PREFACE

This thesis has been written as the final part of the Master of Science programme in Industrial Engineering and Management at Lund University, Faculty of Engineering (LTH). The study was carried out as an internship for the European Space Agency (ESA) at the European Space Research and Technology Centre (ESTEC) in Noordwijk, the Netherlands. The thesis is focused on evaluating different software solutions that should support the Risk Management process while implementing complex space projects at ESA.

There are a lot of people I would like to thank for assisting me throughout this project. First my supervisor at ESA, Zaky El Hamel who organized my training period and guided me through the whole project from start to end; Bertil Nilsson, my supervisor at Lund University, who has provided lots of support and feedback and helped me with the academic part of the thesis; everyone at ESTEC who has taken an active part in the project and provided me with valuable advices, guidance, information and support when writing this report including Massimo Falcolini, Bernard Weymiens, Maria-Gabriella Sarah, Salim Ansari, Isidro De Paz, Louise Daly, Raul Alarcon, and Raffaele Tosellini.

I would also like to take the opportunity to thank everyone else, especially the members of the JWST team, who ensured a pleasant and rewarding placement at ESTEC.

Although I have interacted with several people during the completion of this report it is in the end me, the author, who is responsible for the report and its contents.

Lund 2010-06-03
Claes Ohlsson

ABSTRACT

Projects in the space domain are extremely complex and often characterized as being “one-off”, which makes it very difficult to make good predictions on future developments. Furthermore, space projects are also associated with state-of-the-art technology, high costs and long development time. Risks are therefore a threat to project success because they may have negative effects on the project cost, schedule and technical performance.

In order to properly manage these potential risks, a Risk Management (RM) process is implemented as a support in the various project phases. The RM discipline provides a framework for an iterative process that shall be used for finding, dealing and working proactively with project risks.

To facilitate the proper implementation of the RM activities ESA has developed, together with a software company, a Risk Management system, Alpha. This is a customized solution and a question has been raised whether or not the customized solution is the best approach. Some reasons being that ESA has to take all the cost and initiative for further development of the system. As an alternative, a COTS solution could be implemented. In order to find out what direction to take a question needs to be initially answered: *Are there any available COTS solutions that are capable in supporting ESA’s RM process and replacing the existing solution?*

This report has tried to answer the question through conducting a survey of commercially available RM tools and through performing a benchmarking exercise where four COTS solutions were compared with the existing customized solution. The survey was based on some of the major RM elements suggested by the ECSS standard for RM with the purpose to find and down select four tools to be included in the benchmark. The benchmark was in general based on a framework for software requirements suggested by Soren Lausen and interviews with relevant ESA personal but in particular based on the ECSS standard for RM.

Several capable solutions where found in the survey but an analysis of the results separated four tools (Alpha, Beta, Gamma and Delta) to be included in the benchmark. The systems acquired the following score for the mandatory requirements: Alpha 80 %, Beta 67 %, Gamma 79 % and Delta 74 %.

From these results and the benchmark the author drew the following conclusions:

- Alpha is performing well and the tool is superior, compared to the evaluated commercial tools, in terms of reporting requirements.
- Two tools, Gamma and Delta, are able to compete with Alpha in terms of overall performance. Gamma scored almost equally with Alpha and if the tool supports the claimed configuration possibilities it could achieve a perceivable increase in score. This basically means that if ESA would change strategy and implement a commercial tool instead, the agency would not have to sacrifice anything in terms of relative performance (there would of course be gains/sacrifices for specific requirements).
- Beta is currently not able to compete in terms of performance with the other tools.
- The approach of sending the requirement list as an enquiry to Epsilon's developer did not provide sufficient information to include the system in the benchmark. However, the impression is that the tool may be capable in supporting ESA's RM process.
- Alpha scored 80 % for the mandatory requirements, which means that there is a possibility to improve the system. In chapter six suggestions of further development of the tool has been presented which could increase Alpha's score to 97 %.

While Alfa is definitely a good candidate for continuing supporting the ESA RM process, especially if the suggestions for further developing the tool are taken into consideration, the author's opinion is that the agency should further investigate the possibility of implementing a new RM system. A recommended approach is to extend the investigation described in this report by including additional parameters (e.g. one of them also being financial) with the objective to improve the current process and find a suitable vendor competent in both the IT and RM fields. In this investigation a third party consultant could be included with experience in the area of IT but most importantly also in the RM field. Such project could be beneficiary for ESA both from an IT and from a RM point of view.

The author's opinion is that the developed methodology used in this study has provided ESA with proper results and could be used in similar future studies. However, as the requirements were assessed quantitatively an assessment of the importance or criticality of each requirement would have provided even better results.

SAMMANFATTNING

Projekt inom rymdindustrin är av extremt komplex karaktär och nästan aldrig det andra likt, något som gör det oerhört svårt att förutspå vilka framtida problemscenarion som kan uppstå under projektets gång. De är också associerade med höga kostnader, avancerad teknologi och långa tidshorisonter vilket innebär att oförutsedda problem kan ha en stor negativ påverkan på uppsatta projektmål.

För att kunna arbeta konstruktivt med de problem som kan uppstå under projektets gång har ESA implementerat en riskhanteringsprocess till stöd för projektprocessen. Detta för att säkerställa att man arbetar proaktivt med olika risker i ett projekt och att rätt beslut fattas. För att underlätta och effektivisera riskhanteringsarbetet har man också tillsammans med ett mjukvaruföretag utvecklat ett riskhanteringssystem, Alpha. Huruvida detta är den bästa lösningen har dock på senare tid ifrågasatts när faktorer som att ESA får ta all kostnad och allt initiativ för vidareutveckling av systemet tas i beaktning. Ett möjligt alternativ är att istället för den befintliga lösningen köpa in ett kommersiellt standardsystem där utvecklaren är specialiserad på just riskhantering. För att undersöka saken vidare måste en viktig fråga först besvaras: *Finns det några standardlösningar på den kommersiella marknaden som är kapabla att stödja ESAs riskhanteringsprocess?*

Denna rapport har försökt att svara på denna fråga genom att genomföra en undersökning av den kommersiella marknaden för riskhanteringssystem och med detta som utgångspunkt, testa och jämföra några av dessa lösningar mot det befintliga systemet. Undersökningen är baserad på de viktigaste elementen från ECSS-standarden för riskhantering och jämförelsen av systemen är baserad på Soren Lausens bok *Software Requirements – Styles and Techniques*, på intervjuer med anställda på ESA och mer djupt ingående på ECSS-standarden för riskhantering.

Flera intressanta lösningar hittades i den initiala undersökningen, dock var det fyra system (Alpha, Beta, Gamma och Delta) som utmärkte sig och dessa blev därmed inkluderade i den slutgiltiga jämförelsen. Respektive system erhöll följande poäng för de obligatoriska kravspecifikationerna: Alpha 80 %, Beta 67 %, Gamma 79 % och Delta 74 %.

Nedan följer de slutsatser som författaren drog utifrån resultatet av jämförelsen:

- Alpha är ett bra system på alla punkter och är överlägsen de andra systemen på att generera önskvärda rapportformat.
- Prestandamässigt är två system, Gamma och Delta, konkurrenskraftiga. Gamma erhöll en poäng likvärdig Alphas. Om systemet går att konfigurera i den utsträckning som är påstådd av utvecklaren skulle Gamma kunna erhålla en märkbar poängökning. Det betyder att om ESA skulle ändra strategi och implementera en kommersiell lösning, skulle inte organisationen behöva uppoffra någon relativ prestanda (det skulle dock självklart leda till förbättring/försämring på specifika punkter).
- Enligt utvärderingen är Beta inte tillräckligt bra för att konkurrera med de tre toppnoterade systemen.
- Tillvägagångssättet att skicka kravspecifikationslistan till Epsilon's utvecklare och låta företaget använda listan för att utvärdera sin egen produkt gav inte tillräckligt bra information för att ha med systemet i den slutgiltiga jämförelsen. Den kvarvarande uppfattningen är dock att systemet kan vara kapabel att stödja ESA's riskhanteringsprocess.
- Alpha uppnådde 80 % av de obligatoriska kraven, vilket innebär att det finns utrymme för förbättringar. I sjätte kapitlet har författaren gett förslag på förbättringar vilka skulle kunna öka Alpha's poäng till 97 %.

Eftersom det finns kommersiellt tillgängliga system som är kapabla att stödja ESA's riskhanteringsprocess anser författaren att organisationen ska fortsätta att överväga att implementera ett nytt system. Något man först dock borde ifrågasätta är varför en rymdorganisation utvecklar system för att stödja affärsprocesser om det redan existerar flera befintliga aktörer med mångårig erfarenhet inom ämnet. En rekommendation är att utvidga undersökningen gjord av denna rapport och denna gång inkludera fler parametrar t.ex. ekonomiska. Detta med syftet att förbättra processen och att hitta en passande utvecklare som har sin nisch i IT– och riskhanteringsområdet. I denna undersökning skulle man i så fall kunna inkludera en tredjepartskonsult som har erfarenhet inom områdena. En sådan undersökning skulle ESA kunna dra fördel av både genom en förbättrad process och ett förbättrat system.

TABLE OF CONTENTS

1 INTRODUCTION

In this chapter the author aims to give the reader an understanding of the report's background. The chapter will also include a presentation of the European Space Agency as well as the report's purposes and objectives.

1.1 Background

Projects in the space domain are extremely complex and often characterized as being "one-off", which makes it very difficult to make good predictions on future developments. Furthermore, space projects are also associated with state-of-the-art technology, high costs and long development time. Risks are therefore a threat to project success because they may have negative effects on the project cost, schedule and technical performance. A "good" example is the Hubble Space Telescope, a project that was carried out by the National Aeronautics and Space Administration (NASA). The project was delayed 7 years beyond its original launch date and the cost had increased with a factor 4 or 5 times its original cost estimates before the telescope was finally put into orbit in 1990 to a cost of around $1.6 billion.[1] But the setbacks did not end there. Due to a problem with the primary mirror the telescope sent blurry pictures back to earth and a repair mission was implemented ending up with an additional price tag of $700 million.[2] The Hubble project is unfortunately not an exception in the space industry. When it comes to space projects, a majority of the projects have overruns in terms of cost and duration.

To guarantee, to a project's stakeholders, ESA's capabilities and preparedness to set objectives and pursue their successful attainment the agency has implemented Risk Management (RM) as a support to the project process. The requirements for the RM process are defined in documents such as the "ESA Risk Management Policy" and standards e.g. "Space Project Management – Risk Management" provided by the "European Cooperation for Space Standardization" (ECSS).[3] These documents and standards stress i.a the

[1] Wilson R.N, 1999, *Reflecting Telescope Optics II*, p. 193
[2] http://www.wired.com/science/discoveries/news/2004/02/62242, *Hubble Space Telescope: 1990-2007*, 2009-07-15
[3] ESA Risk Management Policy

importance of documenting, communicating and reporting risks throughout the process.

For an international organization such as ESA, implementing Risk Management means that a lot of information and data need to be handled and thus the organization decided to develop an IT-system to facilitate the process. ESA outsourced the development of the software but decided to develop the system in-house and according to the organization's preferences.

1.2 European Space Agency (ESA)

ESA is an intergovernmental organisation dedicated to space oriented activities. The agency's mission is to:

"*Shape the development of Europe's space capability and ensure that investment in space continues to deliver benefits to the citizens of Europe and the world"*. – ESA website

This is carried out by elaborating and implementing a European space policy, suggesting and implementing (approved ones) space activities and projects and coordinating the European space programme, a mission with solely peaceful intentions.

1.2.1 History

After the Second World War European scientists realized that space projects and research on a national basis in Europe would not be able to compete with the ones carried out in the US and the Soviet Union. As a result, ESA's predecessor, European Space Research Organisation (ESRO) was formed in 1961 by ten European countries with the mission to develop a European space programme. Three years later the member states decided to have two different agencies, one responsible for developing spacecrafts (ESRO) and one, European Launch Development Organisation (ELDO), responsible for developing a launch system.

ESA, in its current form, was founded in 1975 by ten European countries (Belgium, Germany, Denmark, France, United Kingdom, Italy, the Netherlands, Sweden, Switzerland and Spain) through a merger between ESRO and ELDO. Since then the agency has extended its number of member states to 18 (2009) with Ireland, Austria, Finland, Greece, Czech Republic, Portugal, Luxembourg and Norway as affiliating nations. Further; Canada, Hungary, Romania, Poland, Slovenia and Estonia have signed cooperation agreements with the agency.

ESA has throughout its history implemented several different space projects. Venus Express was launched in November 2005 with the purpose to study the planet Venus. It has made several discoveries including finding evidence that the planet once had surface water. Rosetta (launch date: 2004-03-02) is another example of an ESA project and the first mission designed to orbit and land on a comet (expected arrival in 2014). The agency is also involved in international projects, e.g. the ISS (International Space Station) to which ESA has made contributions such as the science laboratory module, Columbus. In addition to these projects the agency also has a human spaceflight programme. This programme has in cooperation with NASA and RKA sent several European astronauts into space.

1.2.2 Organisation and sites

As being an intergovernmental organization, ESA has a governing organ, “the Council”, which is composed by representatives from the agency’s member states. The council is responsible for:

- Drawing up the European space plan and ensuring that it is being followed
- Approving both ongoing and future Programmes
- Deciding on the level of resources to be made available to ESA[4]

Another of the Council’s responsibilities is to appoint a “Director General” (DG), the chief executive officer and legal representative of ESA who is managing the agency in accordance with the directives set by the Council.[5]

All the activities carried out at ESA are divided into 10 different directorates (see figure 1.1), each headed by a director who reports directly to the DG and each with a specific area of responsibility.

[4] http://www.esa.int/esaCP/ESATE4UM5JC_index_0.html, *The ESA Council*, 2009-07-16
[5] Convention for the establishment of a European Space Agency & ESA Council – Rules of procedure, March 2003

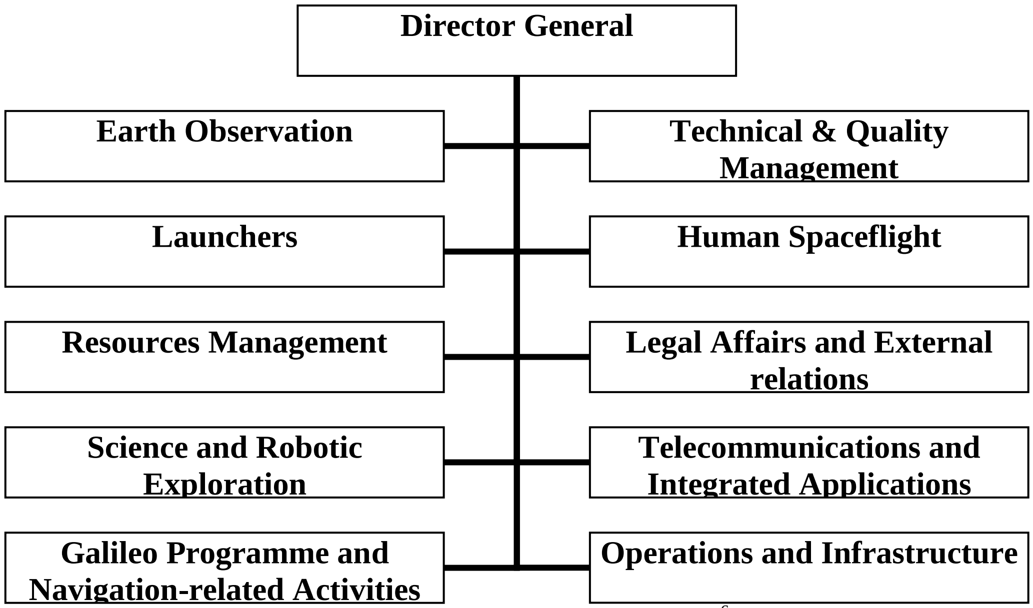

Figure 1.1 Organisational structure for the DG and the Directorates[6]

The agency has around 2000 employees and an annual budget of €3591 million (2009). The main sites constituting ESA are:

- Headquarter in Paris, France.
- EAC, the European Astronauts Centre in Cologne, Germany.
- ESAC, the European Space Astronomy Centre, in Villanueva de la Canada, Madrid, Spain.
- ESOC, the European Space Operations Centre in Darmstadt, Germany.
- ESRIN, the ESA centre for Earth Observation, in Frascati, near Rome, Italy.
- ESTEC, the European Space Research and Technology Centre, Noordwijk, the Netherlands.

