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Jet Propulsion Laboratory
California Institute of Technology

Mars Exploration Rover Operations Phase Real-time Risk Management

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Mars Exploration Rover (MER)



Spirit at Gusev
Sol 671
(5.4 km to sol)

Opportunity at Meridiani
Sol 650
(6.5 km to sol)

As of 11/21/05

JKE - 2



Operations Risk Management Processes (1)

- **Starts with identifying and establishing a project risk posture**
 - **Initially established pre-launch**
 - **Consists of:**
 - **formal documentation of operations plans**
 - **major h/w, s/w, and environmental risks to those plans**
 - **Note - not all risks are known pre-launch , or even post mission!**
 - **Staffing levels for executing those plans, and**
 - **Staff training levels in executing those plans**
 - **Is updated as new operational risks are identified and mitigated**
 - **Updates are communicated to upper management through a variety of means including Monthly Project Status Reports, Quarterly GPMC reports, FMECAs, 5 x 5 matrices, etc**
 - **Goal is to have a common understanding across the management levels as to what the likelihood of mission success is.**



Operations Risk Management Processes (2)

- **Several different processes in parallel**
- **Non-real time strategic risk management process**
 - **Keep organization on the previously agreed to mission plan and risk posture**
 - **Background effort to understand and close anomaly reports**
 - **Monitor operations processes**
 - **Correct errors in processes**
 - **Keep staff trained**
 - **Retrain present team members if required**
 - **Keep new people in the training pipe for replacements**
 - **Keep Upper management aligned with the project on what the risk posture is (GPMC and PSR reports)**



Operations Risk Management Processes (3)

- **Near-real time tactical management process**
 - **Have teams aligned (trained) on the tactical processes used to command the vehicles to stay within the agreed to risk posture**
 - **Have adequate oversight on the tactical activities**
- **Real-time response**
 - **Identify activities that have gone outside the risk posture**
 - **Could be a new h/w or s/w anomaly**
 - **Could be a new or newly identified environmental issue**
 - **Could be staffing changes**
 - **Could be budget cuts**
 - **Bring the mission back into the agreed on risk posture**
 - **Anomaly recovery, retraining, staffing augmentation**
 - **Understand and negotiate a new risk posture with upper management**



Real Time Response Risk Management

- **Want to focus in on the real time portion of the operations risk management process**
 - **Have a test case to discuss - the Opportunity rover embedding itself in a sand dune**
 - **This test case is a good example of the way risk in operations can be managed, from the initial surprise to the final closeout.**
- **Will quickly lay out the facts, then discuss issues of risk management**



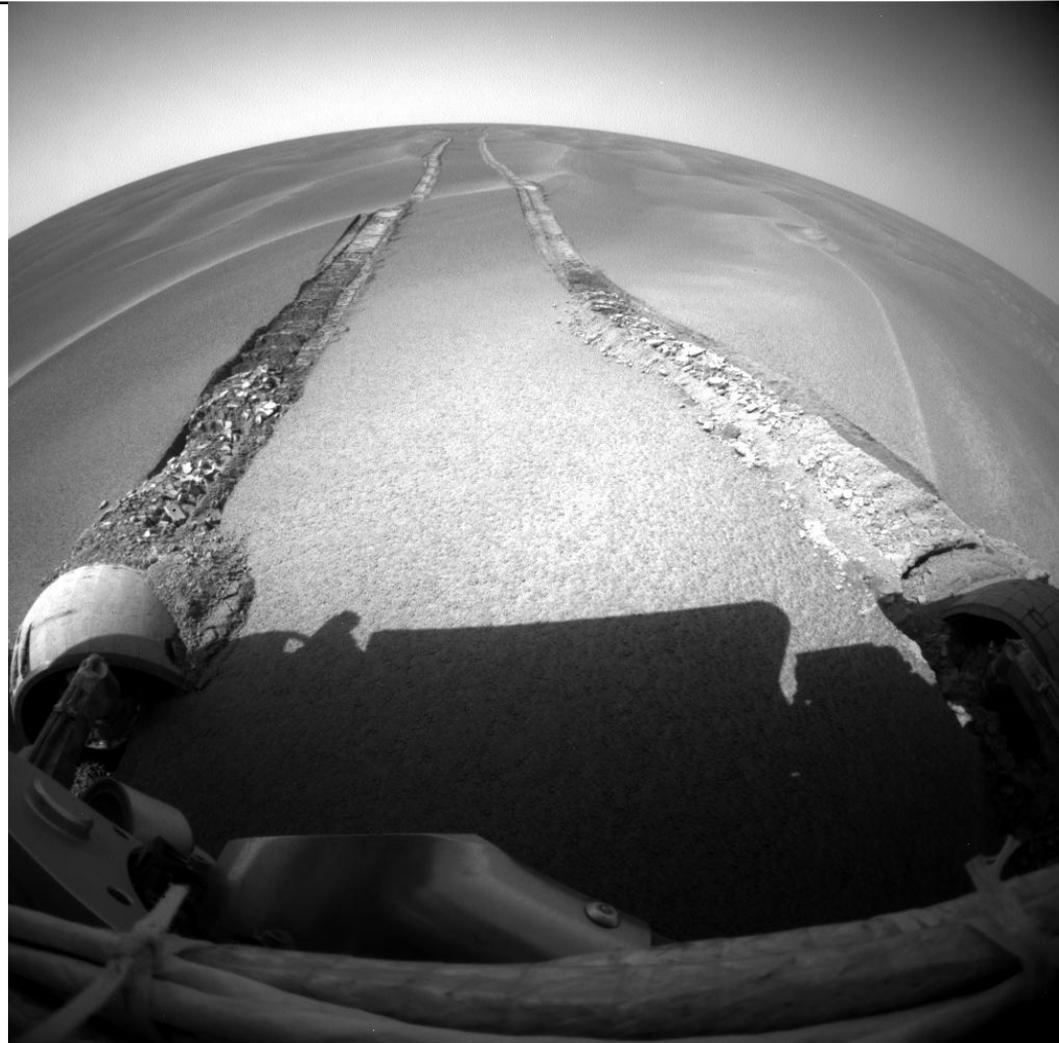
Opportunity Dune Embedding (1)

