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CONFRONTING SPACE DEBRIS

STRATEGIES AND WARNINGS FROM COMPARABLE EXAMPLES INCLUDING DEEPWATER HORIZON

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Prepared for the Defense Advanced Research Projects Agency

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Summary

Background and Objective

Orbital (space) debris represents a growing threat to the operation of man-made objects in space.[2] According to Nick Johnson, NASA's chief scientist for orbital debris, "[T]he current orbital debris environment poses a real, albeit low level, threat to the operation of spacecraft" in both LEO and GEO (Johnson, 2010). There are currently hundreds of thousands of objects greater than one centimeter in diameter in Earth's orbit. The collision of any one of these objects with an operational satellite would cause catastrophic failure of that satellite.

DARPA, within the context of the Catcher's Mitt study, is in the preliminary stages of investigating potential technical solutions for remediating debris.[3] This investigation is a critical step because even the most rudimentary cleanup techniques will require significant research and field testing before they can be successfully implemented. In addition, future pathfinder missions will require extensive resources,

2 NASA defines orbital debris as "artificial objects, including derelict spacecraft and spent launch vehicle orbital stages, left in orbit which no longer serve a useful purpose" (NASA-Handbook 8719.14, 2008).

3 The DARPA Catcher's Mitt study is tasked with the following objectives: model the space debris problem and its future growth; determine which class of satellites is most affected; and, if appropriate, explore technically feasible solutions for debris removal. DARPA intends to use the results of the Catcher's Mitt study to determine if they should invest in a space debris remediation program (Jones, undated).

and the U.S. government will need sufficient justification before pursuing these programs.[4]

With this background in mind, this research had three primary goals. The first was to determine whether analogous problems from outside the aerospace industry exist that are comparable to space debris. Assuming that such problems exist, the second goal was to develop a list of identifying characteristics along with an associated framework that could be used to describe all of these problems, including debris. The final goal, provided that the first two were possible, was to use this framework to draw comparisons between orbital debris and the analogous problems. Ultimately, we hoped to provide context and insight for decisionmakers by asking the following question: How have other industries approached *their* "orbital debris–like" problems? What lessons can be learned from these cases before proceeding with mitigation or remediation measures?

Comparable Problems

We identified a set of comparable problems that share similarities with orbital debris and narrowed this set down to the following nine issues: acid rain, airline security, asbestos, chlorofluorocarbons (CFCs), hazardous waste, oil spills, radon, spam, and U.S. border control.[5]

These problems are related because they all share the following set of characteristics:

- Behavioral norms (past and/or present) do not address the problem in a satisfactory manner.
- If the problem is ignored, the risk of collateral damage will be significant.
- There will always be an endless supply of "rule-breakers."

[4] Within the scope of this document, we define the word *pathfinder* to mean an experimental prototype used to prove a capability.

[5] We do not describe the rationale behind this statement in the executive summary. However, more information about the comparable problems is available in Chapter Three and in Appendixes A and B.

- The problem will likely never be considered solved because the root cause is difficult to eliminate.

Nomenclature

We refer to the terms *mitigation* and *remediation* throughout this analysis, so it is important to provide our definitions for these terms:

- *Mitigation* refers to a class of actions designed to lessen the pain or reduce the severity of a problem. Mitigation measures are inherently preventive, and they are enacted to prevent a problem or to prevent one from getting worse.
- *Remediation* refers to the act of applying a remedy in order to reverse events or stop undesired effects. Remedies are targeted reactions often designed to address an undesirable event that has already occurred.

Methodology

We used a literature survey and interviews with experts to gather the following pieces of information for each of the comparable problems:

1. **Basic overview.** What is the problem?
2. **Calendar dates of key milestones.** When was the problem first identified? When were major mitigation measures imposed? When (if at all) were remedies fielded?
3. **Stakeholder demographics.** Who is viewed as having caused the problem? Who is affected by it? How large is each group? How diverse are their interests?
4. **Current status.** What was the status of each of the problems, as of May 2010? Was it being remedied or simply mitigated?

