Master of Science

Part D: Finalizing and Summary

Project: Wire Gear for Small Rotary Actuator

Contracting Authority: Kongsberg Space Systems

Rev:	Date:	Author:
5.0	210518	VOA

i. Abstract

In this Part D, the thesis is summarized, a status of requirements and stakeholders are discussed, and risk analysis revisited. Additionally, the system and suggested future work are present and discussed. The purpose of revisiting requirements, stakeholders and risk is to see how the thesis and project changed during development. This should give insights or confirmed the first analysis regarding requirements, stakeholders and risk. What is changed? This question is to be answered.

From Part D, we observe that our prediction regarding requirements, stakeholders and risk was feasible with only minor changes. This shows that appliance of System Engineering is working, and the project is well executed with feasible results.

ii. Contents

iii. Figure List

iv. Abbreviations

CUS	-	Customer
EREQ	-	Environmental Requirement
KSS	-	Kongsberg Space System
REQ	-	Requirement
SRA	-	Small Rotary Actuator
TREQ	-	Technical Requirement
TST	-	Test
UIT/UiT	-	The Arctic University of Norway
US	-	United States
VOA	-	Vebjørn Orre Aarud

1. Introduction

During this Part D, a systematic revisit to requirement status, stakeholder status and risk status are done. We wish to analyze how many requirements are removed, not met, not evaluated, met and partly met. We want to do this to obtain an "value-of-satisfaction". This value is used for the next iteration- almost like a new input or a new set of rules, often called second start from scratch. We also want to analyze how our prediction regarding stakeholders evolved. Did we have the right focus? How did it change during the project? Did we find any new stakeholders? This are questions to be answered. We do this again to get a "value-of-satisfaction" and use this value as described for requirements – input to the new start. Finally, risk management. How did the risk evolve during the project? Did we manage to reduce some risk? Did new risk occur? A complete redo of the risk management is done, often called mitigation phase status. This will directly give information on how the project evolved risk wise.

Figure 1 shows how this value, experience is used to obtain the correct solution. All the solutions in the figure is correct, all solutions are a safe swing from a tree in the garden, but they are all different!

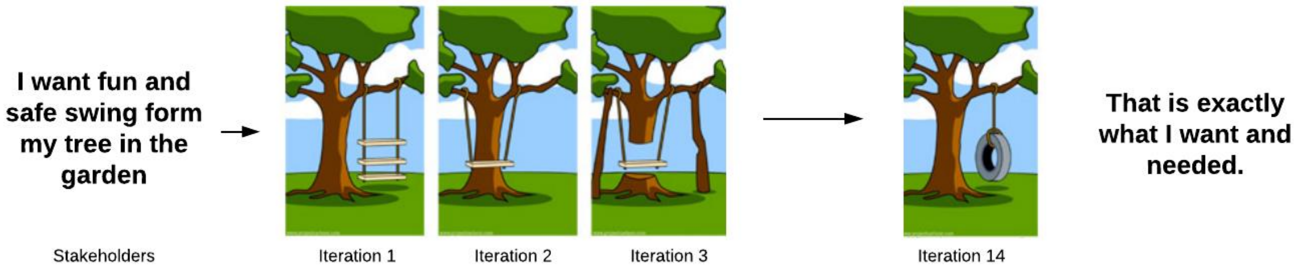


Figure 1: Purpose on iteration and value-of-satisfaction [1].

2. Requirement and stakeholder status

Recall all the requirements from Part A, and the verification methods and test stated. These requirements were tested and investigated during Part C with the stated methods.

By result of the initial requirement following diagram applies.