1.2.3 Funding

The majority of the programmes carried out at ESA are funded by its member states, but a single member state can still to some extent decide its level of involvement. As a member it is compulsory to contribute, based on a member state's Gross Domestic Product (GDP), to the activities which fall under the

[6] http://www.esa.int/esaCP/ESATE4UM5JC_index_0.html, *The ESA Council*, 2009-07-16

general budget and the scientific programme. These are called the "mandatory" activities and include basic activities such as studies on future projects and technology research. On the contrary there are the "optional" activities (e.g. activities that falls under the earth observation and human spaceflight programme) for which member states can decide their level of involvement. The figure below shows 2009's budget for the mandatory and optional programmes.

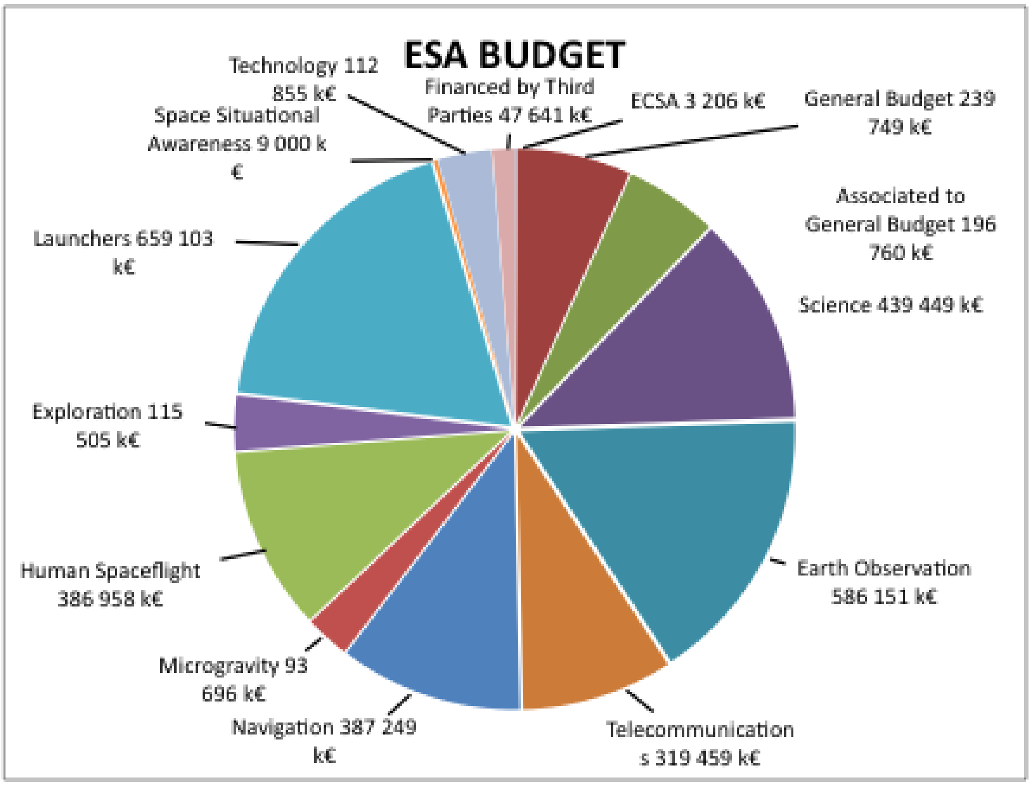

Fig 1.2 ESA's budget 2009 by programme

1.2.4 A cooperation with European industry

After getting an insight in how ESA's activities are funded one could ask themselves what the benefits as a member state are and why a member state should contribute to the optional activities. The answer to this starts with getting a general understanding of ESA's role in a project. When space projects are born and developed at ESA the agency works closely with the European industry. Though ESA is coordinating the project from an idea phase to the actual implementation some processes are outsourced to commercial companies within the agency's member states. Such contracted processes include for example manufacturing which exclude a common misconception that "ESA is producing satellites". Which company/companies that will be involved in the project is/are to some extent regulated through something called the "geographical return". This means that ESA is investing a more or less equivalent amount of a member state's contribution back into the country's local industry. Thus ESA is not only providing European citizens with benefits through technology and research but also in terms of jobs and economic growth within its member states.[7]

1.3 Problem description

Some years ago one of ESA's directorates, Science and Robotic Exploration (SRE), contracted a software developer to create a fully customized IT tool to be used as a support for SRE's RM process. Since then the tool has been in constant development adding new functionality according to SRE's needs. Compared to a commercial standard solution, it is questionable whether or not the customized solution is the most effective one. Especially when considering the following aspects:

- The contracted company may not have the necessary competency in the field of RM, which may lead into problems during the development of the tool
- All initiative and associated costs for further development/enhancement of the tool are to be born by the Agency.
- As being the only customer of the tool, the Agency shall also cover the necessary costs for maintenance and support.

The list can be made long, but there are of course also sizeable benefits when going for a fully customized solution. Most importantly, SRE can control the development according to the directorate's needs.

If there are no commercially available tools capable in supporting ESA's RM process, then a customized solution is the only option. If this is not the case, the agency may reconsider its approach. In order to fully understand what options

[7] http://www.esa.int/esaMI/About_ESA/SEMW16ARR1F_0.html, *What is ESA?,* 2009-07-16

ESA and SRE have available today, a project was initiated to benchmark the existing tool and together with suitable commercially available solutions.

The main question this report will try to answer is:

- How well does the existing tool perform compared to solutions available on the commercial market?

1.4 Focus and delimitations

The project will focus on finding what Soren Lausen in his book "Software Requirements – Styles and Techniques" refers to as a COTS (Commercial Off The Shelf) system. In this report this will also refer to software only, not hardware.

The report will focus on finding a support tool for *risk management on a project basis*. Thus, it will not consider the process of managing operational risks. Neither will the report focus on questioning the risk management process itself and will therefore mainly consider, in the theory chapter, the approach provided by the European Corporation of Space Standardisation (ECSS).

The presented considerations and recommendations will almost entirely be based on software performances/capabilities, based on a consolidated set of requirements identified together with the SRE management and potential users. No recommendations will be presented of what option ESA should proceed with (the already implemented customized solution or any of the commercially available tools) as this would require an investigation of several other aspects (e.g. return on investment, long term pros/cons etc.), outside of the scope of this work.

1.5 Target group

The primary target group is ESA staff members dealing with Project Management, Project Control, Quality Assurance and System Engineering. The second target group include University students in the fields of Risk, Project and Quality Management as well as Information Technology.

1.6 Purpose and goals

The main purpose of this report is to provide ESA with a relative comparison (mainly in terms of performances and capabilities) between the agency's customized RM solution and commercially available RM solutions. With this as a base the author will provide ESA with, for each tested tool, recommendations and aspects to consider. Thus, the benchmarking will also address what each tool lacks and where there are room for improvements. To verify and present the final recommendations the study has been broken down into a number of phases:

- Empirical study of ESA's (SRE's) RM process
- Survey of commercially available RM tools
- Down selection and demo acquisition
- Development of user/software requirements list
- Evaluation and benchmarking
- Final considerations and recommendations

1.7 Report outline

The report will consist of the following main chapters:

Methodology
The methodology chapter will present and discuss the methodological approach that was used in the report. The aim of the chapter is to provide a clear and complete description of the steps when writing the thesis and to ensure that the research has been carried out properly.

Theoretical framework
This chapter will have two parts. The first one will present the Risk Management process suggested by the ECSS, which will form a foundation for the coming chapters. It will also be used to validate the input from the software users. The second part will present a framework when defining and structuring software requirements.

Empirical study of ESA RM process
Basically, one could define a requirement list based entirely on the ECSS standard. This would however not be appropriate as the standard is intended to provide a framework for the actual work tasks and thus there will be some

differences between practise and theory. This chapter aims to provide a general understanding of the actual RM process at ESA. The approach does also provide an opportunity to validate and compare the user requirements.

Tool for selection and market survey

The aim with the report is to find a number of commercial RM tools and compare them with the existing one. This chapter will explain and present the survey that was conducted in order to investigate the market and to down select a number of tools to be further analysed and included in the benchmark.

Software Requirements

Based on ESA's current RM process, requirement engineering was performed in order to create a framework for the benchmark. In this chapter the developed list of requirements that was used in the benchmark will be explained. The actual requirements are listed in Appendix VI.

Benchmarking: Analysis and Results

The outcome of the benchmark will be presented and analysed in this chapter. It will start with a presentation and an overview of the benchmark. Then each tool is presented along with their major strengths and weaknesses. Finally, a relative comparison between the tools is presented.

Considerations and Recommendations

With the previous chapter as a base, considerations and recommendations for each evaluated tool is presented in this chapter depending on ESA's future approach.

Conclusion and Reflections

The conclusion will summarize the most important parts in the previous chapters and answer how well the existing RM tool is performing compared with the commercial solutions. The chapter will also present some reflections the author got from the project.

2 METHODOLOGY

In this chapter the author will discuss the used methodology when writing the thesis.

2.1 ECSS-M-ST-80C and Case Study

In order to understand the requirements for a RM solution the actual process has to be described and studied. As ESA's RM process is aligned with ECSS's standard for RM (ECSS-M-ST-80C, see part 3.2 for more information), this will be considered as the main theoretical framework for understanding the process and the base for both the *tool for selection* and the *benchmark*.

An empirical study of the actual process will also be carried out in order to provide a deeper understanding of how the standard has been implemented. Thus, the standard does only provide a framework for how the process should be implemented which means that in most cases there is room for interpretation. For this part the author will primarily use the *case study* approach. This means that when describing ESA's actual RM process, a specific case will be studied and this case will be considered to represent the whole organization. This approach has both pros and cons compared with studying several cases more superficially. The pros including: less time consuming and deeper understanding of the specific case. The cons including: the case might not be representative for the organization and important parts might be missed.

The empirical study of ESA's RM process will be represented by the activities carried out under the directorate of Science and Robotic Exploration (SRE) for the James Webb Space Telescope project. The reason for this is mainly because the directorate is in the frontline of implementing RM at ESA (which implies that the studied case is representing how ESA actually wants to work with RM). Some other projects will also be superficially studied, as this will provide an idea of the needed flexibility of the RM tool.

In cases where the aim is to define a number of software requirements the *case study* approach can be beneficial because it will most probably narrow down the scope of each requirement. This will further define a better system standard and a standard way of doing things, something that large organizations such as ESA are striving for.

The study will be performed primarily through gathering relevant information from RM documentation and through in depth interviews with the *project group*. The aim for the study is to provide additional and more accurate information for the *tool for selection* and the *benchmark.*

2.2 Tool for selection and survey

One of the first tasks in this project is to find four suitable tools to be compared with the existing solution. The natural approach is thus to initially find as many tools as possible that fits ESA's basic criteria for a RM solution, and from this population select four tools with the most potential for the comparison. There is of course an option to include all the tools in the benchmark but that would not be feasible from a time point of view. Commercially available RM solutions will mainly be found through searching the Internet but also through asking employees at ESA with experience in the field as well as actors in the same and related industry.

The question that now needs to be answered is: which of the investigated solutions will be selected for the benchmark? The answer to this starts with developing a *tool for selection,* which will form the foundation for the decision-making. This tool will consist of some of the basic requirements for a RM solution and provide information to be analyzed for each of the found solutions. The analyzed information will then be presented and discussed together with the *project group,* which will eventually lead to a decision for the tools to be included in the benchmark. The *project group* consists of ESA employees with relevant experience in the RM and IT field including the SRE-M management (see part 4.4), project members from the JWST project and representatives from the Directorate of Technical and Quality Management and the Director General's Policy Office.

A part from some basic requirements stemming from the ECSS standard for RM, the *tool for selection* will also include information about the perceived credibility of the supplier and some other and technical information that needs to be considered. This part of the tool will be based upon an empirical case study. The actual information about the developers and their RM applications will be gathered from marketed material, telephone and e-mail conversations.

2.3 Qualitative vs. Quantitative methodology

Qualitative methodology is a less formalized methodology (compared to quantitative) where the purpose is to obtain a deeper understanding of the problem that is studied and to make a complete detailed description. Quantitative methodology is more focused on collecting data in primarily numerical form to be used in statistical models. [8]

Using one of the methods does not rule out the use of the other method. Sometime it is preferred to use a combination of them. A qualitative approach will be used when making the empirical study in order to provide a deeper understanding of the process, but also when evaluating the data in the *benchmark.* The quantitative approach will be used in order to assess the score of each tool. With this combination approach we benefit both from the structure of the quantitative method and its strong analytical qualities as well as the flexibility of the qualitative method. Thus, in this type of project it is both important to be able to compare the evaluated tools in terms of numbers but at the same time remain flexible when evaluating software. A flexible requirement will not disregard a solution just because it is different.

2.4 Operationalizing ECSS-M-ST-80C and the Case Study

Operationalization is the process of converting the used theoretical frameworks and concepts into something measurable.[9] In this case we want to operationalize the concepts and frameworks provided by the ECSS-M-ST-80C and the case study in order to create the *tool for selection* and the *framework for the benchmark.* Thus, in the first case the task is to measure different commercially available RM solutions in order to find the four most appropriate ones. The second task is to, more deeply, measure these four tools and the existing solution to provide a relative comparison between the tools.

The *tool for selection* will, as discussed before, consist of some basic generalized requirements. You could say that the tool is a superficial version of the benchmark.

The next task is to operationalize the concepts into an in depth measurable investigation for the benchmark. For the conversion part the author will study

[8] Holme I.M, Solvang B.K, 1997, *Forskningsmetodik,* p. 76-79
[9] Holme I.M, Solvang B.K, 1997, *Forskningsmetodik,* p. 159-160

literature in the subject, i.e. requirements engineering. Thus, a software requirement can translate a real task into an IT-system demand. The foundation for the benchmarking will consist of a list of defined requirements for which each tool's performance is quantified and evaluated.

2.5 Benchmark

The list of down selected tools will include the internally developed solution and those solutions with the highest ranking according to the *tool for selection/ survey*. The actual evaluation will then be assessed through testing demo versions (except for the existing tool, where the actual implemented software is tested) acquired from the developers. Any restraints in the demo versions will also be assessed.

Each requirement will be assessed in terms of the level of fulfillment and verified as objectively as possible. Some requirements, e.g. *The RM tool shall support a "multiuser" environment*, are easier to assess objectively as the level of fulfilment can be verified numerically, in this case the number of users that the tool supports. Others, e.g. *The RM tool shall be user friendly and easily deployable to non expert users*, is harder to assess objectively without performing a survey including several different users. As time is a restraint, these types of requirements will have to be assessed in a more qualitative manner based on the author's perception.

2.6 Process description

The figure below aims to visualize and describe the process and the interaction between gathered material and tasks when carrying out this project.

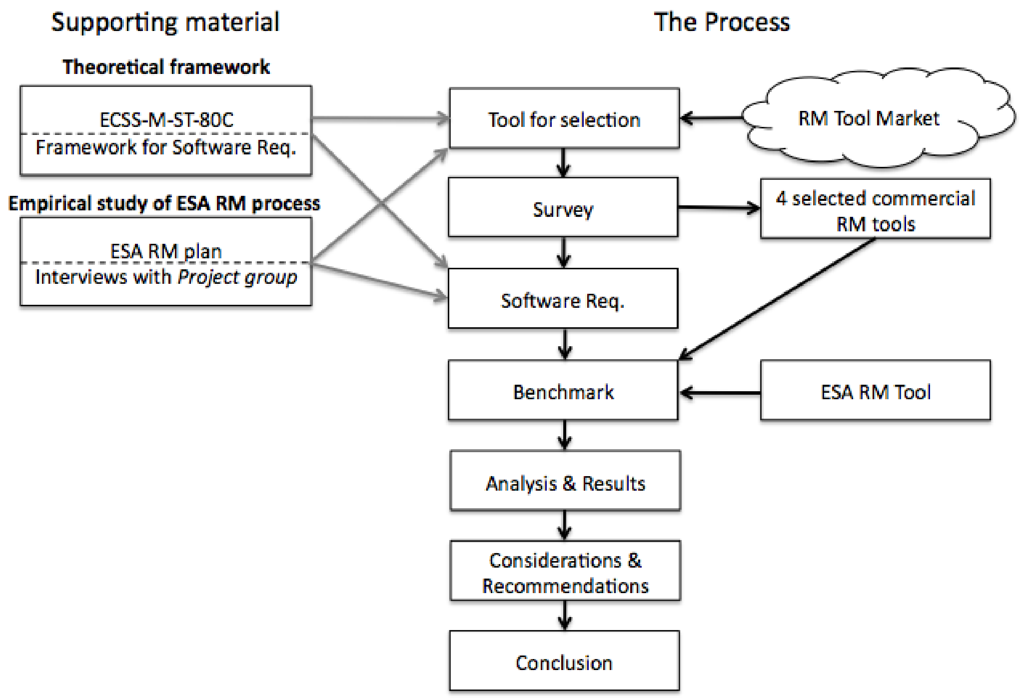

Fig 2.1 Process description

On the left side, under "supporting material", it is shown how the theoretical framework and the case study have been used to create the tool for selection and the list of software requirements. On the right side, under "the process", it is shown how the *tool for selection* is used to perform a survey on the *RM Tool Market,* which results in four down selected tools. These are later included together with ESA's tool in the benchmark (which is based on the defined list of software requirements) where the output information is presented and analyzed. Considerations and recommendations will then be provided to ESA, which will be followed by some final conclusions drawn by the author.