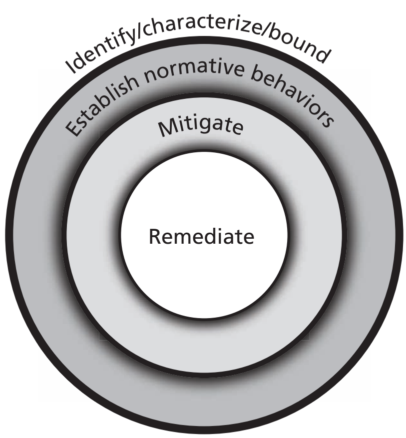
The Framework

Once we had this information, we designed a framework that could be used to describe the process for addressing orbital debris and any of the comparable problems. We identified four stages of increasingly aggressive measures that could be used to address the various problems: identifying, characterizing, and bounding the problem; establishing normative behaviors; mitigation; and remediation.

These stages can be represented with a series of concentric rings, as shown in Figure S.1. This concentric geometry highlights an important feature of the approach: As the community moves toward the center (which indicates increasingly aggressive deterrents), the size of the risk-generating population decreases with each inward step.

The progression through these stages is determined by the risk tolerance of the affected entities. Specifically, decisionmakers should proceed to the next stage when the existing population of unwanted incidents exceeds the community's risk tolerance level. For example, catastrophes—such as an oil spill—can cause a community to reassess (and often lower) its risk tolerance, and additional mitigation or remediation strategies may be needed after such an event.

Figure S.1
Framework Stages via Concentric Rings



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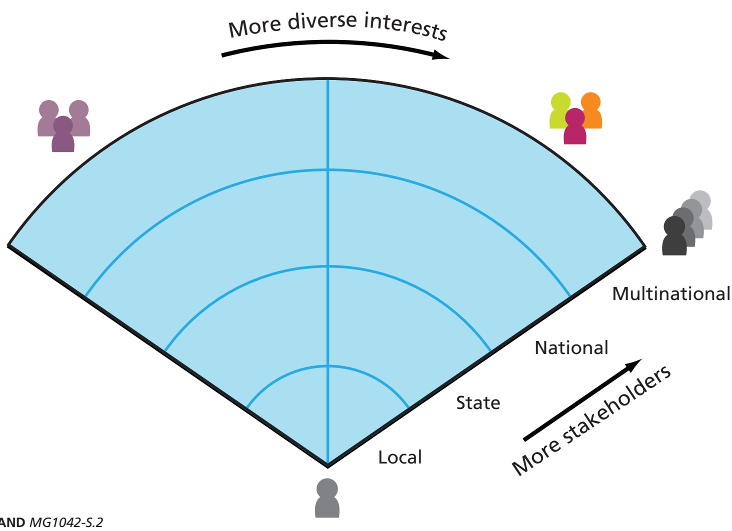
It is also important to note that eliminating the problem is not necessarily the primary objective. Instead, the goal should be reducing the risk posed by unwanted phenomena (air pollution, radon levels, aircraft hijackings) to a level that the affected stakeholders find acceptable.

We also developed two tools to aid in describing the stakeholder communities. These tools are shown in Figures S.2 and S.3, and more information is provided in Chapter Seven.

Figure S.2
Stakeholder Diversity and Type



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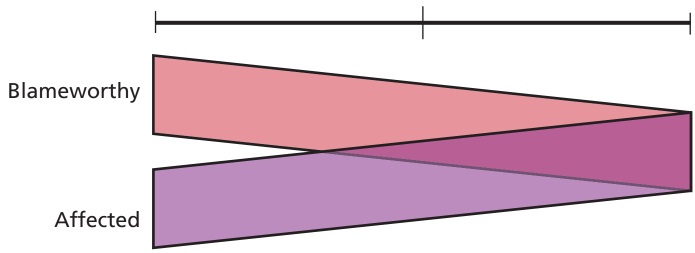
Analysis: Comparing the Relative Time Spent in Each Stage

