Technology Infusion Challenges from a Decision Support Perspective

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Abstract—In a restricted science budget environment and increasingly numerous required technology developments, the technology investment decisions within NASA are objectively more and more difficult to make such that the end results are satisfying the technical objectives and all the organizational constraints. Under these conditions it is rationally desirable to build an investment portfolio, which has the highest possible technology infusion rate. Arguably the path to infusion is subject to many influencing factors, but here only the challenges associated with the very initial stages are addressed: defining the needs and the subsequent investment decision-support process. It is conceivable that decision consistency and possibly its quality suffer when the decision-making process has limited or no traceability.

This paper[1,2] presents a structured decision-support framework aiming to provide traceable, auditable, infusion-driven recommendations towards a selection process in which these recommendations are used as reference points in further discussions among stakeholders. In this framework addressing well-defined requirements, different measures of success can be defined based on traceability to specific selection criteria. As a direct result, even by using simplified decision models the likelihood of infusion can be probed and consequently improved.

Keywords: decision support, technology infusion

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1. Overview

Historically, NASA has been an engine for scientific and technological progress, with significant gains from space exploration missions. Important technological advances have resulted from internal investments in R&D projects at NASA centers, and from contributions by extramural research programs, such as those directed to the small business community. In many instances, through commercialization within earth-bound applications, space exploration technologies have contributed to improving the quality of life in the USA and around the world.

In the past few years, when NASA has undergone budgetary reductions, cutbacks were accommodated in a variety of ways, e.g. by reducing the number and size of internal technology development programs. However, while the magnitude of the congressionally mandated projects has been increasing, restrictions attaching administrative charges to these projects have tightened budgetary constraints of other assignments, further impacting financial resources. [1] In this monetary environment it has become necessary to align better the future technological developments with actual mission requirements, such that the likelihood of infusion of the solutions is maximized. Given that the emphasis of sponsored external R&D was placed on fostering commercialization of innovative solutions, it is reasonable to attempt a sensible increase in the infusion rate of the external technology developments.

"For NASA, technology infusion is the process of strategically binding technical needs and potential solutions. These innovative solutions, be they hardware or software, enhancing or enabling, near-term or far-term, low Technology Readiness Level (TRL) or High TRL, NASA internally or externally developed, must all be managed through some aspect of transition from their originating source to the targeted challenges within NASA's programs and projects". [2]

The infusion process is logistically intricate; in the majority of cases it occurs on time scales of several years and its outcomes are subject not only to inherent uncertainties, but also to the targeted project uncertainties. Although there are many important factors affecting the infusion process, this

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paper focuses on the initial links in the overall chain of events: less on defining the capability needs, and more on the ensuing investment decision-making stage. It is conceivable that decision consistency and possibly its quality suffer when the overall decision-making process has limited or no traceability.

This issue is even more acute in a complex organization such as NASA, where dispersion of the decision making power on multiple levels of management is present, and the stakeholders are exercising different strategic or short-term concerns. Moreover, there are many decision challenges associated with the effort of increasing the likelihood of infusion of R&D developed technologies, such as insufficient or incomplete information and inertia in communication; technological or political uncertainties; dependencies among objectives and non-technical constraints; resistance to openness in large organizations.

Given the complexity of the infusion process, the discussion here will be limited to its early stages, on how to improve the selection of investments from competed proposals. To this effect a structured decision-support framework producing a set of traceable and auditable recommendations can be constructed. These "objective" recommendations are then used as a basis for further discussions among the stakeholders in the selection process.

In the distribution of R&D funds, NASA uses peer review and expert panels as quality assurance for selecting the best projects. The peer reviews have clear norms for assessments (and are federally regulated); however there may be a detectable variation in what criteria the expert panels emphasize - and how they are emphasized. It was shown in [3] that in the situations with variable criteria the determinants of peer review may be accidental, in the sense that who reviews what research and how reviews are organized may determine outcomes. A central finding of [3] is that rating scales and budget restrictions are more important than review guidelines for the kind of criteria applied by the reviewers. Furthermore, the decision-making methods applied by the review panels when ranking proposals were found to have substantial effects on the outcome. Some ranking methods tended to favor uncontroversial and safe projects, whereas other methods gave better chances for scholarly pluralism and controversial research [3]. Similar observations were realized during the course of this study, despite significant differences seen in the context and substance of the NASA competed R&D environment (where in addition to soundness, technical propositions need to possess a strong innovative flavor and, for some programs, a sizable commercial potential). Here, data sources included interviews with panel members, direct observation of panel meetings, and trial applications of the proposed approach.