2.7 Criticism of the sources

When performing the survey the credibility of the provided information from RM software suppliers will be questioned. Thus, suppliers' marketed materials along with information provided from sales persons have a tendency to exaggerate the capabilities of their product. However, the suppliers will also be required to send screenshots of their product's interface while it is performing different tasks, something that often provides good information of what the product is really capable of doing.

For the case study, the information will also be gathered through interviews with people from the *project group* in general and the head of SRE-MC in particular, which could in principle offer a sometime biased view. Therefore, the author will, to the greatest possible extent, use multiple sources in order establish an independent assessment of the information..

2.8 Restricted material

Due to some of the investigated material being internal not all information can be published in this report. This specifically refers to the information gathered during the evaluation process of the down selected tools. Evaluated tools will therefore be referred to as letters in the Greek alphabet (Alpha, Beta, Gamma etc). ESA´s existing RM solution will be referred to as Alpha, the four tools included in the benchmark as the four consecutive letters (Beta, Gamma, Delta, Epsilon) and the same will be applicable for the tools included in the survey starting from Zeta. If letters run out, numbers starting from 1 will be applied after the Greek letters.

If the information has not been gathered from a company's marketed material, or e.g. is a widely known methodology the report will not describe in detail *how* a tool solves a problem/ fulfil a requirement only *if* it solves the problem/ fulfil the requirement. This is also applicable on information gathered through other types of information exchange (telephone conversations, e-mail, documents etc.) where classification has been stated.

Further, some of the information gathered from ESA documents has been excluded. This especially applies to specific information about projects under development where confidential/proprietary information is being addressed.

These exclusions will not influence the reading nor interfere with the review of the thesis.

3 THEORETICAL FRAMEWORK

This chapter will provide a fundamental exposition of the theories and concepts used in this project. The chapter will also form the foundation for the following chapters and discussions.

"Risk - The possibility of incurring misfortune or loss."[10]

"Risk is a problem that has not happened – yet."[11]

Above are two definitions of what a risk is. Both definitions imply that a risk is something negative, which some people would disagree with. They would say that a risk could have both a negative and a positive outcome. The Chinese language has for example the same sign for both risk and chance.[12] For the author, however, a risk does imply a possible unfortunate event and thus will throughout the report have a negative notion to it.

3.1 Risk Management

The concept of Risk Management originates from the U.S in the 1950s. It was at that time associated with the activities for handling a company's insurances. Since then the area of Risk Management has broadened and it now includes several processes and activities that has the end purpose of reducing future losses/damages.[13]

The original American definition of Risk Management is pretty simple but still quite accurate: "RM is common sense when finding cost effective ways to either prevent or pay for accidental losses". It has the purpose to limit the amount and the magnitude of damages to the lowest possible protection cost. Thus, it will always be a consideration between the damage cost and the cost of preventing the damage from occurring with the end purpose to maximize profit. Most people would probably agree so far. The systematic process for dealing

[10] Collins English Dictionary & Thesaurus
[11] H. Frank Cervone, *Project risk management*, OCLC Systems & Services, Vol. 22 No. 4, 2006
[12] Hamilton G, 1996, *Risk Management*, p. 13
[13] Hamilton G, 1996, *Risk Management*, p. 9-11

with risks will however differ depending on whom you ask and what kind of risks you are dealing with. Gustaf Hamilton suggests a four-step process with the following activities:

1. Risk analysis – Map the risk environment. Identify, assess and prioritize the risks.
2. Risk treatment – Take measures in order to reduce the probability of the risks.
3. Damage treatment – Reduce the consequences of the risk.
4. Damage financing – Elicit the needed resources for repairing or compensating the loss/damage.

There are several different approaches and methods for each of the steps, especially for the risk analysis, but this report will from this point onward focus on the ones suggested by the ECSS.

3.2 Risks in projects

In the context of projects, a risk is commonly described as an uncertain event/series of events that, if occurring, could affect the project objectives negatively. This is sometimes also referred to as a risk scenario and described through a cause and a consequence. For example, a cause could be that a technology planned to be used in a project has not yet matured within the given time frame and if occurring this could have negative consequences in regard to cost, schedule, performances etc. Making this kind of description is included in the identification of risks, one of the steps in the RM process.

Stakeholders in a project are almost certain in wanting information about the involved risks before investing any resources. To be able to take proper decisions a description of the cause and consequence is not enough, the risk scenario must also be measured somehow. This is most commonly done through assessing the likelihood/probability of occurrence and the severity of impact of the risk scenario.[14] Depending on the risk's and project's characteristics there are different methods when carrying out the assessment activity. Basically these methods can be categorized into two groups,

[14] Ayyub B.M, 2003, *Risk Analysis in Engineering and Economics*, p. 35

quantitative and qualitative assessment. Quantitative assessment is the most objective approach. It relies on statistical data and defines the probability and severity of impact in numerical values. For example, there is a *62.5 %* probability that the risk will have a cost impact of *€ 20 000*. Qualitative assessment uses judgement and expert opinions to define the probability and severity of impact and is thus more of a subjective approach. The output when using this approach could for example be; it is *likely* that the risk will have a *significant* impact on project costs.

The approach to use depends on the availability of data and the complexity of the risk. The quantitative method demands a lot more detailed information compared with the qualitative and is used more commonly for known and less complex systems. The opposite is applicable on the qualitative approach and is thus more commonly used for risk management at project level.[15]

The Risk Management process adds the controlling of risks to the previous described identification and assessment activities. Controlling of risks include activities such as monitoring, communication and mitigation. If applied to projects, this can be referred to as Project Risk Management (is equivalent to Risk Management in this report). The discipline will be thoroughly described as a process, specifically drawn up for the space industry, later in the chapter.

3.3 ECSS and ECSS-M-ST-80C

As mentioned in the introduction, ESA is an international agency incorporating a vast number of different actors from different nationalities. This is almost certain to result in problems in terms of high costs and ineffectiveness because of the usage of different standards. An example of how devastating this could be was in 1999 when NASA lost a $125 million Mars orbiter. According to a later published review the loss was simply due to a metric confusion where one engineering team used metric units while another one used imperial units for a key spacecraft operation.[16]

To reach a common consensus the European Cooperation for Space Standardisation (ECSS) was formed in the autumn 1993. ECSS consists of

[15] Ayyub B.M, 2003, *Risk Analysis in Engineering and Economics*, p. 84

[16] http://www.cnn.com/TECH/space/9909/30/mars.metric.02/, *Metric mishap caused loss of NASA orbiter*, 2009-06-19

participants from ESA, other European space agencies (and the Canadian Space Agency), industry (Eurospace is representing the European industry) and other associated organisations. The cooperation's goal is to increase the efficiency and strengthen the international competitiveness of the European space industry through standardisation of the activities carried out in space projects. These activities could be categorized into five domains:

- **Project management** - responsible for the organisation of a project, making sure it reaches its objectives in a timely and cost effective manner.
- **Engineering –** responsible for the system's design, structure and verifying that the technical requirements specified by the customer are achieved.
- **Production –** responsible for manufacturing the system specified by the engineering domain.
- **Operations –** responsible for making sure the system achieves its objectives during the operational phases.
- **Product assurance –** responsible mainly for the quality assurance part of a project.[17]

The standard developed by ECSS for risk management, ECSS-M-ST-80C: Space project management – Risk management, was published 31 July 2008 and contains guidelines, principles and tools for the risk management process. It is intended for the project management, engineering and product assurance domain of a space project.

3.4 The Risk Management Process for Space Projects

The risk management process *"consists of all the project activities related to the identification, assessment, reduction, acceptance and feedback of risks".* The process can be divided into four steps, where the last three steps are iterated throughout the project phases (see fig 3.1). Each step consists of a number of tasks (see fig 3.2).

[17] http://www.ecss.nl/, *ECSS – A Single Set of European Space Standards*, 2009-06-16

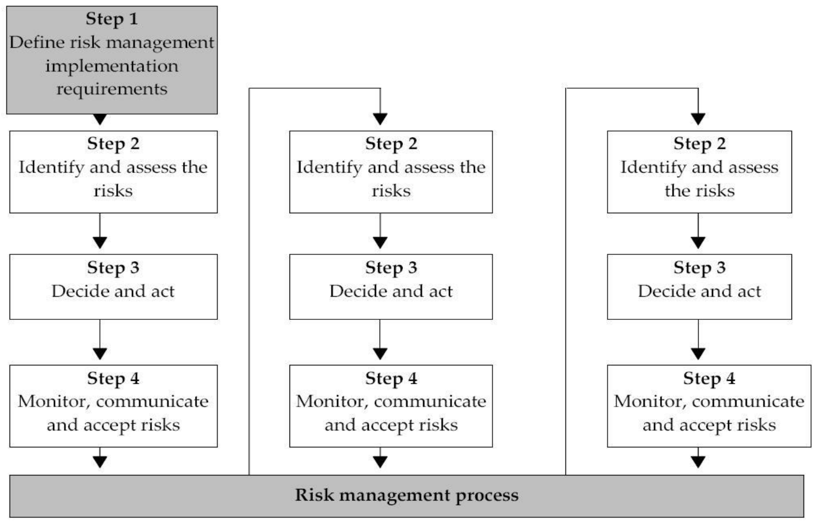

Figure 3.1: The steps in the risk management process.

The figure (3.1) above illustrates how the RM process starts with defining the risk management implementation requirements and then continues with three steps (identification and assessment, decide and act, monitor, communicate and accept risks), which are iterated throughout the project process.

The next figure (3.2) shows the tasks included in each of the steps. The steps and the included tasks will be deeply described in the next parts (3.3.1-4).

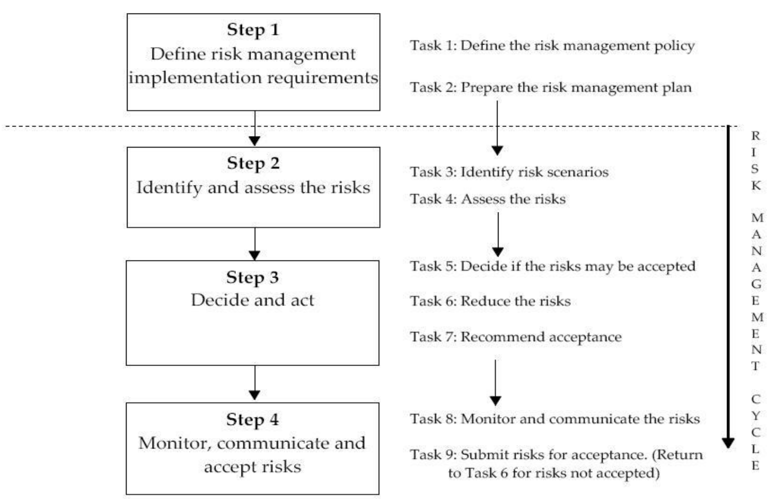

Figure 3.2: The tasks associated with the different steps in the risk management process.

3.4.1 Step 1: Define risk management implementation requirements

The initial step initiates the risk management process and consists of two tasks where the first one is to **define the risk management policy**. This policy shall define and include the following:

- The set of resources with impact on risks.
- The project goals and resource constraints.
- A strategy for dealing with risks.
- Scoring schemes for the severity of consequences (impact) a risk has on a certain resource and the likelihood of this risk to occur (see fig 3.3 and 3.4).

Score	Severity	Severity of consequence: impact on (for example) cost
5	Catastrophic	Leads to termination of the project
4	Critical	Project cost increase > tbd %
3	Major	Project cost increase > tbd %
2	Significant	Project cost increase < tbd %
1	Negligible	Minimal or no impact

Figure 3.3. Example of a scoring scheme for severity of consequence (tbd is an abbreviation for “to be determined”).

Score	Likelihood	Likelihood of occurrence
E	Maximum	Certain to occur, will occur one or more times per project
D	High	Will occur **frequently**, about 1 in 10 projects
C	Medium	Will occur **sometimes**, about 1 in 100 projects
B	Low	Will **seldom** occur, about 1 in 1000 projects
A	Minimum	Will **almost never** occur, 1 of 10 000 or more projects

Figure 3.4. Example of a scoring scheme for likelihood of occurrence

- A risk index scheme to communicate the magnitude for a certain risk (see fig 3.5). The risk magnitude is decided through creating a scheme with the likelihood of occurrence on the y-axis and the severity of consequence on the x-axis. A risk is then given its corresponding magnitude depending on where in the scheme it is located. The red area indicates high risks and the green area low risks.

Risk Index: Combination of Severity and Likelihood

Likelihood	1	2	3	4	5
E	Low	Medium	High	Very High	Very High
D	Low	Low	Medium	High	Very High
C	Very Low	Low	Low	Medium	High
B	Very Low	Very Low	Low	Low	Medium
A	Very Low	Very Low	Very Low	Very Low	Low
	Severity				

"Red" "Yellow" "Green"

Figure 3.5. Example of risk index scheme

- The actions to be taken for various risk magnitude (see fig 3.6).

Risk Index	Risk Magnitude	Proposed actions
E4, E5, D5	Very High Risk	Unacceptable risk: implement new team process or change team baseline - seek project management attention at appropriate high management level as defined in the risk management plan.
E3, D4, C5	High Risk	Unacceptable risk: see above.
E2, D3, C4, B5	Medium Risk	Unacceptable risk: aggressively manage, consider alternative team process or baseline - seek attention at appropriate management level as defined in the risk management plan.
E1, D1, D2, C2, C3, B3, B4, A5	Low Risk	Acceptable risk: control, monitor - seek responsible work package management attention.
C1, B1, A1, B2, A2, A3, A4	Very Low Risk	Acceptable risk: see above.

Figure 3.6. Example of proposed actions to be taken for different risk index/magnitude

- The magnitude of an acceptable risk.

- A method for ranking and comparing risks.
- A method to measure the overall risk.
- When the overall risk has reach an acceptable level.
- How to monitor risks and what format to use when communicating risks to decision-makers.

The second task in the first step is to **prepare the risk management plan**. This document typically contains the following data:

- A description of the risk management organisation, defining different roles and responsibilities.
- Summary of the risk management policy.
- Format of documentation used during the risk management process.
- How the risk management activities should be implemented during the project duration.

3.4.2 Step 2: Identify and assess the risks

The second step initiates the actual iterative process that is carried out throughout the project duration. The first part in this step is the **identification of risks** which is done according to the risk management policy. This part includes defining; cause, consequences and project objectives at stake for each identified risk.

The next task is to **assess the identified risks**, which is done according to the defined scoring schemes (see fig 3.3-5). Activities in this task include:

- Determination of severity of consequence, likelihood of occurrence and risk index for each risk.
- Determination of the magnitude for each risk.
- Determination of the overall project risk.

3.4.3 Step 3: Decide and act

After a risk scenario has been identified and assessed, a strategy has to be set in defining how to deal with the risk and what actions to be taken. The first task in this step is to decide whether the risk shall be accepted or if a reduction/mitigation plan shall be applied, which is mainly based on the magnitude of the risk. If the decision is to accept the risk proceed directly to step 4 (Monitor, communicate and accept risks) but if the decision is to set a treatment plan the next task will be to **reduce the risk.** This task includes the following activities:

- Determine what actions that can be taken to mitigate the risk.
- Determine the criteria for mitigation success, failure and verification.
- Decide what action(s) to be taken in order to reduce the risk, taking into consideration the resources needed to be invested.
- Verification of risk reduction.
- Identify and present the risks that cannot be reduced or verified in having been reduced to appropriate management level.
- Determine how the potential risk reduction efforts will affect the overall risk.
- Document the resolved and unresolved risks in two separate lists.

The next task is to **recommend acceptance** which include presentation of resolved and unresolved risks. This in order to seek approval for the resolved risks and to take further actions for the unresolved risks.

