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Methodology Development for Assessment of Spaceport Technology Returns and Risks

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Executive Summary

As part of Kennedy Space Center's (KSC's) challenge to open the space frontier, new spaceport technologies must be developed, matured and successfully transitioned to operational systems. R&D investment decisions can be considered from multiple perspectives. Near, mid and far term technology horizons must be understood. Because a multitude of technology investment opportunities are available, we must identify choices that promise the greatest likelihood of significant lifecycle benefits. At the same time, the costs and risks of any choice must be well understood and balanced against its potential returns. The problem is not one of simply rank-ordering projects in terms of their desirability. KSC wants to determine a portfolio of projects that simultaneously satisfies multiple goals, such as getting the biggest bang for the buck, supporting projects that may be too risky for private funding, staying within annual budget cycles without foregoing the requirements of a long term technology vision, and ensuring the development of a diversity of technologies that support the variety of operational functions involved in space transportation.

This work aims to assist in the development of methods and techniques that support strategic technology investment decisions and ease the process of determining an optimal portfolio of spaceport R&D investments. Available literature on risks and returns to R&D is reviewed and most useful pieces are brought to the attention of the Spaceport Technology Development Office (STDO). KSC's current project management procedures are reviewed. It is found that the "one size fits all" nature of KSC's existing procedures and project selection criteria is not conducive to prudent decision-making. Directions for improving KSC's procedures and criteria are outlined. With help of a contractor, STDO is currently developing a tool, named Change Management Analysis Tool (CMAT)/ Portfolio Analysis Tool (PAT), to assist KSC's R&D portfolio determination. A critical review of CMAT/PAT is undertaken. Directions for the improvement of this tool are provided. STDO and KSC intend to follow up on many, if not all, of the recommendations provided.

Methodology Development for Assessment of Spaceport Technology Returns and Risks

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1. INTRODUCTION

As part of Kennedy Space Center's (KSC's) challenge to open the space frontier, new spaceport technologies must be developed, matured and successfully transitioned to operational systems. R&D investment decisions can be considered from multiple perspectives. Near, mid and far term technology horizons must be understood. Because a multitude of technology investment opportunities are available, we must identify choices that promise the greatest likelihood of significant lifecycle benefits. At the same time, the costs and risks of any choice must be well understood and balanced against its potential returns. The problem is not one of simply rank-ordering projects in terms of their desirability. KSC wants to determine a portfolio of projects that simultaneously satisfies multiple goals, including getting the biggest bang for the buck, supporting projects that may be too risky for private funding, staying within annual budget cycles without ignoring the requirements of a long term technology vision, and ensuring the development of a diversity of technologies that support the variety of operational functions involved in space transportation.

This work aims to assist in the development of methods and techniques that support strategic technology investment decisions and ease the process of determining an optimal portfolio of spaceport R&D investments. Towards that goal, this summer, I pursued three different paths. First, I reviewed available literature on risks and returns to R&D. My findings and recommendations from this review are summarized in Section 2. Second, I reviewed KSC's current project management procedures in terms of their ability to support prudent R&D project selection. The findings from that review are summarized in Section 3. Third, I undertook a critical review of a tool, named Change Management Analysis Tool (CMAT)/ Portfolio Analysis Tool (PAT), currently being developed by Knowledge Based Systems, Inc. (KBSI) under a contract from KSC. My findings and recommendations from that review are summarized in Section 4. The final section summarizes the recommendations from all three paths of my activity.

2. A REVIEW OF RELEVANT LITERATURE

I identified, gathered, browsed through numerous books and articles on such topics as:

- Technology Management [1], [5], [12], [13], [16]
- R&D Project Selection [2], [4], [9], [11]
- Cost-Benefit Analysis [6], [7], [8], [10], [15]
- Analysis of Public Decisions [3], [14]
- Risk Assessment and Decision Making [2], [4], [9], [11], [13] and
- Measuring Technology Investment Payoffs [2], [3], [5], [10], [11], [13], [15].

Several pieces in the general R&D literature had references to space transportation R&D. However, I could not locate a single piece that was exclusively devoted to spaceport R&D project selection. Although more focused on industry rather than government, the available *literature is vast*. I have limited the references only to the works that may be most useful to STDO/ KSC. I would recommend that project selection decision-makers at KSC/ STDO should familiarize themselves with at least one or two works in each of the topic areas listed above.