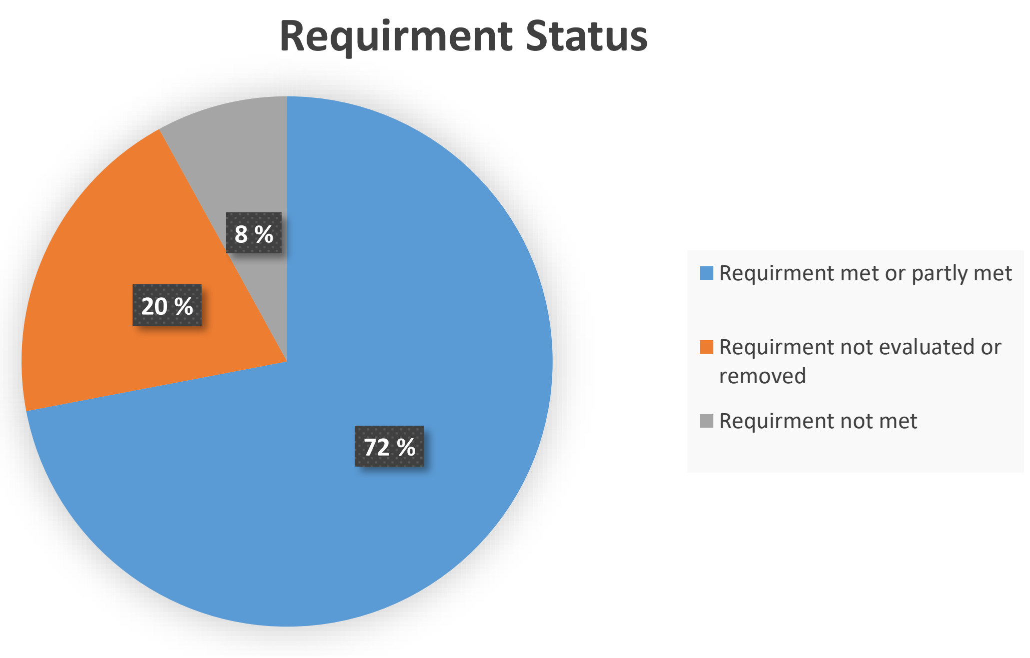


Figure 2: Requirement status.

By this we observe that 72% of the initial requirement is met or partly met. The reason for partly met can be several things. Example requirement TREQ-2 and the respectively test TST-8 related to pointing error is only partly met. This because the pointing budget is weak, and not validated / discussed with KSS. However, it gives a highly estimate on the behavior.

No new global requirements were found. However, the understanding of some requirements was changed. Example TREQ-1, the SRA must have a center hole larger than 30.00mm. At first, I thought this was including test equipment such as loadcell and brackets. This was wrong, and does only apply when all test equipment is removed.

The most important change in this field of the thesis is the initial stakeholder map. Figure 3 shows the stakeholders identified at the beginning of the project and the stakeholders at the end of the project. The most noticeable changes are that UIT had significantly increased in influence. This because they are responsible for the vacuum chamber and external test equipment. This changed during the thesis because KSS did not have available chambers at the given time. In addition, CUS has decreased some in influence but increased in interest. The increase in interest is because of the news of Elon Musk Starlink project being accepted by the US government.

