Programmatic Risk Balancing

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Abstract. A lifecycle risk management decision-support tool developed for NASA space systems is used to assess and visualize risk in a research and applications program. This paper presents the first tool demonstration and assessment for balancing programmatic risk. The NASA program for case study has a principal goal development of geospatial information products for decision-support systems. Risk balancing is performed by selecting optimal combinations of risk controls, such as planning activities, assessments, research and applications projects. Marginal benefits are measured in terms of residual risk. Relative differences in risk impact and control effectiveness provide an indication of program integration across science, technology and applications. Results are preliminary. Sensitivity analysis suggests that at implementation, prioritization and coordination with government agencies are mitigations yielding the greatest marginal benefit towards requirements attainment. At introduction of projects, establishing performance characteristics yields the greatest marginal benefit. The framework helps strategy design, execution, integration and prioritization. —

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Introduction

A lifecycle risk management decision-support software tool – *Defect Detection and Prevention* (DDP) [1, 2, 3, 4] developed by the National Aeronautics and Space Administration (NASA) for complex space systems is used to assess and visualize risk in the planning, formulation and implementation of a NASA research and applications program now in formulation. DDP tool development is part of an overall Failure Detection and Prevention Program sponsored by NASA's Office of Safety and Mission Assurance. The DDP tool previously has been applied to assess the maturity of component technologies and subsystems and is being piloted for a Mars mission currently in early formulation phase. This paper presents the first case study demonstration and preliminary assessment of the DDP tool for balancing programmatic risk.

The intent herein is to use or otherwise adapt DDP to provide an architectural framework that integrates across NASA Earth Science Enterprise missions, science and technology, and aids in the prioritization of applications projects as an investment portfolio. The results are presented as a case study. The input requirements and risk elements are obtained from strategic planning activities and prior elicitations from program stakeholder and expert user panel discussions, and partially include a previously documented technology capability needs assessment. The anticipated effectiveness of risk control options is guided also by stakeholder elicitations as available or input by the author as an initial value and are assessed in terms of residual risk profiles at select program lifecycle stages. These values are subject to subsequent sensitivity analyses or later modifications as deemed necessary to achieve the consensus of program management and stakeholders.

DDP provides the program manager with a risk management decision-support capability to help the execution of a strategic program plan, and potentially guide the solicitation and selection of projects. Furthermore, DDP provides a method to continually assess program changes and associated resources on the basis of managing attendant risks to the program. The risks are defined in terms of impact and likelihood of not meeting high-level program goals or requirements. These requirements may be weighted to emphasize different performance targets as the program matures.

APPROACH

DDP is an interactive software tool that establishes the relative significance of specific risk elements (REs) by evaluating the impact of their occurrence on the program requirements or goals. The tool evaluates the effectiveness of various solution options (SOs) allowing one to determine an optimum set with which to manage the risk within the resource constraints of the program at a particular program lifecycle stage.

The DDP process requires establishing the impact of the occurrence of each RE on program success by scoring across all goals (requirements). Each potential RE is then weighted by its likelihood of occurrence if nothing is done to retire or mitigate the risk. The impact on various program goals is established using a non-linear scale of significance. The scale ranges from 0 for no impact to 1.0 for catastrophic impact. The non-linearity arises from the logarithmic nature of applying risks and mitigations serially to a given requirement or risk, respectively. Given the qualitative nature of this adaptation of DDP for programmatic risk, values corresponding to high, medium and low are assigned as 0.9, 0.7 and 0.3, respectively. Two extremal values, 0.99 and 0.1 are used to indicate near absolute impact or nominal impact, respectively. This specification of RE impacts against program requirements specifies the *requirements matrix*. The product of likelihood of occurrence and impact weighted for each RE can then be plotted to determine the relative criticality of the REs to the success of the program, measured as requirements attainment. *Driving requirements* thus are defined or ranked as carrying the greatest impact across all risks identified to the program.

The weighted REs are used to determine the proper courses of action to manage the associated most significant active risks. This involves establishing the relative chance that a RE will go undetected and/or will not be prevented by the SO set already planned, or possible within resource constraints. Different SO sets will have different escape probabilities for different REs (chance of missing the RE). These escape probabilities are entered into the *effectiveness matrix*. By multiplying the escape probabilities from all of the SOs for each RE, one can obtain the net likelihood of "escape." The resultant risk for an RE then is obtained by taking the product of the impact of the RE on requirements and the escape probability for each SO combination considered. This process is repeated for each RE. Different combinations of SOs result in different risk balances.

