Risk Management in ESA's Scientific Directorate: A Case Study

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A practical example of the implementation of Risk Management within ESA's Science Directorate is presented, both with a view to further promoting the use of this valuable programme-management tool, and also as a catalyst to promote the exchange of experience and know-how in this domain. A summary of a Risk Management Policy for the Directorate's Scientific Projects Department is provided here, followed by a brief description of a 'real-life' systematic risk assessment and the results achieved.

Introduction

In the European space environment, Risk Management (Fig. 1) has evolved to the point of being the subject of an ECSS (European Cooperation for Space Standardization) Management Standard in April 2000. Compared to other Risk Management standards (e.g. those of governmental organisations in the United States or Australia), the ECSS standard (ECSS-M-00-03A) used by the European space community represents a state-of-the-art approach. It is comprehensive, provides a common understanding of the subject, and also serves as a contribution to the establishment of an international ISO standard on Risk Management in Space Projects.

Definition of Risk Management implementation requirements

Risk Management is considered to be an important asset in the Scientific Projects Department, which therefore has its own Risk Management Policy. This Policy serves as a guide for the quantification of individual and overall risks, also promoting a common understanding of the subject within the Department. The aim is to appraise the Department's activities as a system in terms of technical, social and managerial factors, to provide clarity and visibility of the risks that influence the achievement of its overall objectives, as well as those of each of the scientific projects, to assess and quantify these risks, and to put the necessary solutions in place.

Goals and resource constraints

The Scientific Projects Department is charged with the implementation of the Horizons 2000 Programme, which involves a broad spectrum of current and future scientific missions. Each of these missions has its own objectives, resources, and constraints, based on the

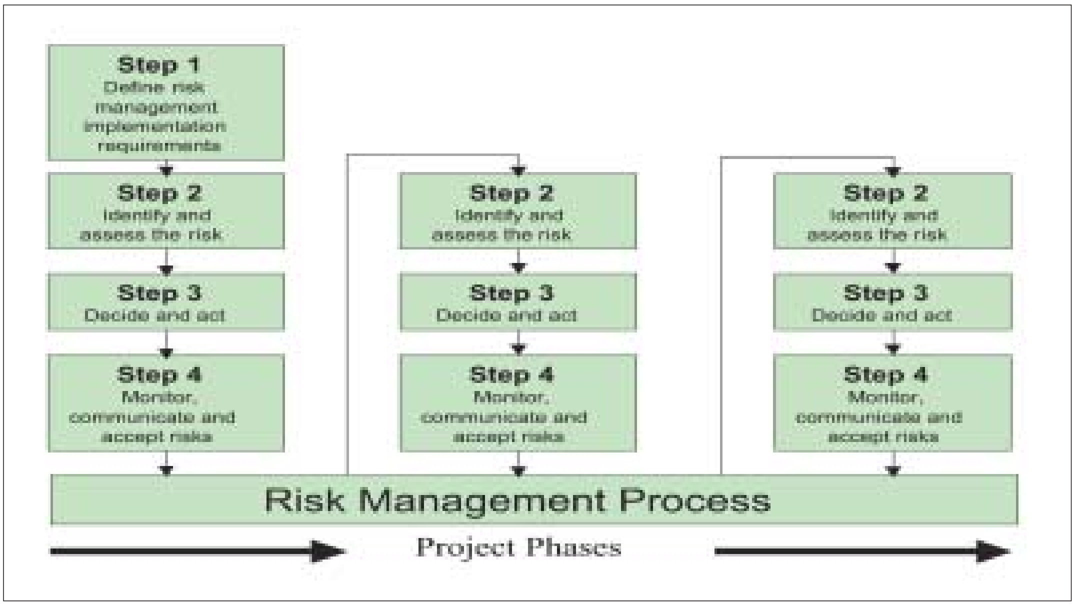


Figure 1. The Risk Management process

recommendations of the European space-science community and the decisions of ESA's Science Programme Committee (SPC). The Scientific Projects Department is responsible for designing, building and launching the scientific spacecraft and commissioning them for operation by ESA's European Space Operations Centre (ESOC). The ESA Space Science Department then operates the scientific instruments and realises the eventual scientific return.

The Scientific Project Department's resources or domains that may be affected by risk are:
– technical
– schedule
– cost
– science value.