NASA's Innovative Partnership Program Office (IPPO), which manages NASA's participation in several external R&D and partnership programs [4, 5, 6], has manifested a strong interest (expressed in a funded task) to augment the existing ranking processes with a transparent, quantitative decision-support capability based on specific criteria, which could enhance the potential for funded technologies to be used in NASA missions. This interest can be met under a general framework designed to assist in making technology R&D investments decisions, as described below.

The decision on how best to invest limited financial and other resources in support of capability and technology R&D is affected by many factors, including [7]:

(1) Long-term, overarching institutional mission and goals.

(2) Institutional priorities of achieving various desirable future scenarios and/or implementing different types of missions.

(3) Capability requirements imposed by future scenarios or future missions.

(4) The state of the art of different capabilities or technologies, and the need for further R&D funding imposed by future requirements.

(5) Costs, development schedules, risks and advantages associated with different technological solutions or capabilities.

(6) Resources available, including funding, infrastructure, personnel, and development timelines, as well as the overall planning horizon.

(7) Trade-offs between investing in capabilities needed by multiple alternative scenarios or missions versus those required by a single scenario or mission.

(8) Time requirements for capability development versus the development freeze dates for individual scenarios or missions.

(9) The likelihood of adoption of different technological solutions by administrators, mission managers, and stakeholder organizations.

(10) The requisite to include programmatic and institutional factors in the overall decision process.

Acquiring, analyzing and synthesizing the large amount of information that is required for a rational decision places a significant burden on program and mission managers, institutional decision-makers, strategic planners and capability/technology developers.

It should be noted that the factors mentioned above are not unique to NASA, but rather affect virtually all major federal R&D programs, including those of DoE [8], DoD [9, 10], the Department of Homeland Security, etc., as well as science-driven funding agencies such as NSF [11] and NIH, and industrial research [12].

In addition to the intellectual challenges posed by addressing the many factors that feed into the decision process, there are increasing governmental and public requirements and pressures for the decision-making process to be conducted in transparent, auditable and repeatable ways, as well as making explicit the assumptions, priorities and programmatic constraints of the decision-makers and the institutions involved. For NASA, these accountability structures include the Office of Management and Budget (OMB) and the Office of Science and Technology Policy (OSTP).

Owing to the increased need for consistent, transparent and auditable decision-making processes and tools [13, 14], a methodology dubbed START (STrategic Assessment of Risk and Technology) has been developed, and implemented in a quantitative multi-attribute decision support system [7, 14]. START combines analytical decision-theoretic models with pragmatic data elicitation steps to provide a systematic methodology for assessing and selecting technologies and capabilities investments, and for determining optimal investment portfolios. Project investments are selected through optimization of net mission value as a function of capability level achieved, subject to cost and time constraints. The underlying data set, which quantitatively characterizes requirements (performance, cost, schedule, risk) and proposed technological solutions (achievable capabilities, resource requirements, degree of maturity, schedule), is replete with uncertainty. This inherent uncertainty of the input data must be combined into a global confidence range, which provides the decision maker with an overall sense of quality and likelihood of success of the investment strategy.

START has been used extensively in the assessment and prioritization of investment portfolios for technologies and capabilities across several NASA programs and directorates. START is currently being employed to prioritize investments for NASA's Exploration Technology development Program (ETDP). It has been used in technology portfolio analysis for NASA's Exploration Systems Architecture Study (ESAS) [15], Mars missions under the Science Mission Directorate (SMD) [16, 17], capability portfolio planning for the Aeronautics Research Mission Directorate (ARMD) [18, 19, 20], and technology planning for JPL's Office of the Chief Technologist (CTO) [21, 22].