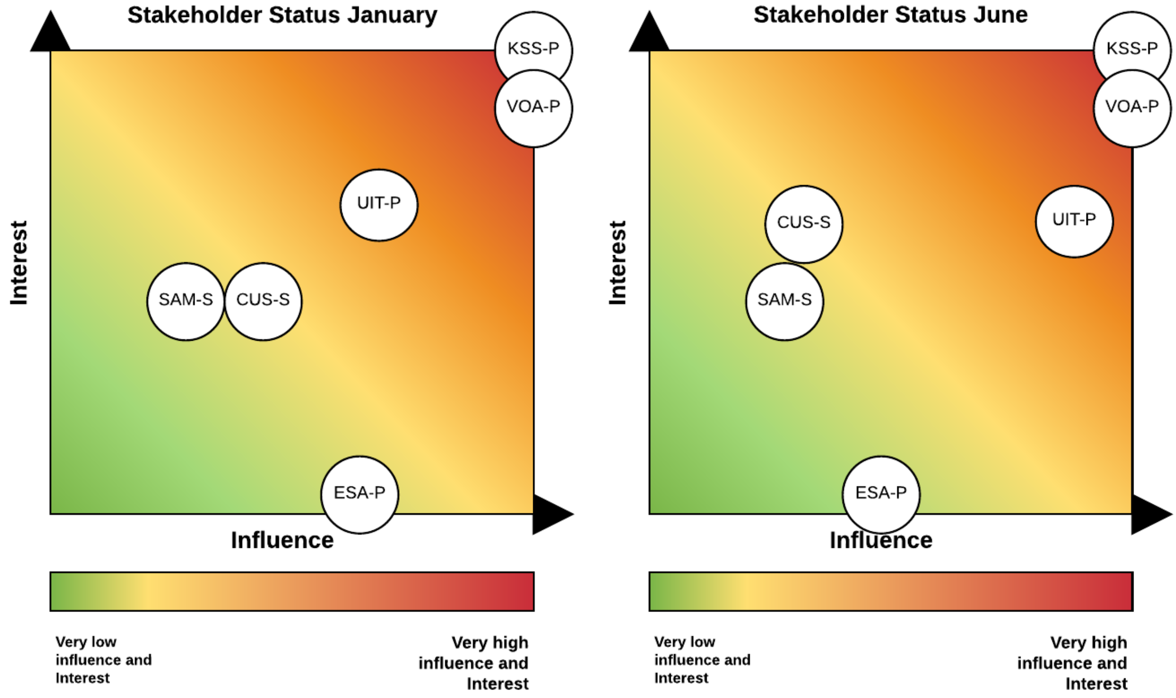


Figure 3: Stakeholders January vs June.

3. Risk Status

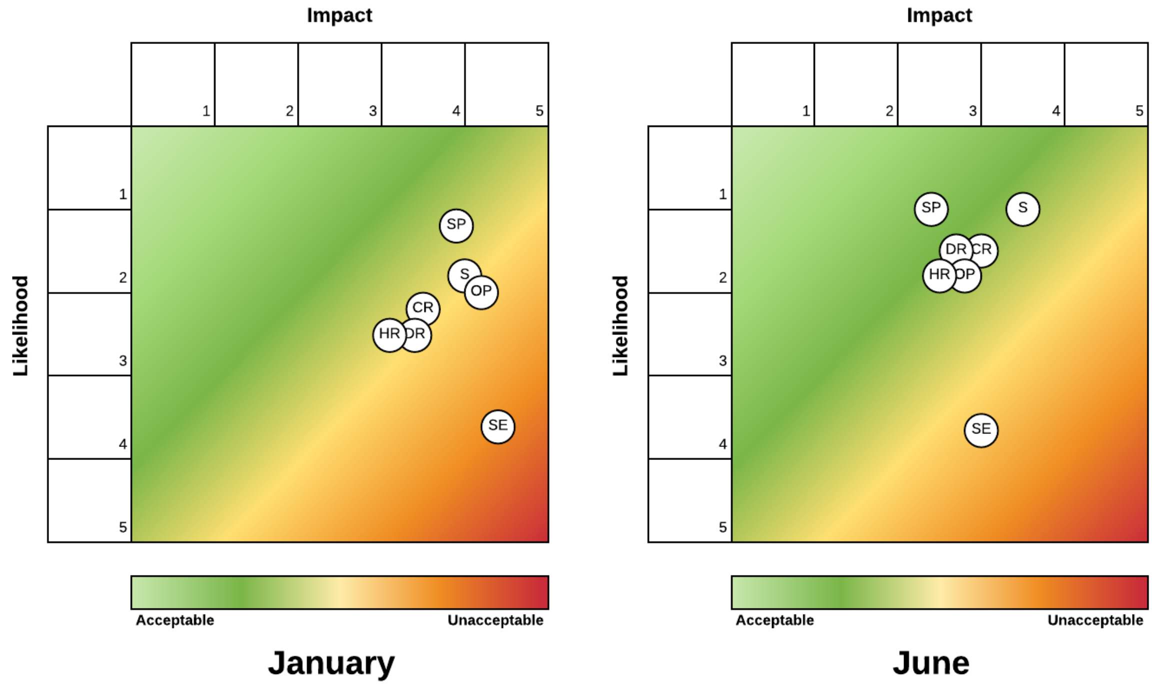
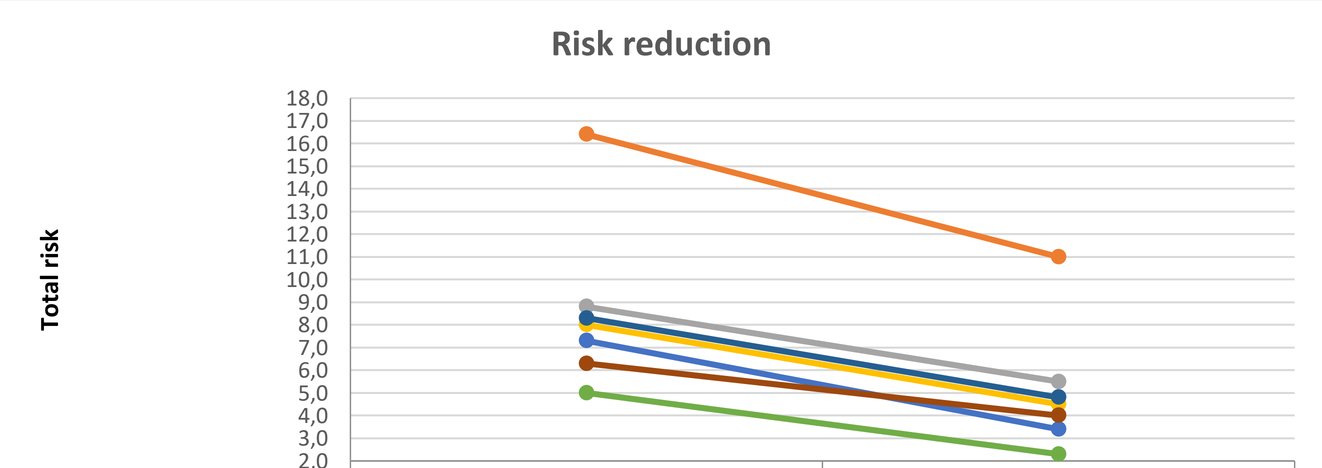