The 'science value' domain addresses issues that can have an impact on the expected scientific return from a mission. The reason for introducing this domain is that, although a spacecraft may be delivered on time, within the planned cost envelope, and also delivers the required technical performance, there may still be inherent risks that can cause a loss of scientific return.

Strategy and approach
The role of the Risk Management Strategy is to proactively address risks before they become problems involving serious cost, schedule, technical-performance or science-value impacts. This strategy is considered an integral part of the Department's management approach in the implementation of Horizons 2000. The potential risks therefore have to be well-understood in order to evaluate the decision options and identify the appropriate actions as early as possible, to mitigate in particular all risks designated as category 3C and above (see below).

The Project must use a structured assessment approach to identify and analyse those items that are critical to meeting the project objectives. The risk mitigation options developed need to be monitored for their effectiveness. Careful identification of the resources required is crucial for the successful implementation of the risk treatment options chosen. Once approved, the chosen options need to be incorporated into the Department's overall planning and reporting. Furthermore, the risk-assessment process needs to be continuously updated using the latest risk-management tools available.

An updated risk assessment is mandatory prior to a project-milestone review (preferably conducted with external expertise). As new information becomes available, the project should conduct additional reviews if necessary to ascertain if new risks exist. The goal is to be continuously looking to the future for emerging risk items that may severely impact the programme.

Ranking risks
The procedural approach for ranking risk objectives is as follows:
1. Understand the system (technical, non-technical) and the environment of the project.
2. Identify as many risk items as possible by employing the most effective methods.
3. Analyse all identified risks in order to fully understand them.
4. Assess the impact of the identified risk items on the objectives.
5. Accept the risk if possible.
6. Risks that are not acceptable are to be avoided, mitigated or transferred in the most effective way, but will still need elaborating to ascertain their possible implications.

Identified risks should be quantified in terms of likelihood of occurrence and severity of consequence using Tables 1 and 2. The likelihood of occurrence is normalised on a scale of A to E, and the severity of consequence on a scale of 1 to 5.

Table 1. Likelihood-of-occurrence scoring scheme for the Scientific Projects Department

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

A Risk Index is usually a combination of the likelihood of occurrence and the severity of the consequences for a given risk item. For the Scientific Projects Department, risk ratings of low, medium or high are to be assigned, based on the Risk Index Scheme criteria shown in Table 3. The highest possible Risk Index will therefore be 5E, and the lowest 1A.

Action criteria
The purpose of Risk Management is to identify what actions should be taken, and when. Experience shows that it is mandatory for all identified risk items in the 3C-5C-3C-3E quadrant to be analysed and responded to with proposals for risk treatment actions. For the remaining risk items, there should be an alert issued regarding a possible increase in the Risk Index.

Table 2. Severity of consequence – scoring scheme for the Scientific Projects Department

Score	Severity	Severity of consequence with impact on			
		cost	schedule	technical	science value**
5	High	Cost increase beyond the CaC and therefore approval at level of SPC	Impact on the planned launch date of a mission or a key milestone	Unacceptable impact such that the mission is in danger or that projects are also affected.	Impact that leads to more than 30 % science loss
4	medium / high	More than 80 % but less than 100% of the financial contingency is impacted	No direct impact on the planned launch date. However more than 50 % of the schedule margin is affected. Major slip in key milestone or critical path impacted.	Acceptable*. However no remaining margin	Impact that leads to more than 20 % science loss
3	medium	More than 50 % but less than 80% of the financial contingency is impacted	Minor slip in key milestone. No direct impact on the planned launch date. However up to 50 % of the schedule margin is affected.	Acceptable with significant reduction in margin	Impact that leads to more than 10 % science loss
2	low / medium	More than 20 % but less than 50% of the financial contingency is impacted	No direct impact on the planned launch. However up to 25 % of the schedule margin is affected.	Acceptable with some reduction in margin	Impact that leads to more than 5 % science loss
1	low	Up to 20 % of the financial contingency is impacted 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	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

* Acceptability in the technical domain is considered if the identified risk item is not mission critical
** For reasons of simplification a rule of thumb for the measurement of science loss should be calculated linearly e.g. if a spacecraft has ten instruments, then the loss of one instrument would be 10%.