One can also formulate a figure-of-merit for various SO combinations based on the extent to which risk is detected or prevented by summing the products of the impacts of the REs on requirements and the probability of an individual SO detecting or preventing the active REs. This figure-of-merit can then be used to decide when enough SOs have been selected or can be used to establish a baseline about which one can perform incremental changes. The outcome measured against program requirements is in terms of residual risk from one SO scenario to another (see Fig. 4 below).

Marginal benefit across the program thereby is assessed in terms of residual risk profiles – a histogram of all active risks and their severity measured in units of requirements lost (i.e. at risk). The DDP tool addresses residual risk as a function of various risk control or solution options. The program manager selects from a set of risk control options for alleviation, detection or mitigation, each with an estimated effectiveness against risk elements. Program linkages are embedded in the DDP architecture, through the requirements and effectiveness matrices.

The DDP software enables sensitivity analysis of SO effectiveness. Given the difficultly in assigning a quantitative value to what are typically qualitative assessments of SO effectiveness against programmatic risk elements, those SOs can be flagged and a sensitivity analysis performed by prescribing selected "what-if" effectiveness values. The sensitivity analyses also sweeps across a range of prescribed values for all quantitatively (i.e. non-flagged) effectiveness values. A figure-of-merit provides the change to the attainment of requirements by a given change in SO effectiveness – a metric of marginal benefit that is anchored to the goals and high-level requirements of the program.

CASE STUDY

This case study is being carried out as part of the Program Planning and Analysis (PP&A) the NASA Earth Science Enterprise (ESE) in support of the Applications Program (see "Practical Benefits" in www.earth.nasa.gov). The Earth Science Applications Program serves ESE by demonstrating practical uses of NASA-sponsored *observations* from remote sensing systems and *predictions* from scientific research. NASA implements projects through partnerships with public, private, and academic organizations. These partnerships focus on innovative approaches for using Earth science information for decision support systems that can be adapted in applications nationwide. The PP&A strategy towards accomplishing the Program vision, mission, and goals (for the ten-year period from 2002-2012) focuses on identifying and selecting the highest priority national needs and opportunities.

In this case context, risk balancing is achieved by selecting an optimal combination of risk controls, constrained by available program resources – funding, program duration and enterprise organization. For example, risk controls may be planning activities with program stakeholders (e.g. data providers, collaborators, product users, sponsors), analyses, research, developments and applications projects in a manner that retires overall programmatic risk to acceptable or desired levels at specific program stages – formulation, implementation and ultimately self-sustainable operations in decision-support systems. Projects, linked directly to meeting program requirements, are treated as *investment options* to mitigate risks to the program, thus yielding the investment return or benefit to the enterprise.

In order to systematically address application priorities in the national interest, program planning consists of three stages: (1) identification of candidate applications, (2) prioritization and selection of applications, and (3) identification and selection of projects for applications. DDP is assessed in part herein for program management decision-support of these three stages.

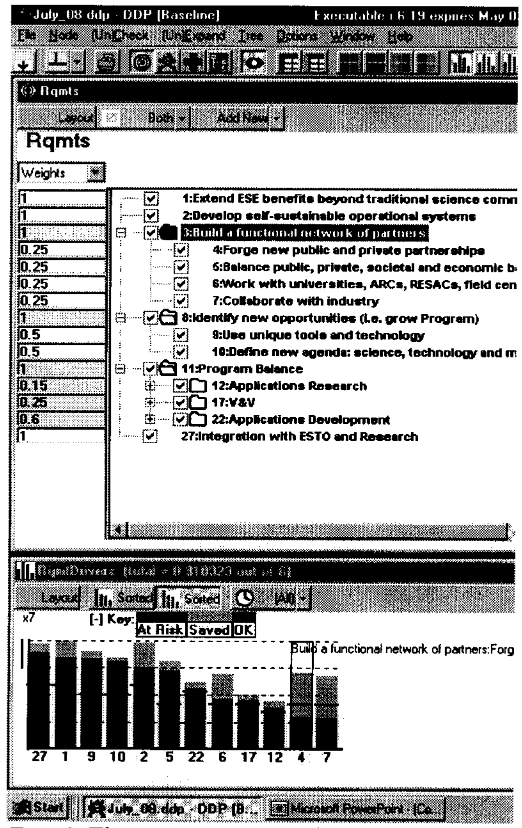

Fig. 1. The tree structure of the requirements is shown in the upper window of the DDP graphical user interface (GUI). The bottom window shows the driving requirements sorted in decreasing order. Each parent requirement in this example is given a weight of 1; weights are assigned to children requirements on the basis of the parent weight. Of the 6 Level-I parent requirements, only 0.31 of 6 is not at risk in this particular illustration.