Although there are a few reports of successful practical applications, most of the literature is *theoretical*. On the other hand, as most personnel at KSC (a science focused organization) would agree, there is nothing more practical than a good theory. The literature that I have cited is *conceptually very rich and quite applicable* to KSC's project development and portfolio selection problem.

In particular, *Martino[11] and Brandenburg [2]* seem most relevant, for the following reasons:

- ✓ KSC has been using *scoring models* in all kinds of decision areas for quite some time now. These books provide a better understanding of theoretical underpinnings of scoring models and explain proper ways of developing scoring schemes.
- ✓ Martino ([11], Ch. 5) presents a *mathematical programming (constrained optimization) model* that may be most applicable to KSC's R&D portfolio selection problem since it is best suited to deal with *the multiplicity of goals KSC wants to accomplish*, such as:
  - Fund projects with the *greatest likely benefits*,
  - Fund projects *too risky* for private investment,
  - Fund projects that are *adequately diverse* in terms of:
    - o the Spaceport Technology Development Initiative (STDI) areas supported
    - o the TRL levels they seek to accomplish
    - o risky and not-so-risky projects
    - o old (on-going) projects and new projects Comply with the annual budget cycles and still have a long-term perspective on the technologies funded,
  - Provide well-structured justification for growth in KSC's R&D budget in competition with NASA's traditional R&D centers,
  - Within each Spaceport Transportation Development Initiative (STDI) area, ensure that available KSC employees and contractor/ university personnel can meet the FTE requirements of funded projects.

  A constrained optimization model also allows one to accommodate constraints such as:

  - Maximum budget to be spent, year by year
  - Maximum funds to be spent on projects in specific functional areas (e.g., fluid systems, or command and control, etc.)
  - Minimum % of total spending to go to specific STDI
  - Maximum number of projects to be funded

  Finally, through a properly done sensitivity analysis, a constrained optimization model can give us valuable information about the robustness of an optimal solution and about the impact of relaxing certain constraints or changing certain objectives.

3. A REVIEW OF KSC'S PROJECT MANAGEMENT PROCEDURES

On KSC's internal website, I located numerous documents that describe KSC's "authorized" procedures, practices, and data requirements for R&D project formulation, review, selection and management. Below is a partial list of those documents.

- o KDP-KSC-P-2764 Program/ Project Management Process
- o KDP-KSC-P-2755 Initial Project Formulation
- o KDP-F-5002 Research Project Plan
- o KDP-KSC-P-2602 Project Approval

- KDP-P-1453 KSC Independent Assessment Process
- KDP-P-5016 SE&T Project Management Process

A careful study of these documents suggests that KSC is interested in using a *systematic and uniform process for managing all R&D projects*. While this approach helps seemingly "fair and equitable" practice of such administrative functions as budget administration, project documentation, and auditing, I believe its "one size fits all" nature is *not conducive to prudent project/ portfolio selection. Uniformity* requires that the process, the data requirements, and the compliance expectations must be *simple enough* to be not too onerous on small projects. Perhaps, that is why the only project selection guidance that KSC procedures provide is a "Feasibility Check List" (KDP-KSC-P-2755).

Although components of returns, costs, and risks are mentioned, the "Feasibility Check List" provides is *no guidance on the metrics* to be used. Even familiar issues of cost/ benefit measurement [e.g., valuation of (a) facility costs, (b) KSC FTEs, (c) multi-year cash flows] are not addressed. The only prescribed feasibility *criterion* seems to be *availability of adequate funding*. KSC procedures do not address issues of

(a) Comparing costs and benefits that may be in different units of measurement,
(b) Minimum expected return on investment,
(c) Establishing the desirability of one project over another
(d) Assessing synergies between different projects.

Thus, even decisions about large-scale projects involving millions of dollars of investment must be based on the limited data and guidance the required Feasibility Check List provides.

I recommend that *KSC should develop different processes and criteria for small, medium, and large projects*. Particularly for selection among large projects, provide better metrics of benefits and costs, some guidance on how to resolve classical cost benefit analysis issues, how to establish relative desirability among projects, and how to seek an optimal portfolio of projects.

4. A CRITIQUE OF CMAT/ PAT

CMAT/PAT is still evolving. This critique is based on CMAT/PAT documents here should be taken not as a "judgment" of CMAT but as *an aid to further development of the tool*.