Table 3. The Risk Index scheme

Risk Index: Severity & Likelihood

Severity	A	B	C	D	E
5	5A	5B	5C	5D	5E
4	4A	4B	4C	4D	4E
3	3A	3B	3C	3D	3E
2	2A	2B	2C	2D	2E
1	1A	1B	1C	1D	1E

Likelihood

Red Yellow Green

The aim is not to accept every risk blindly, but only with a full understanding of the scale of the risk and why acceptance is justifiable. Ideally, all risk items should have reached a level of justifiable acceptance at the end of a project. It is the Project Manager's responsibility to decide on final risk acceptance. Where a risk cannot be accepted, appropriate action – risk avoidance, mitigation or transfer (see below) – is needed to achieve the necessary countermeasure(s) as effectively as possible. Within the lifecycle of the Project, individual items with a (currently) high Risk Index may be put on hold with respect to their acceptability, but only if it is clear that treatment may take place at a later stage without loss of effectiveness, or that alleviation may occur automatically over time because the item is triggered by other circumstances. However, a justification for not taking action, based on an analysis of the particular issue, is again needed.

The Project Manager acts as the integrator of the Risk Management activities across all of the project domains concerned, taking responsibility for reporting the results to Departmental management.

Deciding and acting

In evaluating the various options available, the following possibilities can be taken into account:

- *Avoiding the risk,* by deciding either not to proceed with the activity that involves an unacceptable risk, or choosing an alternative more acceptable or a less risky course of action that still meets the objectives. Reducing requirements as a risk-avoidance technique will be used only as a last resort, and then only with the participation of the Head of the Scientific Projects Department.
- *Mitigating the risk,* by reducing its likelihood of occurrence or the severity of its conse-

quences, or both. There is usually a trade-off to be made between the magnitude of the risk and the resources needed to reduce that risk to an acceptable level.
– *Transferring the risk,* in full or in part, to another party. Risk transfer may not reduce the magnitude of the risk, but in most cases merely reallocates the associated costs to different parties. In transferring risk to other parties, one must also consider the implications for one's own environment.

The results of such evaluations and the choices of risk-treatment options should always be documented and monitored to clearly establish whether the magnitude of the risk for the item in question has been reduced to an acceptable level.

Communication is an important consideration at each step in the Risk Management process. Effective internal and external communication is important to ensure that all parties directly involved in the Project, or who have a vested interest, understand the basis on which the decisions are being made and why particular actions are required. The different stakeholders' perceptions of risk can vary, due to differences in their assumptions, concepts, needs, issues and concerns.

An example of risk identification and assessment

What follows is a brief description of a risk identification and assessment performed for the main development phases (Phase-C/D) of the current scientific projects, and the consolidation of the results at Scientific Project Department level.

Methodology

Within the ESA Scientific Programme, a degree of technical risk due to technology advancement and the uniqueness of every mission is normal. This favours the use of a qualitative risk-assessment method, which not only looks for quantifiable schedule and financial impacts, but also pinpoints the exact cause and consequences of each risk item identified in terms of system understanding and lessons learnt.

The methodology used to identify the risk items was that of interviewing of the project's key staff. This approach was regarded as the most suitable, despite being more time-consuming than structured brainstorming techniques (e.g. the meta-plan technique). It also circumvents negative group-dynamic situations in which project team members tend to be less vocal than on a one-to-one basis. The initial interviews were conducted by an ESA staff member not belonging to the project team, but who was sufficiently familiar with the Agency's projects and environment. One underlying principle of Risk Management is that the project should be able to identify and assess its risks internally. When the interviewer does not belong to the project, there is always the chance that the project team might be reluctant to expose any shortcomings. The question of using an external person should therefore be treated very carefully, with due respect for the project team's feelings and wishes. One possibility is to have the outsider conduct only the initial risk identification exercise, leaving the recurring tasks to someone within the project itself.

To help in identifying the risk items, a checklist has been established for use as an interviewing guide (Fig. 2). This list, covering the spacecraft, payload and programmatic domains, has been developed in close collaboration with experienced Directorate staff and supporting parties, in order to be as comprehensive as possible. The spacecraft domain covers issues concerning the service module on which the scientific instruments (making up the payload) are mounted, the payload domain covers the scientific instruments themselves, while the programmatic domain deals with the typical managerial issues, such as project phasing, team motivation, records of contractors, financial and contractual items, etc.