Level I Program requirements are obtained from the *NASA Ten-Year Applications Strategy* www.earth.nasa.gov/visions/appstrat2002.pdf and are input accordingly to DDP. Level II implementation requirements and solution options input in DDP are obtained from PP&A activities, stakeholder panel discussions and expert-user recommendations thereof. PP&A relies on such inputs of a broad user community and private sector data and service supplier organizations, to foster resource-sharing partnerships and opportunities for making data and information products available. DDP, as a risk management process, can be used to foster discussion in such panels and drive consensus regarding requirements, risk impacts and effectiveness of mitigations or controls.

Program requirements are well documented; and can be weighted and structured in the DDP tool as trees. Similarly, risk trees, analogous to fault trees, with a logical structure of "and" and "or" gates are derived and captured as a result of program planning meetings held with stakeholders, and from gaps in underlying science and technology capability, and from factors assessed external to the program. For example, risks may be due to incomplete planning, unavailability of enabling technology or data, the economic and competitive landscapes, and ultimately to an unbalanced portfolio of projects.

Representative Level I driving requirements for this case study are:

- Extend ESE benefits beyond the traditional science community
- Develop self-sustainable operational systems
- Use unique [NASA] tools and technology
- Define new agenda of science, technology and missions
- Balance public, private, societal and economic benefits

Two additional requirements are incorporated as study objectives:

- Integrate Program with the Earth Science Technology Office (ESTO) and Research Division
- Program Balance (distribution of projects in terms of applications research, verification and validation, and development).

There are a total of 22 requirements, at parent and children level in the tree structure, incorporated in the DDP architecture of this study.

The current portfolio of applications projects represents in part the Applications Program at Level III as project-based solution options towards meeting Level I requirements. The current risk baseline of the Program is established in terms of meeting Level I requirements, and includes addressing Level II strategic implementation elements as further solution options. While Level II in fact represents implementation requirements, it is important to structure the DDP approach such that the overarching requirements are only at Level I and the implementation requirements are rather solution options whose effectiveness against programmatic risk can be assessed. Furthermore, the implementation requirements also may range from firm requirements to recommendations, as obtained from the PP&A panels for example.

Resources limit the set of implementation solution options available to the program manager. DDP provides a means of selecting solution options, phased across the program lifecycle, based on available resources and balancing the programmatic risk profile. In the current architecture, there are over 110 risk elements identified (including parents and children) and over 70 solution options thusfar incorporated in this ongoing study. Examples of risk elements and solution options are described below.

The DDP architectural framework also is intended to support the Program from planning and formulation into implementation. Regular market and technology assessments, program performance evaluations, combined with continual user needs identification, are core elements within PP&A in its design of a balanced Investment Portfolio Strategy (IPS). This Strategy addresses technology maturity levels, including the commercial and socio-economic landscape, market readiness to adopt innovative geospatial technology solutions, educational and workforce training considerations. DDP would enable investment prioritization and benefit analysis by mapping to program Level I requirements through the corresponding risk balancing.

DDP is being assessed for supporting the design and implementation of the IPS, and for integrating technology and market readiness (and risk) considerations with NASA and appropriate non-NASA solution options. In this pilot study, DDP is used to architect an integration of solution options represented by the Earth Science Research and the Technology Programs towards meeting the goals of the Applications Program.

The Applications strategy indeed builds on the strategies and results of the research and technology programs. For example, the focus of the research strategy is on earth system science, from the perspectives of phenomenological causes of system change, attendant system response to and consequence of change, and predictive capability. The technology program supports the research program by developing advanced technology and tools associated with orbital and sub-orbital missions using innovative sensors and instruments, platforms, remote sensing and information system technologies. Both are necessary elements towards attaining program requirements, and in fact represent their own respective sets of REs and SOs.

Representative risk elements (RE) of the over than 110 incorporated in this study are listed below, with a two-level (parent and child) tree structure as suggested by indentation:

- Technological Landscape
    - Lack of data availability
    - Poor data marketing and pricing barriers
    - Lack of standards and practices
    - Low adoption of enabling geospatial technologies
    - Insufficient education
    - Inadequate workforce training
- Observations and Challenges
    - Needs and priorities defined independent of science
    - Shorter-term (1-3 yr) development horizon
    - No focus on affordability and adoption
    - Unbalanced stakeholder interests
- No adherence to project selection criteria
    - Not of national importance
    - Lack of pervasiveness
    - NASA contribution not unique
    - No partnership investment
    - High cost/benefit ratio
    - No potential commercial impact
    - No capability of documenting results

The technological landscape pertains to REs external to the Program but of potential impact to meeting Program goals and requirements. Observations and challenges were identified in early program planning activities. Project selection criteria map to requirements, hence projects that do not meet these criteria in part or in whole leave some requirements unmet.