Figure 4: Risk illustration January-June.



	Total risk in January	Total risk in June
Space Environment	16,4	11,0
Operational Risks	8,8	5,5
Cost risks	8,0	4,5
Schedule risks	7,3	3,4
Safety Risks	5,0	2,3
Development risk	8,3	4,8
Human resources risk	6,3	4,0

Figure 5: Risk result January-June.

From Figure 5 and Figure 4 we have the following outcome:

Space environment risk (SE) is reduced by 33%. This mainly because the mitigation plan related to selecting correct materials and following safety factors for structures are being executed. I know I have selected correct material and reduced the risk by 50% because of this. I know this because I followed ECSS guidelines for material selection. However, the risk is still at 11, which means that it's still unacceptable in a global matter and measures should be taken to eliminate the risk even more in future iterations.

Operation risk (OP) is reduced by 38%. This mainly because the mitigation plan related to selecting correct materials and following ESA standards are being followed. In addition, power consumption and lubrication are issues has been investigated. The risk is now 5,5 meaning that its acceptable, but measures should still be taken to reduce the risk even more in future iterations.

Human Resources risk (HR) is reduced by 37%. This mainly because the mitigation plan related to work environment and health is constantly being monitored. The time left per 23.5.18 is small and the impact of sickness or supervisor leaving is small. The risk is now 4.0 meaning that its acceptable, but measures should still be taken to reduce the risk even more in future iterations. Sickness is the variable here.

Development risk (DR) is reduced by 42%. This mainly because the mitigation plan related to design is being followed. The prototype is done, and work as desired. Because the likelihood for design errors is set to 1 because of everything works. The risk is now 4.8 meaning that its acceptable, but measures should still be taken to reduce the risk even more in future iterations. Testing is the key variable for even more reduction.

Cost Risk (CR) is reduced by 44%. This mainly because the mitigation plan related to all cost post are finished, no new purchases is being made. There exist no indicators on issue with cost. The risk is now 4.5 meaning that its acceptable, but measures should still be taken to reduce the risk even more in future iterations. Impact reduction is the key variable for the next iteration – a more comprehensive cost budget should be made.

Schedule Risk (S) is reduced by 53%. This mainly because the mitigation plan related to the likelihood of risk. The project is almost finished, and the there is small to non-risk of schedule issues the last weeks. The risk is now 3.4 meaning that its acceptable and measures may be taken to reduce the risk, but not needed.

