To repair worn rubber components some chemical solutions are used to fill cracks or change of whole seal is a more reliable solution.
Structural integrity impaired.	Evidence of failure is mostly visual, impaired system is jolting while in motion, elastic motions could be seen and when reaching point of isolation system may look shifted by a certain angle. To repair damaged structure technician should first try to fasten screws that connect metal plates with each other. Other repair processes are dependent on the nature of the fracture and it is impossible to predict repair procedures.
Input notches.	Damaged input notches lead to water leakage and pools of water near the equipment could be seen. Replacement of damaged notches is most obvious solution.

In what way does each failure matter?

RCM process requires detailed description about each failure consequence. Knowledge about severity of each failure can assist in planning preventive measures and categorize them accordingly. Table 6 is drawn for failure consequences analysis.

Table 6 Failure consequences. (Abramov 2015)

Failure	Consequence (I – safety and environmental, II – operational)
Accumulator failure	**I** – Leakage of liquid can result in slippery surface and that is dangerous to the crew, equipment in the compartment is metallic and falling down on it could result in fatal injury. **II** – Pressure loss decreases overall system response to the commands. Not enough pressure may bring system to full stop.
Motor Pump failure	**I** – Faulty motor pump can produce high decibel noise that can damage hearing of personnel that is working nearby. Leakage can be harmful in the same way as mentioned above. **II** – Pressure loss can affect operations in the same way as mentioned above. Unavailability of this piece of equipment leads to impossibility of system operation.
Tank failure	**I** – Leakage can be harmful in the same way as mentioned above. **II** – If leakage is severe and there is no way to fix that, pressure loss can affect operations in the same way as mentioned above. Built up sludge can damage equipment that is operated by the hydraulic liquid.
Filter failure	**I** – No severe damage to the environment or crew, but failure itself can lead to damage of auxiliary equipment that can bring harm to the personnel. **II** – No severe intervention to the system operation. Failure to repair filter can result in damage of other hydraulic components that are involved in operation.
Power Unit Controllers failure	**I** – If crew is working nearby moving parts of the equipment and controllers will fail it can result in serious injury. **II** – System will fully stop or finish last task it received to carry out.
Directional valve is not switching liquid flow direction	**I** – No severe damage to the crew if works nearby are carried out with

	adequate prudence. **II** – System would be brought to the full stop or will move only one way as flow direction to the opposite way is compromised.
Piston components worn out.	**I** – Noise produced by worn off components can damage hearing ability over some time, while working in that area. Instant release of payload due to piston wear can lead to fatal injury. **II** – System would be brought to the full stop and become unavailable.
Physical obstruction.	**I** – Due to unpredictable nature of obstruction it can damage personnel working nearby with sudden rebound of stuck object. **II** – System would still be operational. Purpose of isolating deployment area would be compromised.
Sealing components worn out.	**I** – Water coming from deployment area can lead to slippery surface and that can damage the personnel working nearby. **II** – Depending on amount of water that has got through sealing area, ranking of the failure could be approximated. Too much water can influence lubricated surfaces nearby and lead to a corrosion of metallic surfaces.
Structural integrity impaired.	**I** – Due to pressure applied from above the compromised structure, some parts can suddenly rebound and damage personnel. **II** – Leakage of water is possible. Too much water can influence lubricated surfaces nearby and lead to a corrosion of metallic surfaces.
Input notches.	**I** – Possibility of slippery surface nearby. Pressure of structure above can result in rebound of some damaged notch parts resulting in injuries. **II** – Leakage of water can influence in the same way as mentioned in structural integrity and sealing components failures above.

What can be done to predict or prevent each failure?

According to presented data above, prevention maintenance table can be created for each failure. Failures with most severe consequences are the ones that require maintenance more often than the others. To sort failures, I have divided them into 3 colours to simplify understanding of their importance. First category is red as this colour is most aggressive and resembles high importance. Second colour was chosen yellow, it resembles neutral attitude to the issue but still brings sense of caution to the observer. Green colour is internationally approved colour of acceptance and implies that something is of acceptable standard. According to colour differentiation it is possible to make decision about maintaining component or understand severity of possible failure. Visual inspection is compulsory for all of the examined components before and after operations.

