BALANCING SAFETY WITH ENTERPRISE RISKS AND OPPORTUNITIES IN HIGH-TECH ORGANIZATIONS

Allan S. Benjamin
Consultant for NASA Projects: 13219 Cedarbrook Ave. NE, Albuquerque, NM, 87111, USA, asbenja@gmail.com

Organizations that are devoted to technical research, integration, and operation (referred to as TRIO enterprises) are concerned with achieving a reasonable balance between the desire to have a successful operation and the need to have a safe one. Enterprise risk and opportunity management (EROM) concerns the means by which organizations develop an integrated, organization-wide, understanding of the risks that affect the success of the organization and a perspective on how to balance risk against opportunity. The objective of this paper is to discuss the basic principles of EROM as a generalization of safety risk management, and to show how they can be translated into implementation for TRIO enterprises. The paper also addresses new requirements issued by the US Office of Management and Budget for Government agencies to integrate EROM with the development and maintenance of internal controls. It provides an illustration of how safety concerns can be integrated with other risks and opportunities within the EROM framework using NASA's James Webb Space Telescope (JWST) project as a topical example.

I. INTRODUCTION

Space agencies such as NASA and its many partners and providers, both domestic and international, are examples of a general class of organizations that are charged with pioneering the development of new technology and applying it to complex systems. We refer to such organizations as "TRIO enterprises," where TRIO is an acronym standing for "Technical Research, Integration, and Operation." These organizations are, like all risk-taking enterprises, deeply concerned with risks to safety. At the same time, moreover, they are concerned with achieving a reasonable balance, and if possible an optimal one, between having a safe operation and a successful one, where success is defined in terms of scientific and technological advancement.

The NASA Administrator, Charles Bolden, addressed the search for a balanced approach to risk and opportunity in a letter to employees dated April 19, 2013, from which the following sentences are excerpted: "Throughout our history NASA's explorer spirit has led us deeper into the unknown where we continue to learn as much from our failures as our successes. One of the things that impress me most about our workforce is the willingness of so many to dream big, think outside the box, and take risks. …We have to be willing to do daring things. Put another way, risk intolerance is a guarantee of failure to accomplish anything of significance. … I ask you to continue to think about how we can identify and seize opportunities to make progress quickly and affordably, identify and manage risks, learn fast and adapt our plans to take the next steps. While we do this, we must constantly balance our risks and rewards and always, always put the lives and safety of our people first."

The balancing of safety risks with other risks, and the balancing of risks with opportunities, are the main objectives of Enterprise Risk and Opportunity Management (EROM), often referred to more simply as Enterprise Risk Management (ERM). This paper provides a summary exposition of the main principles and methods pursued within EROM for TRIO enterprises, and then provides an illustration of how safety concerns can be integrated with other risks and opportunities, using NASA's James Webb Space Telescope (JWST) project as a topical example.

EROM has lately been receiving increased attention within US Government agencies because of recent directives from the executive branch of the government.[1,2] For example, the Office of Management and Budget (OMB) Circular A-123 now "requires" agencies to proceed in "integrating risk management and internal control activities into an … ERM framework to improve mission delivery."

Part of the work presented in this paper was funded by NASA in an effort to explore the ways in which that agency can comply with the new OMB directives. Beyond the NASA application, the paper also deals more generally with the subject of EROM as it applies to both public and private (commercial) TRIO enterprises. More details than can be provided in this paper may be found in a concurrent NASA report[3] entitled "Enterprise Risk and Opportunity Management: Concepts and Applications Relevant to NASA", and in a publication-ready book[4] entitled: "Enterprise Risk and Opportunity Management: Concepts and Step-by-Step Examples for Pioneering Scientific and Technical Enterprises".

II. PRINCIPLES AND CONCEPTS

II.A. Types of Risk Considered within EROM for TRIO Enterprises

EROM is concerned with the enterprise-wide management of a variety of types of risk, wherein the acceptance of any one risk type (e.g., safety risks) has to be balanced against the acceptance of all the other types of risk. Within the general context of EROM for TRIO enterprises, the principal types of risks may be characterized as follows:[3-7]

