

# Cassini Risk Management During Mission Operations and Data Analysis – Application & Lessons Learned<sup>1,2</sup>

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*Abstract*— Risk is defined as the combination of the likelihood of occurrence of an undesired event and the severity of the consequences should that event occur. Risk management is the organized means of risk planning, identification & assessment, decision making and tracking risks. It is a well defined, structured approach required by the National Aeronautics and Space Administration (NASA) to manage risk during the development and operation of its spacecraft flight missions.

Cassini is a joint NASA / European Space Agency (ESA) Mission to Saturn. The Cassini Program began the spacecraft and mission design/development in the early nineties and implemented a risk management process during that phase of the mission, as required. While risk management was conducted on Cassini during the development phase of the program, the process did not continue when the mission transitioned into the Mission Operations and Data Analysis (MO&DA) Phase. As a NASA required discipline, risk management was re-introduced to the program after approximately three years of successful mission operations.

Following a year of workshops, training, initial risk list development and on-line risk system tailoring, Risk Management was successfully implemented on Cassini. The process has been embraced by the Program and is working well.

Risk Management implementation on Cassini however, was not without its share of lessons learned. The Cassini process development presented challenges that if not aggressively addressed, could increase the risk of failure to others who try to introduce a new process during MO&DA.

This paper will detail some of the key challenges faced while introducing Risk Management to the mission operations team. It is hoped that the lessons learned during the implementation of the Cassini Risk Management Process will assist others in developing a robust process for use during Mission Operations.

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## 1. INTRODUCTION

Mission Operations is a challenging but rewarding phase of the project lifecycle. Successful mission operations are critical to achieving the detailed technical and science requirements, that were laid out during the development phase of the mission. Resources, plans and schedules have long since been defined and there is typically little room for modification.

The Cassini spacecraft was launched and the team has been performing routine mission operations for the past five years. No trades can be made between resources at this phase of the mission and the option of delaying an encounter or fly-by are out of the question. Proactive identification of possible risk areas is critical to being prepared to deal with them, should they occur in the future. It is for this reason that a robust Risk Management Process was implemented to aggressively identify, assess, track and control risks before they become problems. An effective, forward looking Risk Management Process is critical to increasing the likelihood of achieving the full mission success, as outlined in the mission requirements and objectives.

### *Mission Background*

Cassini/Huygens is a planetary mission to Saturn, that was jointly developed by NASA and ESA. It was launched on October 15, 1997 from the Kennedy Space Center and is scheduled to arrive at Saturn on July 1, 2004. In December 2004, Cassini will release the Huygens Probe on a trajectory to the surface of Saturn's largest moon Titan. The Huygens Probe Relay portion of the mission is scheduled to last for approximately 2.5 hours, relaying data back to the Cassini

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Orbiter, who then in turn will relay the data to Earth. Following the Huygens Probe portion of the mission, the Cassini Orbiter will continue on a four-year orbital tour of the Saturnian System, studying its many moons, rings and icy satellites.

#### *Mission Operations Team*

The Cassini Mission Operations Team consists of many individual teams, distributed across both the United States and Europe. Program Management and core engineering capabilities at JPL are responsible for daily engineering as well as sequencing and commanding activities. There are also twelve instrument operations teams that participate actively in daily mission operations. Eight of the twelve are Principal Investigator (PI) led teams, while the remaining four represent Facility Instruments. Of the four Facility Instrument teams, two are resident at JPL. With the exception of the two Facility Instrument teams at JPL, the remaining science teams are distributed amongst various government and university facilities throughout the United States and Europe.

The remote nature of this distributed operations environment present unique challenges to not only managing and operating the mission, but also to implementing an effective Risk Management Process. The majority of meetings are conducted via teleconference and the use of email, Internet services and videoconference facilities are critical to ensuring effective communication and interactions between all teams.

#### *Mission Operations Assurance*

Mission Operations Assurance (MOA) is a process that engages mission operations teams in assurance related activities, such as anomaly reporting / resolution, risk management and configuration management. MOA is a function to ensure that process and procedures are strictly adhered to and that teams are doing the right things right. While operations assurance has been in place at JPL for many years, it was a function that was sometimes omitted by projects during the Operations Phase, due to budget shortfalls.