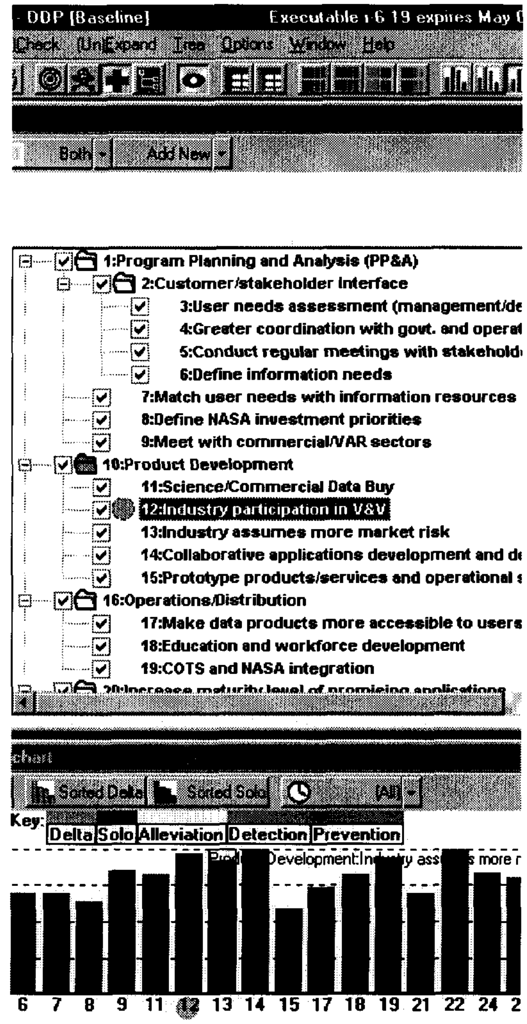

Fig. 2. DDP GUI window showing the solution options (SO) as a tree structure. The height of a given SO indicates its effectiveness across all risk elements that it addresses. Any SO can be highlighted, as in this case number 12 which is "Industry participation in V&V" to indicate its properties, such as cost and program phase. SOs can be color-coded according to whether they are for alleviation, detection or prevention of risks.

The Earth Science Technology Office (ESTO) performed and documented a Capabilities Needs Assessment (CNA) [Ref. August, 2000]. For architectural purposes, the CNA provides the integration link to technological risk elements internal to the Enterprise (as opposed to Technological Landscape REs above). SOs that are selected to mitigate Applications Program risks may also address these particular REs, and conversely activities and investments made by ESTO may mitigate Applications Program risks in a cross-cutting manner. DDP thereby allows integration of different programs that share requirements, REs and/or SOs.

- ESTO-recognized technology challenges (partial list)
  - Weak biomass estimation procedures
  - Algorithms that are not verifiable
  - No day and night image coverage
  - No quick turnaround remote sensing data
  - Few automated detection techniques
  - Little demonstration of 3-D visualization
  - Little data fusion capability
  - Little GPS-based integration of multiple image source information
  - Little validation of interferometric synthetic aperture radar and LIDAR
  - Unreliable techniques for detection of subsurface volcanic activity
  - Little R&D on electro-optical image calibration
  - Inadequate automated prediction models

Program Balance is used in this case study to refer to a current and desired distribution of project functional types in the Program Portfolio. These functions – applications research, verification and validation (V&V), and applications development and demonstration – also define a progression towards meeting the Level I program goals.

- Lack of Program balance
  - Application Research
  - Verification and Validation
  - Applications Development and Demonstration

Each of these three functions has four application theme areas that are addressed by strategic design of the Program: natural resource management, disaster management, community growth and infrastructure, and environmental assessment. A baseline project portfolio distribution of 15/25/60% respectively is used to weigh these functional requirements and to steer the portfolio as the Program matures. This effort falls under Integration and Prioritization (I&P), a key element of PP&A and addressable with the DDP architecture of this study.

PP&A panel sessions to-date have identified a total of 48 priority areas (24, 9, 10 and 5 respectively for each of the four application themes in the abovementioned order). Not following these priorities (Level III requirements, recalling that Level II are strategic implementation requirements) has an impact on meeting Program requirements at Level I.

In addition, the Applications Program has more recently defined 12 National Applications that are the current focus of the Program (see www.esad.ssc.nasa.gov.) These too have been incorporated into the DDP architecture. While there is some thematic overlap, performance evaluation against the four aforementioned themes can be carried out in parallel with these twelve applications. Residual risk levels can be aggregated at theme or functional level, or assessed on an application-specific basis.