- ***Strategic risk*** refers to shortfalls in the ability of an organization to adequately achieve the long-term goals of its stated mission. In part, strategic risk may be equated with the potential for an organization to fail in accomplishing one or more of its strategic objectives. Inferentially, it additionally includes the potential for an organization to fail to formulate its strategic objectives in a manner that best serves its overall mission.
- ***Program/project risk (including safety risk)*** is the potential for performance shortfalls, which may be realized in the future, with respect to achieving explicitly established and stated program/project performance requirements. Performance shortfalls for programs/projects may be related to any or all of the following mission execution domains: safety, technical performance, cost, and schedule.
- ***Institutional risk*** concerns risks to infrastructure, information technology, personnel, other resources and assets, processes, occupational safety, environmental management, and security. These risks affect capabilities and resources necessary for mission success, including institutional flexibility to respond to changing mission needs and compliance with external requirements such as Government regulations.
- ***Requirement risk*** is the risk of not satisfying the requirements of the organization's stakeholders and regulators. Requirements to be satisfied may include environmental safety and health (ES&H) protection, protection against fraud and misconduct, equal opportunity and other labor requirements, and in the case of Federal agencies, Federal mandates directed at achieving specific goals in the areas of public education, international cooperation, and commercial partnerships.
- ***Reputational risk*** concerns risks that could jeopardize the viability of the organization, and includes risks to financial health, legal risks, and public confidence risks. The latter category includes the risk of a catastrophic accident or other high profile loss attributable to mismanagement or malfeasance.

II.B How EROM Balances the Decision Maker's Risk Tolerance and Opportunity Appetite

The concept of balancing risk against opportunity is illustrated schematically in Fig. 1. As shown in the figure, the balance is a reflection of the decision maker's sense of the risk relative to his/her sense of the opportunity for each objective of the organization. In this context, "sense of the risk" is equivalent to one's tolerance for the risk as presently perceived, and "sense of the opportunity" is equivalent to one's appetite for the opportunity as presently perceived. A variety of factors, such as prescribed safety requirements, the availability of resources or assets, and other fixed constraints, enter into the decision maker's sense of risk or opportunity.

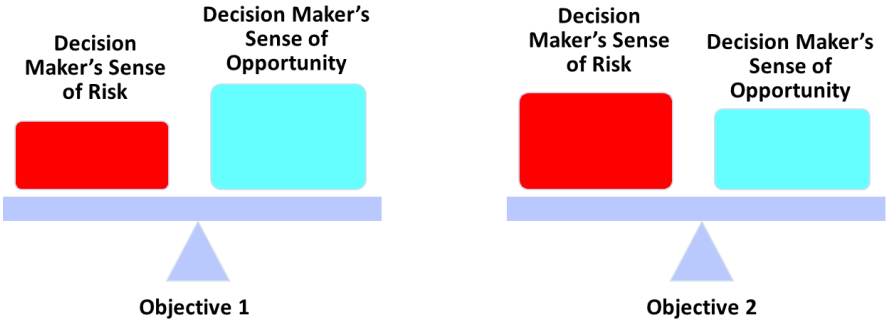


Fig. 1. Decision Making is a Balance between Risk and Opportunity.

The balance between tolerating risks and seizing opportunities is informed by guidance provided at the executive level, such as the NASA Administrator's comments cited in the Introduction, which imply that the organization must manage risks and opportunities in a graded manner across its portfolio of activities. As shown in Fig. 2, most organizations have stricter standards (low tolerance for risk) relative to preserving its core capabilities and human lives and safety, while at the same time having more lenient standards (tolerating higher risk) relative to accepting the

possibility of losing hardware in the pursuit of pioneering or capability-expanding activities that create new opportunities to more effectively advance the organization's mission. This considered grading of risk tolerance during strategic planning and during execution of the plan sets the ground-rules for *strategic risk taking* that is essential for progress and success over the long-term. It creates areas where the organization learns rapidly, in part through acceptable setbacks, as well as promoting areas where the gains made through high risk activities are consolidated and institutionalized into a more capable organization.

