Technology Alignment and Portfolio Prioritization (TAPP)

Advanced Methods in Strategic Analysis, Technology Forecasting and Long Term Planning for Human Exploration and Operations, Advanced Exploration Systems and Advanced Concepts

Gregory V. Funaro
All Points Logistics – Jacobs ESSSA Group, Huntsville, AL 35806

and

Reginald A. Alexander
NASA, Marshall Space Flight Center, AL 35812

Technology Alignment and Portfolio Prioritization (TAPP) is a method being developed by the Advanced Concepts Office, at NASA Marshall Space Flight Center. The TAPP method expands on current technology assessment methods by incorporating the technological structure underlying technology development, e.g., organizational structures and resources, institutional policy and strategy, and the factors that motivate technological change. This paper discusses the methods ACO is currently developing to better perform technology assessments while taking into consideration Strategic Alignment, Technology Forecasting, and Long Term Planning.

I. Introduction

The Advanced Concepts Office (ACO) at NASA, Marshall Space Flight Center is expanding its current technology assessment methodologies. ACO is developing a new framework called TAPP that uses a variety of methods, such as association rule learning from data mining, analysis of technology system structures using a Technological Innovation System (TIS), and social network modeling to measure structural relationships between multiple technological systems. The reason ACO performs technology assessments are to 1) produce a broad spectrum of ideas and alternatives for a variety of NASA's missions, 2) determine mission architecture feasibility and appropriateness to NASA's strategic plans, and 3) define a project in enough detail to establish an initial baseline capable of meeting mission objectives

ACO's role supports the decision-making process associated with the maturation of concepts for traveling through, living in, and understanding space. ACO performs concept studies and technology assessments to determine the degree of alignment between mission objectives and new technologies.

The first step in technology assessment is to identify the current technology maturity in terms of a technology readiness level (TRL). The second step is to determine the difficulty associated with advancing a technology from one state to the next state.[1]

NASA has used TRLs since 1970[2] and ACO formalized them in 1995.[3] Many government and commercial industries use modified TRL definitions to perform technological assessments. The DoD, ESA, Oil & Gas, and DoE have adopted TRLs as a means to assess technology maturity. However, "with the emergence of more complex systems and system of systems, it has been increasingly recognized that TRL assessments have limitations, especially when considering [the] integration of complex systems.[2]"

When performing the second step in a technology assessment, NASA requires that an Advancement Degree of Difficulty (AD2) method be utilized. NASA has developed and used a variety of methods to perform this step: Expert Opinion or Delphi Approach, Value Engineering or Value Stream, Analytical Hierarchy Process (AHP), and other multi-criteria decision making methods.[4] These methods can be labor-intensive, contain parochial bias, and seldom consider the competing prioritization between mission architectures.

Assessing technological change is particularly challenging due to a multitude of relationships. The central idea in technology dynamics is to consider all activities that contribute to the development, diffusion, and use of innovations as system functions.[5] Bergek, in Ref. 5, defines these system functions within a TIS to address what is actually happening and identify the technologies that have a direct influence on the ultimate performance of the system and technology development. ACO uses similar metrics and is expanding these metrics to account for the structure and context of the technology.

At NASA technology, strategy and policy is strongly interrelated. NASA's Strategic Space Technology Investment Plan (SSTIP) prioritizes technologies essential to the pursuit of NASA's missions and national interests. The SSTIP is coupled to NASA's Technology Roadmaps, which provide investment guidance during the next four years, within a twenty-year horizon.[6]

This paper discusses the methods ACO is currently developing to better perform technology assessments while taking into consideration Strategic Alignment, Technology Forecasting, and Long Term Planning.

II. Background

"Measuring technological change is difficult.[7]"

There are two reasons for this statement. Giovanni Dosi in Ref. 8, *Technology Paradigms and Technology Trajectories,* states "technological knowledge is much less articulated than scientific knowledge" and technological paradigms[*] "have a powerful exclusion effect since they are often focused on precise, prescribed directions with an associated "momentum of its own", or a natural trajectory of technological progress."

Technology Paradigm is not the same as Scientific Paradigm

Technological Trajectories[†] have a natural bias built into the direction selected.

In Ref. 9, *Technological Revolutions and Techno-economic Paradigms*, Carlota Perez reiterates these points as well, saying that a technological paradigm represents "the tacit agreement of the agents involved as to what is a valid search direction and what will be considered an improvement or a superior version of a product, service or technology." Technological Trajectories are influenced by policy, institutional structures and policies, and interrelated technological systems. Technological progress is incremental. Perez hypothesizes that a technological revolution[‡] occurs when there is a strong interconnectedness between technological systems with the capacity to transform profoundly the rest of an economy.

III. Methods of Measuring the State of Technology and Technological Trajectories

There are many papers written on the processes, methods and tools necessary to perform a Technology Assessment and the trajectories available to the technology. Table 1 provides a few representative methods used by ACO. Common to the methods listed are dependency structures in the form of matrices and networks that model the relationship between objects of interest. While each method has its strength, each method also has a shortcoming. This does not imply any particular method is bad, it implies each method has a focused purpose. Ideally a Technology Assessment should be able to span across a variety of methods, adjusting the fidelity, scale and resolution of the analysis to accommodate the task at hand.