2. Approach

Ideally, a competed R&D investment selection process should be based on a fine-grained characterization of the contending solutions to the extent that all major discriminators are taken into account. For large programs, this often leads to substantial inflows of data, which are difficult to process without specialized decision support systems. To this effect, START is a comprehensive methodology for capability and technology portfolio assessment and planning, which can support large programs [7, 14, 15, 23, 24]. It allows decision-makers to see explicitly the information and the assumptions that go into the analysis process, to guide the decision process through the establishment of institutional constraints and priorities, and to conduct "what-if" experiments with different scenarios and assumptions. The results of the analyses are presented to the decision-maker in tabular and graphical forms, allowing often massive amounts of information to be conveyed rapidly and accurately. START is composed of both an operational sequence of steps, and an analytical decision framework.

The operational sequence of steps in the application of the START methodology is listed below:

(1) Develop a clear, complete statement of the decision problem to be studied. This includes eliciting the pertinent policy, schedule, and budget constraints, as well as all relevant assumptions.

(2) Identify the goals and priorities of the decision-maker, and the associated metrics. This includes relative priorities or range of relative priorities among multiple goals.

(3) Identify the scenarios, programs or mission architectures that are to be fulfilled.

(4) Identify the capabilities and/or technologies required by the scenarios, programs or missions.

(5) Characterize the capabilities and/or technologies using a variety of metrics, including the state of the art (SOA), desired performance levels, development cost and risk, influence on goal(s), etc., and validate the data collected.

(6) Capture the perceived importance and risk of the required performance domain through a corresponding utility range.

(7) Compute optimal portfolios in the limits of investment budgets and timelines that are of interest to the decision-maker.

(8) Validate the results, both through consistency checks of the data and through automated sensitivity analysis of the results. This allows the decision-maker to have confidence metrics associated with the results.

The analytical framework used for START is based primarily on decision-theoretical methods [25, 26]. The data used to characterize the requirements is used to assess the expected utility of different capabilities or technologies,