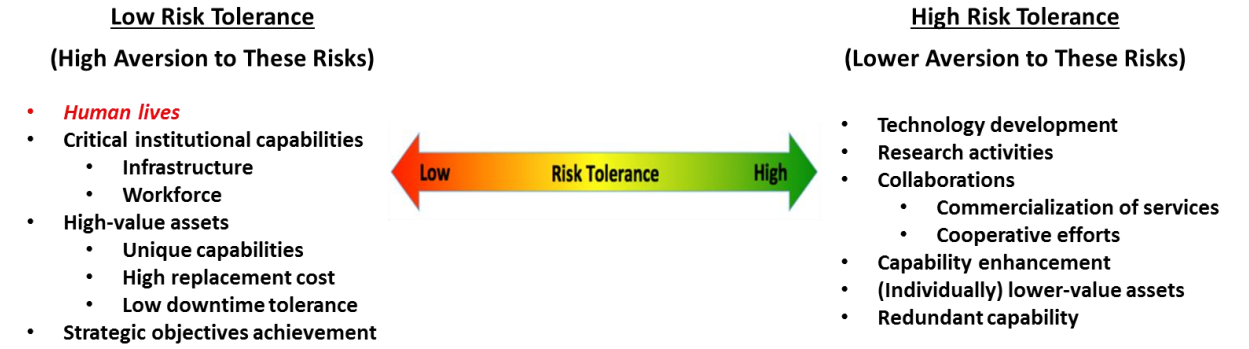


Fig. 2. Risk Tolerance Relative to Diverse Goals and Objectives.

II.C. Risk and Opportunity Parity Statements

The risk tolerances and opportunity appetites elicited from the stakeholders may be expressed in the form of risk and opportunity parity statements. These statements define boundaries between tolerable and intolerable risks, and between significant and insignificant opportunities.

Each risk and opportunity parity statement reflects a common level of pain or gain from the stakeholders' perspective. This enables comparisons between risk and opportunity to be meaningful because:

- The amount of risk perceived by the stakeholders (i.e., their level of pain) is the same for each parity statement
- The amount of opportunity perceived by the stakeholders (i.e., their level of gain) is the same for each opportunity parity statement
- For each pairing of risk and opportunity parity statements, the amount of risk (pain) is balanced by the amount of opportunity (gain)

Risk tolerance and opportunity appetite statements that are elicited from the stakeholders can take various forms. For example, they may involve probabilities of failure or success in satisfying a particular objective, or they may involve changes in the achievable values of key performance parameters that affect a particular objective. To illustrate this point, consider the following hypothetical risk and opportunity parity statements:

Examples of Risk and Opportunity Parity Statements for the Mars Human Landing Program

(Hypothetical Values)

Example Risk Tolerance Statements: A risk scenario is considered to reach the risk intolerance boundary if:
1. The likelihood of failure to land humans on Mars by 2035 increases from its targeted value of 10% to 50%, or
2. The targeted date of 2035 for landing humans on Mars increases to 2050, or
3. The total cost of landing humans on Mars by 2035 increases by 50%, or
4. The overall probability of loss of crew during the first mission increases from its targeted value of one in 100 to one in 30.

Example Opportunity Appetite Statements: An opportunity scenario is considered to reach the opportunity appetite boundary if:
1. The total cost of landing humans on Mars by 2035 decreases by 25%, or
2. The launch system for landing humans on Mars will also be capable of being used for exploratory missions to the moons of Jupiter and Saturn.

The implication of parity suggests that these six statements involve equal pain or gain. In short, strategic decisions between disparate choices can be made if the baselines for risk and opportunity, as defined by the boundaries, are commensurate in terms pain and gain.

II.D. The EROM Analysis Framework and Interactions with Management

For any well-established organization, the EROM approach is framed and structured to synchronize with and facilitate the philosophy and management processes that already exist within that organization. The manner in which EROM assists management in developing a responsive and achievable plan is illustrated in Fig. 3. Following is a more detailed summary of the EROM activities that provide inputs to management:

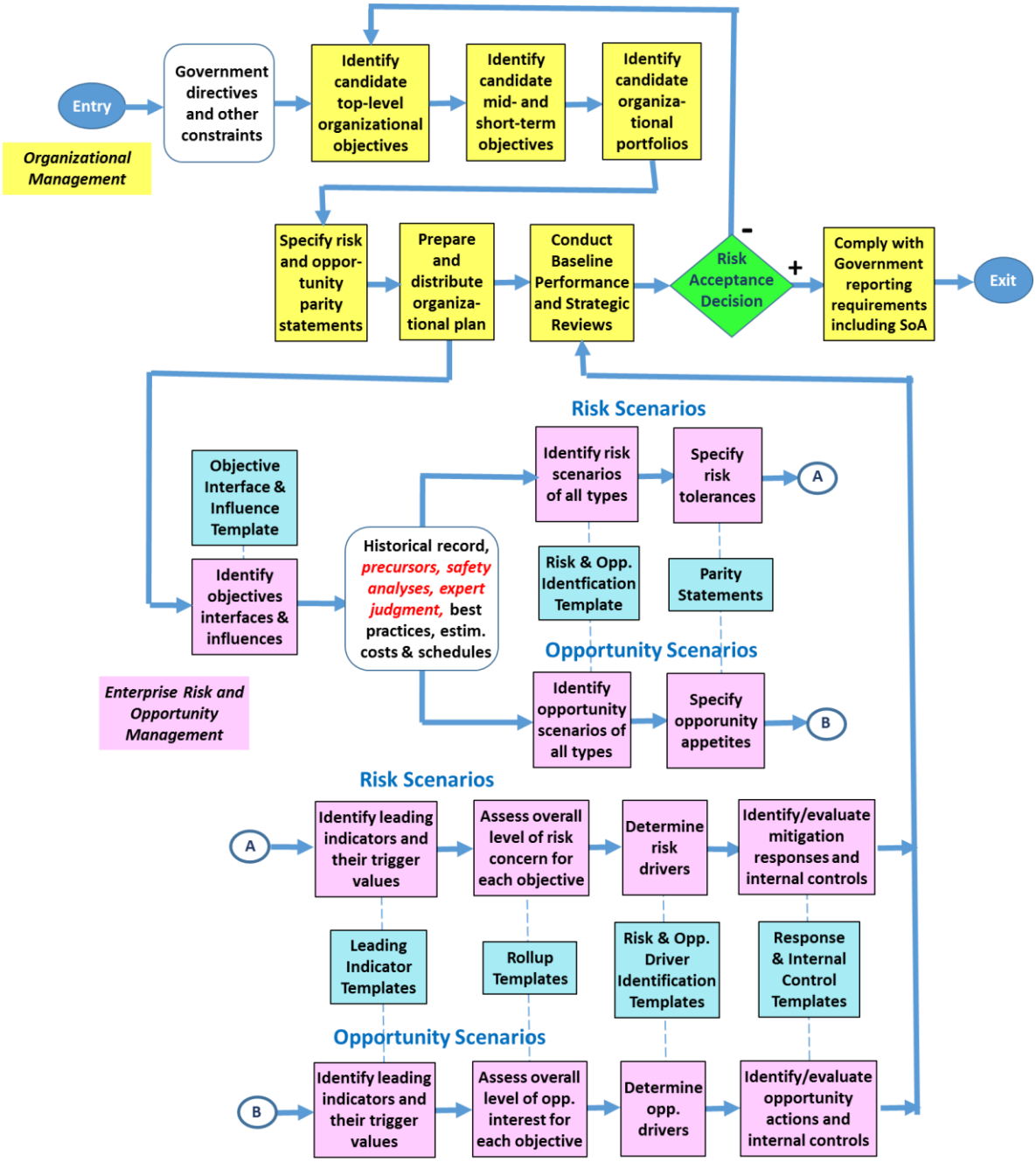


Fig. 3. EROM Tasks in Relation to Organizational Management Activities.

EROM activities that support management's selection of objectives and portfolios from among a set of alternatives and preparing the strategic plan include: (1) characterizing and understanding all relevant historical experience pertaining to failures, successes, precursors, anomalies, unexpected opportunities, and lessons learned/best practices, as well as past and current analyses pertaining to expectations in the domains of safety, technical performance, costs, and schedules; (2) identifying risks and opportunities for each alternative set of objectives and program/project/activity portfolios based on the historical record, expert judgment, and relevant analyses; (3) specifying risk tolerances and opportunity appetites for each objective based on management's parity statements; (4) assessing the state of risks/opportunities as they pertain to the likelihood of achieving each objective, using past experience and current risk/opportunity leading indicators as a basis; and (5) providing recommendations for reducing risks while seizing worthwhile opportunities.