Safety Risk (SP) is reduced by 54%. This mainly because the mitigation plan related injuries, work overload is being followed, but mostly because the project is on schedule and almost finished. The risk is now 2.3 meaning that its acceptable and no mitigation needed.

The total project risk is reduced by 41% from 8,6 to 5.0. This means that the project state at this point is acceptable, but measure should still be taken to eliminate risk. This is normal, and more iterations especially related to the technical parts should be executed. See appendix 7.1 for details.

4. System Status

4.1. Stakeholder status within the system

The system is stable, and the stakeholders seems satisfied at this point. A slightly increase in awareness regarding UiT as a stakeholder is the only change related to focus points. Because of this I believe that the right focus was given to the right stakeholder. This is also fairly described and illustrated in selection 2. As mentioned UiT as a stakeholder increased slightly in influence and customer increased slightly in interest. This is the only changes related to stakeholder influence and interest during the project. Additionally, no new stakeholders were found.

As a sub stakeholder status conclusion, the prediction was good, and the focus point was correct. This also is easily to see because of the extremely good prototype.

4.2. Requirement status within the system

It seems that the focus on the pre-empathized requirements was correct. No major time-slips or issues was discovered or handled regarding requirements. This shows that the requirements were fairly correct from the beginning, just small adjustments as discussed in selection 2. No big changes were made, some requirements were removed and some reinterpreted, but causes no big issues. No new significant requirement was identified.

As a sub requirement conclusion, the prediction regarding needed requirements was on point. However, several fields related to non-including topics such as the effect of vibration during launch will affect the requirement table in a major part.

4.3. Risk status within the system

The risk is reduced by 41% as stated in selection 3. It has a value of 5 which means that measures still should be taken. This risk management apply only to this thesis and can be seen as the risk management for the purpose of this thesis. We did manage to reduce the risk with engineering and documentation, and we did not find any new significant risks.

As for a sub risk conclusion, the risk is reduced but not accepted, mainly due to space environment. Note that space environment is not that important for the test in this thesis, but important in the big picture and future iterations. I will say that the risk management worked and proved good information during this thesis. Recall that the prototype is perfectly working as desired.

4.4. Product status within the system

The product work perfectly and as desired. However, after 600,000 cycles a squeaking noise is observed during test but not investigated by 5 of June 2018. The design remarks have not been investigated after the lifetime test neither so this to be continued.

By 7 of June 2018, the squeaking noise was identified in the bearing package and might come from poor lubrication or to high preload in the bearings. Not investigated future. The design remarks had no interference during test. Total thesis conclusion can be found in “Master thesis 2018 Vebjørn Orre Aarud”.

5. Suggested work for next iteration

For the next iteration I suggest that the WG-SRA complete 5M cycles with the following modifications:

- Increase the pitch on the input pully to 2,25mm up from 1,75mm. This because the issue regarding wire contact on the input pully will probably be eliminated.
- Investigate bearing package to eliminate squeezing noise. This to be sure that the bearing package does not compromise the new test round.
- Calibrate loadcell from start and monitor from start with specified load. This to obtain a better view of how the thread behaves from a specific start “point” and to gain more information.
- Continue test – start from Zero and achieve 5M cycles. This to achieve full life cycle.

6. References

[1] "aninquiringmind.org," [Online]. Available: http://www.aninquiringmind.org/wp-content/uploads/2016/06/tire_swing.jpg. [Accessed 24 05 2018].