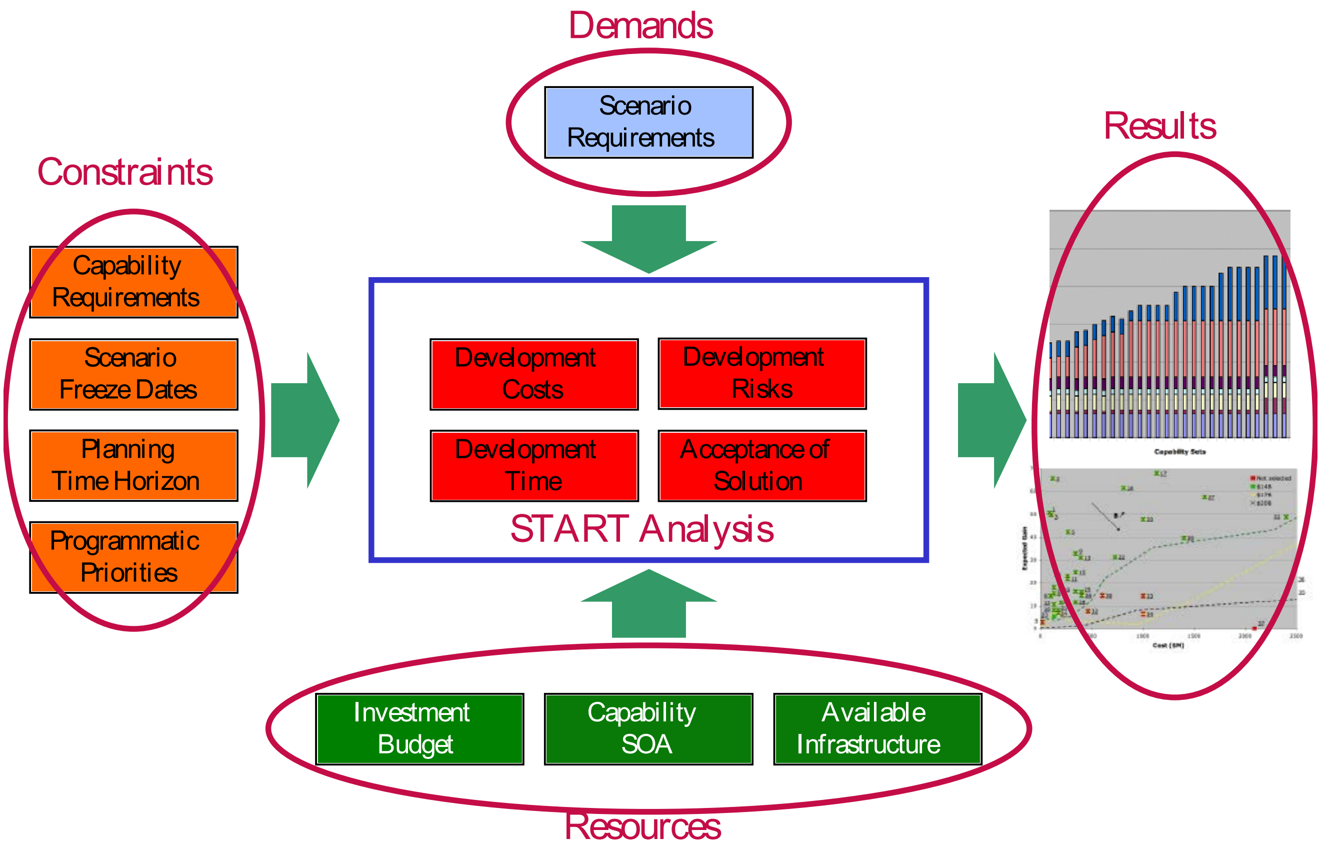

Figure 1: START system view

again based on their quantitative and qualitative description. Capabilities or technologies are "matched" against the requirements using concepts from multi-objective decision theory [27] to compute this expected utility. This information, together with the associated development costs, is used as input to a knapsack optimization algorithm to compute the best portfolio possible under the given available investment budget, and taking into account the various constraints associated with the problem [14].

START's analysis capabilities, shown in Figure 1, are the result of its available functional features, which include the mission directorates. In the simplified approach, all eight operational steps would be followed; nevertheless the level of detail and the decisional structure density is significantly reduced.

The application of any decision support system to meet specific objectives cannot be done without customization, which is closely linked to the model of the overall process in which the decisions are made. In the case of competed R&D technology investments at NASA, the corrective/improving actions recommended (including the customization of the START-Lite system) to achieve the goal of increasing the infusion likelihood of selected developments emerged from the infusion path model depicted in Figure 2.

Based on this model, the analysis of the actual process has identified in the early stages an important contributing factor in inhibiting infusion that needs to be addressed: non-specific alignment of solutions with mission requirements. Furthermore, without information about projected quantification of deliverables (the performance range) in the submitted proposals, it did not appear feasible to assess the likelihood of meeting an actual mission requirement (low chance of technology infusion).

The recommended recourse was to increase the specificity of the solicitation narrative (which historically emphasized innovation and commercialization, but not infusion) coupled with the usage of an open decision support system (START-Lite) to match better the mission requirements with technology solutions having the highest infusion potential. START-Lite employs a decision matrix to capture the preferences of the selection process stakeholders such that it:

(1) Provides a structured decision framework for prioritization of needs and solutions.

(2) Facilitates the desired features of transparency, auditability, traceability and consistency for the selection process.

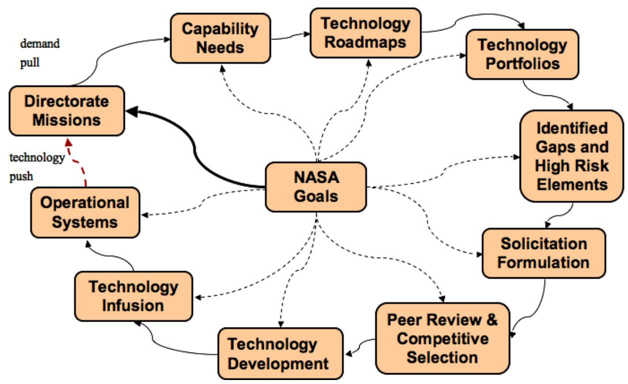

Figure 2: Infusion path model

(3) Is based on key infusion-driven criteria/attributes and strategic priorities elicited separately from each of the mission directorates.

(4) Reduces the overall prioritization and selection effort.