Table 1 Representative Methods, Processes and Tools for Performing Technology Assessment

[*] Technological Paradigm: a "model" and a "pattern" of solution of *selected* technological problem based on *selected* principles derived from natural sciences and on *selected* material technologies.[8]

[†] Technological Trajectory: the pattern of "normal" problem solving activity (i.e. of "progress") on the ground of a technological paradigm.[8]

[‡] Technological revolution: a set of interrelated radical breakthroughs, forming a major constellation of interdependent technologies; a cluster of clusters or a system of systems.[9]

Year	Objective	Shortcomings	Primary References
1970 - 1990	Measuring the state of technology through readiness levels	Assumes technologies exist independently, does not consider the technological system or system architecture Qualitative, subjective and parochial bias	Ref. 3: Technique based on defining the state of a technology
1995-2005	Optimization Multi-Criteria Decision Analysis (MCDA)	Technology Trajectory is design focused, surrogate model building time consuming process Assumes technologies exist independently with linear evaluation criteria	Ref. 10: Technique based on multi-attribute decision-making and morphological matrices
2002-2010	Technology Gap and Prioritization	Labor Intensive, requires support from expert technologist Technology trajectory is design focused	Ref. 4: Technique based on interviews and Delphi
2005-2010	Technological Change	Ability to adequately model the institutional and technological structures Ability to obtain information is labor intensive	Ref. 5: Assessment based on assessment of a variety of readiness levels, not uniformly applied Ref. 12: Adds Fuzzy Analytical Hierarchy Approach (FAHP)
2011-	Technology Innovation System Analysis	Policy and Institutional focused Performance metrics	Ref. 13: Network of interacting agents Ref. 14: Complex system and functional dependencies networks and relationships

In Ref. 15, *Technology Readiness Levels at 40: A study of the state of the Art: Use, Challenges and Opportunities*, Olechowski, Eppinger, and Joglekar evaluate various methods of performing Technology Assessment and describes 15 challenges relating to the use of TRL in practice today. The results of these findings are grouped into three categories:

- System Complexity
  7 challenges related to the complexity of the system, whether it is at the component level, architectural level or system as a whole (across missions)
- Planning and Review
  6 challenges related to the decision process and technological progression
- Assessment Validation
  2 challenges related to quality of the information, subjectivity and imprecision

IV. Previous Technology Assessments and Methodologies

In an era of reduced funding and increasing mission/vehicle complexity, NASA needs tools and methodologies to rapidly and accurately assess the benefits and costs of technologies that may enhance or enable its mission. As early as 2002 NASA had begun developing tools and methodologies to rapidly and comprehensively assess technologies for integrated mission architectures. The first of these and one of the most comprehensive was for the Second Generation Reusable Launch Vehicle Space Launch Initiative (2nd Gen RLV SLI). NASA formed a multi-center team called the Intercenter Systems Analysis Team (ISAT) lead by the Program Development Office at the Marshall Space Flight Center. This team conducted the technology and architecture assessments. The team's objectives were 1) determine the impact of individual technologies on reference reusable launch vehicle architectures, 2) identify technologies which provide the most benefit to launch architectures, 3) evaluate combination of technologies in conjunction with one another, and 4) analyze the affects of sequentially adding funded technologies to a reference concept. The process developed to perform these assessments is shown in **Error! Reference source not found.**.

Key to this process is an understanding of the program/Agency goals (Program Requirements), the collection of the technology data, and the actual technology assessments. The process requires significant input in the form of interviews with technologist throughout the industry/government /academia. Also, the technology assessments require systems assessments using multiple discipline analysts and multiple systems design tools. These processes are both laborious and time intensive due to the nature of the information technology of the time and the available information. Each of which could lend itself to automation. The requirements of this process, while extremely beneficial, could be limiting due to time and cost constraints. The results of the study were technology suites that were selected based on a number of figures-of-merit such as performance, cost, and reliability. These suites offered to program management a set of investment recommendations and roadmaps that would enable such mission to be accomplished.