Table 7 Failure prevention. (Abramov 2015)

Failure	Prevention advice
Accumulator failure	Operating principle of this part of equipment relies on building up pressure and manipulation with valves. Preventive maintenance procedures should be made according to manufacturer provided standards. Isolation of the system should be checked to avoid faulty states. Systems with pressure manipulation are made with high durability and most likely will not fail really often.
Motor Pump failure	This component should be maintained more often than other components of HPU unit because failure of this component leads to noise pollution that makes deployment compartment unpleasant place to work in along with system inoperability. Maintenance procedures should include checking of force and torque produced by motor, flow of operated liquid and for the possibility of leakage.
Tank failure	Amongst maintenance procedures, required by the manufacturer, tank should be checked for leakage, especially if it is pressurized.
Filter failure	As mentioned in previous tables, filters are often self-contained, meaning that maintenance of their internal systems is predefined by manufacturer. If operating liquid requires more often change of filter it should be scheduled accordingly.
Power Unit Controllers failure	Modern control units could be made by means of electronic equipment and in this case software should be checked for bugs and possible flows. IT personnel should be informed right away if control system is influencing daily operations with software problems. Maintenance, predefined by manufacturer, should be carried out with local software changes taken into account. If system is operated by means of push buttons, it should be checked regularly for adequate response time.

Directional valve is not switching liquid flow direction	While checking, valve should switch both ways with the same response time. Possibility of leakage should be tested. Manufacturer set procedures should also be carried out.
Piston components worn out.	Nondestructive testing techniques revealing structural changes should be made and therefore list of changes from previous maintenance procedures is essential in this case. Visual check is also of great importance, since piston is self-lubricated with operating liquid and observation of changes in this matter can reveal failure of other components.
Physical obstruction.	To prevent this failure, local supervisor should be aware about his workers safety knowledge. Personnel should be informed that moving parts of the system should not be obstructed with anything.
Sealing components worn out.	Regular visual check of components should be carried out to notice cracks in rubber material. Nondestructive testing techniques can reveal structural changes in this component.
Structural integrity impaired.	To prevent impairs of structure, regular fastening of screws and other possible connection means should be done. Nondestructive testing techniques can reveal integrity impairs.
Input notches.	Nondestructive testing along with visual inspection reveals status of this component.

What if a suitable proactive task cannot be found?

To answer this question group of people working on maintenance decisions should gather and decide what should be done. There are 2 options that are available: Failure-finding and redesign. Failure-finding means that people operating the equipment along with maintenance professionals, would provide information about failures and decisions would be made accordingly. Redesign means that equipment could not be handled efficiently enough without redesigning weak parts of the system. In case of this thesis project it is impossible to predict what could happen so that proactive task would not be found. (Moubray, J 1997)
To give better view about failures and how to utilize them, fault tree analysis is made in next chapters.

4.2 Fault Tree Analysis

With this method better reliability estimates could be done. RCM gives detailed view about failures and FTA assists in their utilization. Basic Boolean logic is used in modelling and it gives possibility to build fault trees of different complexity. Relations between events, also known as blocks, are explained with different gates defined by the Boolean algebra. This concept was developed by Bell Telephone Laboratories in 1962 for US Air Force to use it with Minuteman system. Later Boeing Company has adopted it and extensively applied it as the aircraft faults where severe and needed precise analysis models. Fault tree is one of many different analytical logic techniques. It was chosen for this research as it provides good visual explanation about failures and gives solid basis of improvement. (Weibull, 2015) Figure 9 demonstrates fault tree example.

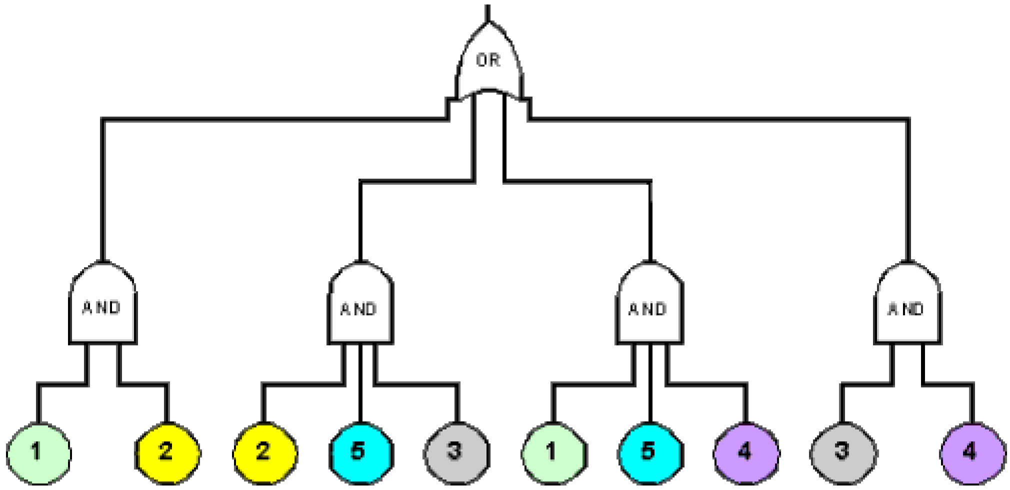

Figure 9 Example of the fault tree. (Weibull, 2015)