Solution options (SOs) for risk mitigation are representative as follows, recognizing that PP&A and Integration & Prioritization (I&P) are investments at the program management or activity level, as opposed to scientific, technological, project or mission investments.

- Program Planning and Analysis (PP&A) – partial list
  - Customer/stakeholder interfacing
  - User needs assessment (for management/decision-support – DSS)
  - Greater coordination with government and operational agencies
  - Define information needs
  - Match user needs with information resources
- Integration and Prioritization (I&P) – partial list
  - Risk assessments
  - Technology and science assessments
  - Socio-economic benefit assessments
  - Development of outcomes-based performance metrics

Product Development and Maturation, and Operations and Distribution are additional classes of phased risk mitigation or risk retirement and investment options (SOs) that provide a critical link between program activities and project-based investments.

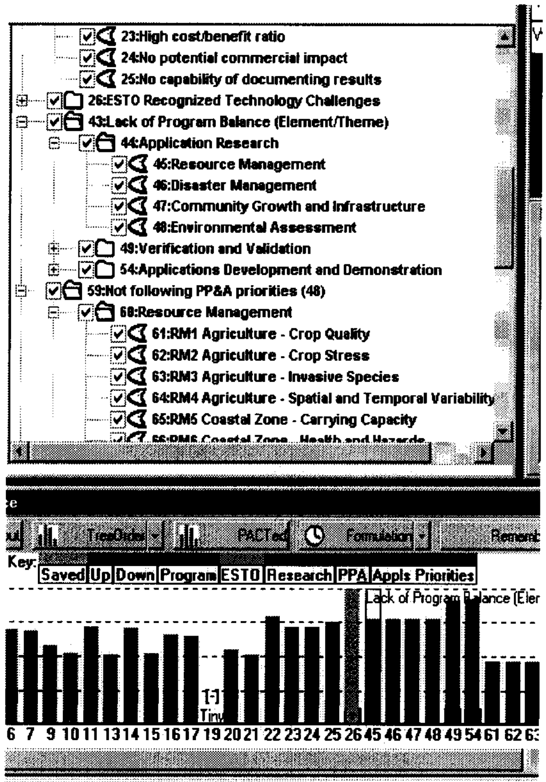

Fig. 3. An illustrative programmatic risk baseline indicating risk levels prior to selection of phased mitigations and investments. Risks are color-coded as to whether they are associated with program management, ESTO capabilities needs, research priorities, PP&A management activities and panel-derived applications priorities. Each risk is numbered and its height determined by its overall impact across all requirements.

- Product Development
  - Science/Commercial Data Buy
  - Industry participation in V&V
  - Industry assumes more market risk
  - Collaborative applications development and demonstration
  - Prototype products/services and operational systems
- Operations/Distribution
  - Make data products more accessible to users
  - Education and workforce development
  - COTS and NASA integration
- Increase maturity level of promising applications
  - Increase science readiness
  - Increase technology readiness
- Validation of operational readiness
  - Establish performance characteristics
- Demonstration of operational prototype

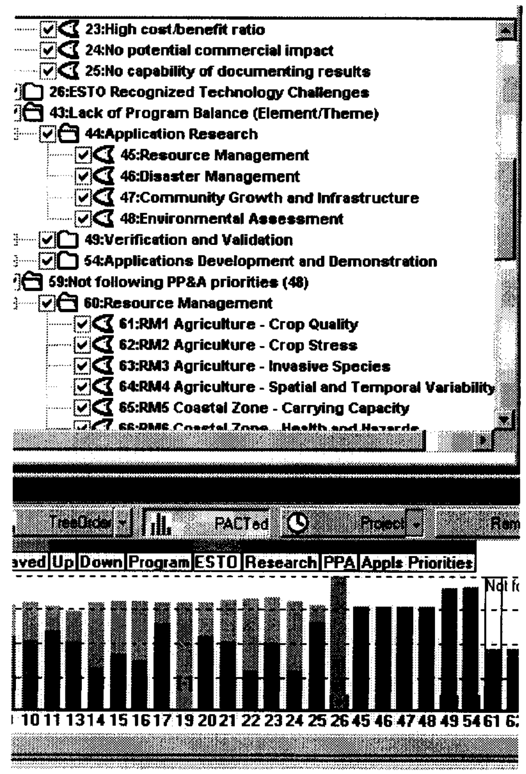

Fig. 4. Residual risk levels after selection of solution options at program formulation, the mitigation effect of which is indicated in green to indicate the residual risk.