3.4.4 Step 4: Monitor, communicate and accept risks

The last step in the RM process consists of the two tasks: **monitor and communicate the risks** and **submit risks for acceptance.**

The identified risks have to be updated and reassessed regularly to be able to track the progress of the RM work. Thus, the attributes of the risk could have changed over time and the efforts to reduce the risk might not have been successful. This information should then be communicated to appropriate management level.

An example in how to illustrate the risk evolution is through a risk trend chart. This chart shows how the magnitude has changed over time. In figure 3.7, three risk scenarios’ (S1, S2 and S3) changes in magnitude during different project phases have been illustrated through a risk trend chart.

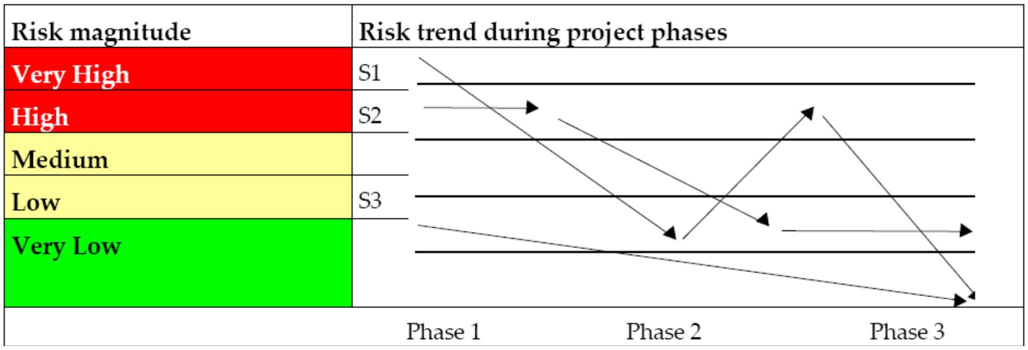

Figure 3.7. Risk trend chart for three different risks; S1, S2 and S3.

In the final task the risk should be submitted to appropriate management level for formal risk acceptance. If the risk is not accepted further actions has to be taken in order to reduce the risk.

In the end, risks will always be taken during the project process but it is up to management to decide whether or not to stop with the mitigation actions. This decision will always be a consideration between the magnitude of the risk (severity of consequence and the probability of occurrence) and the set of resources needed to mitigate the risk to an acceptable level.

An ESA spacecraft, Rosetta, with the main purpose to study the comet 46P/Wirtanen was scheduled to launch in January 2003. However, due to a failure in the planned launch vehicle the month before liftoff, the risk of losing Rosetta was considered too high and therefore the spacecraft was grounded. The launch was postponed and the scientists had to look for new alternatives, new comet to study, new trajectory for Rosetta etc. Hence, the spacecraft was planned to encounter an object covering a huge distance on its path through the solar system which means that if missing the relatively short launch window, it might take a while to the next opportunity. This stress the importance of keeping the project up to schedule in some space missions. Though the risk scenario described above had been taken in to account no real actions were implemented to mitigate the risk as the necessary resources were considered to be too high.

3.5 Developing software requirements

The information in this part derives from Soren Lausen's "Software Requirements – Styles and Techniques", if not otherwise is stated.

3.5.1 Software Requirements – An introduction

The aim when specifying a system's requirements is to describe what the system should do, basically the system's inputs and outputs.

Depending on what type of system the customer is looking for and the chosen process leading up to its implementation, the requirements could vary in character and importance. In cases where the requirement list is used as a contract between customer and supplier, for example when acquiring a fully customized solution, the list is crucial as it must be well defined in order to meet the stakeholders expectations and could be used as reference in case of disputes. When looking for an off-the-shelf product, a requirement list is more used for a comparison between different solutions. Still, the list is important to find the "best" and most suitable solution but every single requirement does not need to be exactly defined if it is not crucial. On the contrary, if a requirement should solve a problem through an already existing function, an "over defined" requirement could sort out capable solutions just because it does not follow the requirement exactly.

As mentioned in the introduction, the focus for this study is to identify COTS (Commercial Off The Shelf) systems, which denote an already existing commercial package solution (e.g. Microsoft Office, SAP solutions). Some of the COTS systems are static (e.g. Microsoft Office) and others are more flexible and can be configured in such extent that the customer needs a consultant to do it (e.g. SAP). There are two different terms when referring to a COTS system:

- **COTS purchase** – refers to the purchase of a fully off-the-shelf product. Any required configurations will be performed by the customer itself.
- **COTS- based acquisition** – refers to the acquisition of a solution built around off-the-shelf parts but to some extent tailor-made by the supplier to meet the customer's need.

3.5.2 Requirement list – contents overview

As mentioned earlier the requirements should specify the input and outputs of the system. There are a wide number of different types of requirements and below follows some central parts (categories) in a requirement list:

- **Data requirements -** specifies the system input and output and what data to be stored internally in for example a database. The requirement can be described in several different ways e.g. through a data model or through a simple textual description.
- **Functional requirements** – specifies how the system records, computes, transforms and transmits data.
- **Quality requirements –** specifies how well the system performs its intended functions. This is for example measured in terms of respond time and usability.
- **Other deliverables –** specifies requirements for other deliverables e.g. documentation.
- **Managerial requirements –** specifies time frames for implementation, price, legal matters etc. This type of requirements could be more of a contractual issue.

3.5.3 Requirement level

Depending on the situation and the purpose of the requirement list there are a number of different levels to choose from when specifying and phrasing each requirement. When for example a management consultant agency is the system supplier, it might be enough for the customer to specify the business goals that the software is intended to help achieve. In other cases when for example the customer is looking for a fully customized solution and is specifying the requirements directly to a software supplier the requirements need to be more thoroughly specified, as the supplier often does not have sufficient knowledge about the specific business process the software is intended to support. Soren Lausen is separating four requirement levels:

- **Goal-level requirement** – defines the business goal and the purpose of the product. E.g. *the product shall ensure that at least 90 % of the organization's projects are within time and budget.*
- **Domain-level requirement –** domain-level refers to the activities and tasks that shall be supported by the system but are carried out outside the actual product. Thus, a requirement on domain-level does not tell how the product shall perform something. E.g. *the product shall support the reduction planning of risks.*

- **Product-level requirement** – the actual input/output of the product is specified in this type of requirement. E.g. *the product shall for each risk record and retrieve (text) a reduction plan.*
- **Design-level requirement** – in this type of requirement the actual interface is specified. E.g. *the product shall provide a data entry screen as seen in fig x.*

3.5.4 The traditional approach: product-level requirements

There is no standard way in how to combine the different types of requirements and what approach to use when structuring a requirement list, mainly because of the different nature for these types of projects. However, there are some guidelines/models that can be used as a basis depending on the project type. When carrying out a benchmarking exercise for a COTS system, the customer often has a number of desired features that he/she wants to compare different products against. The suggested model when creating the requirement list is then *the traditional approach: product-level requirements*. In this model the stakeholders are interviewed, relevant documents are studied and brainstorming activities are conducted. The central parts in the specification list are the following:

- Introductory parts (including business goals)
- The limits of the system
- Data requirements
- Product-level functional requirements
- Quality requirements

When creating and implementing a system specification list, each of the requirements needs to be *verified* and *validated*. Verification of a requirement means that the product is tested against the requirement in order to assure that it is fulfilled, while validation infers a test of the actual requirement in order to assure that it corresponds to; what the customer really want/ the actual task that shall be supported.

4 EMPIRICAL STUDY OF ESA RM PROCESS

The following part aims to present how the risk management process and work proceeds at the European Space Agency. The presented information is gathered through reviewing a RM process carried out at the SRE directorate and originates mainly from interviews with JWST project members and from JWST risk management plan.

4.1 Step 1: Define RM implementation requirements

The first step in ESA's RM process is to elaborate a project specific RM plan. This step contains elements from the first two tasks (i.e. "define the risk management policy" and "prepare the risk management plan") in the RM process suggested by ECSS (see figure 3.1). ESA has developed a separate "Agency level" risk management policy, which is very generic and does require a dedicated plan addressing its implementation, which is currently being prepared. Furthermore the ongoing certification in the frame of ISO 9001 would require the preparation of additional procedures.

The risk management plan is specific for each project and includes the following:

Objectives of the risk management implementation
An introduction stating what the purpose is (enlarge visibility, ensure effective communication in the project etc.) when carrying out risk management.

Mission objectives and risks domain
In this part the objectives, the requirements for successful attainment, the sources of risks and the domains of impact are presented. For example:

- Mission objective: study the atmospheric composition of exoplanets (planets outside our solar system).
- Requirements: put an instrument in orbit around earth on-time with no cost overruns and provide scientists with data from at least 500 objects.
- Sources of risks: launcher vehicle, subsystems etc.
- Domains of impact: technical performance, schedule, cost etc.

Risk management strategy and approach

Explains the general RM approach for the particular mission and defines the schemes and metrics used in the assessment step. This is an important part in order to successfully assess the risks and is something that differs from project to project depending on the project scope, complexity and allocated resources. For risks with an impact on cost and schedule the scores (except the highest ones) are defined in terms of contingency loss (measured in %). Thus, all risks with an impact leading to project cost and duration overruns, even the smallest one, will be assessed with the highest score as they would lead to an unsuccessful attainment of project objectives. The scoring schemes used for the James Webb Space Telescope Project (JWST) can be viewed in Appendix I.

Risk management process

This part explains the systematic approach suggested by the ECSS and how it should be implemented for the mission in particular.

Roles, responsibilities and procedure for risk management

Different people have different roles in a project according to their area of expertise. The RM responsibilities within the JWST project team are:

- *Project Manager* - Has the overall responsibility for the RM process within the ESA part of a mission. Holds regular meetings (in JWST at least every 12 weeks) with the project leads with the purpose to review identified and assessed risks and associated action plans.
- *Project Assurance Manager* – Is in charge of the risk register, the supporting software and updates the risk register in accordance with the risk review meetings.
- *Risk owner* - Is in charge for the specific risk. The risk a person will be responsible for commonly reflects the project task one has. Thus, it is the person responsible for the specific activity or sub process that also holds the knowledge about the involved risks within his/her area. These are categorized into areas of concern or sources of risks. For example, a source could be the launcher vehicle that has an assigned coordinator and it is his/her responsibility to identify, assess and report the associated risks, changes, coordinate action tasks for mitigation etc.

The RM process is continuous, which means that as soon as a risk is identified this is communicated to the Project Manager and to the Project Assurance Manager. Together with the project leads, they will review the risk, decide if it is going to be implemented in the risk register and if so assign a risk owner. The risk review meetings are formal activities to further ensure, review and discuss the risks.

Risk management documentation and follow-up
This part defines and explains the reasons for the risk documentation to be used throughout the RM process. These are as follows:

- to ensure and demonstrate a proper conducted RM process
- to provide evidence for a systematic approach
- to provide a historical record
- to provide decision makers with sufficient information
- to facilitate continuous monitoring and review
- to provide an audit trail
- to share and communicate information
- to increase efficiency and effectiveness in managing the project's problem areas

The actual reporting frameworks are described in step 4.

4.2 Step 2: Identify and assess the risks

While the first step mainly exists to define the project specific framework for the risk management activities, it is in the second step the actual RM work to be carried out throughout the project life-cycle starts.

Basically a risk is identified through a risk title, cause, consequence and the domain(s) for which the risk has an impact (i.e. financial, schedule etc.). When a risk is first identified a number of additional information is recorded to keep track of the risk and further categorize it. This includes:

- Risk originator – Person who identifies the risk
- Risk owner – See *Roles, responsibilities and procedure for risk management*
- Risk source – See *Mission objectives and risk domain*
- Risk horizon – The time frame for when the risk can materialize
- Project/Organisation – The affected entity/entities (e.g. JWST, SRE)

The risk assessment is based on the perception of the people responsible for the risk, using the scoring schemes defined in the risk management plan. The assessment of risks is discussed at dedicated review meetings in order to ensure that the proposed scoring is not based on one person's subjective perception. The severity of consequence and the likelihood of occurrence is scored through an ordinal scale from 1 to 5 respectively A to E. The two metrics define the risk index (e.g. 5E) and the risk magnitude (Red, Yellow, Green or High, Medium, Low). The risk magnitude is determined depending on where in the risk index scheme the assessed risk is located. Examples of a risk register and the scoring schemes can be viewed in Appendix I-III.

The assessment of risks is an important activity in the RM process as it communicates the importance and criticality of the risk and is often the foundation from which decisions are taken.

All project members and supporting staffs are requested to contribute to the risk identification and assessment activities. Further shall all risks with a possible impact on project objectives, whether originating internally or externally, be included when identifying the risks. This means that subcontractors are also responsible to carry out RM on their activities and provide the project teams at ESA with risk reports. These are reviewed and it is then decided whether or not to integrate the risks in ESA's system.

Note: In the ECSS standard one of the bullets was to determine the overall project risk. This is not done through any calculations and should be treated with caution. A qualitative assessment does not provide any numbers that can be used mathematically even though the actual risks have an impact on the same domain. Also, two risks with an impact on different domains are not comparable (in many cases risks have an impact on several domains). There are other RM approaches that provide a methodology for determining the overall project risk. This will be presented briefly later in the report.

4.3 Step 3: Decide and act

After a risk has been identified, assessed and stored in the risk register the options for handling the risk will be considered. Below follows examples of handling strategies that can be considered:

- **Risk avoidance** - if an activity is associated with an unacceptable risk the preferred strategy could be not to proceed with the activity or replace it with another one which meets the project objectives.
- **Risk mitigation** - refers to reducing the risk's likelihood of occurrence and/ or its severity of consequence. A consideration will be made between the risk magnitude and the needed resources in order to reduce the risk. Reducing a risk's likelihood of occurrence is more common than reducing its severity of consequence, because of the former most often demands less resources. Imagine an identified risk being a tank leakage leading to an uncontrolled ignition of the propellant causing the launcher vehicle to explode. In order to reduce the severity of consequence this would probably have to be done through developing a total new way of launching the vehicle or researching a new type of propellant. This would further lead to a revision of several of the vehicles already existing functions. On the other hand, reducing the risk's likelihood of occurrence could be done through strengthen and isolating the tank or implementing routines for inspection.
- **Risk transfer** – refers to transfer the risk, in part or in full, to another party. This commonly means a reallocation of the costs to different parties which could be done through e.g. insurance.
- **Risk defer** – if a risk is automatically reduced over time due to being triggered by external circumstances, or if a treatment action is foreseen to take place at a later stage the risk could be deferred.

In order to achieve the handling strategy, a number of actions are planned which are later implemented accordingly. Recorded information associated with actions includes basically who shall do what, when, the planned residual risk magnitude after implementation and the means for verifying successful attainment.

4.4 Step 4: Monitor, communicate and accept risks

The purpose when monitoring risks is to obtain clarification of how the risk reduction measures are proceeding and how the risks are changing over time. Risks and the effectiveness of control measures need to be monitored in order to ensure changing circumstances do not alter risk priorities. New factors may arise changing the assessment metrics as well as the suitability of assigned resources for reduction. To keep track of any changes the status of the risk is updated continuously.

Both the ESA risk management policy and the ECSS-M-ST-80C stress the importance of communicating and reporting risks internally and externally. These are some of the major elements in the RM process and partially exist to provide stakeholders and management with information concerning the different risks associated with their area of interest and responsibility. Thus, in the end it is the upper level management that are taking the overall decisions, holds the final responsibility for the agency's activities and it is the stakeholder's resources that are put at risk. Effective internal and external communication is therefore of great importance to be able to understand the basis of which decisions are taken and why particular actions are required.

In each step when reporting upwards in the hierarchy the major risk items and the process of managing them are monitored and discussed to ensure the RM process has been carried out properly.

The structure of the SRE directorate is presented in figure 4.1.