4.2.1 ELMAS Modelling

ELMAS – Event logic modelling and analysis software. It is a software for modelling logical relations between events. An event can mean that change of any situation have happened. Other event related features could be modelled with many different methods. The created model is used to expand knowledge about analysed system and to document data. Software uses common model structure and it is possible to model any object with it. I will use most common application of this software – FTA. For time period of 10 years I will simulate possibilities of failure according to data provided with RCM analysis based on answering 7 basic questions. (Ramentor, 2015)

From internet sources and personal contacts, cost of each component was estimated and is presented in table 8. Approximated costs demonstrate that system would cost around EUR 20.000 – 25.000 if it would be used as a service for offshore vessel operators. Capital spent on the installation of the system is expected to pay off when one would operate system in harsh environments, on the chartering rates that were not possible earlier because of the weather conditions. Costs provided are entered in the ELMAS software and several simulation runs have shown that if maintenance technician would do equipment change rather than repairmen it would cost for ten years not more than EUR 200.000, therefore client can relate those costs with profits of the typical operation and would decide whether to implement this feature to his vessel or not.

Table 8 Component cost estimation. (Abramov 2015)

Component	**Cost**
Steel Bars for carcass	EUR 4000
Galvanized steel sheets 5 pieces	EUR 73 (EUR 14.6 each)
Hydraulic power unit	EUR 1000
Hydraulic piston of required size and stroke	EUR 2900
Hydraulic tank unit	EUR 350
Accumulator	EUR 180
Directional valve	EUR 80-100
Hydraulic Piping	EUR 20-100 for each component

FTA from Figure 10 that is made in ELMAS software, shows how two main groups of the system components are influencing overall operability. According to the approximation guidelines, components where given mean time before failure and that is most important entry to approximate probability of failure during the given time (CITAITON) . Most components where estimated to fail at least once in a year, but actual time to failure is calculated by the software. Red blocks represent components with highest probability rate of failure. Yellow and green blocks are less significant but still are of importance as they affect system availability. To simplify understanding of fault tree, it is important to explain relation of blocks. Block number one that is event of our interest is triggered when one of the blocks 2 or 3 is true. Blocks 2 or 3 that represent equipment groups are triggered only when root failure events, at the lowest row, have happened.

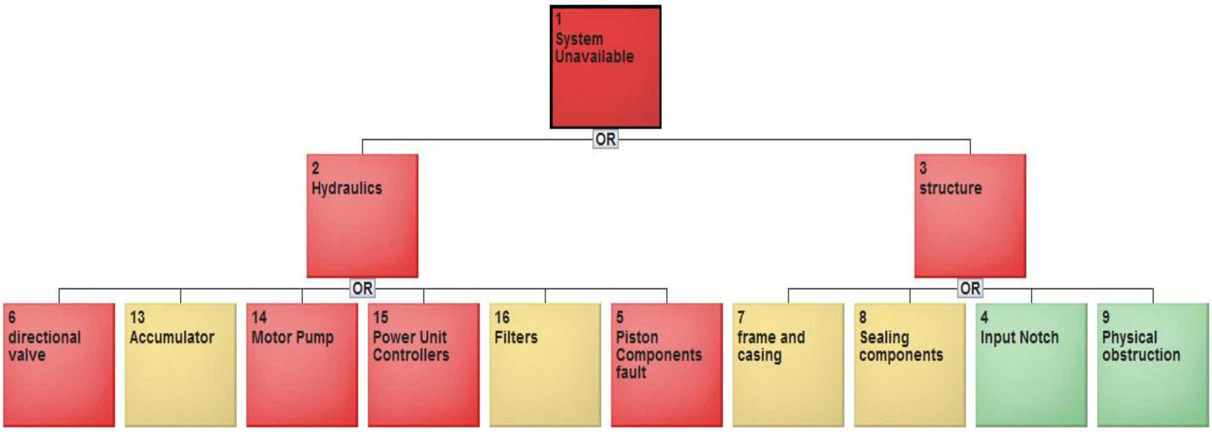

Figure 10 Fault tree of the researched system. (Abramov 2015)

ELMAS software provides its user with simulation tool and in case of the FTA one can estimate quantity of failures during given period of time. As it was mentioned above, ten years of service is the target time period to be examined. In Figure 11 simulation result window is shown and according to this information it is possible to explain each failure one by one.