Announcements of Opportunity, NASA Research Announcements, and Broad Agency Announcements are additional programmatic risk mitigation investments (solution options) towards filling gaps in meeting Program goals. It is anticipated that further case study of DDP for programmatic risk balancing may help identify cross-cutting opportunities, to be described in such solicitations and to establish further selection criteria that are based on filling gaps in meeting program requirements and goals.

Along these lines, two studies or assessments of previously selected projects were conducted in parallel to this effort and their results incorporated in this DDP case study. On October 6, 2000, NASA issued NRA-00-OES-08 soliciting research proposals for Carbon Cycle Science and Related Opportunities in Biology and Biogeochemistry of Ecosystems and Applications. An assessment of applications projects selected from this Carbon Cycle NRA under the Ecology was performed and scored in terms of their effectiveness in mitigating identified programmatic risks, using a simple high, medium and low scoring. [This effort was performed by S. Drake of the University of Arizona, and incorporated into this DDP case study]. Similarly, a Research project assessment (performed by L. Biehl, Purdue University) investigated the linkages of projects, in the context of the Applications Program, from the following five NASA ESE Programs:

- Upper Atmosphere Research Program / Atmospheric Chemistry Modeling and Analysis Program
- Land Cover/Land Use Change Program
- Terrestrial Ecology Program
- Land Surface Hydrology Program
- Solid Earth and Natural Hazards Program

The intent herein is thus to use DDP architecture not only to enable an assessment of the integration between science, technology and applications at the Enterprise level, but also between the various science (and technology) programs and their corresponding funded projects.

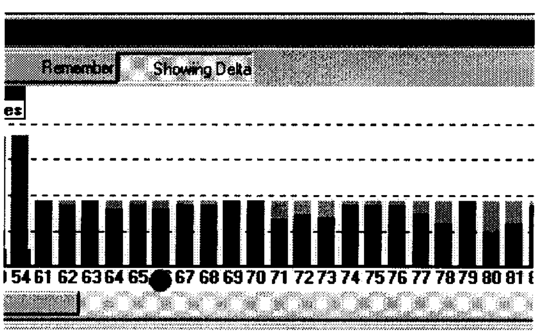

Fig. 5. Risk mitigation effect of project-based investments in shown on the risks of not following applications priorities in areas of resource management (Applications Priorities REs are color-coded purple).

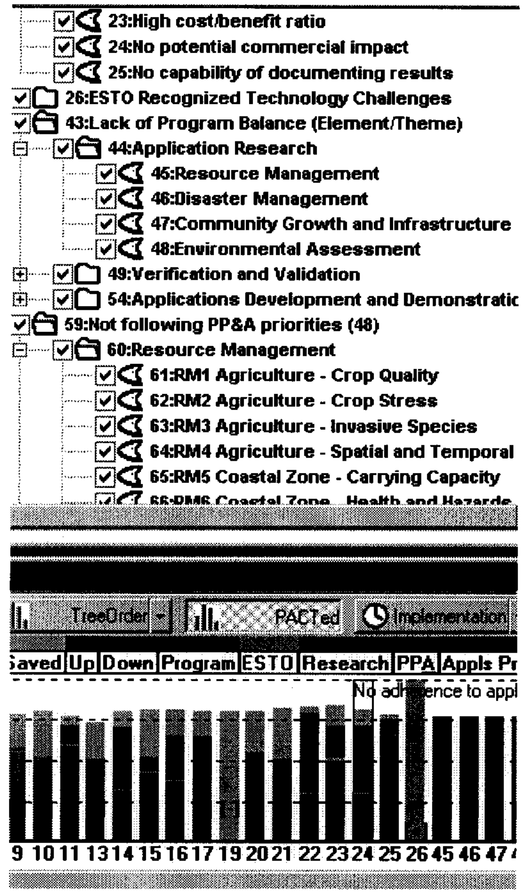

Fig. 6. Further risk reduction (shown in dark green) from program formulation to implementation phase due to selection of additional mitigations and investments.

For example, the goal of the newly formed Cross Cutting Solutions Program (CCSP) is to provide the Applications Program with systems engineering support that leads to scalable, systemic, and sustainable solutions and processes that contribute to the success of the mission, goals and objectives of the Applications Program. Given that the objective of the CCSP is to enable and support the national applications as they develop and move specific assessments, decision support systems, and workforce development and outreach programs from research to operations, DDP is in fact a systems engineering software tool that may prove valuable for integrating the outcomes of further planned assessments, supporting requirements of multi-agency decision support systems and benchmarking, and Program performance evaluation.