EROM activities that support management's conduct of baseline performance and strategic reviews and reporting to the Government include: (1) tracking leading indicators that pertain to organizational risks and opportunities, noting that the leading indicators may emanate from external sources (such as political, economic, or regulatory changes) or from internal sources (such as the depletion of reserves and margins in any of the mission execution domains); (2) assessing the significance of the risks and opportunities at each level in the organizational objectives hierarchy, based on the current values of the leading indicators; (3) determining the principal risk and opportunity drivers (i.e., the risk and opportunity scenarios, specific events within scenarios, root causes of events, key assumptions, internal control deficiencies, and/or other organizational and programmatic factors that drive the cumulative risk and opportunity for each objective); (4) performing an analysis when risks are of concern, or when opportunities are attractive, to suggest options that may be pursued to mitigate the risk drivers or pursue the opportunity drivers; and (5) risk-informing the selection and application of internal controls

As shown in Fig. 3, a set of templates is available within the aforementioned NASA report and book to help EROM practitioners in performing these tasks.[3,4] The templates result in a rolled-up ranking, or rating, of each objective in the objectives hierarchy in terms of its cumulative risk and cumulative opportunity. The rationale behind the roll-up and propagation of ratings is recorded in the roll-up templates and is the basis for identifying the risk and opportunity drivers for each objective. The identification of drivers ultimately provides the basis for suggesting effective responses for mitigating risks, actions for availing opportunities, and internal controls.

III. EXAMPLE APPLICATION RELEVANT TO THE US SPACE PROGRAM

III.A. Background

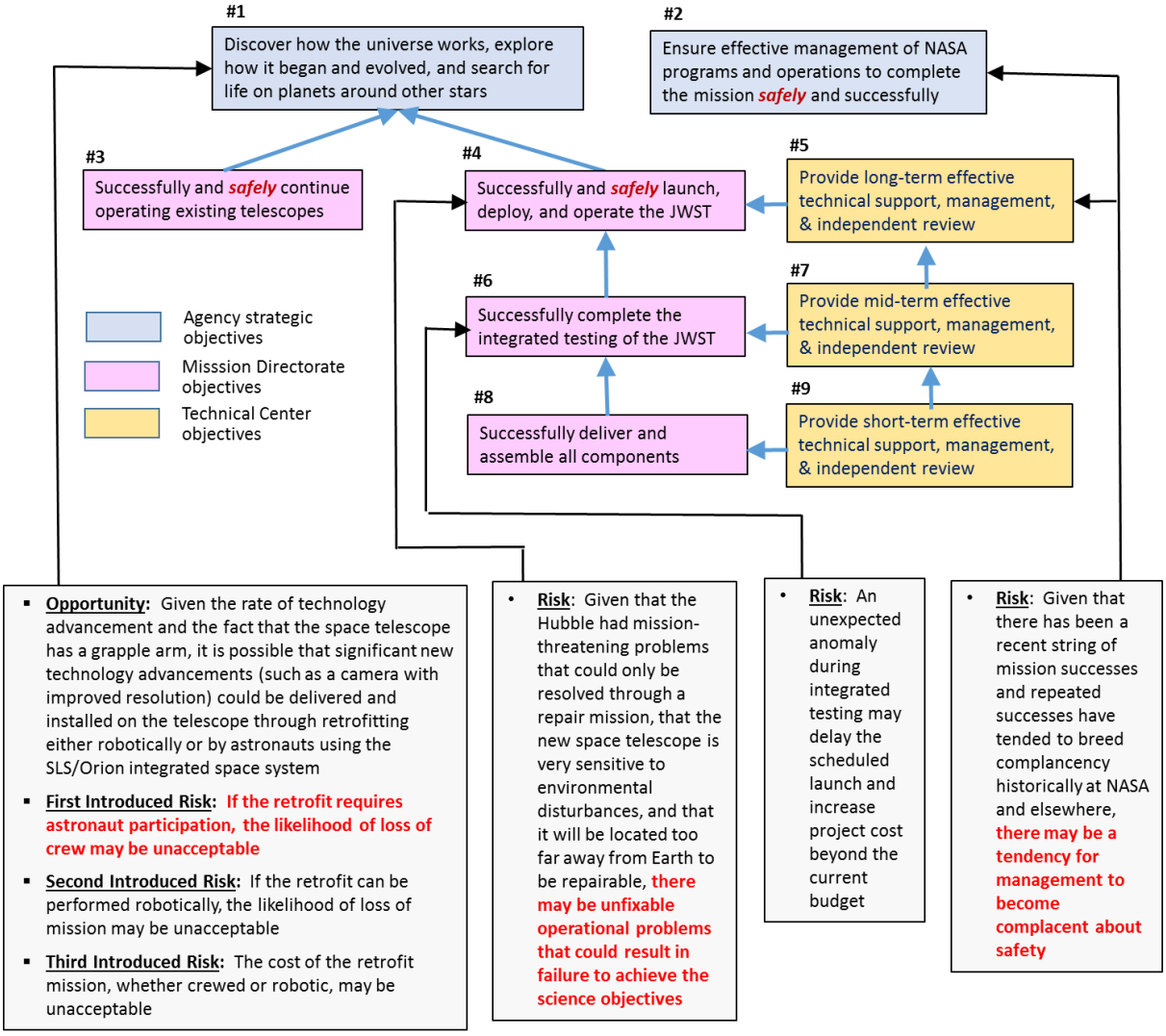
To test the framework depicted in Fig. 3, we used as an example the NASA James Webb Space Telescope (JWST) project. According to the US Government Accountability Office (GAO),[8] the JWST is one of the most complex projects in NASA's history, from the viewpoint of both design complexity and the complexity of the integration and test effort. The cryogenic cooler (cryocooler) subsystem is particularly challenging because of the relatively great distance between the cooling components and the need to overcome multiple sources of unwanted heat. In addition, successful attainment of high resolution camera data from the JWST requires a highly controlled environment, including minimum vibration, minimum stray light, particularly in the mid-infrared range, and minimum departures from a cold and stable temperature environment.[8,9] Because of escalating development costs associated with unexpected technical problems, the White House and Congress have at times sparred about cancelling other existing operating programs (e.g., SOFIA and Spitzer) to fund the JWST project, although no such cancellations have yet occurred.[10]