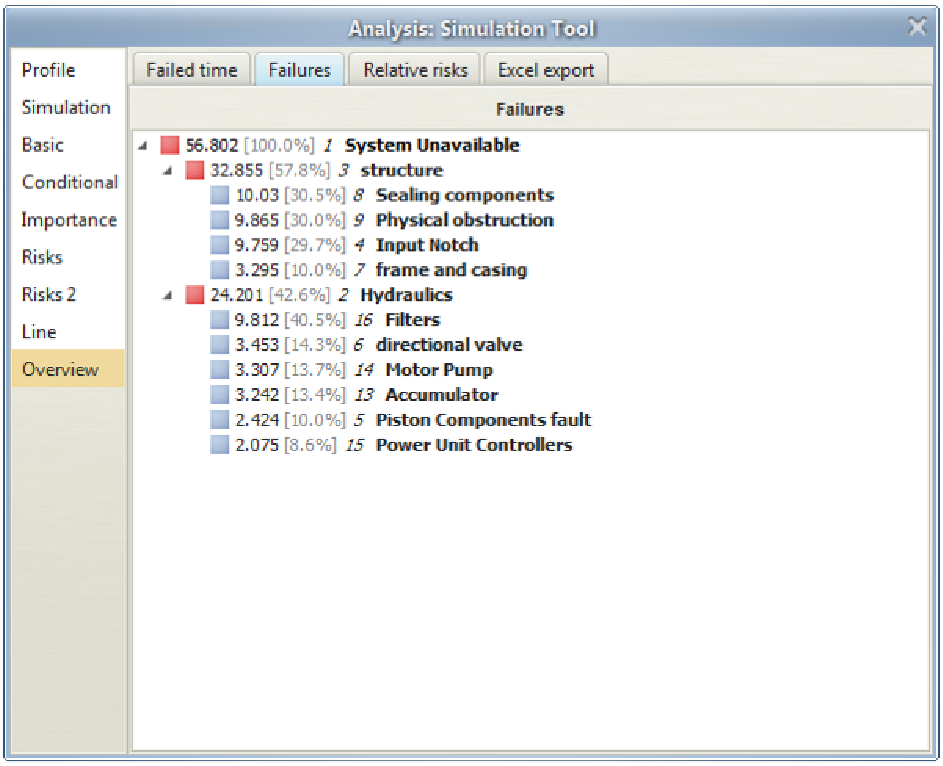

Figure 11 Simulation results. (Abramov 2015)

First thing that is noticed is that the system was unavailable around 57 times during time period of ten years. This number of events includes 32.855 failures that happened because structure was compromised. Hydraulics influenced system availability 24.201 times. As the components have different significance in the terms of failures each of them must be analysed and according to that sort most influential ones from the insignificant. Table 9 demonstrates results of simulation, numeric quantity of each failure and its significance. According to that data it could be seen that amongst 56.802 times of failure, only 32.608 of those failures are of significant value. Quantity of failures show that main components that are in danger of failure are hydraulic filters and mechanical parts of moving structure. Filters could be replaced so it is wise to have pair of those for replacement, moving parts on the other hand require regular non-destructive testing and personnel operating them should report if strange behavior of the equipment is noticed. Presented results lead to a conclusion that without preventive maintenance system would fail 3 times a year and that would lead to the unnecessary investments in repair. If good preventive maintenance practises would be applied it is possible to negate all of the presented failures.

Table 9 Simulation results analysis. (Abramov 2015)