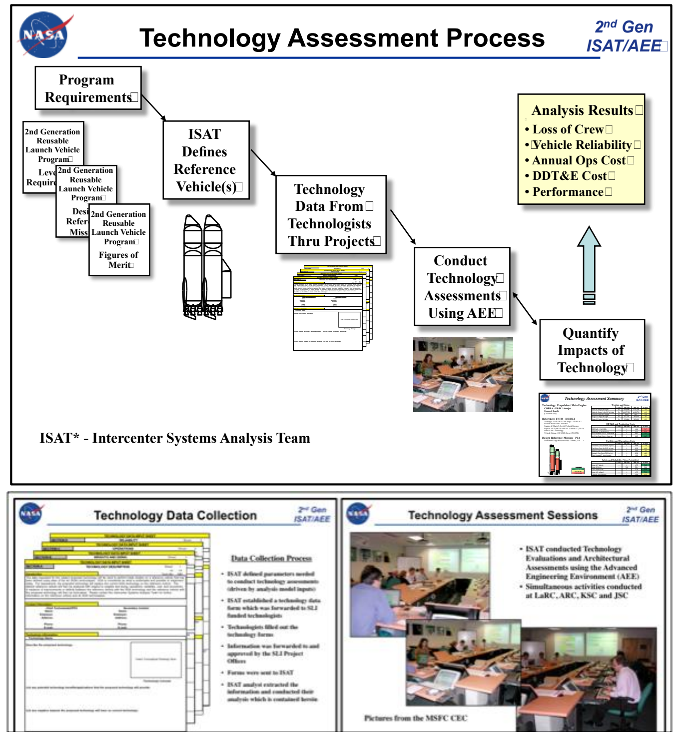

Figure 1 ISAT Technology Assessment Process

Another exercise that NASA led was the Next Generation Launch Technology (NGLT) Systems Analyses, which had a goal similar to that of the ISAT. The primary difference between these two activities is the vehicle architectures assessed and the methodologies associated with the mission analyses and the technology assessments. Hypersonic air-breathing vehicles were a component of these studies along with reusable rocket launch vehicles. Also, a technology assessment tool, Value Stream Technology Profiler (VSTeP), was added to the tool suite. VSTeP provided technology availability data as well as capability with its data being populated by industry, government, and academia technologists. The step forward is that the profiler used computer databases with online access enabling rapid manipulation of data for the required analyses. Additionally, response surfaces enabled high volume systems analyses, which allowed for statistical analyses of technology and mission analysis suites.

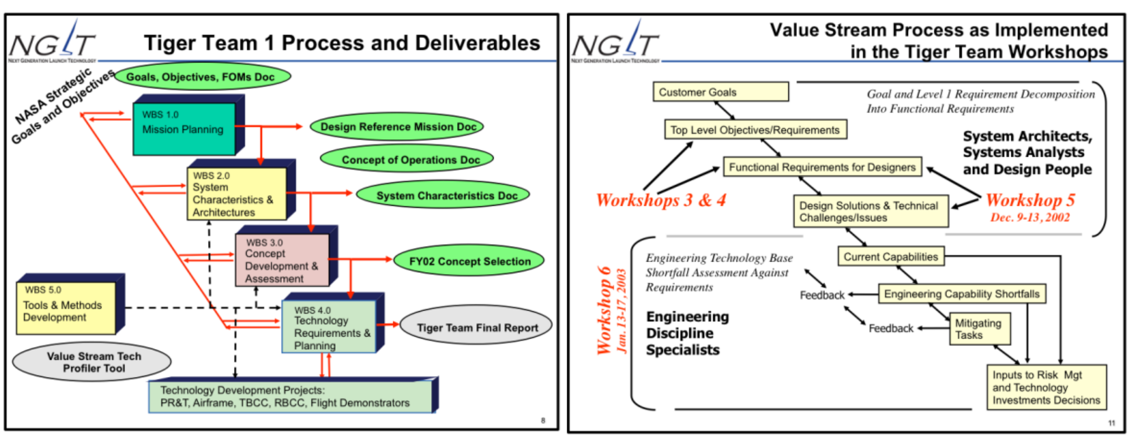

Figure 2 NGLT Systems Analysis and Technology Assessment Process

Both of these studies represented dramatic leaps forward in tool integration, systems analysis and integrated vehicle analyses. These activities represented the vision of future technology assessments and portfolio planning. The computing and networking technologies were largely the limiting factors of the times. The next phase of technology planning and assessments, new tools will be needed that enable broad information searching, data manipulation, and decrease cycle analysis time.

V. Expanding Technology Assessment Methodologies

Technology is neither good nor bad; nor is it neutral – Melvin Kranzberg – Six Laws of Technology

The Advanced Concepts Office began expanding its methods for technology assessment about three years ago with a focus on incorporating overall strategic mission objectives with engineering design concept trade studies. ACO identified three goals with regard to expanding our current technology assessment methodologies.

- Improve stakeholders' ability to make decisions regarding technology
- Enable "information-based decisions"
- Lead the effort to align MSFC's organizational posture toward its corporate business objectives

To accomplish these goals, ACO began incorporating the methods described in Ref. 16, *Analyzing the Functional Dynamics of Technological Innovation Systems* (TIS). Since TIS focuses more on policy and strategy, it mapped well with goal three: aligning organizational structure to business objectives. ACO then incorporated NASA's Strategic Space Technology Investment Plan[§] (SSTIP), Technology Roadmaps, the National Resource Council assessment of these technologies[17], the Human Exploration and Operations (HEO), Advanced Exploration Systems (AES) projects[**], as well as MSFC Engineering Departments, HEOMD Strategic Knowledge Gaps[††] and other associated information. The first assessment was to compare an engineering trade study for the Dual Use Upper Stage (DUUS) concept against NASA's overall Strategic Plan. The DUUS is described in Ref. 18.

Figure 3 Comparison of Engineering Trade Study with NASA strategic Goals, shows a dashboard depicting the relationship between the DUUS engineering trade study using MCDA optimization methods and NASA's SSTIP using TIS methods. This figure demonstrates that optimizing for design does not necessarily align with strategic goals, nor should it. It does demonstrate the contribution the DUUS element has on the overall strategy however. The dashboard was dynamic so that a decision maker could assess how technological criteria aligned against strategic goals. By adjusting the weight assigned to each criterion, one could balance (optimize) both the DUUS and strategic goals. In this particular case, the decision maker had to give up schedule and cost constraints to balance both goals.