Experience with the Hubble Space Telescope (HST) has indicated that operational difficulties may be a serious problem once the JWST is deployed in space. The Hubble required servicing missions to perform several retrofits and corrective actions, including the famous mirror fabrication error which greatly degraded the quality of the image. Other operational difficulties that required a servicing mission included replacement of solar panels to correct a jitter problem caused by excessive flexing due to orbital cycling of solar input, and replacement of several gyros that were adversely affected by the launch environment.[11] New opportunities were also availed through HST servicing missions, including incorporation of new, more sensitive instruments and addition of the Advanced Camera for Surveys, which was used to explore dark energy and other cosmological findings revealed by the HST.[12]

The JWST is presently considered unserviceable, since it will be located far from Earth at the second LaGrange point approximately 1 million miles away. Although nominally unserviceable, however, the JWST is designed to have a grapple arm for docking, implying that the option to conduct servicing missions has not been completely relinquished.[8]

III.B. Results

Fig. 5 shows the integrated objectives hierarchy, the risk and opportunity scenarios, and the leading indicators considered for this JWST demonstration. (Obviously, this is a rather simplified representation of the entire set of objectives, risks, and opportunities for the JWST.) At the top of the hierarchy are two of NASA's fifteen strategic objectives:[13] (1) discover how the universe works, explore how it began and evolved, and search for life on planets



Representative Leading Indicators			
1	Present schedule reserve for SLS/Orion deployment	9	Technology readiness level for key SLS/Orion components
2	Projected schedule reserve for SLS/Orion deployment	10	Present political support (Rank 1-5)
3	Present cost reserve for SLS/Orion deployment	11	Projected political support (Rank 1-5)
4	Projected cost reserve for SLS/Orion deployment	12	Present economic indicators
5	**Reserve for probability of loss of crew**	13	Projected economic indicators
6	Complexity of design (Rank 1-5)	14	Present contractor viability (Rank 1-5)
7	Complexity of integrated testing (Rank 1-5)	15	Projected contractor viability (Rank 1-5)
8	Complexity of mission (Rank 1-5)		

Fig. 5. A Simplified Example of an Integrated Objectives Hierarchy for the Space Program with Selected Risk and Opportunity Scenarios.

around other stars; and (2) ensure effective management of NASA programs and operations to complete the mission safely and successfully. Below the agency-level strategic objectives are selected objectives from NASA contributing programmatic and technical organizations. The risk scenarios, opportunity scenarios, and leading indicators in the figure reflect the principal observations described in the first three paragraphs of this section.

Table I shows the risk and opportunity drivers that resulted from the demonstration analysis, along with the key assumptions needing to be controlled and the proposed internal controls. Two types of drivers are listed: (1) scenario

TABLE I. Risk and Opportunity Drivers, Key Assumptions, and Proposed Internal Controls for the simplified Space Program Example.