Finally, NASA investments in earth observation satellites and attendant systems are a significant means of addressing programmatic goals. A study conducted by group led by D. Powe of the Earth Science Applications Directorate of the NASA John C. Stennis Space Center (see www.esad.ssc.nasa.gov) assessed the application domains of systematic measurement, exploratory, and operational precursor and technology demonstrator missions; NOAA satellites also are included. These results were incorporated into this study. However, the effectiveness of these systems against the application themes has not been fully carried out or "scored," in DDP parlance. A preliminary sensitivity analysis nonetheless suggested the effectiveness of such large-scale SOs towards meeting Level I goals. Investments in projects similarly are effective SOs with through-going effects that are being furthered mapped into the current DDP architectural framework. These areas, the mission set and project portfolio assessments are in progress.

Determining the qualitative impacts of these risk elements on the requirements results in a prioritized set of risk elements with attendant identification of risk-driving requirements (see Fig. 1). The following risk mitigation and investment or solution options phases have been defined in DDP to enable residual risk profiling over the principal program lifecycle stages:

- Phase A (Program Planning)
    - Strategic Plan (Level I)
    - Strategic Implementation Recommendations (Level II)
    - PP&A Activities and Implementation Planning (Level III)
    - Current portfolio of projects (Level IV) – again see www.esad.ssc.nasa.gov
    -
- Phase B (Program Formulation into Implementation)
    - Product Development
    - Validation/Demonstration
- Phase C (Program Implementation into Operations)
    - Operational prototype demonstrations towards self-sustainable operations

Resource constraints and allocations similarly can be prescribed by program lifecycle phases and used to guide risk balancing in a viable and feasible manner.

DISCUSSION OF RESULTS

The results presented in this paper must be viewed as preliminary and as part of an ongoing case study analysis. The discussion of results to-date, similarly, is intended to illustrate how DDP can be used as a programmatic risk management tool. The intent at this stage is not at all to offer or suggest the appropriateness of any identified solution options or investments. The impact of risk elements (REs) on requirements is a qualitative exercise (unlike prior applications of DDP to component technologies of mission systems, see [1] for example), as is assessment of solution option (SO) effectiveness. Nonetheless, relative differences can be manifested and sensitivity analyses or what-if scenarios performed to verify and validate DDP results.

In this particular case study assessment, there are six parent requirements at Level I (22 total if children are also counted). Each parent requirement was given a weight of 1. By resetting the various weights, the residual risk profiles can be changed in a manner that reflects the architectural linkages between risk elements (REs) and the solution options (SOs). Note that this weighting change is also manifested in the residual risk profile. Of the 6 weighted requirements, only 0.3 are met through the selected SOs, given the assigned effectiveness values (see Fig. 1). This is only a snapshot at this stage of the inputs and analysis.

Risk is in units of unmet requirements. In this same snapshot, the requirements are at risk. This can be interpreted simply as the state of the Program at its initial, again with the aforementioned caveats. Only two of the requirements, namely forging new public and private partnerships and collaboration with industry, are partially met (indexed 4 and 7 in Fig. 1). The remaining 4 parent requirements are more than 100% at risk (these in fact are expanded in Fig. 1 to show children). This is due to the and/or structure of identified risk elements, whereby there are more than a single RE whose aggregate impact is the non-attainment of a particular program goal. The range from highest to lowest requirement at risk is about a factor of 50 as the scale is logarithmic given the multiplicative nature of applying risks sequentially to the prior balance that is not at risk.

The highest or "tall-pole" risk element in this example or snapshot is the lack of program balance in applications research, V&V, development and demonstration. However, at this stage of the case study this simply reflects that all projects have not been input (hence, there are no effectiveness entries).

The following is a list of the medium-level or next tier risk elements (REs):

- ESTO recognized technology challenges (e.g. capability needs)
- Lack of research strategy balance
- No capability of documenting results
- Unbalanced stakeholder interests
- Emergence of new capabilities
- Poor data marketing and pricing barriers
- Lack of pervasiveness

Recall that the data that would address the science research strategy balance was incomplete at the time of this study.

A few risk element scenarios were undertaken, to assess alternative preliminary outcomes to this study and the robustness of the DDP architecture. For instance, if the following risk elements (from the above list) are removed, due to the incompleteness of the data entry at this stage: ESTO recognized technology challenges, lack of applications program balance, and lack of research strategy balance, then progressive attainment of the 6 parent (each with a weight of 1) Level I requirements is as follows:

- 1.1 at or before formulation
- 3.1 at or before implementation
- 4.0 at or before project-based investments

The attendant risk drivers are extending ESE benefits beyond the traditional science community and developing self-sustainable operational systems, which indeed are recognized as the two principal objectives of the Applications Program without the addition of the integration requirements. The latter are introduced, as mentioned above in the Case Study section, as specific assessment objectives of this study.