Following the loss of two Mars Missions in late 1999, the MOA function became a project requirement, imposed by JPL Management. MOA is implemented under the guidance of a Mission Assurance Manager (MAM), who reports directly to both the Program/Project Manager, as well as the Safety and Mission Assurance Directorate (SMAD) at JPL. The MAM is chartered to ensure that mission operations is conducted in a disciplined, reliable manner to increase the chances of achieving mission success. The Cassini MAM joined the mission operations team in the fall of 2000 and immediately began the task of developing and implementing a Risk Management Process for the Program.

## 2. RISK MANAGEMENT IMPLEMENTATION

A disciplined Risk Management Process was conducted on Cassini during the Development Phase of the Program, but did not cross over and continue on when the mission transitioned into MO&DA. As a NASA required discipline, Risk Management was re-introduced to the program, after three successful years of mission operations.

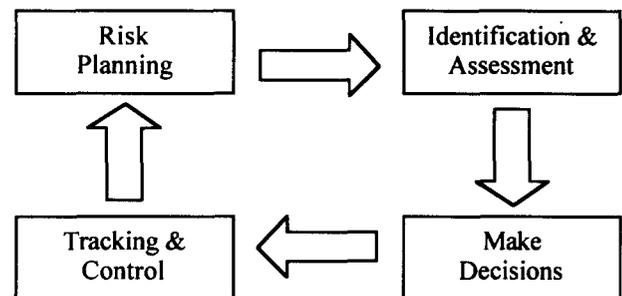
#### *Workshops and Tutorials*

Cassini Risk Management Process development began in the fall of 2000, with a series of workshops and tutorials. The Futron Corporation was contracted as a consultant, to assist the MAM and facilitate much of the workgroup tutorials and training workshops. A kick off briefing was held in November 2000, followed by a series of training workshops in early 2001. Brainstorming sessions were conducted with mission operations team members and initial risk statements were captured. While the kick off meeting was targeted to key Program Staff, the training workshops were geared toward reaching the entire mission operations team. The message conveyed to the team was "everyone has the responsibility to push the alert button."

#### *Risk Management Process*

As the workshops were conducted, the Risk Management Process began to take form and achieve buy-in from the participants. The Risk Management Plan was developed and a schedule for implementation was put in place.

Risk Management on Cassini is a continuous process that will be conducted through the end of the mission. The high level Cassini Risk Management Process is illustrated in Figure 1.



**Figure 1** Cassini Risk Management Process Flow

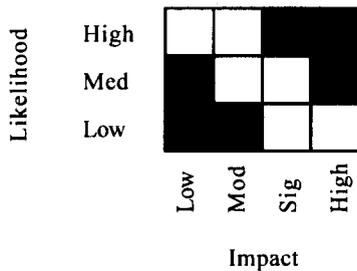
#### *Significant Risk List*

The early workshops and tutorials set the stage and some initial risk statements were documented during the brainstorming exercises. The next part of the plan called for developing a Significant Risk List (SRL), to capture all of the risks, as well as mitigation efforts to prevent those risks from occurring. During this timeframe risks were also triaged with respect to the likelihood and impact of their occurrence. Following triage, the initial risk statements

were documented and assigned to Risk Owners, responsible for ensuring the integrity of the risk statements, as well as the implementation of the mitigation measures. Risks were further categorized into Mission Phases (Cruise, Tour, Saturn Orbit Insertion and Probe Mission) to facilitate risk tracking and the disposition of retired risks.

*Risk Triage & Decision Making*

As risks were identified, they needed to be assessed in terms of overall risk to the Program. Cassini developed a 3X4 triage matrix to facilitate this risk assessment. Initial risk assessments were performed by the Risk Owners, with final concurrence on the risk assessments being achieved at quarterly risk team meetings. The Cassini Triage Matrix is illustrated in Figure 2.



**Figure 2** Cassini Risk Triage Matrix

As risks were triaged, decisions had to be made with respect to what needed to be done next. Criteria were established for which risks required mitigation, which may or may not require some amount of mitigation and which ones were to be accepted and monitored on a regular basis. The decision making criteria developed by the Cassini Team are represented in Table 1.

**Table 1** Risk Decision Making Criteria

	Green	Accept without further mitigation. Track regularly for change in status.
	Yellow	May require mitigation. Alternate strategies identified, trade-offs conducted to determine mitigation. Cost & schedule impacts assessed.
	Red	Primary Risks - must be controlled. Mitigation options developed, with budget and schedule impact assessments.