(5) Stores the decisional information in a database and post-audit/feedback studies can be performed to measure the effectiveness of the selections over the years.

In the START-Lite application to competitive selection the management policy information (relative preferences) is captured through the relative weights among attributes and the scoring distribution within an attribute. Then proposals are characterized in terms of attribute levels and START-Lite can be used to generate a relative ranking, which arguably reflects the infusion potential of each suggested solution. The ranking is based on a simple weighted average, which represents the expected value of each proposed solution (where the technical feasibility score of each proposal is utilized as probability of success in delivering the promised approach). The ranking can then be used towards the final discussion, as it can identify the top, the lowest and the trade-off candidates. After these three bins have been identified the actual ranking becomes of secondary importance, and the attention can be directed to the trade-off candidates.

Currently, the competitive selection decision is the result of multi-role [strategic/operational, risk management] & multi-level preference groups [center management, program or division management, and/or directorate management]. If possible, within one single decision unit (e.g. a division or a program), a consensus on a common set of attributes should be attempted - this will insure consistency of rankings, and facilitate systematic comparisons to be made. Even so, the associated attribute weights and scores will naturally vary with the role and the level in the decision process, as observed in several expert panel meetings. Finally, in many instances the ranking provided by START-Lite could differ from what the decision maker would have expected, thus providing an excellent basis for discussion, as this could mean an inconsistency in the decision made or a need to improve the decision model. Documenting and explaining the differences between the START-Lite ranking and expert panel preferences at different levels increase the potential for improvement of future decisions. In the end, the selection can be made robust against parameter uncertainties by performing a sensitivity analysis (a feature in the START-Lite system) to the range of weights and scores encountered in bottom-up decision process.

3. APPLICATIONS

The START-Lite methodology has been tested and applied in ranking sessions across several NASA directorates and programs with various degrees of acceptance and success. Two illustrative cases are presented here, along with the challenges and the progress made in disseminating this approach.

Case 1 – Center level ranking session

There were preliminary ranking sessions held for each of the three technical areas considered in which expert and management opinions were exchanged. In these ranking meetings, there were a limited number of attributes elicited and presented; however, the attribute values were not addressed explicitly or consistently during the ranking discussions. Ultimately, the attribute values were presumed to be absorbed in the preferences expressed by the experts for each proposal, and ensuing rankings for each technical area were determined through open vote and negotiations. Subsequently an integrated ordering was assembled using qualitative data from the preliminary technical area rankings and used as initial input (anchor) to the center level board meeting. The integrated list was more or less in correspondence with the final recommendations of the technical area sessions. At the center level, the final ranking emerged from discussions and negotiations among board members over the proposals placed within the estimated funding threshold (mostly the middle ranked proposals).

With the aim of uncovering the decision structure the original list of ordered proposals were qualified *a posteriori* against an extended set of nine binary attributes (called here figures of merit – FOM – to distinguish them from the more nuanced attributes). Figure 3 shows the resulting table where each candidate technology solution is judged against each figure of merit, and used to deduce the relative preferences for each FOM (numbered 1 through 9). The "Technology" column shows the individual ranks from each of the three technology areas considered, symbolically denoted here with *r, s,* and *t.* The integrated list is a combination of these preliminary ranks, and the initial overall ordering corresponds to the order of the items in the table. The "Final

			FOMS								
			1	2	3	4	5	6	7	8	9
Final Rank	Technology	Company	Strong Advocacy	Good Infusion Potential	Innovative	Low Risk	Strong Commercial Potential	Strong Company	Critical Need	Significant Improved Performance Over SOA	Aligned to Center Priority
1	s1	C1	x	x	x		x	x	x	x	x
2	r1	C2	x	x		x		x	x		x
3	t1	C3	x	x		x	x	x	x		
4	r2	C4	x	x	x		x		x	x	
5	r3	C5	x	x		x	x	x			x
9	r4	C6	x		x	x	x			x	
6	s2	C7	x	x	x	x				x	
7	s3	C8		x		x				x	x
8	t2	C9			x		x			x	
10	r5	C10	x			x		x		x	
13	r6	C11				x		x		x	x
12	s4	C12		x		x	x			x	
11	t3	C13					x	x			
14	t4	C14		x		x				x	
15	r7	C15			x					x	
16	r8	C16			x			x		x	
17	s5	C17		x	x					x	
18	t5	C18				x		x			
19	r9	C19			x					x	

Figure 3: Filled FOM table

Rank" column contains the final ordering of the candidates after discussions between the decision-makers.