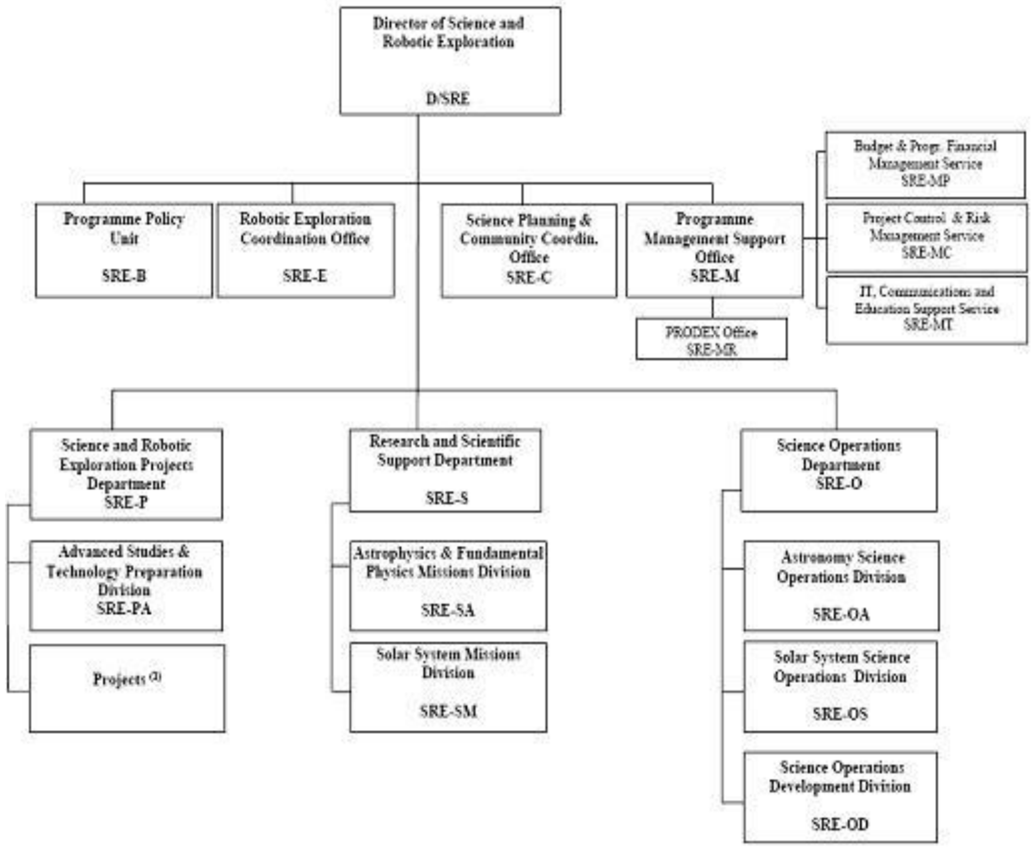

Figure 4.1 Structure of the SRE Directorate

The specific project process under the SRE directorate is carried out within the directorate's departments and offices, where the departments functions as the initiators and implementers of the process and the offices as a support for this. The general responsibility of each department includes:

- **Science and Robotic Exploration Projects Department (SRE-P)** – determining needs for projects and the management of all approved ones from the initial definition phase to in-orbit commissioning.
- **Research and Scientific Support Department (SRE-S)** – providing scientific expertise and support to projects and studies in all phases.
- **Science Operations Department (SRE-O)** – managing and operating missions ones they have been successfully commissioned and ensuring

maximum scientific return within the technical and budgetary constraints.[18]

During a project's duration at SRE the different departments and the Project Control and Risk Management Service (SRE-MC) work closely with carrying out the risk management process. The project teams within the divisions hold the expert knowledge concerning specific risks and are providing SRE-MC with risk inputs. Relevant information (major risk items and the process of managing these risks) are reported to the head of each department and continues upwards to the director of the directorate and finally to the DG.

Due to having different concerns, needs, assumptions and constraints the perception of the same risk can vary from one stakeholder to another. Because of the significant impact stakeholders can have on the decision-making this is something that has to be taken into account by the PM when communicating the risks.

Within projects and between SRE-MC, risks are basically communicated through a risk register (see Appendix III), presenting the current information of the specific risk. When communicating and reporting to upper level management a heat map (i.e. the risk magnitude is illustrated through a position in the risk matrix) and a risk trend chart (i.e. illustrating the evolution of the risk magnitude over time, see Appendix IV) are presented in order to provide an overview of the organisation's/project's risks and how the RM work is proceeding.

A risk is basically accepted when it reaches the green area in the risk index scheme (low magnitude risk). In some cases, higher magnitude risks may also be accepted. Thus, in the end the decision of accepting a risk will always be a consideration between the risk magnitude and the demanded resources for reducing the risk. The acceptance of risks does not mean that the risk will not be further considered, it will be monitored thus circumstances and risk magnitude may still change over time.

[18] Directorate of Science and Robotic Exploration (Admin), 2009-04-23

4.5 An iterative process

New risks will be identified and controlled throughout the project life cycle according to the last three steps in the RM process. This is also the case for existing risks that are yet to be accepted, making RM an iterative process. The existing risks are reconsidered at least every review meeting in order to update the risk information and to plan any further handling strategy.

4.6 RM at agency level

The actual RM process at agency level is basically the same as the one implemented at SRE with one major exception: The scale for the severity of consequence and likelihood of occurrence is based on a 3-part scale. This means that the risk index scheme is a 3x3 matrix and all risks eventually escalated from project level will have to be re-assessed according to the new scale.

5 TOOL FOR SELECTION AND MARKET SURVEY

This chapter aims to describe the survey and down selection of commercially available RM tools.

The purpose with the survey was to investigate the commercial market and see if there were any available RM tools with the potential of supporting ESA's RM process. The survey would also form the decision base for which tools to be included in the benchmark (if there were any with the capability). It was carried out through gathering information from RM tool developers' websites, brochures and through e-mail/ telephone conversations. A first consideration was taken to the *suitability of the tool* i.e. how well in line with ESA's risk management process the software is:

1. **Project and risk specification**. The ability to start a new project and define risk categories, impact areas etc.
2. **Identification and assessment**. The ability to define risk scenario attributes (e.g. title, owner, cause, consequence, impact domain etc.), carry out qualitative assessment (likelihood of occurrence, severity of consequence, risk index etc.) of the risk scenarios and store them in a risk register/database. The ability to rank risk scenarios, thus to identify the most critical ones.
3. **Decide and act**. The ability to record a reduction strategy, the action to be taken and the status of the risk scenario.
4. **Monitoring and communicating the risks**. Produce reports and risk index scheme (heat maps) to provide a good overview for upper level management. Tracking of the evolution of identified risk items through e.g. risk trend chart.

Three measurements, some with a more subjective (from the author's point of view) nature, were then evaluated.

1. **Company credibility**. The main question to ask here is: Does the company manage to successfully convey a credible image through their website? This is partially done through investigating:

    - General information about the company.

- Previous customers.
- Website layout and structure.
- Contact information.
- If the information about the company's products are well structured and informative.

The credibility has also been investigated by searching the Internet in order to find if there are any customer complaints or company appearances in any relevant magazines and/or websites.

2. **Overall marketed features and extra functions** to support ESA's (future) risk management activities.
3. **Tool design.** This is investigated through the first impression that is provided by screenshots of the tool in how user friendly and aesthetically appealing the tool's interface seems to be.

Other and technical information:

1. Integration possibilities with other project management software used at ESA (Microsoft Office, Oracle Project Management etc.).
2. Customization possibilities (and flexibility)
3. Stability, based on the software version.
4. Proceedings for demo acquisition.
5. What platform the software is based on. A web-based application could provide the risk management team with access externally and would facilitate maintenance.
6. Is it a standalone application or does it come with a backend database?
7. Does the tool come with a user administration tool? If the tool shall be incorporated throughout the whole organisation it has to be possible to assign different access and permissions to different users.
8. Firewall restrictions.
9. Cost for setup and maintenance.

In general the abilities to identify and assess risks and associate them with specific projects/organisations are some of the basic functionalities for a tool capable in supporting ESA's RM process. A majority of the tools included in the survey were capable of doing this, but there were basically two distinctive differences in *how* this was done. Several software developers integrate the RM process into the project scheduling activities. This means that when a risk is identified it is more or less associated with a specific task in the project schedule. E.g. Microsoft Project has this feature included and through adding a separate tool, for example Palisades “@Risk for project” it is possible to perform Monte Carlo simulations and additional risk analysis. In this kind of RM it is necessary to use a different approach, than presented in this report, for the assessment of risks (otherwise the provided information could be totally misleading). For more information the author recommends the book *The failure of Risk Management: Why it’s broken and how to fix it* by Douglas W. Hubbard. The other commonly used method lets you add risks separately from the project schedule and store them in a central register. The systems that are supporting this kind of method are often referred to as Enterprise Risk Management systems. As the process is carried out now at ESA the latter is more suitable.

The majority of the analyzed tools that were **not** selected for a more thorough evaluation can be viewed, accompanied with a short comment, in Appendix V: Investigated Tools. Some of these were excluded just by reviewing the marketed material others needed additional information exchange through e-mail and telephone conversations.

The tools selected for the benchmark was Alpha, Beta, Gamma, Delta and Epsilon.

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6 SOFTWARE REQUIREMENTS

This chapter will explain the requirements that were used as a base for the benchmark.

The requirements have been divided into six different groups:

1. **General requirements –** specifies the overall requirements of the system.
2. **Technical requirements** – specifies some overall requirements with a more technical nature. Note: The actual hardware and software requirements have not been evaluated. This has to be tested in order to investigate the possibility to implement the system on ESA's IT infrastructure.
3. **Functional requirements** – specifies how the system records, computes, transforms and transmits data.
4. **Data requirements –** specifies the system's input and output and what data to be stored internally in for example a database.
5. **Reporting requirements** – specifies the system output in terms of generated reports.
6. **Quality requirements –** specifies how well the system performs its intended functions and the provided support.

As the requirements are mainly described as a textual feature description they will be relatively easy to validate, both according to the ECSS-standard and the customer. For the same reason and because demo versions were acquired it was also relatively easy to verify the majority of requirements. However, some of the requirements (mainly in section 1,2 and 6) had to be verified by the vendor, which is of course not an ideal situation.

The full list of 68 mandatory and 12 optional requirements are presented in Appendix VI: Software Requirements List.

7 BENCHMARK: ANALYSIS AND RESULTS

This chapter will provide a short introduction of the tools included in the benchmark, the most important outcome of the evaluation and an analysis of the results.

All tools except Epsilon have been evaluated according to the set of requirements defined in Appendix VI. The approach to Epsilon has been to provide the developer with the list of requirements to be commented on in order to form an opinion. For the tested tools, each requirement has been given a score (Good, Fair and Bad) depending on the level of fulfillment. The general definition and the weight of the score is the following:

- Good – The tool meets (or exceeds) the expectations of fulfilling the requirement. Weight: 1.
- Fair – The tool does partially or not in a fully satisfactory way meet the requirement. Weight: 0.5.
- Bad – The tool does not meet the requirement or does not meet the requirement in a way that can be considered useful. Weight: 0

Table 7.1 presents examples of three assessed requirements (each with a different degree of fulfillment) that have been picked from the evaluation. In addition to the degree of fulfillment a “comment box” has also been used in order to explain and justify the assessment.

ID	Requirement	Degree of Fulfillment			Comments
		Good	Fair	Bad	
1.2	The RM tool shall support a ”multiuser” environment	■			No restraints
3.17	The RM tool shall list all risks that match specific search values.		■		Even with given access over several projects, the search engine only list the searched risks included in the active project and revision.
3.10	The RM tool shall allow the deletion of an existing risk			■	Not supported due to audit trail (will be addressed in the new release)

Table 7.1 Examples of assessed requirements

The total score for each system in the benchmark was calculated as the total level of fulfillment (%), through the following equation:

$$\sum_{i=1}^{j} \frac{w_i}{j}$$

$$w_i = weight\ \ for\ \ requirement\ \ i$$
$$j = total\ \ number\ of\ \ requirements$$

The score alone does not provide enough information for any decision taking. Thus, a system with a score of 0 % for the optional requirements and 50 % for the mandatory requirements could be, if all requirements ranked as fair, a system capable in supporting ESA's RM process. Further, a system could with a score of 100 % for the optional requirements and slightly below 100 % for the mandatory requirements, be a system not capable in supporting ESA's RM process, as one of the most critical requirements was not fulfilled. The score does however provide; an overview of the general capability and suitability of the tool and a foundation for a relative comparison between the tools. In order to create a better foundation for decision-making, the score is followed by an impression and analysis accompanied with an explanation of the tools major strengths and weaknesses (something that could disqualify the tool).

All tested tools support project risk management (i.e. possible to create risks and associate them with projects), which is an indication that the survey has been conducted properly. They support a similar step-by-step process as the one suggested by the ECSS standard for RM. This is done through a "tab structure", meaning: the recording of risk information is split into tabs where each tab presents the user with a screen representing one of the RM steps. Where and how information is recorded differs but it is basically divided into identification, assessment and reduction measures.

7.1 GAMMA

Gamma's developer is focused on providing software solutions and services for Risk Management. Claimed previous customers include Boeing and Lockheed Martin. Gamma is marketed as an Enterprise Risk Management software solution.

Gamma's score

The table below presents the score that Gamma acquired through the benchmark.

Mandatory requirements	Optional Requirements
79 %	**67 %**

Table 7.2 Gamma's Score

Impression and analysis

Gamma "stands out" in a positive way with a logical and intuitive folder structure built around a convenient architecture. When logging on to the application the user will be provided with a view that lists the risks and actions that needs attention. The creation of risks, actions, hierarchies etc. is made through right clicking on an item in the hierarchy structure and then choosing the wanted action. This will lead the user to a new layout where the actual information is recorded.

The tool is capable in supporting SRE's and ESA's Risk Management process. "Capable" meaning, compared to the evaluated demo version, some configurations has to be made and tested before implementation. This should not be a barrier as the needed configurations can be performed by the administrator. What could disqualify the tool is the lack of possibility to define mandatory fields, any restraints in configuring the reporting features and most important the response time.

Major strengths

- **Folder structure and usability -** One of the major strengths of Gamma is the folder structure, where the separate folders can represent different projects and organizations. This provides the user with a logical structure and made the tool the easiest among the tested to understand and use.
- **Configuration and flexibility** – The tool is highly configurable. In order to fully support SRE's RM process, the tool has to be configured to some extent. When evaluating the demo version the author identified a number of areas that would have to be configured, these included: drop down menus, terminology, categories, the risk information input layout and reports (e.g. colors in the probability grid and information

shown in reports). The developer claims that all of these areas are possible to configure by the administrator.

- **Audit trail –** The audit trail records all changes and support a layout were it is possible to see what changes that have been made. It also excludes the need for a "review structure" (refers to the functionality of Alpha).
- **Service –** This was not addressed in the list of requirements but should be taken into consideration. Provided information, material and response time (to set up demo, answering e-mails etc.) were excellent. There was no unwillingness to share information which indicates that in a possible implementation there will be no "unpleasant surprises".

Major weaknesses

- **Mandatory fields –** It is not possible to set mandatory fields in the current version. This is a major weakness because it can lead to inconsistent input information and reports.
- **Numerical index –** This has to be treated with caution. The scales of the assessment metrics are not comparable and can not be used for any further calculations or comparisons.
- **Response time –** The response time of the demo can not be considered as reasonable. This was applicable on the general usage of the tool including performing different actions, inputting data and browsing between the application's different screens.
- **Reports –** The reporting features included in the demo version were not capable in supporting SRE's reporting requirements. There were no comparative reporting feature and no filters for what risks to include in the reports. The tool can generate reports for a specific folder and it is possible to create filters for what risks to be shown in the system (and eventually in the reports) but this is an inconvenient way to solve the problem.

7.2 BETA

Beta's developer is providing systems, engineering, technical and managed services to mainly governmental customers. Claimed customers include Lockheed Martin and T-Mobile. Beta is marketed as an easy-to-use web application for enterprise-wide, program and/ or project Risk Management.

Beta's score

The table below presents the score that Beta acquired through the benchmark.

Mandatory requirements	Optional Requirements
67 %	**54 %**

Table 7.3 Beta's Score

Impression and analysis

Beta runs smoothly and is easy to use and understand. However, it does not manage to fulfill enough of the reporting requirements and are lacking many of the functional and data requirements. The early version of the tool manifests itself through some minor bugs. For example, it is possible to change the date for which the risk was implemented in the system and the residual assessment for the mitigation plan is not connected to the initial assessment.

Major strengths

- **Usability –** The layout and the structure of the tool is good, making it easy to understand.
- **Project screen –** The "Project Screen" provides a good overview of the project risks, which is a nice feature for the Project Manager/ Risk Coordinator.
- **Project step-by-step setup –** The tool provides an easy-to-use step-by-step guide when setting up project attributes.

Major weaknesses

- **License fee for any additional projects –** The pricing strategy of buying a license per every project is adding an additional cost compared with the other evaluated systems. There is a possibility to reuse retired projects but will exclude the functionality of communicating a "lesson learned" as the previous information will be overwritten.
- **Help desk open hours –** The company is situated in a country where the opening hours of the help desk are inconvenient due to the time difference.