*On-line Tool Tailoring & Roll-out*

As the SRL began to take shape, it became clear that a tool was necessary to facilitate tracking and status of the risk statements. What had started as a simple excel spreadsheet, was growing daily in both content and complexity. As the majority of the Cassini information exchange took place via email and web-based applications, there was a strong desire to select some type of web-based system.

An on-line risk tool had been developed for the Space Infrared Telescope Facility (SIRTF) in the late nineties, by the Raytheon Corporation. This same tool later became institutionally supported by the JPL Risk Management Process Owner and has since been tailored for other projects, as needs have arisen. The Cassini MAM evaluated this tool as well as another one recommended by the Futron Corporation. Not wanting to re-invent the wheel regarding Risk Management Tools at JPL, Cassini selected the Raytheon tool. Aside from being institutionally supported, it was selected because of its ease of use, web-based interface and proximity to Raytheon’s developers for tailoring and de-bugging.

Tailoring of the on-line tool was completed by the fall of 2001 and the initial SRL was input into the system. The MAM was given administrative authority in the system to manage user accounts and monitor activity. To maintain the system, the MAM and Raytheon work closely together. Refinements and necessary bug fixes are defined and worked as needed.

Once the tool was in place, action items were assigned to Risk Owners to refine their risk statements, mitigation efforts and risk assessment (triage). Since the fall of 2001 the SRL has undergone significant refinement. Some risks have been combined with others, some have been retired and new ones have been added. Since the initial risk assessment, Cassini has effectively used the triage process and risk mitigation efforts to effectively reduce risk to the Program’s objectives.

**3. RISK MANAGEMENT CHALLENGES**

Introducing Risk Management to an established and functioning mission operations team presented some unique challenges to the Mission Assurance Manager, who was responsible for the effort. Risk Management is a well understood and disciplined process for NASA and JPL missions in the Development Phase; however, the concept continues to remain relatively new to missions in MO&DA. This initial challenge represented the first of several to be faced by the Mission Assurance Manager during the development and implementation of the Cassini Risk Management Process.

*Getting Started*

Being relatively unfamiliar with both Cassini and Risk Management, the MAM was challenged from the outset. The Futron Corporation had previously been hired as a consultant to the MAM to facilitate development of the process and the arrangement worked out well. Futron was able to facilitate the training and brainstorming workshops, while the MAM focused on developing the detailed process for implementation on Cassini and documenting it in the Risk Management Plan.

Risk Management can be defined to be as broad or as narrow as desired by the implementing organization. Scoping the job for the Cassini Program proved to be

particularly challenging, as the mission operations team consisted of over 300 individuals, working on as many as 16 individual teams. Aside from the size of the overall team, the individual teams were located throughout the United States and Europe.

A decision was made early on to scope the job tightly, involving primarily the JPL core management and engineering team. Limiting the scope in this manner allowed the core JPL team to focus in on very high level, programmatic, mission and spacecraft specific risks.

#### *Distributed Operations*

Given that the distributed operations sites working on Cassini were numerous, with membership including both United States citizens and Foreign Nationals, it was decided that core JPL teams would also represent specific others. This decision allowed the process development to proceed locally and limited the impact to remotely located instrument operations teams.

The Spacecraft Office at JPL was assigned responsibility for representing the interests of those on the Huygens mission operations team. This consisted of representing the general interests of the mission team, but not necessarily those specific to ESA. Visibility into the detailed ESA mission operations was not sufficient to facilitate an ESA centric view of risk management, at this level. Probe mission risks were captured and documented based on this premise, with little involvement of the ESA team.

Similarly, the Instrument Operations Team at JPL was assigned the responsibility to represent all instrument operations teams, at a very high level. Rather than capture and work risks for each of the twelve instruments, instrument risks were written to be more generic in nature. Instruments were lumped into one category, to facilitate tracking and the high level, but consciously lacked the depth that individuality would be able to provide. As a result, only a handful of very generic, high level risks were documented for instruments.

The mission and science operations teams for the Cassini Mission consists of members from fourteen countries, including the United States. The distributed nature of the mission operations teams affiliations and locations are illustrated in Table 2.