Objective Index and Description	Objective Cumulative Level of Concern or Interest	Scenario Driver Description	Driver Consti-tuent Number	Driver Constituent Description	Assumption Needing Watchfulness	Proposed Internal Control
#1 Discover how the universe works, explore how it began and evolved, and search for life on planets around other stars	Significant Interest (Opp.)	it may be possible for a camera with improved IR resolution to be delivered and ***safely*** installed on the telescope after its deployment by astronauts during a retrodit mission	1	Technology Readiness Level (TRL) for IR camera	Technical readiness level (TRL) development is being tracked and reported	Protocol for tracking and reporting on IR camera TRL progress
			2	Readiness of SLS/Orion docking capability	Technical readiness level (TRL) development is being tracked and reported	Protocol for tracking and reporting on docking capability progress
	Significant Concern (Introduced Risk)		3	**Predicted probability of loss of crew for SLS/Orion**	A rigorous ***probabilistic risk assessment*** of the retrofit mission will be performed	Provisions to ensure that adequate funding will be available to perform a rigorous ***PRA***
					P(LOC) reserve for unknown and under-appreciated (UU) risks will be sufficient to avoid significant P(LOC) underestimation	Protocol for ensuring that ***P(LOC) reserves*** are consistent with prior experience pertaining to unknown and under-appreciated (UU) risks
			4	Predicted cost for rendezvous mission compared to projected funding availability	Cost reserve for UU risks will be sufficient to avoid significant cost underestimation	Protocol for ensuring that cost reserves are consistent with prior experience pertaining to UU risks
					Early success of space telescope will increase public support for improving its capability when new technology becomes available	Very high quality control and qualification testing to ensure that the telescope has no flaws at the time of launch that would degrade its scientific value
			5	Congress may cancel or defer other SLS/Orion missions	Congress is aware of the benefits of the planned SLS/Orion missions	Provisions to emphasize the value of SLS/Orion missions in communications with Congress and the public
					The economic recovery will increase the willingness of the country to spend more on space	Provisions to track national and global economic trends and factor them into strategic planning
	Marginal Concern (Risk)	There may be unfixable operational problems that could result in failure to achieve the science objectives	6	Unanticipated loads or outright ***failure*** during launch or ascent	Launch and ascent loads and ***failure probabilities*** are well characterized	Independent review to verify that launch & ascent loads and ***failure probs*** are well characterized
			7	Unknown or underappreciated ***(UU) failure mode*** within telescope	A robust margin for has been incorporated to account for ***UU failure modes***	Independent review to verify that the margin to account for ***UU failure modes*** is consistent with experience for other first-of-a-kind systems
#2 Ensure effective management of NASA programs and operations to complete the mission ***safely*** and successfully	Marginal Concern (Risk)	A string of recent successes may cause management to become complacent about ***safety***	8	Insufficient attention by management to **lessons learned**	Current management attention to ***safety lessons learned*** will continue in the future	Audit of management attention to ***safety lessons learned*** with corrective action where needed
			9	Insufficient **safety training** for new managers	Management ***safety training*** reuirements will remain in effect and training will be updated as needed	Audit of management ***safety training*** requirements and course content with corrective action where needed

drivers and (2) constituent drivers. The scenario drivers are the risk and opportunity scenarios that cause the cumulative risk or opportunity of either strategic objective to become either significant or marginally significant (i.e., not insignificant). The constituent drivers are the controllable constituents of the scenario drivers: i.e., the conditions, potential events, root causes, and consequences that can be positively affected through actions and controls. As shown in the table, a total of ten suggested internal controls resulted from this one limited example.

IV. CONCLUSIONS

The EROM framework discussed in this paper is based upon achieving a reasonable balance between safety risks and other risks, and between risks and opportunities, over all types of risks and opportunities faced by an organization. The framework achieves this goal by eliciting the decision maker's sense of risk tolerance and opportunity appetite for each organizational objective, by mapping risk and opportunity scenarios to the organizational objectives, by identifying quantifiable leading indicators of risk and opportunity, and by rolling up the leading indicators for each objective to obtain an understanding of the cumulative, or aggregated, risk and opportunity. For organizations that perform technical research, integration, and operations (TRIO enterprises), the approach is largely qualitative but based on sound, transparent, and well-documented rationale.

To test the framework, we used the NASA James Webb Space Telescope (JWST) project as an example. The example demonstrated that the EROM framework for reaching parity between safety risks and other risks and between risks and opportunities leads to a rational understanding of the risk and opportunity drivers and a solid basis for proposing risk mitigations, opportunity actions, and internal controls.

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