- **Audit trail** – The information stored in the audit trail is insufficient. Basically only the change date along with changes in risk assessment and status are recorded.
- **Lack of search engine** – The tool does not support a search engine within the application.
- **Reports** – The detailed reports are well structured and the filtering options are good but the tool lacks other reporting features such as comparative, distribution, heat map and risk evolution reports. None of the graphical reports provide any real relevant information for RM (more focused towards compliance) e.g. a bar chart showing the amount of new identified risks per month. Further, the tool is lacking "dummy-proofs" as it is possible to for example set unrealistic time horizons and mitigation actions that do not reflect the actual risk assessment.
- **Configuration** – It is possible to set a number of attributes and define some terminology, but the configuration possibilities are not enough in order to align the tool with SRE's RM process.

7.3 DELTA

Delta's developer offers management solutions to a variety of complex technology industries. Claimed previous customers include NASA. Delta is marketed as a web-enabled application database for documenting and communicating information about risks in a manner that enhances the probability of program success.

Delta's score

The table below presents the score that Delta acquired through the benchmark.

Mandatory requirements	Optional Requirements
74 %	**54 %**

Table 7.4 Delta's Score

Impression and analysis

The tool is aligned to a RM process similar to the one suggested by ECSS, but it will most certainly not revolutionize the way RM is carried out at ESA. It does not "stand out" (neither in a positive nor negative way) compared to the other evaluated tools. It supports a hierarchy structure, but this is poorly developed compared to Alpha's.

Major strengths

- **Usability** – The tool is easy to use and no training is needed to understand its basic functionalities.
- **Reporting features** – Delta is the commercial available tool that best fulfills the reporting requirements and the only reporting feature it lacks is a risk distribution table. The tool also provides a convenient filtering feature, making it possible to choose which risks to include in each report. Only the administrator is able to create new revisions therefore it was not possible to generate an evolution or a comparison report in the demo version. This requirement was therefore assessed as fair (with room for corrections). Several reports are generated in Microsoft Office software (Excel, Power Point, Word) which is viewed as beneficiary by some thus making it possible to "post edit" reports. The author's opinion is the opposite for the same reason as this would lead to inconsistency between the reported information and the information recorded in the tool. All editing of information should be done within the tool itself. A weakness for the reporting features is the time it takes to generate a single report in Word, Power Point and Excel.

Major weaknesses

- **Stability** – Delta's version number is quite high, but the demo version did not manage to convey an impression of Delta being a mature and stable system. During the evaluation phase, Delta was the tool with most experienced problems and crashes. The tool does not feel robust and you get the impression that functionality has been added without the code being "renovated".
- **Pricing strategy and maintenance policy** – There is no clear pricing strategy or maintenance policy.
- **Date format** – The recording of dates causes some frustration. First of all the user has to record the date manually, secondly the date format is U.S adjusted meaning MM/DD/YYYY (compared to the European standard: DD/MM/YYYY). Beta uses the same format but the tool had a "Calendar pop up" feature when recording dates. The format could lead some confusion when reading reports generated by both Beta and Delta.

7.4 ALPHA

Alpha's developer has a long history of providing services to ESA (other customers include Astrium). The company's core activity is to develop solutions for project management and control. Alpha is described as a risk management support tool that aims to help identifying, assessing, reducing, accepting and controlling risks during the lifecycle of a project.

Alpha's score

The table below presents the score that Alpha acquired through the benchmark.

Mandatory requirements	Optional Requirements
80 %	**63 %**

Table 7.5 Alpha's Score

Impression and analysis

From the defined list of mandatory requirements, Alpha can be considered as the best application. The tool supports the basic functional and data requirements and is undeniably the best suited to support the reporting requirements. What has to be kept in mind is that a majority of the requirements originates from actual users of Alpha, which gives the tool a "head start". For example, one of the requirements is that the RM tool shall support progressive revisions, which is not necessary with a sufficient audit trail (will be discussed later in the report). Further, does the requirement for a demo tutorial become obsolete as the tool is already implemented at ESA's IT infrastructure.

Alpha has some minor flaws but the major problem is within the application's structure and layout, which impact the usability of the tool. The impression of the tool is that functionality has been picked together and been spread throughout the application with not too much consideration been taken where it should be and how it should be performed according to the process (will be further discussed later in the report).

Major Strengths

- **Reporting features –** Alpha is the only application that more or less supports all the required reporting features.
- **Number of supported functional and data requirements –** The tool does support most of the mandatory functional and data requirements.

Major Weaknesses

- **Organization/Project Structure –** The application does not, in a convenient way, support a hierarchy structure. This is important if implemented as an agency wide tool.
- **Layout –**The layout when browsing through the application is somehow confusing and the screens have not been properly structured.
- **Clone/Copy Risks –** The tool is currently not supporting the copying of risks.

7.5 EPSILON

Epsilon's developer is specialized in developing risk management software with Epsilon as its core product. Previous (and current) claimed customers include NASA and Lockheed Martin. Epsilon is marketed as a highly configurable ERM system, comprehensively covering project, operational and corporate risk management.

Note: There has been no testing of the actual application and the following part is thus based on the perception of the information provided by the developer.

Impression and analysis

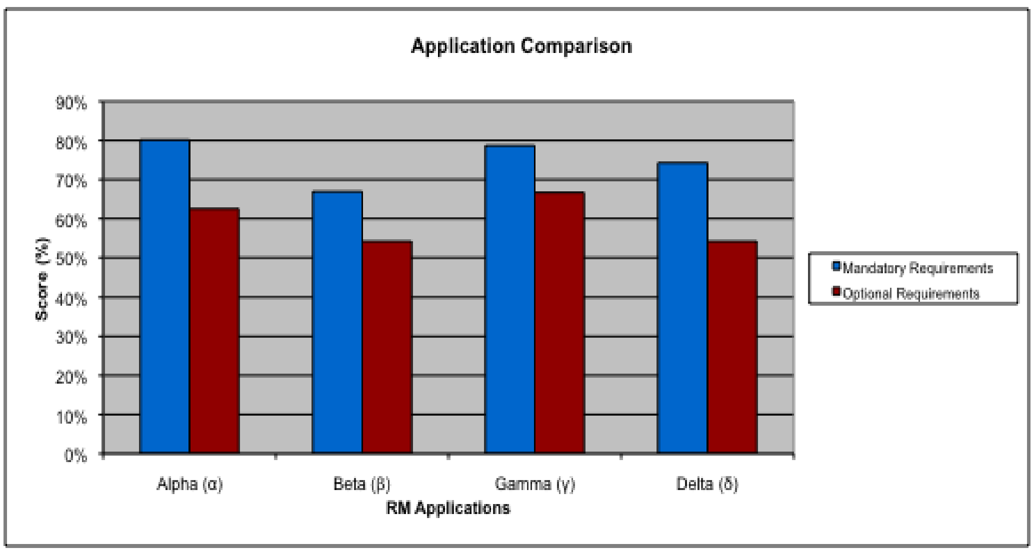
As the scoring system for the level of fulfillment, based on the provided comments, basically becomes obsolete Epsilon would reach a score of 100% for both the mandatory and the optional requirements, provided of course that all information and the verification process can be viewed as credible. In reality this is clearly not the case. The requirement list was developed to be used as a base for testing COTS systems and is not suited to use in this type of investigation, simply because it leaves to much room for interpretation (especially for a sales person). If the reader is not familiar to the ESA RM process, there will be confusion when analyzing the list of requirements. For example, the developer claims the tool supports the recording of a risk originator, something that is not visible in the screenshots and should be in the "identification tab" (note: there is a provided field for origin in Epsilon but this is equal to the requirement for risk source).

Epsilon was not included in the relative comparison because of the reason described above. Based on the completed enquiry and the provided screenshots a general idea about the tool can be formed. It uses a folder structure similar to Gamma and it is aligned with a step-by-step process similar to the one suggested by ECSS. The tool provides a variety of different reporting features and one that is especially interesting is “Risk List”, which is similar to ESA’s directors report.

7.6 COMPARISON OF RESULTS

In figure 7.1 the scores of the evaluated tools has been illustrated through a block diagram. Alpha and Gamma scored almost equal for the mandatory requirements with 80 % respectively 79 %. Delta was close behind with 74 % and Beta scored the lowest with 67 %.

For the optional requirements Gamma scored the highest with 67 %, Alpha second with 63 %, Beta and Delta 54 %. What is noticeable is that Gamma and Beta are the only tools that are currently able to support the assessment at agency level.



	Alpha (α)	Beta (β)	Gamma (γ)	Delta (δ)
Mandatory Requirements	80%	67%	79%	74%
Optional Requirements	63%	54%	67%	54%

Fig 7.1 Scores of the evaluated tools

The big difference between the commercial available tools and Alpha is the reporting features. If the reporting requirements are separated the results are:

- Alpha: 86 %
- Delta: 57 %
- Gamma: 43 %
- Beta: 29 %

A part from an evolution chart the ECSS is not specific enough to what reporting formats that shall be used as standard. As reporting features has been added to Alpha according to SRE's demand it is not a huge surprise why the tool is the most suited in this aspect. However, the commercial tools offer some reporting features not included in the ECSS and Alpha that can still be considered interesting. For example, several of the commercial applications offer a feature to generate a report, which illustrates the planned risk magnitude after action implementation through a schedule or a waterfall chart. This provides management with an overview for the planned reduction measures for each risk and what impact each action will have on the risk magnitude.

It is quite surprising to find two tools that are performing close to Alpha. Alpha should, in my opinion, be superior to the other tools with the main reason being that the system has been developed directly from the process at SRE. The developers of the commercial tools never claimed that their software was aligned with the ECSS, however the suggested RM process is probably a common industry standard.

7.7 THE METHODOLOGY

Elaborating a good methodology has been a central and demanding part for this study. There were a lot of important aspects to consider especially when creating the framework for the benchmark. In order to provide ESA with proper results the requirements needed to be representative for a RM system as it should be: from a business process, ECSS process and an IT-system point of view. At the same time the requirements cannot be too well defined, thus leaving out good solutions just because they are different.

If you do not carry out the methodology properly or in the correct order, it is easy to get lost and biased by impressions and individual views along the way.

Initiating the project with a study of the ECSS standard for RM and a case study of SRE's RM process provided a good view of how ESA wanted the system to work, both in theory and in practice. In addition, the market survey provided some general inputs in how a RM system could work.

It was of great importance not to test the existing solution that should be benchmarked before the list of requirements was made. Thus, this could influence the framework basing it on the existing solution instead of the process.

The author's opinion is that the developed methodology has provided ESA with proper results and could be used in similar future studies. However, as the requirements were assessed quantitatively a slightly different approach would have provided even better results. The requirements were treated with an equal weight with one exception; they were categorized as either mandatory or optional. If time were not a restraint an assessment of the importance or criticality of each requirement would have been more correct. This could have been done through a survey where the potential users assess the importance (e.g. on a scale from 1 to 5) from which the mean value decides the weight of the single requirement.

8 CONSIDERATIONS AND RECOMMENDATIONS

In this chapter, recommendations and considerations for how to proceed with each tool will be presented.

8.1 Recommended approach for the commercial tools

If ESA would decide to further consider any of the tested commercial tools the recommended approach is the following;

Gamma
As the tool scored almost equal to Alpha it should be further considered. However, the following considerations need to be taken:

- Test the application's response time when installed on ESA's infrastructure. This will answer the question if the slow response time was due to slow connection to the demo server or due to "bad programming".
- Investigate the actual capabilities of the administrator tool in order to fully understand the configuration possibilities, especially for the reporting features. Describe, through design level requirements, for Risk Decisions the needed reporting features, what information to be shown and the framework (for example in MS Excel or Power point). It is also important to find out if any of the configurations will cause any implications to the functionality of the tool.
- The structure and the amount of possible information to record have to be "cleaned up" in order to emphasize what is actually important when recording information.

Beta
As the tool scored the lowest, especially for the reporting requirements (not configurable), the recommendation is to exclude the tool from further investigations.

Delta
The tool should be further considered but it should be kept in mind that the

current version does not add any major benefits compared to Alpha. Further, the stability of the tool needs to be tested on ESA's IT infrastructure.

Epsilon
The gathered material is stating that the tool is capable in supporting ESA's RM process, thus it should be further considered. However, it needs be tested according to the list of requirements in order to find out the actual performance of each specific requirement.

8.2 Recommended approach for Alpha

Because of Alpha being a solution customized and controlled by ESA, recommendations in terms of improvement possibilities are presented.

If ESA decides to further develop Alpha, the following improvements could increase (best case scenario) the score to 97 % for the mandatory and 71 % for the optional requirements (the id of the requirement and the expected improvement for the level of fulfillment is shown within brackets):

- **Structure (3.3 and 1.1: fair to good) -** A recommendation is to implement a hierarchy structure, especially if the application shall be used agency-wide. This will provide the user with a logic structure and good visibility of the risks and their associated project/organization. Functionality could also be added making it possible to interact with the folders and the associated risks (e.g. copy/paste risks to different folders, creating folders/sub-folders etc.)

- **Layout (6.5.1: fair to good) -** The layout of the screens should be reconsidered and the structure of recording data. This include re-organizing the fields, tabs, how to input specific data etc. When structuring the screens it is important to emphasize the most critical information to be recorded and base the structure on a step-by-step format similar to the process suggested by ECSS.

- **Search engine (3.16 and 3.17: fair to good) -** The search engine should be able to include all risks the user has a permission to view when performing a search (and not be limited to the active project and revision).

- **Lesson learned and closed projects (3.14: bad to good) -** To provide a "lesson learned" within the organization, the recommendation is to add a feature that list all closed projects and their associated risks in a structured environment (e.g. a folder structure with a search engine). This should be a view-only feature available to all users (some boundaries would have to be set to protect classified/sensitive information).

- **Cause and Consequence fields (4.2.6: bad to good) -** The standard way of describing a risk scenario is through a cause and a consequence. Thus, Alpha should have two fields where it is possible to input this data.

- **Handling Strategy and Actions (4.2.7, 4.2.19 and 4.2.21: fair to good; 4.2.15 and 4.2.17: bad to good) -** Add a field to describe the overall plan for handling the risk depending on chosen strategy. This is more or less the idea for what "approach" is aimed to do. Thus, these two should be bundled and positioned together with actions (the requirements should also be bundled). Further, the available options should be according to ESA's RM plan (i.e. Transfer, Avoid, Mitigate and Defer). Each action should have a data entry same as for the assessment when recording the expected reduction and the possibility to record start/end date and the progress status.

- **Reports (5.1 and 5.5: fair to good) -** Improve the director's report making it possible to view the id of more than 3 risks in the heat map and fix the feature for generating (editable) reports in Power Point. Also, consider implementing a reporting feature that can describe the mitigation plan (through e.g. a Gantt chart, Waterfall chart or similar).

- **Copy Risks (3.24: bad to good) -** Add a feature making it possible to copy risks between projects and organizations.

- **Change log (3.13: fair to good) -** Currently you can see where and when risk information was updated. It is also possible to click and see the updated information, but in many cases you have to manually browse through the screens on different dates in order to identify what the actually changes were. The audit trail should describe what the actual changes were (compared to previous update) or provide an environment where you can compare the information on previous updates.

- **Support assessment at agency level (3.22: bad to good) -** Implement a feature that supports the assessment scale at agency level, making it possible to choose the preferred method when setting up a project/organization.

- **Closure of risks (3.7: fair to good) -** It should always be mandatory to update the conclusion field when closing a risk, thus a risk can be re-opened. Currently this is not the case if something has already been recorded in that field.

- **Deletion of risks (3.10: fair to good) -** It is possible to completely delete risks from the application, but this is currently in the hand of the "super administrator" (i.e. administrator rights possessed by Alpha's developer). A more convenient solution would be to give this right to the user administrating the project.

Each of the requirement has been treated with an equal weight, thus no recommendation can be presented in terms of which improvement is the most important. However, the methodology of weighing each requirement according to importance/criticality was discussed in chapter one. Through carrying out a survey among the users of the tool, this could provide ESA with an indication for which improvements are the most important.

The following suggestions may not directly increase the score of Alpha, but through this study the author has been convinced that these aspects should be considered:

- **Reviews -** The structure of creating "snapshot" reviews is contradicting to a continues process. This practically limits the update of risk information to a single date (which could last up to 6 months depending on the projects RM strategy). The structure also more or less limits the information to only be updated centrally. Re-assessment between review dates will not be considered or recognized by the reporting features, leading to incorrect information in reports such as e.g. the evolution chart. It also causes problems due to the system categorizing risks into review dates (instead of for example risk status), which is problematic when searching for risks and when listing all associated project risks (the system only list risks in the current revision). My recommendation is to delete this feature, improve the audit trail and add one control point meaning; risk information that has been updated (by someone else than the Risk Coordinator/Project Manager) shall be approved by the Risk Coordinator or Project Manager before being fully implemented in the system. According to the author's perception based on the evaluation, this is a much more convenient solution.