Failure block	**№**	**Significance/explanation**

System Unavailable	56.802	Total number of failures.
Structure	32.855	*One of two groups of equipment.*
Sealing Components	10.03 5+5	Yellow block in FTA. This component has relatively low influence on operability, therefore considered as insignificant failure but still can bring nuisance to the personnel as the liquid can effect works in the area, therefore from ten failures half could be significant.
Physical Obstruction	9.865	Green block in FTA. Easily avoided if discipline is kept amongst personnel. Insignificant failure.
Input Notch	9.759	Green block in FTA. Without this component it is still possible to isolate system by mean s of rubber pads even though they could wear much faster in comparison with unbroken component. Insignificant failure.
Frame and Casing	3.295	Yellow block in FTA. Although this component can still perform its functions while failed its significance comes from consequences that it can produce if it would influence other pieces of equipment or even the personnel. Significant failure.
Hydraulics	24.201	*One of two groups of equipment.*
Filters	9.812	Yellow block in FTA. Although this component can still perform its functions while failed its significance comes from consequences that it can produce if it would influence other pieces of equipment. Significant failure.
Directional Valve	3.453	Red block in FTA. If this component would fail system becomes inoperable. Significant failure.
Motor Pump	3.307	Red block in FTA. Component is important in operation, without it hydraulic liquid would not be moving in a system as intended. Significant failure.
Accumulator	3.242	Yellow block in FTA. Consequences produced by failure of this component provide pressure drop in the system making it inoperable. Significant failure.
Piston Components	2.424	Red block in FTA. Moving part of the system, if failed isolation function could not be performed. Significant failure.
Power Unit Controllers	2.075	Red block in FTA. If failed it is not possible to operate system. Significant failure.

4.3 Maintenance recommendations

Recommendation of maintenance practices was chosen to be made with RCM documents. This choice is based on a possibility to implement high quality documentation of the maintenance procedures. To achieve that client should encourage discipline in documentation.

4.3.1 RCM decisions

RCM decisions process is made by filling worksheets with data gathered about the equipment that is going to be examined. Two of the key documents for RCM decision making help track failures, analyse them, predict future ones and plan preventive measures. First document is RCM information worksheet, second one is the RCM decision worksheet. Both of those documents would be applied to the developed system and style of the documents is inspired by the RCM tutoring teacher at HAMK University of applied sciences Heikki Ruohomaa and RCM teaching book called Reliability-centered Maintenance (Moubray, J 1997 198). Documents provided should be considered as the reference material since installed equipment could vary according to clients need and applying them without correct assessment is not recommended.

4.3.2 RCM information worksheet

This paper shows RCM practice called FMEA, failure modes and effects analysis. Document can introduce personnel to the possible failure modes and effects it could produce. Table like style it is visually explaining details of failures and maintenance professional, responsible for decision making can determine further actions after comparing written information with actual status of the system. Figure 12 demonstrates RCM information worksheet designed for this research project. According to a provided data it is possible to track date of worksheet creation and one can estimate how much time have passed and how system behavior has changed during its lifetime. People involved in this project are also mentioned there and if some question would arise it is possible to contact those people for better explanation of provided data.

The RCM II Information Worksheet	**System**	System №	Tutor Teacher	Date	Sheet №
	Isolation structure	1	A. Aimo	25 5 2015	1
	Sub-System	Sub-system №	Auditor	Date	of
	Hydraulics, Structure	1,2	S. Abramov	26 5 2015	1

	FUNCTION		FUNCTIONAL FAILURE (Loss of function)		FAILURE MODE (Cause of failure)	FAILURE EFFECT (What happens when it fails)
1	To provide isolation of moonpool during ROV diving operations	A	Unable to move isolation structure at all	1	Structure integrity compromised	Structure integrity is compromised and it can not move in any direction or is moving in faulty state. Possible to spill water that is meant to be isolated
				2	Hydraulic equipment has failed	System is not moving to any direction and it is noticed visually or speculatively that root cause is hydraulic subsystem failure
		B	System goes only one way up or down	1	Equipment responsible for direction of hydraulic liquid flow has failed	Lifting piston goes only one way. Flow direction switching valve has failed
		C	Isolation compromised	1	Isolation components worn out	Water starts to leak through the isolation means resulting in formation of pool of liquid that could damage personnel due to slippery surfaces.Water sensitive equipment is in danger as well
				2	Isolation components are fractured	More abundant amounts of water are leaking through damaged zones in comparison to isolation components wear

Figure 12 RCM information worksheet. (Abramov 2015)

4.3.3 RCM decision worksheet

Last three of seven basic RCM questions make up the RCM process. According to these questions strategic framework could be made with the help of RCM decision diagram. Figure 13 demonstrates framework that could be applied to each of the failure modes that were listed in the RCM information worksheet.

Questions provided by the decision diagram are guidelines to fill in the decision worksheet. With respect to those answers it is possible to record:

- How often and what kind of a routine maintenance is to be done and by whom
- Which failures are significant enough to prescribe redesign of the system
- Cases where cautious decisions were made and that let failures to happen

There are sixteen columns in the worksheet. First four columns cross-refer data from information worksheet and answer questions from RCM decision diagram. Other columns are self-explanatory.