A: Spacecraft oriented

A.1) Aspects of Technology Readiness
- a.) Technology Advancement
- b.) Technology Development

A.2) Systems Engineering and Integration aspects
- a.) Design maturity (system-subsystem-unit)
- b.) Internal interfaces
- c.) External interfaces
- d.) Complexity total system
- e.) Complexity required tools

A.3) Producibility aspects
- a.) Manufacturing requirements / manufacturing technology

A.4) Procurement aspects
- a.) Supplier availability

A.5) Software aspects
- a.) Software architecture (at all levels)
- b.) Software verification / validation
- c.) Interdependence of the various software (SW/SW interfaces)

A.6) Assembly Integration and Test aspects
- a.) Assembly & integration process, chronology requirements
- b.) Test procedures, customer requirements
- c.) Test facilities availability

C: Programmatic oriented

C.1) Administrative aspects
- a.) Procedures / Regulations

C.2) Financial aspects
- a.) Cost planning / estimation
- b.) Industrial return
- c.) Incentive / Penalty schemes
- d.) Economic constraints
- e.) Contingencies

C.3) Human resources aspects
- a.) Hard skills
- b.) Soft skills
- c.) Motivation team
- d.) Team expertise

C.4) Project planning aspects
- a.) Phasing continuity
- b.) Quality of schedule reporting
- c.) Schedule trend
- d.) Schedule versus launch gate

C.5) Contractual aspects
- a.) Past performance of Contractor
- b.) Relationship Contractor / ESA
- c.) Relationship Prime / subcontractors
- d.) Contract as is

Figure 2. The risk-identification checklist

The data collected was collated in a Risk Register, as shown in Figure 3. For later categorisation, the source of the risk had also to be identified or isolated. The consequences of the identified risks were then quantified in terms of likelihood of occurrence and severity of consequence (cost, schedule, technical or scientific return), in consultation with the Project

Project: Example | Organisation: D/SCI | Source: **IT / Software** | Date: 27. September 2000

Interviewer: SCI MM Jörg Schroeter | Controlled by: | Issue: 1.0

Interviewed: RM | Supported by:

RISK SCENARIO and MAGNITUDE

No. 1 | Risk scenario title: **The chosen Software needs adaptations**

Cause and consequence:

Due to the chosen software (an off the shelf product) the aim was to save time and expenditure. However it seems adapatations to the software are necessary to meet the mission requirements. This causes additional time for design and verification of two months and a current cost increase of 1 Meuro which can not be managed within the approved allocations. The item lies on the critical path and therefore the launch date is in danger.

Severity (S)	Likelihood (L)	Risk Index	RED (*)	YELLOW (*)	GREEN (*)	Risk Domain (**)
Low 1, 2, Medium 3, 4, High 5	Low A, B, Medium C, D, High E	4B		X		S, C

RISK DECISION and ACTION

Accept Risk ☐ | Reduce Risk

Risk reduction measures: | Verification means: | Expected risk reduction (severity, likelihood, risk index):

Action: *A scrutiny team will be set up to analyze the situation* | Status: *Results expected by end of October, thereafter decision how to continue*

Agreed by Project Management: | Risk Rank: 1

Name: | Signature: | Date:

Notes

(*) Mark box as appropriate for the value of "R" (risk index), according to the criteria defined in the risk management policy

(**) Indicate risk domain, e.g. technical, cost or schedule

Figure 3. The Risk Register

Project: **Example** | Organisation: D/SCI | Date: 01 November 2000 | Issue: 1.0

Rank	No.	Risk scenario title	Red (*)	Yellow (*)	Green (*)	Risk Domain (**)	Action / status / comment
1	23	Payload, late delivery of instrument 1	5E			S, SV	*- Submission of small support contracts / expertise where possible - Increase of the work time by working in long work shifts - Submission of human resources from the Prime to the instruments test team - Acceptance of small losses in science performances - Delivery of the instrument in two parts*
2	18	Payload, instrument 2 current unit 1 will not perform well	4D			C	*- As a backup unit can be procured otherwise, however schedule impact*
3	29	Payload, late delivery of instrument 1	4D			S, C	*- Submission of small contract / expertise where possible - Increase of the working time to shift working - Submission of support to the Prime test team - Reviews for rescheduling the test programme performed - Simulator for the payload mounted*
4	7	AIT, Test chronology is highly sequential		3D		S, SV	*- Payload reviews, rescheduling after payload delivery - New container for transportation of complete spacecraft - Improvement of test facilities*
5	27	Managerial, Human resources, key people leave		3C		T, S, C	*- Plan has been discussed how to keep key people until end of project*
6	31	Product assurance, Exchange of Shottky diodes		3C		T, S	*- The consequences and possible workarounds are assessed - On spacecraft an exchange of the diodes will be performed*
7	22	Payload 2, potential detector failure on satellite		4B		S, SV	*- There is a full spare availability, however failure means schedule impact of three months*
8	12	AIT, Testing, insufficiencies might occur		3B		T, S, C	*- Shaker approval by pre-testing it with high masses*
9	15	Operations, Science operations organization not yet fully sufficient		3B		SV	*- Additional team to be set in place and streamline organization*
10	4	Launcher, potential launch postponement		3C		S, C	*- Negotiations with the launcher provider have been taken up*