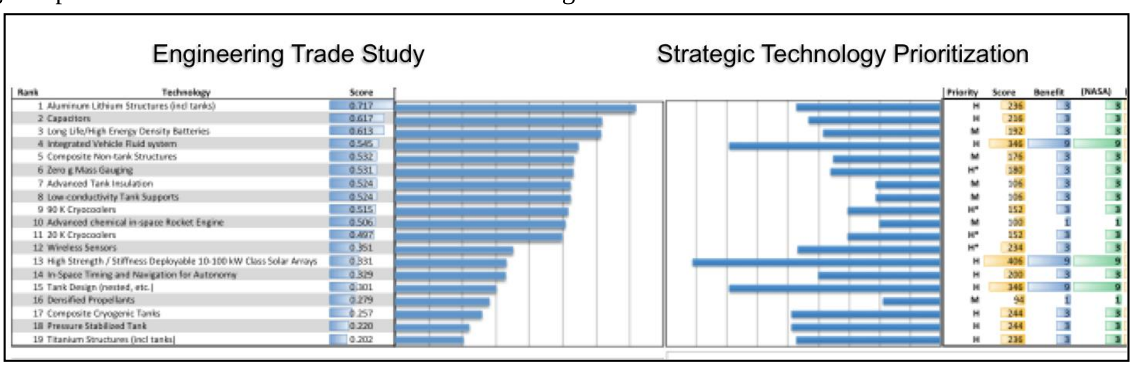

Figure 3 Comparison of Engineering Trade Study with NASA strategic Goals

ACO also performed an assessment between a set of AES projects and the HEOMD Strategic Knowledge Gaps (SKG). For each project, the set of technologies the project was focused on was determined; a mapping was made between technologies and each SKG. A dashboard was built, to determine the alignment between

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[§] http://www.nasa.gov/pdf/674740main_07-17_12DRAFT_Strategic_Space_Tech_plan.pdf
[**] http://www.nasa.gov/directorates/heo/aes/index.html#.VawM7ipViko
[††] http: //science.nasa.gov/media/medialibrary/2012/05/04/HEOMD_Strategic_Knowledge_Gaps_--_Mike_Wargo.pdf

each project and each knowledge gap. Figure 4 Assessing AES Projects and Strategic Knowledge Gaps shows the dashboard comparing the alignment between AES projects and SKG. From this information a decision maker can easily identify which knowledge gaps are not being closed, which knowledge gaps have multiple projects and which projects close multiple gaps. The decision maker can use this information as an assessment tool for project funding and to solicit focused research on hard to close gaps.