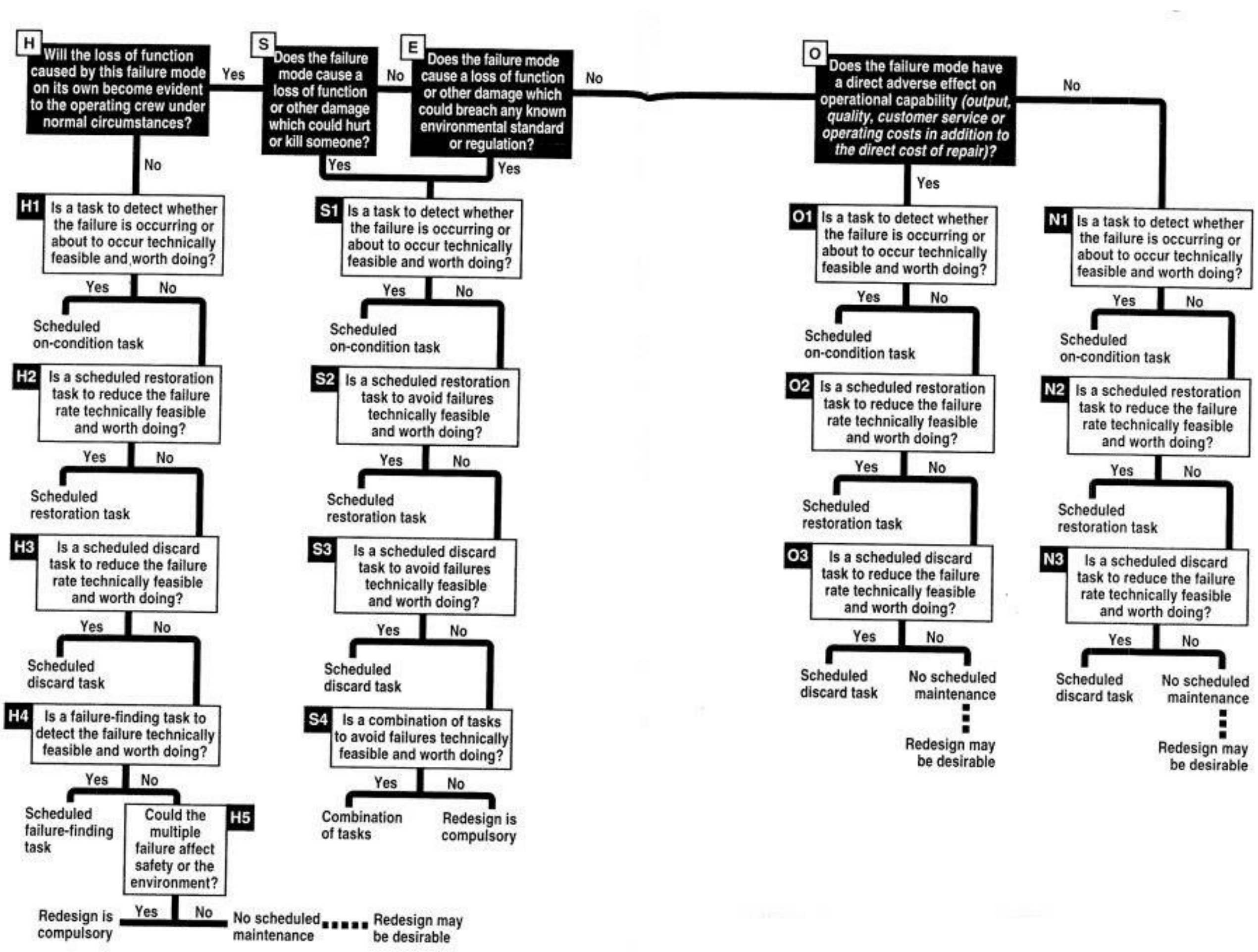

Figure 13 RCM decision diagram (Moubray, J 1997)

Figure 14 demonstrates RCM decision worksheet made by answering questions from RCM decision diagram. Please note that this is general sheet about failure to provide main task of the system. It is possible to create same kind of sheets to every failure mentioned in the previous chapters. Essentially, the RCM worksheets show what course of action and why it was selected to deal with each failure. High importance of this information is based on the possibility to do any maintenance task when required at any time. Documented information also gives ability to trace back each task to the functions, in addition maintenance planning could be up to date if each sheet is stored in a way that you can refer to it while planning current maintenance procedures.