**Table 2** Operations Team Membership

Program Office	NASA	California, USA
Spacecraft Office	NASA	California, USA
Science & Uplink	NASA	California, USA
Mission Support	NASA	California, USA
Instrument Ops	NASA	California, USA
CAPS	NASA	Texas, USA
CDA	ESA	DE
CIRS	NASA	Maryland, USA
Huygens Probe	ESA	DE,FR,US,IT,UK

INMS	NASA	Michigan, USA
ISS	NASA	Colorado, USA
MAG	ESA	UK
MIMI	NASA	Maryland, USA
RADAR	NASA	California, USA
RPWS	NASA	Iowa, USA
RSS	NASA	California, USA
UVIS	NASA	Colorado, USA
VIMS	NASA	Arizona, USA

#### *International Relationships*

The number of international relationships on the Cassini Program further complicated the implementation of a Risk Management Process.

Programmatically and for daily mission operations, European countries are typically 8-9 hours ahead of Pacific Time. For this reason teleconferences are typically held first thing in the morning, California time, to facilitate foreign team member participation. Training European team members and engaging them in Risk Management was an activity that was consciously deferred until the process took hold and was established with the core team at JPL.

NASA Programs and Projects are also required to comply with the International Traffic and Arms Regulations (ITAR). ITAR requirements imposed on the Program severely limit the quantity and quality of information exchange between resident (U.S. citizens or those carrying green cards) NASA employees and their European counterparts. Information exchange is typically limited to essential interface information, except where a specific Memo of Understanding (MOU) or Technical Assistance Agreement (TAA) is in place. Clearly, the ITAR restrictions limited the scope of what could be done regarding Risk Management on Cassini. It was easier to limit the scope, than to risk violation of the ITAR regulations.

## 4. RESULTS AND STATUS TO DATE

Cassini successfully implemented a Risk Management Process during MO&DA. The mission operations team has been trained, risks have been identified and a risk team, consisting of decision makers, meets quarterly to assess and re-assess the Program's risk posture. Risk is at the forefront of everyone's mind, as risks continue to be identified and refined. The on-line tool is in use, after having been tailored and re-tailored to meet Cassini's needs. The tool tracks risk items and provides a snapshot of the current status of each risk. Metrics capabilities have recently been added, to measure and illustrate the effectiveness of the process.

#### *SRL / Quarterly Team Meetings*

The Cassini Risk Team has met quarterly for the past year to assess and re-assess risk in the SRL. Risks are dispositioned one by one, typically by mission phase, at each quarterly team meeting. Action items assigned during

previous team meetings are discussed and concurrence on risk owner's re-assessments is achieved by the team.

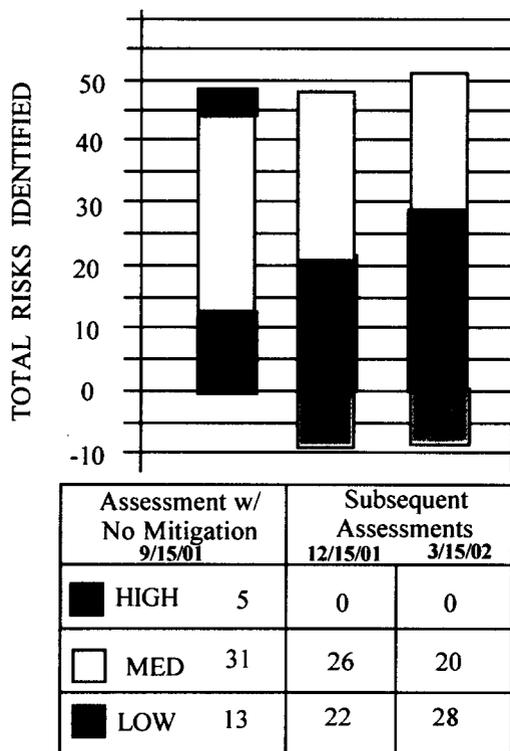
Since the initial risk list development in the fall of 2001, the list has undergone significant revision. Some risks have been combined with others, to eliminate redundancy. Other risks have been eliminated or rejected by the team all together. Risks have also been added to the list, where a particular concern had not been previously captured.

The team continues to meet quarterly, to go over risks not dispositioned at previous meetings. Overall, the process has worked to effectively reduce the Program's Risk Posture throughout the past year.