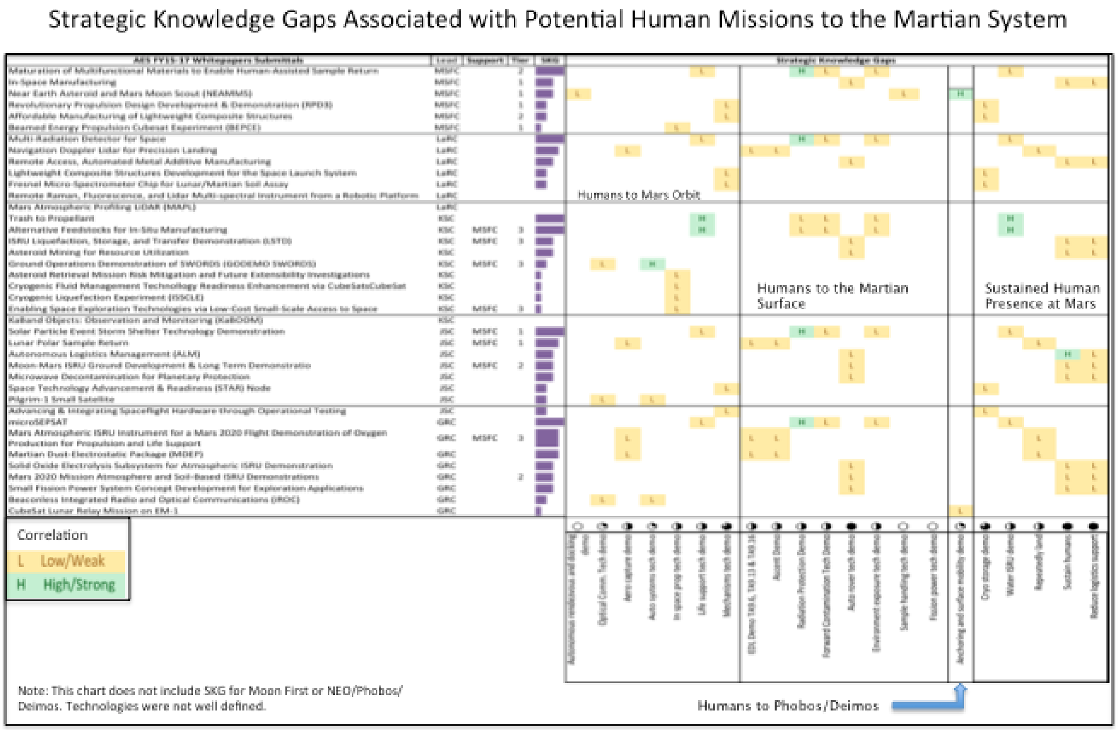

Figure 4 Assessing AES Projects and Strategic Knowledge Gaps

NASA's Office of Chief Technologist approved a study led by ACO to facilitate an assessment of potential partnerships with potential commercial endeavors using Inspiration Mars (IM) as an example mission. Using the SSTIP, Technology Roadmaps and NRC assessments a radar map was created to provide an overall view of potential technology benefits. A set of top-level technologies were identified that would benefit both NASA and a commercial endeavor. Subject matter experts (SME) were interviewed across NASA centers for each top-level technology area to address specific top-level technologies. By performing the analysis first, specific technological benefits could be refined from the experts reducing man-hours. The dashboard is shown in **Error! Reference source not found.**. The radar plot was used to categorize top technologies, such as Autonomous Systems, Human Health, and Material/Structures, where a decision maker could easily identify which

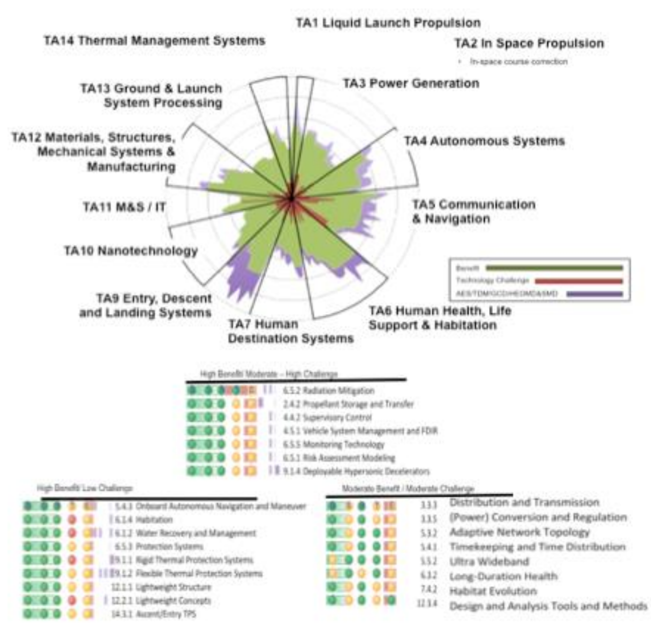

Figure 5 Commercial Partnership Technologies

technologies were the most challenging (long read poles) and which technologies would be most beneficial to the mission. Three tables were created; High-Benefit/High-Challenges NASA focused, High-Benefit/Low Challenge (Commercial Focused) and Moderate Benefit/Moderate Challenges (Partnership).

For another study, ACO considered the relationships between mission categories, the elements that support those missions, the subsystems that enable the elements, the organizational resources required to build the subsystems, the technologies that support this technological system and the scenarios that fund the missions. A dashboard was built so that a decision maker could see the impact one particular mission or funding scenario had on similar missions, elements, subsystems, resources and technologies. The intent was to analyze the structure of the technology system using a Technological Innovation System (TIS) framework, and organizational network modeling. A dashboard was built and is depicted in Figure 6 Dashboard Mission, Elements, Subsystems, Technologies and Resources. The case shown is for Human Mars Mission. Missions are then ordered based on the similarities or required elements, e.g. Human Mars, Human Lunar, Human Mars Moons and Human Near Earth Asteroid are similar mission categories, as are Robotic Missions. Mission Categories require similar elements. Also depicted is an ordered list of subsystems, e.g. Tank design and Cryogenic Fluid Management (CFM). Also shown is perceived the organizational participation required to support these missions. The radar chart is used to assess the mission alignment between the technologies identified in the Technology Roadmaps and supporting subsystems, e.g. Multifunctional Lightweight Tanks and Cryogenic/ Liquid Storable Tanks.