Assuming that the ordering against the FOM set is consistent, there should exist a sequence of non-negative weights w_i (i = 1, 9) such that:

Minimal FOM set: 1, 5, 7, 9
Maximal FOM set : 1, 3, 4, 5, 7, 9
Unusable FOMs: 2, 6, 8

Figure 4: Analysis results

$$\sum_i w_i = 1 \text{ and } \sum_j a_{ij} w_j = b_j \qquad (1)$$

(i = 1, M; j = 1, N; M = 9; N = 19) with $b_1 \geq b_2 \geq \ldots \geq b_N \geq 0$, where a_{ij} represents the qualification matrix (*i.e.* proposal vs. FOM).

The weights, if they exist, will satisfy the above problem formulated as an optimization and solved by linear programming (the objective function is maximizing the sum of weights, which is bounded by unity).

It so happens that in this case there is no solution for the entire set of FOMs before the center level ranking; however, several consistent partial sets (*i.e.* having at least two non-zero weights) were found (Figure 4).

Furthermore, the analysis applied to the final ranking showed there is no reasonable consistency (more than one non-zero weight) between the final ranking and the FOM set as marked in the table. This somewhat academic exercise demonstrates the manner in which existing decisions can be utilized to identify relevant decision discriminators.

An alternative approach was to match elicited data against the center ranking. As mentioned above, in the technical ranking sessions proposals were characterized against a small set of attributes (shown in Figure 5).

To be made usable in START-Lite, this information was necessarily processed as following:

(1) The mission information was translated into a timeframe with earlier missions preferred against later missions or no missions.

(2) The contact information was replaced with the relevant advocacy statements extracted from the technical area meetings.

(3) TRL Level (Entry/Exit) was split into two attributes:

   a. Exit TRL, with preference for the higher exit TRL numbers

   b. TRL Gain = TRL Exit - TRL Entry, with preference for the higher TRL gains

START-Lite Atribute Weigths

Customer Need	Importance	Exit TRL	TRL Gain	Timeframe	Advocacy	Subtopic Rank	Correlation Coef.	Fit Rank
0.10	**0.05**	**0.05**	**0.00**	**0.05**	**0.10**	**0.70**	**0.952631579**	**1**
0	0	0	0	1	1	1	**0.876903515**	**2**
1	1	0	0	0	1	1	**0.841449884**	**3**
1	1	0	1	1	1	1	**0.792982456**	**4**
1	1	0	1	0	1	1	**0.760158082**	**5**
1	1	1	1	1	1	1	**0.713512182**	**6**
1	1	0	0	0	1	0	**0.708433324**	**7**
1	1	1	1	1	1	0	**0.636959745**	**8**
1	1	0	1	1	1	0	**0.632477864**	**9**

Figure 6: Correlation results

Based on the observed selection process at the center level an additional attribute was introduced:

(4) Technical area ranking, with preference for the highest (technical area) ranked proposals.

Using the START-Lite approach, and adding the heuristic that similarly ranked proposals from different technical areas are comparable in worth, the final center ranking was closely captured. To establish the closeness fit a simple rank correlation was used, and found a 0.95 correlation coefficient between the final center level ranking and the START-Lite methodology (Figure 6).

A more appropriate measure is the Kendall tau rank correlation coefficient [28], which evaluates the degree of correspondence between two rankings using the numbers of concordant pairs and discordant pairs in the data sets, and additionally provides the statistical significance of this correspondence. However, in these examples the conclusions based on simple rank correlation were similar to the ones drawn from the Kendall rank correlation analysis: the technical area ranking information is the dominant factor (by about one order of magnitude) in determining the final ranking.

It is likely that the policy of favoring the technical rank over other proposal features may impact adversely the center portfolio performance with respect to the likelihood of infusion, while the connection between the multi-voting results and attributes is rather vague. However, with enough information, the START-Lite methodology can capture quite well the proposal selection process, especially if the distribution preference is clearly stated.