Our literature survey uncovered several important dates, milestones, and achievements associated with all of the comparable problems. We used this information to build a series of timelines that allowed us to compare the different problems. After reviewing these timelines, we made the following observations:

Figure S.3
Stakeholder Spectrum: Blameworthy Versus Affected



RAND *MG1042-S.3*

- It may take several years to identify the problem (acid rain, asbestos, and spam).
- In some cases, a single critical event is enough to propel the problem through several of the stages shown in Figure S.1 at once (airline security, oil spills, radon, and spam).
- A problem need not have existed for a long time before remediation is deemed necessary (hazardous waste, oil spills, and spam).
- Once in remediation, the problem is not considered solved. Airline security, hazardous waste, oil spills, radon, and spam are all examples of problems that are difficult to completely eliminate.

Mitigation Concepts

We identified three mitigation approaches—taken from the environmental protection industry—that can be applied to any of the problems that we considered, including space debris:

- The command and control (C2) approach institutes an incentive structure to control community behavior. This approach is easily understood by most cultures, so it is often the first mitigation strategy to be implemented.
- Market-based approaches acknowledge that the problem exists and organize a formal allocation scheme for the right to engage in that behavior.

- Performance-based strategies use a quota-based system to set a limit on the undesired behavior.

We highlighted the mitigation strategies used to address acid rain, airline security, and radon. Our analysis of these issues yielded the following observations on each.

Acid Rain

- In order to successfully implement a large C2 strategy, the symptoms must be categorized into groups that represent different levels of relative risk.
- A market approach is often most effective only after an effective C2 strategy is already in place.

Airline Security

- Preparing for potential threats requires an efficient and effective system for collecting and disseminating information.
- An effective mitigation strategy evolves over time.
- A successful C2 strategy is enforced by organizations with clearly defined jurisdictions.

Radon

- Nonregulatory approaches may be good at increasing public awareness, but they are unlikely to achieve high levels of compliance.
- Mitigation is relatively straightforward when the problem can be described and measured accurately.

Remediation Concepts

Types of Remedies

Remedies can be classified using two sets of descriptive categories:

- **Relocation versus elimination.** An undesired object can be relocated such that it no longer poses a high risk, or it can be completely eliminated.
- **Targeted versus dragnet.** Undesired objects can be relocated or eliminated using processes that are either targeted or dragnet-like. Targeted removal techniques use a specific method to affect a single, known object. Dragnet strategies indiscriminately trawl space to gather and remove all objects with a particular set of characteristics.

Lessons Learned From the 2010 Deepwater Horizon Oil Spill

Using this oil spill as a case study, we identified the following lessons learned:

- Simply having one or more remediation technologies is not sufficient. The remedies must be tested and proven to work in the expected operating conditions.
- The community will only support the development of an effective remedy when the risk posed by the threat is considered to be unacceptable.
- When reacting to a catastrophe, a dragnet solution is needed to address the aftereffects.
- After a catastrophe, a targeted solution may also be necessary to remedy a problem.
- Remedies must be adaptable so that they may evolve to face the latest challenges.

Summarizing Observations

We noted the following key themes as we compiled the results from this research:

- Improving situational awareness should be an ongoing effort within any community.

- The Superfund could serve as an effective model for orbital debris cleanup.
- Incentive structures (associated with mitigation strategies) work best in the short term. In order to achieve a cost-effective long-term solution, it is necessary to change stakeholder preferences.
- All of the stages shown in Figure S.1 must continually evolve over time along with the problem.

The Case for Additional Mitigation in Orbital Debris

When viewed in light of the comparable problems, there is evidence to suggest that orbital debris does not at present pose a great-enough risk to warrant the deployment of a remediation technology.[6] A community will only move on to the next stage shown in Figure S.1 when the current stage is not sufficient to properly address the problem. While everyone in the space community certainly agrees that orbital debris poses a risk, the lack of government and private industry funding for this effort suggests that the perception of risk has not yet crossed a critical threshold that would prompt demands for remediation.