- **On 4/27/2005, the Opportunity rover embedded itself up to it's hubcaps in a sand dune**
 - **First occurrence of anything on this scale. Previous experience was small scale “digging in place”**
- **First question was - Was it a problem?**
 - **It was outside of our experience base**
 - **By definition was then outside of our risk posture**
 - **Operations team treated it as an anomaly until proven otherwise**
- **Initial r/t response is to identify the timescale of the problem and its required resolution**
 - **If the team paused to analyze the problem, could it kill the rover in minutes? Hours? Days? Weeks?**
 - **After thermal analysis of the vehicle and it's new surface contact paths, no hazards requiring action within days was identified, so we had time for a detailed threat analysis - understanding that any time spent doing analysis was, in itself, a risk to the remaining mission lifetime**



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Opportunity Embedded into Purgatory Dune





Opportunity Dune Embedding (2)

- **Analysis and test proceeded on several fronts**
 - **Was the rover unable to move?**
 - **If it moved, would it drive itself deeper**
 - **If the rover got much deeper, sand might make contact with the underside of the rover and reduce the wheel traction further**
 - **We then might have to wait for wind erosion to dig out the rover**
 - **Could we identify a technique(s) to drive the rover to extricate itself in greatest safety?**
 - **If we can identify a path, how can we mitigate any risks involved?**
 - **Could we simulate the visible symptoms of the problem?**
 - **Wheel cleats showing sand filling the cleat, reducing traction**
 - **Last motion of the vehicle showed a 99.2% slip rate - note not 100%!**
 - **Vehicle digging into the sand material**



Risk Posture Recovery (1)

- **Required 2 1/2 weeks of analysis and review leading to a independent review board examining the plan**
- **Experts identified a mixture of materials that allowed the testbed rover to replicate the symptoms**
 - **Could not replicate 100% - the test facility can't reproduce the atmosphere and gravity.**
 - **Also replicated key parts of the initial drive**
- **Test runs indicated many exit strategies would work - including simply proceeding with initial drive!**
 - **Safest path identified was to use gravity to help us**



Risk Posture Recovery (2)

- **Risk mitigations were identified to increase our confidence in escaping**
 - **Identify expectations of commanded drives versus results**
 - **Command vehicle to go 100 meters, expect to achieve 1/2 meter**
 - **Start slow - 1 meter drive commanded - expected 5 mm of travel**
 - **Work up to 10 meters of commanded driving, 10 cm of achieved result**
 - **Continue with daily review of results, plan next day's drive**
- **Vehicle popped free after 192 meters of commanded travel, achieving 2 meters of actual travel**
 - **Extraction activity took 23 days**



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Opportunity Looking Back





Risk Posture Recovery (3)

- **After safe recovery of vehicle, risk posture of mission was still out of bounds**
 - We had an unknown hazard, with an unknown level of risk
- **Bringing risk posture back into alignment required several steps**
 - **Continuously keep Program management/Project management aligned on the daily risk during the vehicle extraction process**
 - **Investigate and identify the new hazard**
 - **Go back and study the dune**
 - **Mitigate as far as possible the new risk**
 - **Identify new software parameters and driving techniques that would prevent/mitigate the problem in the future**
 - **Brief Program Management on the new residual risks**
 - **Including emphasizing the environmental uncertainties still present**



Conclusion

- **Operations risk management blends virtually seamlessly between the extremes of real time anomaly resolution to strategic planning.**
- **Risk management in this setting concentrates on controlling the things you can control, and ensuring alignment at all levels of the Program and Project on the risks inherent in the things you can't control.**
 - **The second part is as important as the first.**