List of relevant Missions/Projects/Programs
Customer need (Critical, Highly Desirable, Desirable)
Technology readiness level TRL (Entry/Exit)
Importance relative to competitive solutions (Hi, Med, Lo)
Endorsements/contacts (Mission/HQ)

Figure 5: Attribute set

As a consequence of this exercise, the START-Lite methodology was then applied by using the nine FOMs in the next ranking session in one of the technical area meetings, thus providing a translation of the board member votes into an explicit set of criteria and values. Extending this approach to the entire program or division can provide, over the entire infusion cycle, sufficient data to be used in correlating the features of the selected technology proposals with the successfully infused solutions. This also offers a measure for likelihood of infusion and possible control variables to increase the infusion rate.

Case 1 study showed that the initial qualitative process for ranking led to a prioritized list that was inconsistent (for various reasons) with the set of attributes deemed desirable. The START-Lite output was able to fit the ranking order, but only by using a scheme that alternated selections among technical areas ranking. The START-Lite process, when tried for one of the technical areas, led to a recommendation that was consistent with and traceable to a clear set of infusion-driven criteria.

Case 2 – Program (division) level ranking study

Working with the program managers, and after several iterations, an agreement was reached on six attributes against which each proposal would be assessed. For each attribute, the proposal advocates were asked to check a box categorizing that attribute, based on the levels shown in Figure 7.

"Primary Mission Applicability/Time Frame Required?" refers to the period in which the proposed technology would be used.

"Criticality of Technology to Mission" indicates whether the proposed technology would be enabling (essential to a mission because a mission goal could not be achieved without it) or enhancing (not essential, but beneficial).

"Importance of Proposed Solution Over Existing Solutions?" attempts to capture how much improvement the proposed technology would offer over the current state of the art, and the importance attached to that improvement.

"Ratio of Requested Funding Relative to Programmatic Investment" represents how well the program office currently funds the technology area in question: is the area well-funded, underfunded, or completely unfunded? The last two attributes are directly related to the apparent infusibility of the proposed technology.

”In-house Advocates/Project Manager Level Of Interest” and “How Readily Can the Innovation Be Infused Into a Program?”, gauge not only the involvement intensity of a manager with infusion decision power, but also the perceived implementation risk embedded in the solution, if developed successfully.

Several directorate and program managers expressed their preferences by assigning relative weights to each of the attributes, and scores to each of the possible checkbox choices within each attribute. Within "mission need," for example, scores were assigned to "enabling" and "enhancing" to reflect their importance relative to each other, such that their combined scores total 100. Similarly, "mission need" itself was assigned a weight reflecting its importance relative to the other three attributes, such that the weights of all four attributes total 100. It is worthwhile to mention that all the elicited preferences sets (weights and scores) differed from person to person within the same directorate and even program management structure. In this study the set eventually chosen for the START-Lite was based on the preferences of the mission directorate management that favored infusion potential.

The "evaluation score" is the result of a peer-review process to which all of the proposals were subjected as part of program’s office current decision-making process. All proposals scoring below a certain cutoff figure were eliminated from further consideration. The proposals included in this study were those that survived this winnowing process. As mentioned above, the evaluation score is interpreted as a measurement of the degree of certainty that the applicant is capable of delivering the proposed technology.

This information captured from proposal characterization was presented to the program office management in the form of an Excel spreadsheet. Sliders on the spreadsheet enabled analysts to see, in real time, the effects of modifying the weights and attribute level scores.

As with the full START methodology, these START Lite results are intended to provide decision-makers with an opportunity to conduct a "reality check." If the attributes and weightings used here reflect the true priorities of the decision-makers, the generated rankings should seem right to them. In that case, the system provides a quantifiable and traceable process in support of the decisions that they were inclined to make anyway.

On the other hand, if the START-Lite results differ from a decision-maker's expectations, the process provides an opportunity to identify any differences in the perceived objectives, or important attributes that may have been omitted, relative weightings that do not reflect true mission priorities, and any constraints, assumptions, or other underlying factors that may be responsible for the conflicting outcomes.