Figure 4. Ranked risk log

Manager and consistent with the established Risk Management Policy. Identified treatment actions, and their status, were to be assigned as appropriate.

It must be stressed that this risk-assessment approach cannot be claimed to be truly objective. It provides a systematic and consolidated impression of how a project team sees its efforts within the boundaries of set constraints. This, however, provides a starting point and a basis for decision-making.

The next step, after having identified the risks items, was to consolidate the results across the project. During the interviews, it was apparent that different team members quantified identified risk items differently in terms of likelihood of occurrence and severity of consequence. This is why in the final consolidation, the Project Manager, who is ultimately accountable for the project's success or failure, was given the last word. During the consolidation procedure, the perceived criticality of a risk item could change, but at the same time this served as a motivation for the Project Manager to investigate carefully the different opinions within his team.

After consolidation, a ranking of the risks with respect to their risk indexes (i.e. the combination of likelihood and severity) within the project took place (Fig. 4). This gave an overview of the items with the greatest potential impact on the project's objectives solely by their criticality. Other ranking criteria could also be used, such as importance of action or cost of mitigation, etc.

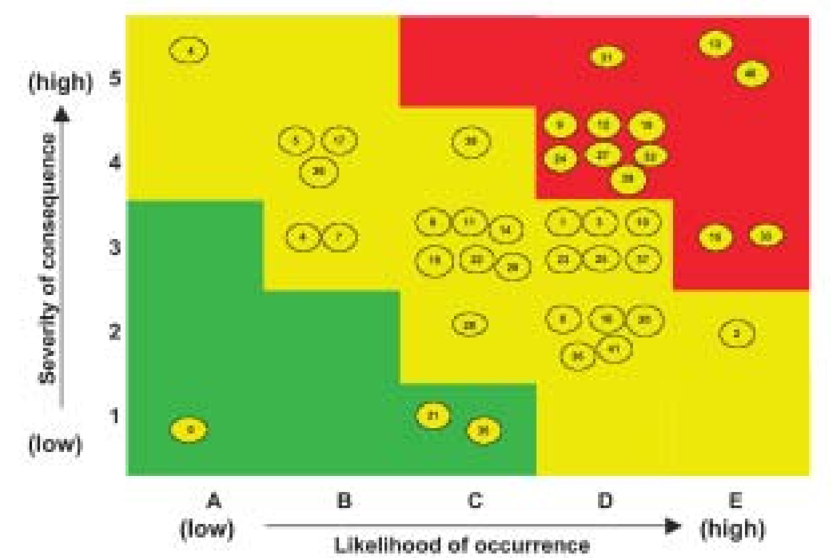
Finally, to obtain a qualitative assessment of the overall risk exposure within a project, all identified risk items were displayed in a so-called 'Risk Portfolio' (Fig. 5), providing a basis for risk trend analysis and reporting for senior management.

For the continuation of the risk-mitigation process within the project, i.e. monitoring of identified risk items, the chart shown in Figure 6 was used to track risk evolution over time. Each line refers to a single risk item; the first appearance of a risk item is indicated by a square, and the acceptance of that risk by a triangle.

Consolidation of results

For the projects in question, a consolidation at Department level was conducted to evaluate the overall risk exposure. Firstly, a categorisation in terms of the different sources of risk was made based on the highest degree of commonality:

– Payload: payload-related issues such as delivery, software aspects, management aspects, etc.
– Managerial: all issues belonging to the management domain, such as ESA internal administration, contractual, procedural, human resources aspects, etc.