- **Risk Status -** For JWST the status of the risks are updated after every review. Currently this information along with the review date is updated manually through adding information about the new status in a "free text field". I recommend that this feature is changed and made similar to the "response" feature in the "update action" layout. Thus, this feature automatically records the time of update, separates and lists the implemented changes.

- **Step-by-step guide -** Implement a step-by-step guide when setting up project properties and consider a feature making it possible to choose a 3x3 matrix for specific organizations (if the application shall be used at agency level).

- **Level of Impact -** The same risk impacting two different levels (e.g. project and directorate) cannot be given similar attributes due to different objectives, making the possibility to record "level of impact" unnecessary. E.g. a 5B Project risk might be a 3B Directorate risk.

- **Risk categorization -** Categorize risks into Pending (not yet approved), Active (Project/Organization Risk), Closed/Accepted and Rejected (Pending risks that were not approved) risks.

9 CONCLUSION AND REFLECTIONS

This chapter will present the conclusions drawn by the author. It will also present some of the author's reflections on the project.

9.1 Conclusion

The conclusions that can be drawn from the benchmark are the following:

- Alpha is performing well and the tool is superior, compared to the evaluated commercial tools, in terms of reporting requirements.

- Two tools, Gamma and Delta, are able to compete with Alpha in terms of overall performance. Gamma scored almost equally with Alpha and if the tool supports the claimed configuration possibilities it could achieve a perceivable increase in score. This basically means that if ESA would change strategy and implement a commercial tool instead, the agency would not have to sacrifice anything in terms of relative performance (there would of course be gains/sacrifices for specific requirements).

- Beta is currently not able to compete in terms of performance with the other tools.

- The approach of sending the requirement list as an enquiry to Epsilon's developer did not provide sufficient information to include the system in the benchmark. However, the impression is that the tool may be capable in supporting ESA's RM process.

- Alpha scored 80 % for the mandatory requirements, which means that there is a possibility to improve the system. In chapter six suggestions of further development of the tool has been presented which could increase Alpha's score to 97 %.

While Alfa definitely is a good candidate for continuing supporting the ESA RM process, especially if the suggestions for further developing the tool are taken into consideration, the author's opinion is that the agency should further investigate the possibility of implementing a new RM system. A recommended approach is to extend the investigation described in this report by including additional parameters (e.g. one of them also being financial) with the objective to improve the current process and find a suitable vendor competent in both the IT and RM fields. In this investigation a third party consultant could be included with experience in the area of IT but most importantly also in the RM field. Such project could be beneficiary for ESA both from an IT and from a RM point of view.

The author's opinion is that the developed methodology used in this study has provided ESA with proper results and could be used in similar future studies. However, as the requirements were assessed quantitatively an assessment of the importance or criticality of each requirement would have provided even better results.

9.2 General Reflections

The following part does not derive from the conducted research in this project, instead it is merely some reflections the author got during the project's duration. It is mainly concerning the RM process and the RM system as they had been implemented at ESA.

First of all, there are some minor discrepancies between the current implemented RM system (Alpha) and the RM process. Why this is, would need a new investigation but Chuang M-L & Shaw W. H present some important critical success factors when implementing an ERP-system in their article "*An empirical study of enterprise resource management systems implementation From ERP to RFID*". They stress for example the importance of the vendor having sufficient business process knowledge and the customer having sufficient system process knowledge. This stresses even more the need to have a vendor that is not only familiar with software development but that also fully understands the RM process.

The main concern is however not the discrepancies between the process and the system, it is the one between the ECSS standard and the RM process carried out at ESA. In the author's opinion this is partially because of the standard not communicating sufficient and clearer guidelines and partially because ESA is still consolidating its implementation across the Agency. However it has to be understood that the ECSS are more tailored to an industrial environment and some specific elements may not be fully applicable to internal processes of organisations like ESA. The first problem is seen in for example the identification step where the ECSS is suggesting that the overall project risk shall be determined, but the standard is not explaining how this should be done. Determining the overall project risk is not currently done formally at ESA. As the assessment is done the determination of an overall project risk would basically be impossible. The provided metrics for the probability and consequence cannot somehow be added into an overall project risk or be used to compare risks between projects. This is important to understand otherwise it could lead to misleading information. Determining the total risk of a project could be done with the Monte Carlo approach but this approach demands that the assessment is much more accurate and consistent.

The assessment of risks brings us to the next part, which is a central part in the RM process but at the same time a bit vague at ESA. Severity of consequence and the likelihood of occurrence is the base from which decisions are taken. Thus, there should be ONE standard policy for how to assess risks in the agency. This should not be done differently between projects, which is sometimes the case right now. Further, the agency is currently using different scoring schemes (3x3 instead of 5x5) at agency level, which further increase the confusion in the author's opinion.

The only way to implement a standard, consistent and accurate measuring method is through starting with assessing the probability and the consequence in a quantitative manner, i.e. in terms of hard numbers which leaves no room for interpretation. As seen in several different RM plans at ESA the qualitative assessment was not consistent. This means that: not only is the assessment based on people with often very different, subjective perception there is also a different perception of the actual scoring schemes. E.g. if a risk's probability is assessed as "likely" the perception will be different for how often something that is "likely" to occur actually occurs. To further explain the problem imagine for example if someone would want to make a purchase for a component where the weight is central. The buyer would not settle with an offer where the weight is specified as "heavy" or just a number, thus this could mean almost anything. Instead the buyer would ask the supplier to specify the weight in terms of a number and a unit e.g. 3 kg or 3 lb. This would provide sufficient, objective information to base a decision upon.

This problem will almost certainly lead to misleading information. Information that is the foundation from which important decisions are taken. As mentioned earlier in the report ESA has a reporting chain in order to mitigate the problem. The assessment of risks along with the risk information is discussed and consolidated before reported to upper level management. However, this is not enough if RM shall be fully implemented throughout the organization. Risks cannot be fully understood and explained at each step throughout the reporting chain because it leads to an inefficient process and also takes away some of the purpose when assessing the risks. If the top manager is provided with two risks both with the same magnitude it should be accurate for him/her to assume that they are equally critical and important. Thus, the risks should be assessed in terms of unambiguous numbers e.g. probability in percent and impact in euros. This does not consequently mean that you have to be fully accurate, which would be impossible for risks at project level, the important thing is that the metric is unambiguous.

In addition to the risk assessment there are additional things that the author believes can be improved with the RM process. Right now there are no accurate measurements at ESA that could answer the question if and by how much the RM process is improving the business. The author suggests that ESA starts a project in order to more clearly define the RM process (through a much more detailed RM policy), to investigate alternatives for the assessment of risks and to find additional reliable KPI's. Thus, with the purpose of making information consistent, more accurate and to put numbers on the benefits provided by RM.

In general it is hard to believe that the implementation of a new IT-system would be defendable from a ROI-perspective when considering the associated risks and costs for such project. Especially if a new system would only replace one with similar functionality and not be implemented with the purpose to improve the business process itself. A new IT-system could of course provide long term cost benefits and the ROI has to be calculated in order to draw any conclusions.

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APPENDIX I: SCORING SCHEMES

Severity of consequence - scoring scheme for ESA's contribution in the JWST Mission

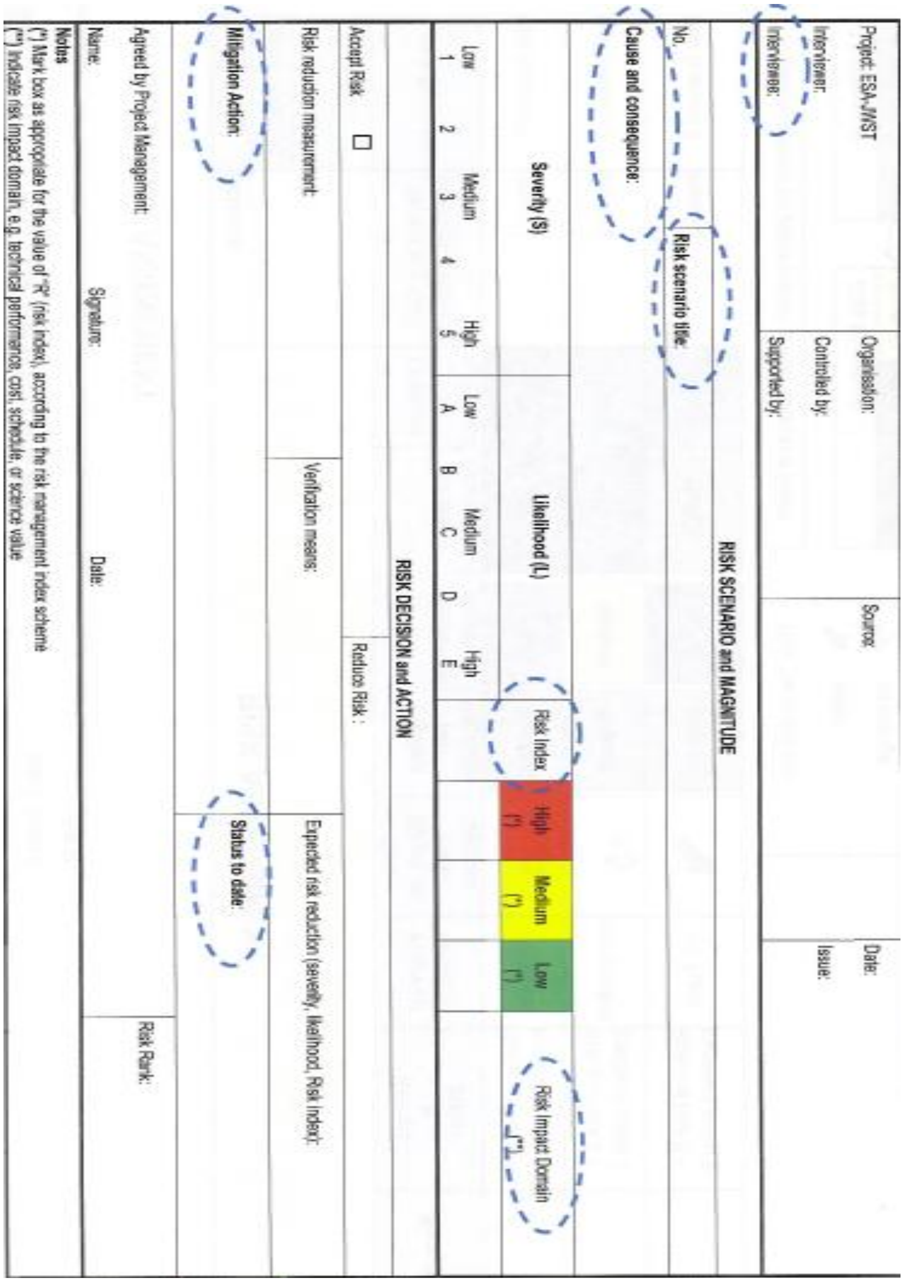
Score	Severity	Severity of consequence with impact on			
		cost	schedule	technical	science value
5	High	cost increase beyond the CaC and therefore need for approval by SPC	Delay of more than 6 months of the planned mission launch date or a key milestone	Unacceptable impact such that the mission is in danger	Loss of a major instrument mode or degradation in performance requiring renegotiation of Level I or Level II requirements.
4	Medium / high	no increase on the CaC, however more than 80 % but less than 100% of the contingency lost	Delay of less than 6 months of the planned mission launch date or a key milestone	Acceptable however remaining technical margin used between 80-100%	Degradation in performance corresponding to 80-100 % of Level II margin.
3	Medium	no increase on the CaC, however more than 50 % but less than 80% of the contingency lost	No direct impact on the planned launch however schedule margin is lost.	Acceptable with significant reduction in margin such as it is used between 50 and 80%	Degradation in performance corresponding to 50-80 % of Level II margin.
2	Low / Medium	no increase on the CaC, however more than 20 % but less than 50% of the contingency lost	No direct impact on the planned launch however 50 % of the schedule margin is lost.	Acceptable with some reduction in margin such as it is used between 20 and 50 %	Degradation in performance corresponding to 20 -50 % of Level II margin.
1	Low	Items of previous higher level after mitigation having a residual impact that is not negligible. Negligible risk items with a potential of increase or being triggered negatively by other risk items.	Items of previous higher level after mitigation having a residual impact that is not negligible. Negligible risk items with a potential of increase or being triggered negatively by other risk items.	Items of previous higher level after mitigation having a residual impact that is not negligible. Negligible risk items with a potential of increase or being triggered negatively by other risk items.	No degradation in performance w.r.t. Level II.

Likelihood of occurrence - scoring scheme for the JWST Mission

Score	Likelihood	Likelihood of occurrence
E	High	Near certainty
D	Medium/High	Highly likely
C	Medium	Likely
B	Low/medium	Possible
A	Low	Remote

APPENDIX II: RISK INDEX SCHEME

APPENDIX III: RISK REGISTER



Project: ESA-JWST
Interviewer:
Interviewee:
Organisation:
Controlled by:
Supported by:
Source:
Date:
Issue:

RISK SCENARIO and MAGNITUDE

No.
Risk scenario title:
Cause and consequence:

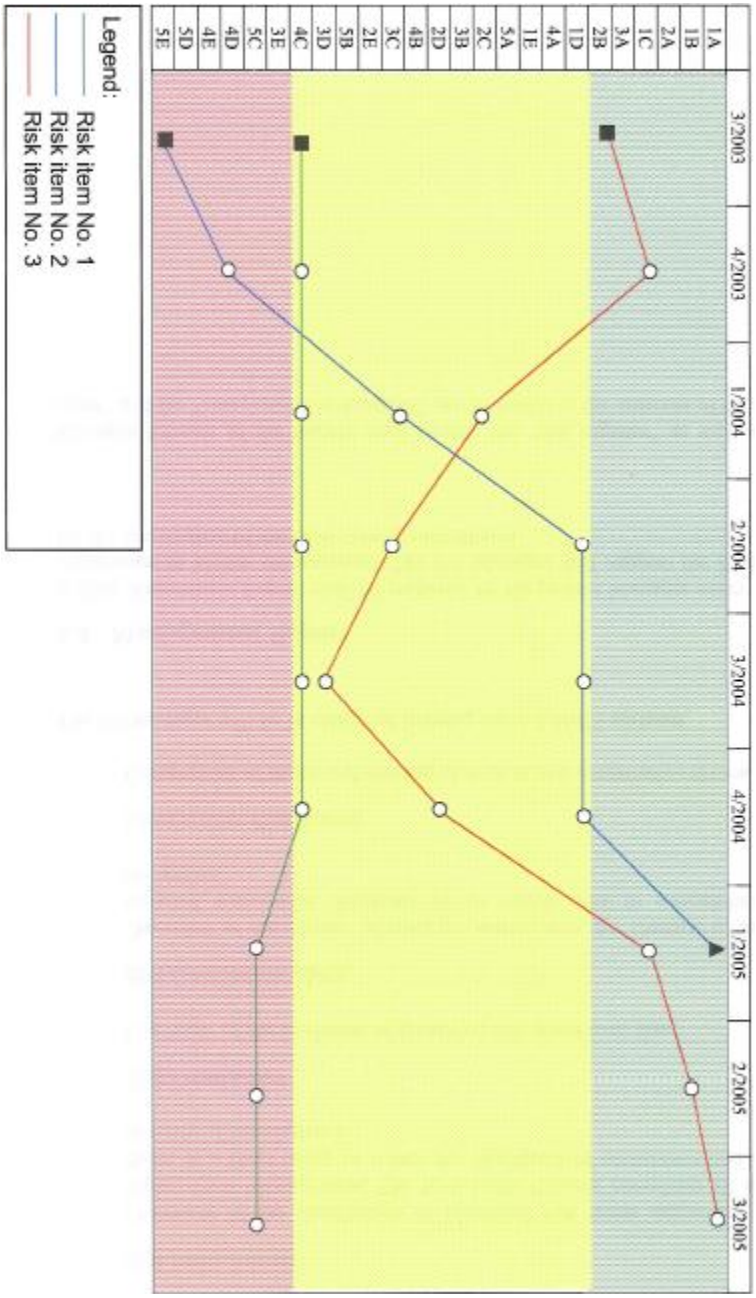
Severity (S)					Likelihood (L)					Risk Index	High (*)	Medium (*)	Low (*)	Risk Impact Domain (**)
Low 1	2	Medium 3	4	High 5	Low A	B	Medium C	D	High E					

RISK DECISION and ACTION

Accept Risk ☐
Reduce Risk :
Risk reduction measurement:
Verification means:
Expected risk reduction (severity, likelihood, Risk index):
Mitigation Action:
Status to date:
Agreed by Project Management:
Name:
Signature:
Date:
Risk Rank:

Notes
(*) Mark box as appropriate for the value of "R" (risk index), according to the risk management index scheme
(**) Indicate risk impact domain, e.g. technical performance, cost, schedule, or science value

APPENDIX IV: RISK TREND CHART



APPENDIX V: INVESTIGATED TOOLS

Tool Name	Comment
Zeta	Solution integrated in MS project/Excel
Eta	Integrated in MS Excel, Simulation & Optimization tool
Theta	Low credibility
Iota	Low credibility. Not meeting enough of the reporting requirements.
Kappa	Security issue due to external database
Lambda[1]	Secondary option
Mu	Not enough relevant functionalities
Nu[2]	Secondary option
Xi	Focused towards health, safety environmental risks
Omicron	Not suitable for ESA RM process and reporting requirements
Pi[1]	Secondary option
Rho	Not aligned with the reporting formats suggested by ECSS. Integrated with PM planning and scheduling software
Sigma	Low credibility. Focused towards the finance and insurance sector.
Tau	Reporting and graphical formats not aligned with ECSS
Upsilon	Risk assessment techniques focused on the process industry

Phi	Server and Database hosted by supplier in Atlanta
Chi	Audit software where risk management is a small part of the solution.
Psi	Integrated solution with RM, internal control, internal audit, governance and IT security management
Omega	Powerful but complex tool. Standalone application. (Multiuser edition scheduled for Q4 2009)
1	Not meeting the reporting requirements. Built around a discussion board and voting system.
2	Provided screenshots indicates that the tool does not meet the data requirements. First version.
3	Not meeting the reporting requirements. More focused towards quantitative assessment.
4[1]	Secondary option
5[1]	Secondary option

[1] These tools did not have any major flaws; however they were missing minor features that were included in the “selected tools”. Further, some of the tools were also less credible and performed functionalities in a less appropriate way compared to the “selected tools”. “Secondary option” means that if ESA any time in the future would decide to replace the existing tool with a COTS solution, these could be included in the investigation.