*Metrics and Statistics*

Metrics and statistics regarding Cassini's Risk Management Process to date have been handled largely on a manual basis. As the metrics were produced and presented, they began to achieve buy in by not only the Program Office and individual team members, but also NASA Headquarters and the Independent Review Team assigned to Cassini. Metrics produced at various shapshots throughout the past year, indicate that the process is effectively reducing the risk posture to the Program.

A recent snapshot, as well as the trend from previous shapshots is illustrated in Figure 3.



**Figure 3** Cassini Risk Metrics

*Success to Date*

The Cassini Risk Management Process is in place and it's working. The MAM has achieved buy-in from the team and the process has been accepted by both NASA Headquarters and an Independent Review Team. Metrics are being produced on a regular basis for reporting at both Monthly and Quarterly Reviews.

The process continues to gain more and more visibility, at bigger and broader programmatic reviews. Risk Management has become a standard topic of discussion at these reviews, which are now being conducted as the mission proceeds toward Saturn Orbit Insertion (SOI) and the execution of the Probe Mission.

**5. IMPLEMENTATION LESSONS LEARNED**

Risk Management is a critical element necessary to achieving mission success during the MO&DA Phase. On Cassini, it is a key process that is facilitated by the MAM. To be successful in operations, it is a process whose execution must be carried forward, from the development phase into the operational phase of the mission.

*Scoping the Job*

Scoping the job proved to be difficult on Cassini, due to the size of the team and the distributed nature of the operations teams involved. While the scope was initially limited to the core engineering teams at JPL, it soon become apparent that this was not sufficient to capture a Programmatic perspective on Risk Management.

An Independent Review Team reviewed the Cassini Risk Management Process in February 2002. They expressed concern that the Instrument Operations Team could not effectively represent all of the individual instrument teams involved in the day to day operations. Upon completion of the review, they recommended involving the instrument Principle Investigators in the process, to effectively capture and assess risks from their perspective.

Similar sentiments were expressed during a Probe Relay Mission Design/Risk Review, conducted in July 2002. While risks had been captured regarding both Probe Release and Probe Relay, they were clearly captured from a spacecraft centric point of view. It became evident that the views and concerns of ESA were not captured into our risk system.

*Participation of Key Players*

Introducing Risk Management to an established mission operations team, who had been working together for three years since launch met with some resistance. Operations, personnel and team relationships had been formed and work was proceeding according to plan. Risk Management was viewed with a skeptical eye, as yet another management task or additional duty that team members were expected to perform.

While the team was resistant, the Program Manager was not. Cassini would do Risk Management and we would implement and execute a successful, value added process. The Program Manager's solid endorsement of the activity was critical to its success on Cassini. Had the top management not been highly supportive and in favor of implementing Risk Management, it would not have been successful.

#### *Value Added*

The value added by performing risk management must be effectively communicated, in order to achieve buy in from both the Program/Project Management and the core operations team. It is difficult to achieve buy-in for an activity that is viewed by some of the team members as "just another management fad."

The Cassini MAM, eager to illustrate the value of Risk Management, established metrics early on. Through these metrics, the MAM was able to convey the effectiveness of the process and illustrate how risk to mission objectives was being reduced. These metrics have now been captured and communicated monthly for the past year. The team has accepted the process and is able to see value through communication via metrics. As the process is on-going, so are the metrics. The risk posture changes over time as the process works and the change in risk is easily visible via these metrics.

## 6. REMAINING IMPLEMENTATION EFFORT

Lessons learned throughout the past year have resulted in some additional implementation effort. Despite efforts to limit the scope of Risk Management on Cassini, it became apparent that limiting the scope was not conducive to developing a robust process that effectively captured all risks throughout the Program.

#### *Principal Investigator Involvement*

Cassini Principal Investigators (PIs) are scattered across the United States and Europe. Their budgets have been scrubbed and rescrubbed during the course of operations thus far. They have little resources to provide support to this important function, however their input is critical to ensuring that instrument risks are effectively captured and mitigated.

PI Risk Management participation is scheduled to be implemented concurrently with the regularly scheduled Project Science Group (PSG) meetings. PSGs are typically conducted three times per year, with one of the three meetings being held overseas. Plans are to address Risk Management, when the PI teams are at JPL for PSG Meetings. This will allow a regularly scheduled, bi-annual focus on all instrument related risks. This forum will also help facilitate information exchange between instrument teams and achieve buy in from the participants.