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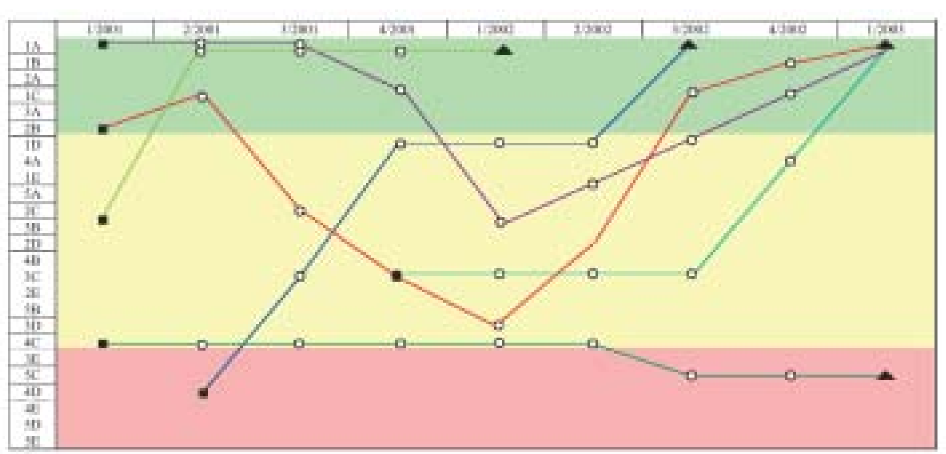
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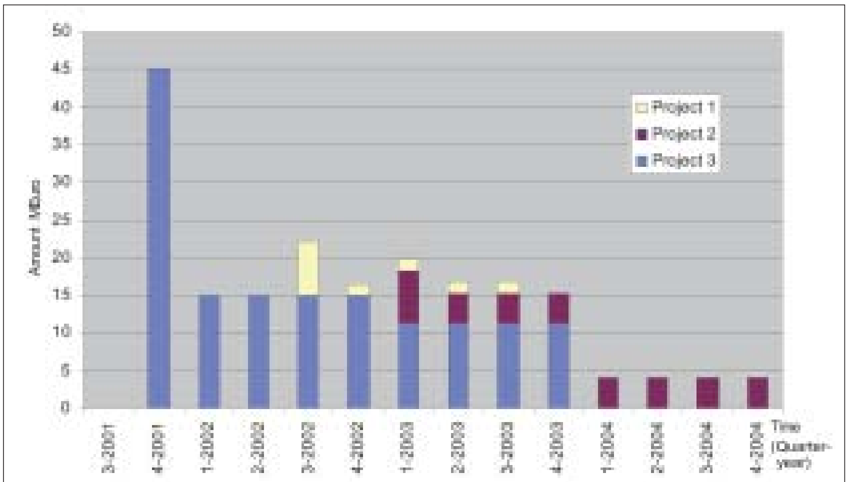

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Figure 5. Risk index scheme/portfolio

Figure 6. Risk evolution chart

Figure 7. Financial exposure

- AIT: all issues related to spacecraft assembly and integration.
- Subsystem: issues related to the spacecraft's subsystems, whether a whole subsystem or individual units or parts of subsystems.
- Suppliers: issues related to the suppliers for a spacecraft, from the level of Prime Contractor down to lower-level subcontractors.
- Operations: issues related to ground, flight and science operations.
- Launcher.
- Product Assurance.
- IT/Software: all issues related to spacecraft software.

In consolidating the financial implications of risks in a project, a distinction has to be made between cost impacts covered by the project's approved financial envelope, and those going beyond that envelope, which must be sanctioned by the Agency's Science Programme Committee (SPC). For the projects treated, the financial impact was analysed and quantified in terms of likelihood and time of occurrence, as well as the actual amount involved. In addition, a basis for satisfactorily quantifying the implications of project exposure to risks affecting the scientific value of and scientific return from a mission still needs to be established.

In consolidating the analysis of schedule risk exposure at Department level, the implications for all projects within the Science Programme have to be assessed due to the constraints imposed by particular launch windows and by contracted launch vehicles and launch dates. The implications for ground-support planning and network availability for the different missions also have to be considered, including the finite adaptation times needed between successive launches. The implications of such schedule risks are illustrated in Figure 8.

In addition to giving an indication of the qualitative risk situation at Department level, consolidating the risk portfolios of all projects provides a unique overview that enhances cross-fertilisation and communication between projects. It should be borne in mind, however, that the aim is not to make direct comparisons between individual projects, given that the scientific goals and hence the levels of inherent and acceptable risk can vary greatly from one project to another.