In the initial trials of this study, the computed results differed dramatically from the evaluations of the program managers. When discrepancies are large, it is strongly suggesting important differences in the criteria used to assign the rankings, and most importantly, in the rating

Attributes	Levels		
	1	2	3
Primary Mission Applicability/Time Frame Required?	Far	Mid	Near
Criticality of Technology to Mission	Enabling	Enhancing	
Ratio of SBIR Funding Relative to Programmatic Investment	Modest	Significant	Dramatic
Importance of Proposed Solution Over Existing Solutions?	Modest	Significant	Dramatic
In-house Advocates/Project Manager Level Of Interest	Indifferent	Weak	Strong
How Readily Can the Innovation Be Infused Into a Program?	Low	Medium	High

Figure 7: Attribute set

C	B
6	6
1	1
12	11
17	14
7	7
10	9
13	12
18	15
4	4
5	[illegible]
[illegible]	[illegible]
8	8
3	[illegible]
16	17
11	10

Full ranking	Kendall tau Rank Correlation
B vs. C	0.932203472
Rejected proposals	
B vs. C	0.894736826
Accepted proposals	
B vs. C	0.883940637

Figure 8: Rank comparison and correlation

scales.

In the later stages, after START-Lite has been calibrated against previous final selection decisions, large differences with respect to the decision maker rankings could indicate inconsistencies in the decision structure. In these instances START-Lite results become immediately useful by providing a reference for discussions among the stakeholders. Identifying and explaining the differences is a crucial step toward the objective of shaping a transparent and traceable decision-making process.

Figure 8 shows the kind of decision support that the calibrated system can provide. Column B represents the combined ranking of the board members, while column C shows the ranking the board members "advised" by START-Lite along with the Kendall tau rank correlation measure. The B vs. C comparison shows the START Lite intervention is well correlated with the board preferences.

This demonstrates that choice discriminators can be captured and recorded reasonably well, which opens the way for measuring the effect of the selection decisions on the overall rate of infusion success.

Case 2 is an example of the end-to-end application of the START-Lite approach, in which the final selection is a combination of the decision-makers' preferences and the "advisory" results of the START-Lite tool. In this respect, the START-Lite methodology offers a prescriptive support model (as opposed to normative decision aids) with the effect of increasing the degree of internal consistency of the decisions made.

4. CONCLUSIONS

A structured decision-support framework to provide traceable and auditable recommendations was presented. In this framework addressing well-defined requirements various measures of success can be defined based on infusion traceability to specific decision criteria.

The augmented decision process has the following distinct elements:

(1) The goal is to have a traceable and auditable proposal selection process with the net effect of increasing the likelihood of infusion of funded technologies.

(2) The specific relevance attributes perceived to have major influence on the stated objective are at the stakeholders' discretion and several sets have been collected.

(3) If the program's management preferences are captured and the proposal characterizations are validated then the resulting ranking is a first order approximation (reference) of an "objective" ordering of the proposals towards meeting the stated goal.

(4) The reference ranking then can be used in an "advisory" role to produce the final funding recommendations where other considerations are introduced (duplicates, change in requirements, etc.) and the change rationale is recorded.

(5) The data collected is to be used to correlate the discriminators of the selected technology proposals with the successfully infused solutions.

(6) The decisions support system provides a structure for measuring the likelihood of infusion and the possibility of identification and control of certain variables to increase the infusion rate.

Two illustrative cases have been presented, one which showed that possible inconsistencies in qualitative decisions could be uncovered and mended, and another one where the end-to-end application of the proposed approach provided and advisory support towards the final selection.

Of course, the quality of the results of the START-Lite system depends not only on the quality of the input (to be thoroughly validated), but mainly on the identification of the relevant discriminators and their associated ratings scales requiring an iterative process of calibration. In this regard, the workload reducing simplifications applied to the full START system most likely lead to a higher degree of subjectivity in the final decisions and impact adversely the optimal quality of the investment portfolio.

Ultimately, this type of decision framework also provides a structure for vertical communication in large organizations in order to achieve a certain goal; for instance making known the desired features to be identified in competed technologies and the basis for the choices made towards the perceived objective, such as increasing the likelihood of infusion of selected technologies.

5. ACKNOWLEDGMENTS

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