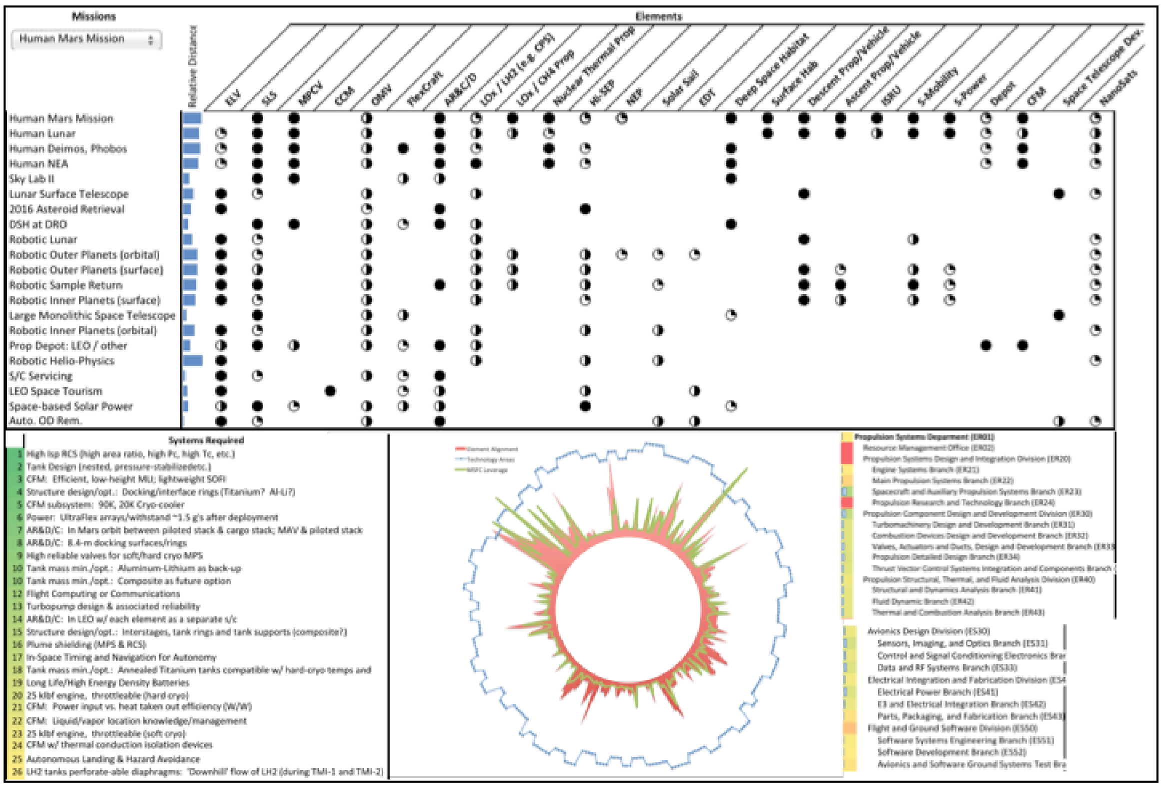

Figure 6 Dashboard Mission, Elements, Subsystems, Technologies and Resources

Over the past three years, ACO has done approximately 15 studies incorporating the TIS methodology to support strategic decision-making based on the relationships from an underlying technological network. There are three common elements in performing these studies.

- Matrix gymnastics
- Textual data mining and expert validation
- Dynamic and Interactive Visualization

The next section discusses these items in a more formal manner.

VI. Technology Assessment Tools

In the past three years, as ACO refined its methods and processes for combining the various information required to do technological assessments, it became apparent that a set of tools will allow ACO to be more efficient. ACO is attempting to address some of the challenges identified in Ref. 15. ACO is doing this by addressing the following:

- Formalizing the language used to communicate Technological Assessment
- Providing easier ways to access and manipulate data
- Providing the ability to present results in an easily a posteriori manner

Most analysis is currently done in spreadsheets and this unlikely to change any time soon. Spreadsheets provide a spectrum of capabilities to the analyst, e.g. matrix manipulation, statistics, optimization, sorting, mapping, filtering, data lookup, chart generation, input forms and a programming language. However, efficiency is contingent on an individual's ability with spreadsheet gymnastics, understanding the statistical tools, optimization techniques, and "speaking the programming language." Take into further consideration that "research has suggested that errors are prevalent in spreadsheets[19]," and the challenges identified by Olechowski, Eppinger and Joglekar, the set of tools need to enable verification, validation and repeatability of assessments, as well as, the ability to model the complexity associated technological structures and trajectories.

A. Formalizing the Language

At a fundamental level, the mathematical methods employed by TAPP are based on Category Theory, Graph Theory and Formal Concept Analysis. Category Theory consists of a collection of objects that are connected by arrows (morphisms) to form directed and undirected graphs[20]. A graph consists of nodes (objects) and edges (relationships between nodes). Graph theory is the study of graphs, which are mathematical structures, used to algebraically model the pairwise relations between objects[21]. Formal Concept Analysis (FCA) is "based on the mathematization of concept and concept hierarchy.[22]" FCA focuses on the ordered sets of objects, object attributes and relationships to establish hierarchies based on lattices, ontologies (Olog) and partially ordered sets (poset).

The motivation for identifying these mathematical frameworks is that it 1) formalizes the methods used in Technology Assessment and 2) formal methods can be programmed, e.g. contextual computing. In the Expanding Technology Assessment Methodologies Section of this paper, an engineering concept analysis was presented on the Dual Use Upper Stage (DUUS). Like most studies, a set of Figures of Merit (FOM) were assigned on a set of alternative technologies, where each technology was assessed its merit based on cost, schedule, performance, safety and relevance. The intent is to find the best engineering solution, based on the FOMs. The FOMs were weighted and ordered using the TOPSIS ‡‡method.

The relationships between elements and subsystems can be stated formally as follows:
Using a graph notation, where ()—[]→() denotes (node)—[relationship]→(node)
(: ELEMENT) —[: DEPEND_ON]→(: SUBSYSTEMS)

(: ELEMENT (*name: 'DUUS'*))—[: DEPEND_ON]→ (: SUBSYSTEMS (*name: 'Structures') [: DEPEND_ON)*)
(TA: TECHNOLOGY (*name: 'Aluminum Lithium Structure',*)
FOM: [(*Cost: 4*), (*Schedule: 8*), (*Performance: 7*), (*Safety: 5*), (*Relevance: 4*)]})

This is often done in tabular (matrix) form with equivalent information

DUUS	FOMS				
Technology	Cost	Schedule	Performance	Safety	Relevance
Aluminum Lithium Structure	4	8	7	5	4

In the strategic domain, relationships are focused on strategic investments and technology roadmaps. Strategic FOMS have a different set of criteria and weighting and decision-making is based on multiple objectives.§§ The relationship between technologies and investment policy can be stated formally as follows:

‡‡ TOPSIS: Technique for Order of Preference by Similarity to Ideal Solution – multi-criteria decision analysis, assumes criterion is monotonically increasing or decreasing

§§ Multi-objective optimization involves more than one objective function so a single solution does not exist. It usually leads to a set of solutions. A dynamic visualization of the Pareto front provides knowledge a posteriori.