In consolidating the distributed risk items from the various sources, a basis for management at senior level can be created, as illustrated in Figure 9.

Conclusion

From the project risk assessments conducted to date, it has been found that technical issues are the major source of the risk items identified. Software development for spacecraft is an area of particular concern, involving high risk and sometimes being mission-critical, with potential for loss of the spacecraft in the worst-case scenario. In some cases the software used was said to be too complex, leading to software development schedule risks, impacting the mission validation activities, and therefore increasing uncertainty – the outcome being forced acceptance of risk without sufficient understanding of the consequences.

The greatest number of risk items identified were in the payload domain, with some being mission-critical. They were not only purely technical, due to the use of new and developing technologies, but some were also due to financial constraints, resulting in the payload-providing institutes and manufacturers having funding, and in some cases human-resource, problems. The payload domain is a

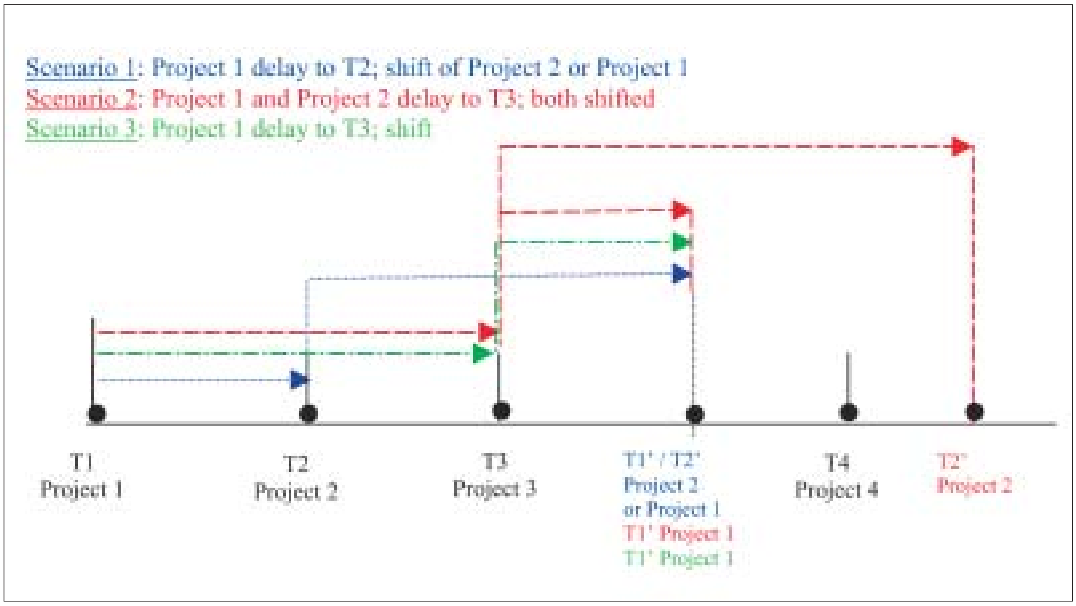

Figure 8. Schedule risk exposure

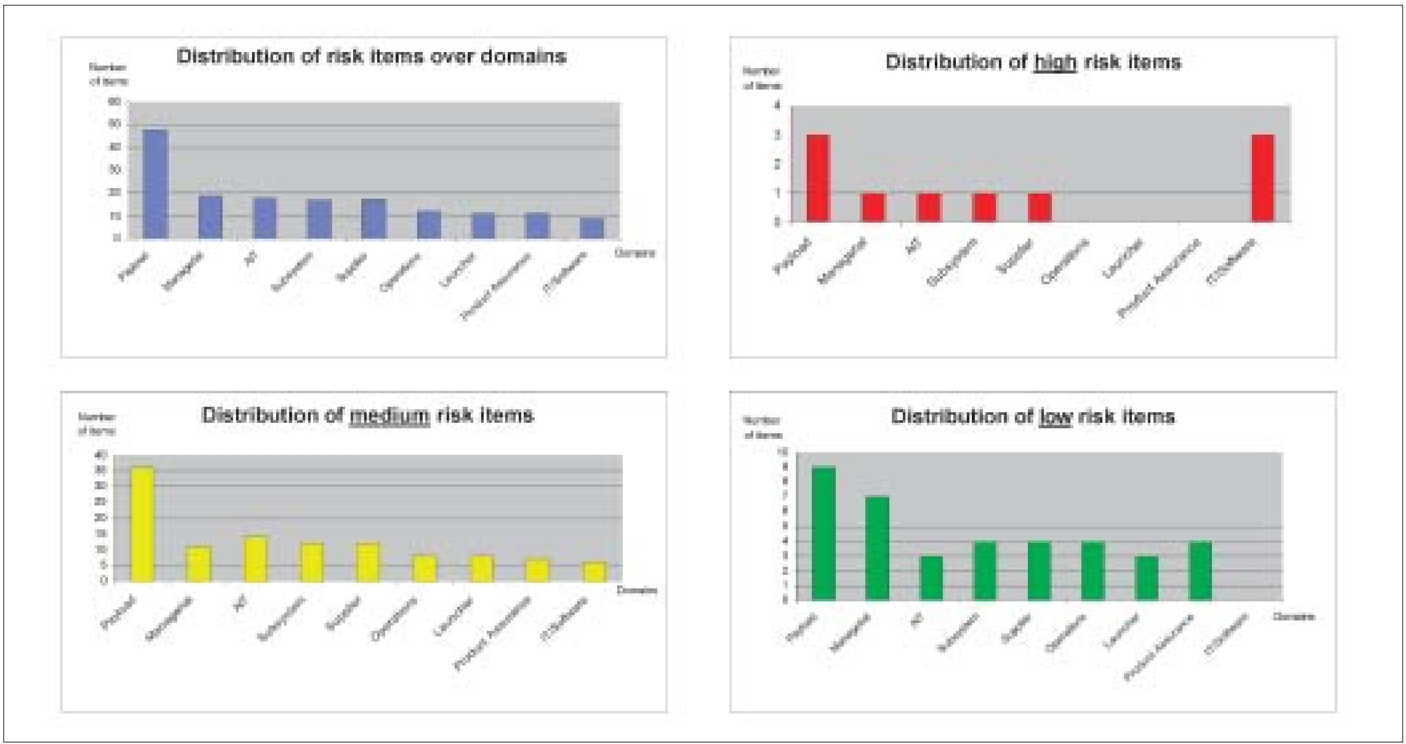

Figure 9. Distribution of risk items over domains

particular concern because responsibility for the design and delivery of the instruments generally does not reside with ESA. The instruments themselves are tending to become more and more complex, taking on the characteristics of small projects within the overall mission, and therefore requiring appropriate project management. There is a growing recognition of a creeping transfer of risk to these external parties, with ESA losing the possibility of risk control. Yet these payload-associated risks can potentially still impact the overall mission, as well as ESA, directly.