With the primary goal of assisting the Strategic Planning Process at KSC, CMAT promises to:

–*Use Fuzzy Logic* to generate strategy ideas, to predict strategic performance, and to provide strategic decision support.
–*Adapt Markovitz' Portfolio Theory* for strategic decision analysis in support of a well rounded, balanced R&D portfolio selection.
–*Analyze the risks* (i.e., the *variance* of the returns) of individual R&D projects as well as that of a portfolio of projects by using "multiple managerial inputs."
–*Use system simulation* to provide predictive analysis of STC change evolution and the "gap" between KSC's technology targets and projected accomplishments.

Roadblocks in the attainment of CMAT/ PAT Objectives

While CMAT's goals are extremely worthy, *they may not be actually attained* due to:

I. Inadequacy of available data.

II. Ambiguous, overlapping, internally inconsistent, and incomplete definitions of required data and metrics.
III. Lack of work on the specification of a good data collection process.
IV. Lack of work on the promised decision support models.*Inadequacy of Data*

Although the CMAT project is already in Phase II, the documents I have examined do not outline precisely what data KBSI would need to build its Fuzzy Logic engine, its System Simulation model, or its Portfolio Analysis Tool and precisely how KBSI would go about collecting the necessary data.

Instead, as requirements of the CMAT/ PAT project KBSI has accepted to

(a) Use existing NASA data sources and systems, and

(b) Minimize new data entry ("minimally intrusive").

Now, I appreciate why Spaceport Technology Development Office (STDO) may have imposed these requirements. Scientists and researchers are typically more interested in satisfying their curiosity and investigating interesting phenomena rather than thinking about potential costs, benefits, and risks of their research. They hate to comply with existing data collection processes and will surely find any additional data requirements as burdensome. Secondly, NASA's engineering/scientific culture emphasizes expertise within well-defined, narrow fields. This culture underestimates the true value of a well-designed, broad information system that supports organizational learning and improved decision-making. Third, even if new data requirements are defined, STDO personnel may have to estimate and enter those data themselves since they have no authority to enforce project managers' compliance with the new requirements.

Unfortunately, *existing NASA data sources and systems are woefully inadequate* for the kind of analysis CMAT aims at. For instance, to develop its "Fuzzy Rules" CMAT would require current and targeted ratings (Low, Medium or High) on such factors as "Design and Engineering Capability," "Science Enabling Capability," "Safety," or "Virtual Collaboration." CMAT would not only need such rating data (albeit "fuzzy") over several years, it would also need data on the correlations between the ratings of various factors. Similarly, PAT's portfolio variance analysis requires either "multiple managerial input" or other means of capturing the standard deviation of projected benefits of individual R&D projects, as well as the co-variances of benefits from different projects (i.e., data on the synergies between projects). NASA's existing data systems have not been collecting such data.

Poor Data Definitions

CMAT's Definition of "Return," as an example,

- Does not value possible one-time benefits of an R&D
- Does not value knowledge contributed by a failed project
- Does not specify how to account for time value of money multi-year benefit flows
- Differs from NASA's standard list of benefits on KDP-KSC-F-2755
- Is subject to several different interpretations and hence vulnerable to intentional or unintentional fudging
- Does not allow for negative rating any of the criteria
- Does not specify the process of arriving at the weights for different criteria

Similarly, CMAT's Definition of "Risk"

- Attempts to use an approach that is logically unacceptable, namely to take a weighted average of
  - (a) costs to TRL9,
  - (b) probability of technical success, and
  - (c) the degree of collaboration.

  I do not know if "Cost to TRL 9" would necessarily increase or decrease a project's probability of failure. However, it is reasonable to assume high levels of "Collaboration" may reduce that probability. However, to capture that relationship I would not use a weighted average approach.
- Is inconsistent with CMAT's definition of "return." CMAT defines returns in terms of "benefits to NASA if the project is successfully implemented," CMAT should not simultaneously say that "Risk as defined here is more from a technology standpoint rather than from an operational standpoint." To be consistent, either the definition of risk or the definition of returns must be modified.