The RCM II Decision Worksheet	System: Isolation structure	System № 1	Tutor Teacher: A. Aimo	Date: 25 5 2015	Sheet № 1
	Sub-System: Hydraulics, Structure	Sub-system № 1,2	Auditor: S. Abramov	Date: 26 5 2015	of 1

Information Reference			Consequence Evaluation				H1 S1 O1 N1	H2 S2 O2 N2	H3 S3 O3 N3	Default Action			Proposed task	Initial Interval	Can be done by
F	FF	FM	H	S	E	O				H4	H5	S4			
1	A	1	Y	Y	N	Y	Y Y						Non-destructive test to check structural integrity	twice a year	NDT specialist
1	A	2	Y	N	N	Y	Y Y						Check hydraulic pressure, internal leakage, control response	annually	Hydraulics specialist
1	B	1	Y	N	N	Y	N	Y					Non-destructive testing	annualy	NDT specialist
1	C	1	Y	Y	Y	N	N	Y					Regular visual check	weekly	Operator
1	C	2	Y	N	Y	Y	Y Y						Non-destructive testing, visual check	annualy weekly	NDT specialist Operator (visual)

Figure 14 RCM decision worksheet. (Abramov 2015)

5 CONCLUSION

During the first steps in the information gathering process for the research project, existing methods of underwater deployment analysed and it became clear to the author that both of them were good in their own ways. The choice of moonpool deployment satisfied the need to implement good practices of equipment handling. The usage of equipment in harsh environments was also possible because of the method chosen.

The main goal was to synergise the knowledge of writing individual with practical experience. Result was better than expected as it was also possible to implement industrial maintenance practices. The author had a vision that students from different fields of engineering should not be bound by their specific field of study. Implementation of different engineering points of view should be encouraged amongst learning facilities and this research project was inspired by this vision.

A hydraulic subsystem was developed in the project and it played a very important role in system operating. Being a student of industrial engineering it was a challenging task to familiarised with marine hydraulics. Thanks to the information provided by HAMK library, it was possible to get acquainted with essentials of the related field.

The developed system major space of improvement. Amongst possible upgrades that could be produced by the students, there are ways to implement automation technology into the compartment. Building automation is also a subject of implementation on-site as the people working there require a pleasant environment so that they are not bothered by the nuisances of humidity, lack of lighting or cold. Building a real working prototype was also possible but it was impossible to implement it into this research project as it required a major investment of time and resources to get acquainted with the material studies. This is also a field of improvement for this project.

Maintenance and design software made this research project possible. Design was made sketch-like in software called Google Sketchup to show visually details of the developed system. Functionality of the design software allowed the author to use real dimensions that led to the adequate approximation of distances between the equipment and their sizes. Maintenance software used was ELMAS by Ramentor. This software allowed the author to simulate failure probabilities and to understand the severity of each possible failure of the system so that the client had information to refer to in case he wanted to implement it.

One of the goals was to create a system or to provide service idea to the offshore industry. This task was fulfilled with the creation of moonpool isolation equipment. It is possible to organise a service that would install and maintain related equipment to vessels that have moonpools.