In addition to assessing various scenarios of REs, a *sensitivity analysis* was performed of the assumed effectiveness of solution options. Under the last scenario, if the ESTO capability needs, program balance and research strategy balance risk elements are removed, at program implementation then prioritization and greater coordination with government agencies are the risk mitigations with the highest impact on requirements attainment by mitigating the REs of no partnership investment and a high cost-to-benefit ratio. The same sensitivity analysis also suggests that at program formulation phase and with the introduction of investments (SOs) in projects, establishing performance characteristics is the risk mitigation with the highest impact on requirements attainment by mitigating the RE of no capability of documenting results.

If the ESTO capability needs, program balance and research strategy balance REs are not removed from this scenario, the sensitivity analysis indicated no change at program implementation whereas at formulation and project-based investments, establishing performance characteristics is the risk mitigation with the highest impact on requirements attainment, again addressing the RE of no capability of documenting results.

CONCLUSIONS

As an architectural framework for balancing programmatic risk, the DDP lifecycle risk management decision-support tool offers a means of capturing and visualizing requirements, the impact of risks on meeting those requirements and the effectiveness of mitigations. The difficulty in applying an analytical software tool lies in numerically assigning the impact of risk elements on program requirements and prescribing quantitatively the effectiveness of potential risk controls. Nonetheless, using a discrete set of values, differences in risk element impact and risk control effectiveness provide a visual indication of relative program risk levels. This can be used to verify aspects of the Program that are perhaps known or intuitive, and to identify and assess parts of the program that are more intricately linked across requirements, risks and controls.

DDP also offers a centralized means of capturing requirements, risks and investments from multiple programs. While this study is incomplete at this stage in terms of technology and science (and mission) risk controls, it is clear that it can provide an integrated enterprise-level perspective across science, technology, missions and applications. This can also help design future solicitations and crosscutting efforts that derive benefits across multiple programs in the enterprise.

An additional and significant benefit of DDP is the process, interactions and discussions that it engenders across various disciplines and stakeholders. DDP is an iterative tool, which permits fine-tuning of the risk management process. The DDP tool allows highly informed and specific risk decisions to be made based on actual identified risk elements and control of the risk they present. This case study obtained several inputs from prior PP&A panel sessions and preliminary strategic planning documents, and two research and application assessments of competitively selected projects. This case study can be used to drive future panel discussions and drive consensus on risk impacts and risk control effectiveness, as part of an annual program evaluation.

This is a preliminary study and work in progress that will continue with program evolution, growth and implementation. It is fair to state that the study is as much an assessment of the applicability of DDP to balancing programmatic risk as it is to assessment the current state of the case study Program. As such, a fair amount of effort was required to develop the architecture and capture the distinction between Level I requirements and Level II requirements which are of implementation and thus treated as risk controls.

Next steps include better representation of the earth observation missions and project portfolio as solution options across the program. A preliminary sensitivity analysis suggested that these contribute significant to requirements attainment – which is intuitively consistent. However, DDP would enable visualization and assessment of different residual risk levels due to each of combinations of missions and through the growth of the project investment portfolio.

The adaptation of DDP for this type of program assessment requires a fair amount of familiarity with the software tool. The value of proceeding with this effort will depend on continuing to input existing and emerging information and using the tool for building scenarios to demonstrate the benefit of potential future investments. Finally, it is noted that no dollar figures were entered for the solution options. If these indeed were input, particularly to reflect the cost of planning and assessment activities, for example, in addition to the funding levels of the application projects, and anticipated future resource levels for activities and opportunities, DDP could be used to derive a cost-benefit map. This map would indicate the entire space of available solution options and their level of program requirements attainment. Benefit, so defined in terms of meeting program requirements or goals, offers a strong metric against which to assess program performance and investment return.

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REFERENCES

[1] Cornford, SL, MS Feather, KA Hicks, *DDP – A tool for lifecycle risk management*, IEEE, 2001.

[2] Feather, MS, SL Cornford, and M Gibbel, "Scalable Mechanisms for Requirements Interaction Management", *in Proc 4th IEEE Intl. Conf. on Requirements Engineering, Schaumburg, Illinois, 19-23 June 2000. IEEE Computer Society.*

[3] Gindorf, T and SL Cornford, *Defect Detection and Prevention (DDP): A Tool for Failure Mode Risk Management, 50th International Astronautical Congress, Amsterdam, The Netherlands, 4-8 Oct. 1999.*

[4] Cornford, SL., "Managing Risk as a Resource using the Defect Detection and

Prevention process," *International Conference on Probabilistic Safety Assessment and Management*, September 13-18, 1998.

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