The current lack of private funding for debris remedies is particularly telling. Today, the majority ownership of operational space assets (as a percentage of the total operational inventory) has shifted from government to commercial industry.[7] For this new majority of commercial stakeholders, the "imperative to create shareholder value entails that any investment in a technical system be guided by its value creation potential" (Brathwaite and Saleh, 2009). In other words, if debris were deemed to represent an unacceptable risk to current or future operations, a remedy would already have been developed by the private sector.

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[6] The use of the word *deployment* is intentional: It implies an operational—and not simply a pathfinder—system.

[7] According to the April 2010 Union of Concerned Scientists (UCS) Satellite Database, 41 percent of the world's active, operational satellites are solely commercial; 17 percent are solely military; 18 percent are solely government; and the remaining 24 percent are either multiuse or used for research or scientific purposes. While the UCS database represents only an approximate count of the world's total satellite inventory, it is useful in providing a quick estimate to support our claim (UCS, undated).

The space industry is currently dealing with the debris problem via mitigation, and we offer the following observations about these efforts:

- Mitigation is an effective way to reduce the probability that a catastrophe will occur.
- Tracking metrics over time is an effective way to measure a mitigation strategy's ongoing effectiveness.

The Case for Developing Remediation Technologies

The lack of funding initiatives associated with developing a deployable remedy for orbital debris suggests that the community currently does not need such a capability. However, our research presents several lessons that suggest it may be wise to develop a pathfinder system in the near term:

- **A community must be prepared for "shocks" or catastrophic events.** Sometimes a single catastrophic event, or shock, is sufficient to propel a community through several of the stages at once. For orbital debris, the Chinese antisatellite test and the Iridium/Cosmos collision are two obvious examples (see Chapter One for more detail about these events). These two events are likely the cause for the increased interest—to include this research—in the debris problem. In addition, remedies are needed to clean up the aftereffects of such catastrophic events. Developing the pathfinder technology now for such a remedy may prove to be a wise decision because on-orbit collisions are likely to continue to occur in the future.
- **Remedies must be designed and tested to work under the actual operating conditions.** This is the biggest lesson from the Deepwater Horizon spill. All of the remedies fielded during the first 40 days of the spill were not effective because they had not been tested or proven to work in deepwater drilling conditions. Fielding a demonstration technology will prove useful only if it will provide operators and engineers with relevant information on technology performance under the actual working conditions. In

addition, decisionmakers will gain important data points on realistic values for recharge times, reaction times, and the magazines associated with any potential remediation technology. Ultimately, the pathfinder system must strive toward remedying a realistic problem, or the development will risk being considered purely academic and not operationally useful.

- **One remedy is not good enough.** A remedy is often used to respond to an event that has already occurred. As a result, remediation technology is often very specialized, and our research indicated that for many problems, several different techniques are necessary. There are examples of this throughout all of the comparable problems. Airline security, asbestos, environmental hazards, oil spills, radon, and spam all use multiple techniques to remedy a problem. For this reason, it may be wise to begin developing a pathfinder system now so that alternative, tangential methods may be developed more quickly in the future.
- **When a problem's effects are not directly observable, a community is likely to underestimate the risk posed by the effects.** Asbestos and radon are invisible, and the cancers they cause may not appear for several decades. Under such circumstances, a community may have a low perception of risk because the cause and effect are separated by long spans of time. By contrast, the neighbors of a polluting factory are likely to see its effects every day. Orbital debris, unfortunately, belongs to the category of problems that are not easily observed either by those who create it or by those who might be harmed by it. Because the harm is virtually invisible until a major collision occurs, the broader community may be simply unaware of the severity of the problem, or they may tend to underestimate the potential risk. Therefore, the technical community should consider implementing an ongoing, metric-based stakeholder awareness program alongside the development of a technical remedy.