7. Appendices

7.1. Risk

7.1.1. Space environment risk with mitigation

	Before mitigation					Mitigation 1			After mitigation 1		
RISK	Likelihood	Impact	Total risk	Explanation Likelihood	Explanation Impact	Mitigation action	Mitigation responsible	Mitigation date	Likelihood	Impact	Total risk
Wrong materials	1,0	4,0	4,0	ESA has good handbooks on selection the right material for space systems.	Wrong materials can cause major mechanical and optical (outgassing) system fails.	Follow ESA standards for materials	VOA	Phase 2	1,0	2,0	2,0
Not defining the right safety factor for components	2,0	4,0	8,0	ESA has good handbooks on selection the right safety factors for space systems.	Wrong saftey factors can cause major mechanical systems fails.	Follow ESA and Kongsberg Space systems recommandations	VOA	Phase 2	2,0	3,0	6,0
Collision	5,0	5,0	25,0	The likelihood of collison with micro meteorites in space is high.	A hole in the mechanism can cause total fail.	Verify sizing with Kongsberg Space System	VOA	Phase 2	5,0	4,0	20,0
Radiation	5,0	4,0	20,0	The SRA will be hit by radiation	Radiation causes the string to degrade	Follow ESA standards for materials and internal testing	VOA	Phase 2	5,0	3,0	15,0
Pressure	5,0	5,0	25,0	The SRA will be operation in vacum	Vacum can cause outgassing of selected component. This may interfere with other systems.	Follow ESA standards and internal testing	VOA	Phase 2	5,0	3,0	15,0
Space Environment	3,6	4,4	**16,4**						3,6	3,0	**11,6**

7.1.2. Operational risk with mitigation

RISK	Likelihood	Impact	Total risk	Explanation Likelihood	Explanation Impact	Mitigation action	Mitigation	Mitigation	Likelihood	Impact	Total risk
Performance degradation	2,0	4,0	8,0	Degradation of the SRA can lead to increased pointing error.	Increased pointing error can lead to underperforming or not preforming at all. This makes the SRA useless	Follow ESA standards for materials and create a worst case pointing budget	VOA	Phase 2	2,0	3,0	6,0
Increased power consumption	1,5	4,0	6,0	Wrong motor or gear ratio can lead to increased use of power.	Increased power consumption can lead to system failure	Follow KSS experiance and ESA standars for motors	VOA	Phase 2	1,0	2,0	2,0
Consumable articles failure	1,5	4,0	6,0	Selection of wrong lubrication etc can lead to worng life time of	This risk can cause decrease the SRA's lifetime.	Following KSS experiance	VOA	Phase 2	1,0	2,0	2,0
Unstable architecture	3,0	5,0	15,0	Limitied time for verification and testing. High demand of test equipment at KSS	An unstable SRA can lead to project hold.	Following KSS experiance	VOA	Phase 2 & 3	3,0	4,0	12,0
Operational Risks	2,0	4,3	**8,8**						1,8	2,8	**5,5**

7.1.3. Cost risk with mitigation

	Before mitigation					Mitigation 1			After mitigation 1		
RISK	Likelihood	Impact	Total risk	Explanation Likelihood	Explanation Impact	Mitigation action	Mitigation responsible	Mitigation date	Likelihood	Impact	Total risk
Going over budget	2,0	3,0	6,0	The budget is set by KSS. The budget is relativy high based on experiance	going over budget results in additonal meeting. Worst case project delays	Contacting KSS ASAP	VOA	Phase 2	1,0	3,0	3,0
Technical budgets	2,5	4,0	10,0	Technical requirments are highly spesifyed in the requirment selection.	By not meeting a requirment the project can have large delays	Quick design reveiw - consecutively verification	VOA	Phase 2	2,0	3,0	6,0
Cost risks	2,3	3,5	**8,0**						1,5	3,0	**4,5**

7.1.4. Schedule risk with mitigation

	Before mitigation					Mitigation 1			After mitigation 1		
RISK	**Likelihood**	**Impact**	**Total risk**	**Explanation Likelihood**	**Explanation Impact**	**Mitigation action**	**Mitigation responsible**	**Mitigation date**	**Likelihood**	**Impact**	**Total risk**
Wrong model	2,5	3,0	7,5	The selected model is a hybrid between two models	following the wrong model can increase cost and cause delays	Part A - CONOPS	VOA	Phase 1	1,0	2,0	2,0
Failure to follow Engineering model	1,5	4,0	6,0	This is the 3th time following this hybrid model for the autor.	following the wrong model can increase cost and cause delays	Part A - CONOPS	VOA	consecutively	1,0	2,0	2,0
Time slips	2,0	4,0	8,0	Some timeslips can not be conntrolled	project delays	Part A - CONOPS	VOA	consecutively	1,0	3,0	3,0
Late changes in requirements	2,0	5,0	10,0	Unseen requirments can apprear	if fundamentals requirments is added or changed large project delays may happen	Part A - CONOPS	VOA	consecutively	1,0	5,0	5,0
Document setup changes	1,0	5,0	5,0	Document setup is set by KSS.	If fundamentals in document setup is added or changed larg project delays may happen.	Part A - CONOPS	VOA	consecutively	1,0	5,0	5,0
Schedule risks	1,8	4,2	**7,3**						1,0	3,4	**3,4**