(: TECHNOLOGY)—[: DEPEND_ON]→(:INVESTMENT (*Policy: SSTIP*))—[: DEPEND_ON]→(: BENEFIT-RISK)

(: ELEMENT (*name: 'DUUS'*))—[: DEPEND_ON]→(: SUBSYSTEMS)→[: DEPEND_ON]→
(12.2.1: TECHNOLOGY (*name: 'Lightweight Concepts',*)
FOM: [(*Benefit: 9*),
(*Technical Risk: 9*),
(*Sequencing: 1*),
(*Effort: -3*)]})

This too can be represented in matrix form.

The benefit of describing the study in graph notation, is that the connection between both studies would be represented formally as follows:
(:INVESTMENT (*Policy: SSTIP*))—[:INFLUENCES]→(: TECHNOLOGY)←[ ]—(: ELEMENT (*name 'DUUS'*))
Then, one can easily create the relationships, without a lot of spreadsheet gymnastics, one can easily incorporate, merge and integrate studies, using the programming languages, and database available today. This is precisely what ACO is attempting to do with TAPP. Drag and drop concept analysis.

Matrix Representation → Graph Representation → Dynamic Dashboard

As shown in Figure 3 Comparison of Engineering Trade Study with NASA strategic Goals, the analyst and decision-maker were presented a dynamic visualization of the two Pareto Domains, Overall Strategic Objectives versus the DUUS Concept. The dynamic dashboard allowed an analyst or decision-maker to adjust the weights of the FOMS, dynamically changing the order of the technology alternatives or strategic objectives, visualizing the impact of changing policy or the impact of changing design. In the study there is a definite benefit with lightweight structures, but overcoming DDT&E timing between alternate materials was one of the biggest constraints. If the analyst had the ability to compare or analyze alternate lightweight materials across all mission systems, a system of systems approach, the benefits associated with lightweight materials could be better ascertained. The optimal solution for the DUUS element may not be the most efficient solution when compared to all elements across all missions. In category theory this would be called a "universal property" used to determine the most efficient solution. Universal properties become important when evaluating the Pareto Efficiency between domains. It is important to understand the morphisms of initial and final properties between the objects. In category theory, one make an abstraction of the DUUS, identifying an initial state and final state by analyzing the range properties have on changing the concept. This method is not new to analysts. Analysts call it commonality.

ACO is also using data mining techniques, including topic mapping and natural language understanding to extract information from a variety of information stores, such as the NASA Scientific and Technical Information Program, NASA Technology Roadmaps, Internal Project, Design Reference, Trade Studies and other available information. The intent of this capability is to drill down as deep as possible to extract information that would be relevant to Technological Assessment. One of the planned exercises is to assess how well natural language understanding can determine technology readiness levels from unstructured text. Another planned exercise is to categorize wireless sensor development by mining approximately 400 documents using a topic mapper, then to combine that information across mission systems to shape a strategy for wireless sensor development. Figure 7 Hierarchical Concept Analysis using Data Mining shows an attempt to merge radiation protection semantic fingerprint to the NASA technology structure.

Figure 7 Hierarchical Concept Analysis using Data Mining

VII. Conclusion

This paper discussed the methods ACO is currently developing to better perform technology assessments while taking into consideration Strategic Alignment, Technology Forecasting, and Long Term Planning. The Advanced Concepts Office (ACO) at NASA, Marshall Space Flight Center is expanding its current technology assessment methodologies by developing a new framework called TAPP based on ACO's history using various processes, methods and tools to perform Technology Assessments. The goal in developing this framework is to improve stakeholder's ability to make decisions regarding technology and enable "information-based decisions.

TAPP addresses three types of challenges.

- **System Complexity** – challenges related to the complexity of the system, whether it be at the component level, architectural level or system as a whole (across missions)
- **Planning and Review** – challenges related to the decision process and technological progression
- **Assessment Validation** – challenges related to quality of the information, subjectivity and imprecision

TAPP focuses on three areas to improve efficiency.

- Formalizing the language used to communicate Technological Assessment
- Providing easier ways to access and manipulate data
- Providing the ability to visualize results in an informative and exploratory manner

ACO is using the TAPP framework to develop new tools to quickly integrate concept studies and information, and put the results into the hands of other analysts and decision-makers.