One issue that has not been taken into account during the assessments described here is simulation of the results being gathered. A variety of mathematical/statistical methods are available, but these mainly consider issues of insurable risk, i.e. they attempt to establish the amount of financial contingency needed to cover the perceived risks with a certain level of confidence. A first prerequisite for this approach to be valid is that the risk items in question can actually be mitigated by financial means. Secondly, the simulated events or scenarios need to be independent of and decoupled from each other in order to allow statistical simulation. This is rarely the case for scientific missions, where it seems that a different approach is needed. In addition, the casual use of numerical simulations might give the illusion that the results thus achieved enjoy a precision that is often completely unrealistic. A qualitative method like the one followed so far does not create this illusion, while at the same time can account for variables that cannot be quantified in a non-controversial way.

Thus, one proposal for scientific missions could be to create an 'expert system', achieved partly by establishing through specialised interviews the rules of thumb that successful managers instinctively apply, and partly by simulating a project as a cybernetic system with a set of linked variables with feedback loops. With such a model, the effects of various possible risk scenarios or decision options could be simulated, but the complexity and cost of defining such a system would have to be traded-off against the gains achieved in mitigating risk.

Having performed the initial structured risk-assessment exercise described in this article, an increased awareness within the Agency of the merits of Risk Management can be observed. Recognition of the practical usefulness of Risk Management is spreading slowly but surely, and the cultural change needed for it to be widely accepted as a valuable management tool is hopefully evolving.

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Further reading:

Space Project Management: Policies and Practices, ECSS-M-00A.
Space Project Management: Risk Management, ECSS-M-00-03A.

These Standards are available from ESA Publications Division.