7.1.5. Saftey risk with mitigation

	Before mitigation					Mitigation 1			After mitigation 1		
RISK	**Likelihood**	**Impact**	**Total risk**	**Explanation Likelihood**	**Explanation Impact**	**Mitigation action**	**Mitigation responsible**	**Mitigation date**	**Likelihood**	**Impact**	**Total risk**
Workplace injury	1,0	4,0	4,0	Norway has strong regulations for school envitoment.	if a workplace injury has happend, large project delays may happen.	Contact UIT	VOA	consecutively	1,0	2,0	2,0
Work overload	2,0	3,5	7,0	Woring estimates on work load is feasable	if it is planned to much work, project can be delyed.	Contact UIT	VOA	consecutively	1,0	2,0	2,0
Unanticipated safety situations	1,0	4,0	4,0		if a Unanticipated safety situationsy has happend, large project delays may happen.	Contact UIT	VOA	consecutively	1,0	3,0	3,0
Safety Risks	1,3	3,8	**5,0**						1,0	2,3	**2,3**

7.1.6. Development risk with mitigation

	Before mitigation					Mitigation 1			After mitigation 1		
RISK	**Likelihood**	**Impact**	**Total risk**	**Explanation Likelihood**	**Explanation Impact**	**Mitigation action**	**Mitigation responsible**	**Mitigation date**	**Likelihood**	**Impact**	**Total risk**
Not vaild test	2,0	3,0	6,0	The author has some experiance with testing at this point	Feasable to happen - medium to small delay	Contact KSS	VOA	phase 3	2,0	3,0	6,0
Wrong test	2,0	3,0	6,0	The author has some experiance with testing at this point	Feasable to happen - medium to small delay	Contact KSS	VOA	phase 1	2,0	3,0	6,0
Fail during test	2,0	4,0	8,0	The author has some experiance with testing at this point	Feasable to happen - medium to small delay	Contact KSS	VOA	phase 3	2,0	3,5	7,0
Design errors	3,0	3,0	9,0	The author has some experiance space solution designing. Wire is a new topic	Feasable to happen - medium to small delay	Contact KSS	VOA	phase 2	1,0	3,0	3,0
Drawing erros	3,0	3,0	9,0	The author has some experiance space solution designing. Wire is a new topic	Feasable to happen - medium to small delay	Contact KSS	VOA	phase 2	1,0	1,0	1,0
Communication errors	3,0	4,0	12,0	Wrong communication between KSS, author and UIT may happen	Feasable to happen - medium to small delay	Contact KSS/UIT	VOA	consecutively	2,0	3,0	6,0
Development risk	2,5	3,3	**8,3**						1,7	2,8	**4,8**

7.1.7. Human Resources risk with mitigation

	Before mitigation					Mitigation 1			After mitigation 1		
RISK	**Likelihood**	**Impact**	**Total risk**	**Explanation Likelihood**	**Explanation Impact**	**Mitigation action**	**Mitigation responsible**	**Mitigation date**	**Likelihood**	**Impact**	**Total risk**
Work enviorment	3,0	3,0	9,0	Disturbation of co-workers is known to happen	Feasable to happen - medium to small delay	Contact UIT	VOA	consecutively	2,0	3,0	6,0
Supervisors leaving	1,0	4,0	4,0	Contract binding supervisor	Can cause large delays	Contact UIT	VOA	consecutively	1,0	2,0	2,0
Sickness	2,0	3,0	6,0	Normal health assumed	Can cause large delays	Contact UIT/KSS	VOA	consecutively	2,0	2,0	4,0
Human resources risk	2,0	3,3	**6,3**						1,7	2,3	**4,0**