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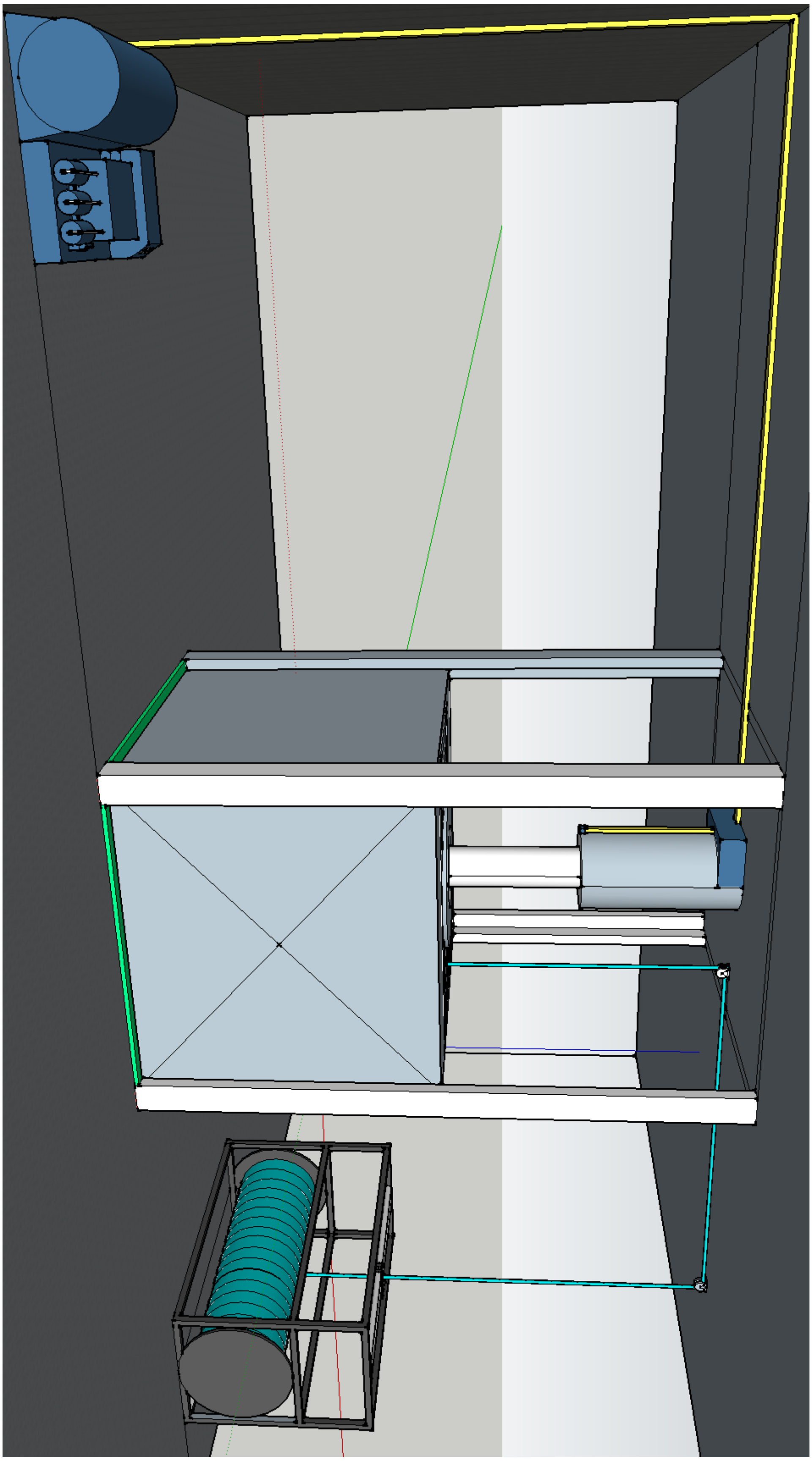
Appendix 1

System sketch drawing



Appendix 2

RCM Information Worksheet

The RCM II Information Worksheet	System: Isolation structure	System № 1	Tutor Teacher: A. Aimo	Date: 25 5 2015	Sheet № 1
	Sub-System: Hydraulics, Structure	Sub-system № 1,2	Auditor: S. Abramov	Date: 26 5 2015	of 1

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		C	Isolation compromised	1	Isolation components worn out	Water starts to leak through the isolation means resulting in formation of pool of liquid that could damage personnel due to slippery surfaces.Water sensitive equipment is in danger as well
				2	Isolation components are fractured	More abundant amounts of water are leaking through damaged zones in comparison to isolation components wear

Appendix 3

RCM Decision Worksheet

The RCM II Decision Worksheet	**System** Isolation structure	System № 1	Tutor Teacher A. Aimo	Date 25 5 2015	Sheet № 1
	Sub-System Hydraulics, Structure	Sub-system № 1,2	Auditor S. Abramov	Date 26 5 2015	of 1

Information Reference F	FF	FM	Consequence Evaluation H	S	E	O	H1 S1 O1 N1	H2 S2 O2 N2	H3 S3 O3 N3	Default Action H4	H5	S4	Proposed task	Initial Interval	Can be done by
1	A	1	Y	Y	N	Y	Y Y						Non-destructive test to check structural integrity	twice a year	NDT specialist
1	A	2	Y	N	N	Y	Y Y						Check hydraulic pressure, internal leakage, control res-ponse	annually	Hydraulics specialist
1	B	1	Y	N	N	Y	N	Y					Non-destructive testing	annualy	NDT specialist
1	C	1	Y	Y	Y	N	N	Y					Regular visual check	weekly	Operator
1	C	2	Y	N	Y	Y	Y Y						Non-destructive testing, visual check	annualy weekly	NDT specialist Operator (visual)