CMAT has not clearly defined "cost" yet. But it must soon confront classical cost measurement issues such as:

- Valuation of existing/ new facilities necessary for the project
- Valuation of NASA FTEs
- Valuation of multi-year costs (that may or may not be incurred) while approving a single year's funding
- Time value of money

Lack of Specification of a Good Data Collection Process

In addition to providing clear and sound data definitions, *KBSI needs to outline a data collection process* that is not too burdensome on the project managers and yet is capable of capturing relevant data with adequate accuracy in a timely manner. Among other things, *the process should specify:*

- Who is to provide what data to whom at what time?
- Who is to verify the reliability, validity, and/or accuracy of the data?
- In the case of subjective ratings, who is to be considered an expert? Who would ensure that the expert is not biased; and how?
- Who has the authority to enter or modify a project's status data (e.g., funded/ rejected, successful/ unsuccessful, actual benefits generated, costs incurred, etc.)?
- Who would have the responsibility to maintain the database over the years?
- How will the data be statistically analyzed to obtain historic success rates, average benefits, costs, etc? And, how will that statistics be used to update CMAT (including its data collection process) and improve KSC's portfolio selection methodology in the future.

In designing the data collection process, an important principle to keep in mind is that *the costs of data collection must be justified by the benefits resulting from the collected data.* Thus, for projects involving relatively small investment, the data requirements must be considerably simpler and smaller than the data requirements for projects involving millions of dollars of investment.

At the same time, it should be realized that, in the long run, *the benefits of informed decision-making and management practices resulting from the data collected using a properly designed process often outweigh the costs of that process.* Particularly in the R&D context, it should be realized that as a project proponent prepares to provide the data required by a well-designed decision-making system, often, he/she is forced to improve the very design of the project so as to make it more acceptable in terms of the organization's decision criteria. Often, such *improved project designs themselves pay for the costs of the data collection system.*

Lack of Work on Decision Support Models

At present, CMAT does not provide a clear and sound method of recommending an "optimal" portfolio of projects. It only attempts to show the costs, risk and returns of a given portfolio, and the diversity that portfolio reflects in terms of TRL levels or STDI area, etc. In other words, at present CMAT is simply a presentation software.

While this presentation software is non-intrusive and supportive, *it would not prove to be practical decision support tool.* An analyst using CMAT would have to input each possible portfolio, print its results and then manually compare all the printed results to identify the most preferred portfolio. The trouble is that if one wanted to select a portfolio consisting of 10 out of 40 projects, there are over 800 million possible alternatives!

Personally, I would recommend the use of a *generic constrained optimization model* (such as the one described by Martino, 1995, Ch. 5) *adapted separately to two sets of projects*

Set 1: Those with beginning TRL 1 to 3 and ending TRL $\leq$ 4 (applied research)

Set 2: Those with beginning TRL 4 to 6 and ending TRL $\leq$ 7 (development)

In my vision, the project selection criteria and the data requirements for Set 1 projects would be far simpler than those for Set 2 projects.

In short, while CMAT's stated goals are laudable, they are unlikely to be attained unless both NASA and KBSI work at removing the four major roadblocks identified above. Otherwise, with all the charts and diagrams it can produce, CMAT would prove to be an impressive presentation software. However, it would hardly be worthy of being called, "Change Management Analysis Tool."

5. CONCLUSION/ RECOMMENDATIONS

KSC should recognize that the "one size fits all" nature of its current project management procedures is not conducive to prudent R&D portfolio selection. KSC must work on suitably modifying those procedures and the criteria used for project selection.

KSC should also recognize

(a) The inadequacy of its existing data sources and systems, and

(b) The true value of a properly designed data collection system for R&D projects

and remove the requirement on CMAT to use only exiting data sources and systems.

KBSI and KSC should together come up with data definitions that are clear, theoretically sound, internally consistent, and complete.

In consultation with KSC/ STDO, KBSI should outline a data collection process that is not too burdensome on the project managers and yet is capable of capturing relevant data with adequate accuracy in a timely manner. The designed process must ensure that the costs of data collection are justified by the benefits resulting from the collected data. This calculus should recognize

(a) The long term the benefits of informed decision-making and management practices, and

(b) The benefits of improved project designs

resulting from a properly designed data collection system.

If KSC truly desires to bring about a strategic change in its R&D endeavors, the Center must be willing to change its data culture. This includes giving adequate authority to STDO to be able to collect the necessary data. The concern for not overwhelming researchers and developers with demanding data requirements must be balanced against organizational need to make informed decisions in support of its strategic goals.

Finally, KBSI should develop and validate theoretically sound yet practical models that will truly support KSC's decision-making, be it in the area of project portfolio selection, or predicting strategic performance, or identifying technology gap. KSC should work towards a full realization of CMAT's stated goals by using such rigorous models.

I am pleased to note that STDO/ KSC intend to follow up on many, if not all, of my recommendations.

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