#### *European Space Agency Involvement*

The European Space Agency (ESA) plays a vital role in the Cassini Mission. To date they have not participated in the Risk Management Process, but this is an effort to be explored in the future. As it became clear that the Probe Mission risks captured to date were very Orbiter centric, the desire to get ESA involved in the process intensified.

Clearly, however, NASA and ESA manage different sides of a clearly defined interface. NASA manages the Orbiter and many science instruments, while ESA is responsible for management of the Probe Mission and a few other instruments. As with the PIs, ESA representatives will be approached regarding participation in the Risk Management Process. Their involvement would benefit the Program greatly, by providing an assessment of risk from both sides, regarding the Probe Mission. Risk Management, however, is not a requirement levied on Programs by ESA. While ESA involvement will be encouraged and is planned, it's unclear at this time whether or not it will be effectively realized.

#### *Risk Tool Refinements*

With the added participation of the instrument PIs and representatives from ESA, several additional modifications will be necessary to the on-line risk tool. User accounts will have to be established, privileges assigned and pull down menus modified to include participation from their respective teams.

The Mission Phase breakdown for risks will also be modified to better capture the Probe Mission specific risks. As the probe mission consists of two separate mission events, Probe Release and Probe Relay, the database will be modified to adequately specify which event each particular risk applies to. Because the SRL and probe risks as they exist today are very orbiter centric, a Mission Phase entitled "ESA Mission" will be established to capture ESA centric risks.

#### *Continuous Process*

Risk Management is a continuous process and that can't be stressed enough. In order for Risk Management to be effective, it must also be proactive. This requires a regularly scheduled process to assess and reassess risks. Existing risks are reassessed for any changes to the likelihood or impact of their occurrence. Changes to mission or sequence scenarios are evaluated to determine whether any new risks have been introduced. Additionally, mission milestones and any changes to events are evaluated to allow any risks tied to a mission event to be retired.

Risk Team Meetings will continue to be conducted on a quarterly basis at JPL. Risk items will continue to be identified, refined as necessary and retired when feasible. Additionally, the PI Risk Team will also begin to meet bi-

annually and concurrently with PSGs at JPL.

## 7. CONCLUSIONS

The Cassini Risk Management Process has been operating effectively and efficiently for the past year. Despite some early reservations and concerns regarding team member participation and the scope of the job, the effort has become accepted as the way business is to be conducted during MO&DA. The Program Manager has supported the process from the outset and this has been key to its success.

Risk Management during MO&DA continues to be a new concept to mission teams at JPL. It will continue to evolve over time, into as disciplined a process as is conducted during development. It is hoped that the Cassini effort will help pave the way for others as they venture into Risk Management for spacecraft mission operations.

The process was implemented with an established flight operations team, from the ground up. There have been some unique challenges and lessons learned along the way. It is these challenges and lessons that will facilitate revisions that will make the process even better. With the changes outlined above and the continuous nature of the Risk Management Process, it is believed that Cassini will soon establish an even more effective Risk Management Process than it has today.

## 8. RECOMMENDATIONS

The lessons learned in the past year on Cassini have resulted in a few recommendations to those who are chartered with implementing Risk Management during MO&DA. This will continue to be a challenging task, until the process is more widely used in operations and flows more smoothly from development.

It is critical that risk management be embedded into programs and projects early on and continue into MO&DA, to maintain its momentum and effectiveness. Future missions must address MO&DA risks and issues in their risk management process early, during the development phase, to ensure that the process continues into operations. The risk management process must be forward looking, so that it effectively captures risk items well beyond launch and into other key milestones during spacecraft mission operations. Risks must be captured as far into the mission operations phase, as possibly feasible. These are the risks that the mission operations team will inherit, to begin the Risk Management Process for operations. This handover must be smooth and seamless, to ensure the effectiveness of the process is not compromised.

The scope of the work must be adequately defined and adhered to. Changing the scope of a Risk Management Process, as it is being worked and implemented can cause confusion and frustration. While scope changes can be

made, as in Cassini's case, having an established scope that everyone agrees to will greatly simplify things later on and eliminate the second guessing.

Lastly, an effective, flexible tool is critical to managing and controlling the risk database. Excel spreadsheets, although easy to use, can quickly become unmanageable. Where possible, the risk database should be accessed via a web-base browser interface. This interface should be universal to eliminate the cross platform issues that arise between PCs and Macs, as well as Unix and Sun Workstations.

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