[2] It is questionable whether or not the developer to Nu is offering COTS solutions. On one hand they are offering solutions with already existing functionalities but still, on the other hand, you would in most cases need a Nu consultant to implement and tailor the tool according to the customer’s need. When the aim is to find a COTS tool, which supports one specific defined process, the author’s personal opinion is to be a bit hesitant when it comes to companies that are focused on supplying systems supporting almost every business process. Basically because their core competence seldom lies within a specific module (e.g. one supporting RM). On strategic level it is of course viewed as beneficiary to find a standard system for the whole organization supporting all its processes, but the specific module has to be investigated on the same terms as all the other commercial solutions. These reasons can not in any way exclude Nu, thus the RM solution might be suitable for SRE’s RM process. The tool does not have any major flaws,

however it fails to meet some of the data requirements (originator, source etc.) and the “risk response” feature is not appropriate for SRE.

The tools selected for the benchmarking are presented in the table below:

Tool Name
Alpha[1]
Beta
Gamma
Delta
Epsilon[2]

[1] Alpha is the tool already implemented to support ESA’s RM process.
[2] Epsilon’s developer were unable to provide a demo version. Instead of evaluating the tool, the list of requirements was sent as an “enquiry” to the developer.

APPENDIX VI: SOFTWARE REQUIREMENTS LIST

ID	Requirement	Additional info and verification	Mandatory/ Optional
1	**General Requirements**	**Specifies the overall requirements of the system.**	
1,1	The RM tool shall support a "multiproject/multiorganization" environment	Good > 100	**M**
1,2	The RM tool shall support a "multiuser" environment	Good > 2000	**M**
1,3	The RM tool shall support a "multirisk" environment	Good > 5000	**M**
1,4	Users shall be assigned permissions, access, functionalities according to their role	See note 1	**M**
1,5	The RM tool shall be "administered" by the customer		**M**
1,6	It shall be possible to customize the RM tool	This requirement refers to the possibilities to customize the tool in order to fit it to SRE's RM process, e.g. the terminology, layout, reports etc. Consideration will mainly be taken to the configuration possibilities made by the customer.	**O**
1,7	The RM tool shall have a clear pricing	The usual associated costs when implementing the system. Is there a clear pricing strategy (per user, per consulting hour etc.)?	**M**
2	**Technical Requirements**		
2,1	The supplier shall be able to provide ESA with documentation regarding the technical requirements	To ensure no software or hardware constraints in a potential implementation.	**M**

2,2	The RM tool shall Interface to external tools	Even if the tool is providing the required reporting and data output formats it will be considered as a strength if the tool can export/import the information to other data handling software. Thus, the tool is unlikely to provide the same capabilities for editing and handling data as for example MS Excel or MS Word.	**O**
2,3	The RM tools shall support a centralized backend database, located at customer's premises	This requirement was partially identified due to some of the suppliers were only capable in offering a 'hosted' solution (i.e. actual software located at the supplier's premises), which causes security complications as valuable and classified information will be stored and handled by the tool.	**M**
2,4	The RM tool shall be under configuration/version control	If the supplier are releasing any updates, this should not in any way 'reset' the system or impose a new process to its users.	**M**
2,5	The RM tool shall be able to operate "standalone" or together with software already existing at ESA	ESA should not be forced to acquire any (new) 3rd party software. If so, this cost must also be presented by the supplier.	**M**
2,6	The RM tool shall support a back up feature	In order to mitigate the risk of loosing valuable information	**M**
3	**Functional Requirements**		
3,1	The RM tool shall be able to create new risks		**M**
3,2	The RM tool shall be able to create new projects		**M**
3,3	The RM tool shall be able to create new organizations		**M**
3,4	The RM tool shall be able to create proposed risks to be sent for approval	Risk to be sent for approval shall have the same data requirements as risks	**O**

3,5	The RM tool shall send an e-mail notification for approval when inserted as proposed into the system	It shall be possible to disable this feature. If risk information is implemented centrally in the system by the project/organization group this feature is unnecessary	**O**
3,6	The RM tool shall send an e-mail notification to the assigned risk owner	Same as 3.5	**O**
3,7	The RM tool shall allow the closure of a risk with related justification (free text field)	The closure (in contrast to the acceptance) of a risk refers to a risk that can not materialize (e.g. elapsed time horizon	**M**
3,8	The RM shall allow modifications of existing data in the current revision/scenario by all users with the necessary access rights		**M**
3,9	The RM tool shall allow re-opening of a Closed Risk.		**M**
3,10	The RM tool shall allow the Deletion of an existing risk	By authorized user	**M**
3,11	The RM tool shall allow "Copy and Paste" from documents into fields.		**M**
3,12	The RM tool shall allow "risk attachments"/ files (especially for actions)		**O**
3,13	The RM tool shall support an Audit Trail record (change log)		**M**
3,14	The RM tool shall store closed projects and risks in a structured way, with a search engine accessible by all users	With the purpose to communicate previous risks and provide a "lesson learned" (viewing only)	**M**
3,15	The RM tool shall support required and optional fields when recording information		**M**
3,16	The RM tool shall support searches within the database		**M**
3,17	The RM tool shall list all risks that match specific search values.		**M**
3,18	The RM tool shall have a "My Risks" view	I.e. risks for which the User is either Risk Originator, Risk Owner and/or Actionee	**O**
3,19	The RM tool shall support progressive "revisions/scenarios" of the same project	Revisions of a risk shall not overwrite data associated with a risk in a previous revision. This to be able to perform a	**M**

		comparative analysis over a period of time.	
3,20	The assessment of previous revisions/scenarios shall not be editable.		**M**
3,21	The RM tool shall support a 5x5 risk matrix		**M**
3,22	The RM tool shall support a customized risk matrix per each project (e.g 3x3)	This requirement originates from the RM framework at agency level.	**O**
3,23	The RM tool shall allow for local replicas on laptops/computers		**O**
3,24	The RM tool shall have the ability to clone/copy risks	To another Project or Organization	**M**
4	**Data Requirements**	**Data to be stored (recorded and retrieved) associated with specific items. Any data restraints shall be informed by the supplier. See Note 2.**	
4,1	**Project & Organization**	**Data to be stored for specific Projects & Organizations**	
4.1.1	The RM tool shall record for each project the title	Text (Good)	**M**
4.1.2	The RM tool shall record for each organization the title	Text (Good)	**M**
4.1.3	The RM tool shall record for each project/organization the established project/organization strategy for dealing with the risks	In accordance with the related Project Risk Management Plan. Table (Good), Text (Fair)	**O**
4.1.4	The RM tool shall record for each project/organization the established project scoring scheme for the severity of consequence and likelihood of occurrence	In accordance with the related Project Risk Management Plan. Table (Good), Text (Fair)	**O**
4,2	**Risks**	**Data to be stored for specific risk items**	
4.2.1	The RM tool shall record per each risk the name of the organization	e.g. ESA Directorate. Automatic recording (Good)	**M**

4.2.2	The RM tool shall record per each risk the name of the project	Automatic recording (Good)	**M**
4.2.3	The RM tool shall record per each risk the risk title	Text (Good)	**M**
4.2.4	The RM tool shall record per each risk the name of the Risk Owner	Predefined dropdown list (Good), Text (Fair)	**M**
4.2.5	The RM tool shall record per each risk the source of the risk	e.g. Payload, spacecraft, launcher, operations, etc. Predefined dropdown list (Good), Text (Fair)	**M**
4.2.6	The RM tool shall have a field to describe the nature of the risk and the potential consequences	Text (Good)	**M**
4.2.7	The RM tool shall record per each risk the selected approach with some description	Possible letters summarizing the approach: T (Transfer), A (Avoid), M (Mitigate), D (Defer) + "Unlimited" text field. Predefined dropdown list + text (Good), Dropdown list or text (Fair)	**M**
4.2.8	The RM tool shall record per each risk the potential domain(s) of impact of the subject risk	e.g. cost, schedule, performances (science, technical). : Predefined dropdown list (Good), Text (Fair)	**M**
4.2.9	The RM tool shall record the time frame for the risk (risk horizon)	Pop up schedule, predefined dropdown list etc. (Good), text (Fair)	**M**
4.2.10	The RM tool shall record per each risk the name of the Risk Originator	Predefined dropdown list (Good), Text (Fair)	**M**
4.2.11	The RM tool shall record per each risk the severity of consequence of the risk	Qualitatively from predefined dropdown list/ risk matrix: scale 1-5, 1-3 (Good), entering digit/quantitatively/text (Fair)	**M**
4.2.12	The RM tool shall record per each risk the likelihood of occurrence of the risk	Qualitatively from predefined dropdown list/ risk matrix: scale 1-5, 1-3 (Good), entering digit/quantitatively/text (Fair)	**M**
4.2.13	The RM tool shall record per each risk the corresponding risk index	Automatic recording (Good), Text (Fair)	**M**
4.2.14	The RM tool shall record per each risk the corresponding risk magnitude	e.g. very high (Red), high (red), medium (yellow), medium (yellow), low (yellow), very low (green). Automatic recording in risk matrix (Good), Other recording/ Text (Fair)	**M**

4.2.15	The RM tool shall record per each risk the eventual risk reduction measures	Text (Good)	**M**
4.2.16	The RM tool shall record per each risk the verification means of the risk reduction measures (Reduction Indicators)	Shall not be a required field. Text (Good)	**M**
4.2.17	The RM tool shall record per each risk the expected risk reductions of the risk reduction measures	i.e. severity, likelihood, risk index. Shall not be a required field. Qualitatively from predefined dropdown list/ risk matrix: scale 1-5, 1-3 (Good), entering digit/quantitatively/text (Fair)	**M**
4.2.18	The RM tool shall list per each risk the actions related to the risk	The feature can be used for action also related to the assessment, approach, monitoring, etc. and not only for mitigation. Text (Good)	**M**
4.2.19	The RM tool shall record the time frame for the actions to be taken	Predefined dropdown list/from pop up schedule (Good), Manual input text/number (Fair)	**M**
4.2.20	The RM tool shall list per each action the name of the actionee	Predefined dropdown list (Good), Text (Fair)	**M**
4.2.21	The RM tool shall record the status of the actions related to the risk	Text (Good)	**M**
4.2.22	The RM tool shall record the name/role that shall agree/accept the proposed risk disposition	Predefined dropdown list (Good), Text (Fair)	**M**
4.2.23	The RM tool shall have a field to describe the progress status/evolution of the risk	The status of the previous revisions shall be carried forward in the new revision (unlimited text field). Text (Good)	**M**
4.2.24	The RM tool shall be able to record a risk as accepted	Check box (Good), Dropdown list or similar (Fair)	**M**
5	**Reporting requirements**		
5,1	All reports shall be in (or exportable to) Html, pdf, MS Excel, MS, Word, MS Powerpoint.		**M**
5,2	The RM tool shall be able to generate reports using filters	Filter risks, filter per domain of impact, for risk index, etc	**M**

5,3	The RM tool shall generate a risk register (with the filtered risks) for the selected project		**M**
5,4	The RM tool shall generate the distribution report/risk table (with the filtered risks) for the selected project		**M**
5,5	The RM tool shall generate the risk matrix/heat map (with the filtered risks) for the selected project/organization		**M**
5,6	The RM tool shall generate a trend chart/evolution report (with the filtered risks) for the selected project		**M**
5,7	The RM tool shall generate a comparative report (with the filtered risks) for the selected project between current and previous revisions		**M**
6	**Quality requirements**		
6,1	The RM tool shall have a comprehensive list of previous/current users in an ESA comparable environment/domain	Previous customers etc.	**M**
6,2	The RM tool shall be a stable system	Verified through no experienced crashes during testing	**M**
6,3	**Performance**		
6.3.1	The RM tool shall have a reasonable response time	When creating reports, implementing risks, calculating risk magnitude, performing searches etc. "Peak in traffic"	**M**
6,4	**Maintenance and support requirements**		
6.4.1	The help desk shall be easily accessible	Both phone and e-mail	**M**
6.4.2	The RM tool shall provide on line training possibilities and demo example		**O**

6.4.3	The RM tool shall provide on line help and user/administrator tutorial/help guide		**M**
6.4.4	The supplier shall have a clear maintenance policy		**M**
6,5	**Usability**		
6.5.1	The RM tool shall be user friendly and easily deployable to non expert users	Verified through 3 peoples opinions/ first time users	**M**

Note 1: User access and permissions (explanation of requirement 1.2 and 1.3)

Below follows a suggestion of the user structure, consisting of two users and one administrator.

- ***General user***
  Create, Edit, Update, Delete Risk Proposals (Risk that has not yet been approved as a Project/Programme Risk), Overview closed Risk items and Read Risk information.

  The Edit, Update and Deletion refers only to the Risk Proposed by the user, which means that the user can not Edit, Update or Delete any Risks that have been proposed by another user.

  If a General User is assigned to a Risk as a *Risk Owner* the person will be able to Edit and Update the assigned Risk (the changes are stored in the audit trail/ change log). All the user permissions will still apply.

- ***Project/Organisation Risk Manager***
  Has the permission to do all of the above. In addition, edit project information, approve risks, edit all risks, create reports etc.

  Note: All permissions, except the Overview of closed risks, are connected to a specific Project/Organisation. For example, a user connected to Project1 have no permission to Create, Edit, Update, Delete or Read Risk information connected to Project2. However, a user can be connected to multiple Projects/Organisations.

- ***System Administrator***
  All above with the addition to; configure the system (terminology etc.), create, edit and delete users, assign permissions, create project/programme classes.

Note 2: Class relations

The Project/Organisation class can have none, one or many associated Risk items and the Risk can impact one Project/ Organisation class as illustrated in the figure below.

N.B. In practise risks can affect several Projects/Organisations. E.g. a project risk might be of such magnitude that it could affect the whole organisation's objectives or several projects might be reliant on the same source. However, the same risk will be input twice in the system if also affecting a different class, thus some attributes might change when a risk is escalated from project to organisation level. Further, from project to project the perception of the same risk might be different and the assessment will most certainly change due to different project objectives and restraints.

APPENDIX VII: ABBREVIATIONS

COTS	Commercial Of The Shelf
ECSS	European Cooperation for Space Standardisation
ELDO	European Launch Development Organisation
ESA	European Space Agency
ESRO	European Space Research Organisation
ESTEC	European Space Technology and Research Center
ISS	International Space Station
JWST	James Webb Space Telescope
NASA	National Aeronautics and Space Administration
RKA	Russian Federal Space Agency
ROI	Return On Investment
RM	Risk Management
SRE	Science and Robotic Exploration (ESA directorate)