VIII. References

1. NASA. NASA Systems Engineering Handbook (NASA/sp-2007-6105 Rev1) Retrieved from http://ntrs.nasa.gov/search.jsp?R=20080008301&hterms=SYstems+Engineering+Handbook&qs=N%3D0%26Ntk%3DAll%26Ntt%3D%2522SYstems%2520Engineering%2520Handbook%2522%26Ntx%3Dmode%2520matchallpartial
2. Fernandez, J. A. Contextual Role of TRLs and MRLs in Technology Management. Sandia National Lab, California, SAND2010-7595., Retrieved from http://prod.sandia.gov/techlib/access-control.cgi/2010/107595.pdf3. J. C. mankins, White Paper, April 6, (1995).
4. Hueter, U., Tyson, Richard. Ares Project Technology Assessment-Approach and Tools, Retrieved from http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20100040545.pdf
5. Bergek, A. Shaping and exploiting technological opportunities: the case of renewable energy technology in Sweden, Department of Industrial Dynamics, Chalmers University of Technology Göteborg, Sweden. Retrieved from http://energimyndigheten.se/Global/Forskning/Energisystemstudier/Shaping and exploiting technological opportunities.pdf, (2002).
6. Steitz, D. E. NASA Unveils Strategic Space Technology Investment Plan, Retrieved from http://www.nasa.gov/home/hqnews/2013/feb/HQ_13-039_NASA_SSTIP_prt.htm
7. Knutsen, C. H. Democracy, Dictatorship and Technological Change, Retrieved from http://www.sv.uio.no/esop/english/research/news-and-events/events/2009/DemocTechnolCHK.pdf
8. Dosi, G. Technological Paradigms and Technological Trajectories: A Suggested Interpretation of the Determinants and Directions of Technical Change. Research policy, 11(3)(3), d. 147-162, Retrieved from http://www.eawag.ch/forschung/cirus/lehre/fruehere_veranstaltungen/hs08/downloads_ewv/Dosi_1982.pdf
9. Perez, C. A New Age of Technological Progress, Retrieved from http://www.carlotaperez.org/downloads/pubs/A New Age of Technological Progress.pdf
10. Olds, J. R., A Review of Technology Assessment Methods for Space Transportation Systems, (2005)
11. Bilbro, J. W. A Suite of Tools for Technology Assessment, Retrieved from http://www.dtic.mil/dtic/tr/fulltext/u2/a507181.pdf
12. Zhao, D., & Wei, F, (2015). Advancement Degree of Difficulty Assessment Method for Complex Products, Proceedings of the 5th International Asia Conference on Industrial Engineering and Management Innovation, 105 (2015)
13. Hekkert, M., Negro, S., Heimeriks, G., & Harmsen, R. Technological Innovation. System Analysis. A Manual for Analysts, Utrecht University, Report for Joint Research Center, Energy Institute, (2011)
14. Guariniello, C., & DeLaurentis, D. Integrated Analysis of Functional and Developmental Interdependencies to Quantify and Trade-Off ilities for System-of-systems Design, Architecture, and

EVOLUTION. PROCEDIA COMPUTER SCIENCE, 28, D. 728-735., RETRIEVED FROM HTTP://WWW.SCIENCEDIRECT.COM/SCIENCE/ARTICLE/PII/S1877050914001501 (2014).

15. OLECHOWSKI, A. L., EPPINGER, S. D., & JOGLEKAR, N. TECHNOLOGY READINESS LEVELS AT 40: A STUDY OF STATE-OF-THE-ART USE, CHALLENGES, AND OPPORTUNITIES, RETRIEVED FROM HTTP://DSPACE.MIT.EDU/BITSTREAM/HANDLE/1721.1/96307/MITSLOANWP5127-15_EPPINGER_PICMET.PDF?SEQUENCE=1 (2015).
16. BERGEK, A., JACOBSSON, S., CARLSSON, B., LINDMARK, S., & RICKNE, A. ANALYZING THE FUNCTIONAL DYNAMICS OF TECHNOLOGICAL INNOVATION SYSTEMS: A SCHEME OF ANALYSIS. RESEARCH POLICY, 37(3)(3), D. 407-429., RETRIEVED FROM HTTP://WWW.DIVA-PORTAL.ORG/SMASH/GET/DIVA2:267496/FULLTEXT01.PDF, (2008).
17. A. A. S. E. BOARD, S. C. F. N. A. S. A. T. ROADMAPS, D. O. E. A. P. SCIENCES, N. R. COUNCIL, N. ACADEMIES, NASA SPACE TECHNOLOGY ROADMAPS AND PRIORITIES:: RESTORING NASA'S TECHNOLOGICAL EDGE AND PAVING THE WAY FOR A NEW ERA IN SPACE (NATIONAL ACADEMIES PRESS, ED. PAP/CDR, 2012), PP. 122.
18. J. HOLLADAY, SLS DUAL USE UPPER STAGE (DUUS) OPPORTUNITIES. NTRS.NASA.GOV., RETRIEVED FROM HTTP://NTRS.NASA.GOV/ARCHIVE/NASA/CASI.NTRS.NASA.GOV/20130013953.PDF, (2013).
19. POWELL, S. G., BAKER, K. R., & LAWSON, B. (2008). A CRITICAL REVIEW OF THE LITERATURE ON SPREADSHEET ERRORS, DECISION SUPPORT SYSTEMS, 46(1), 128-138, (2008), RETRIEVED FROM HTTP://MBA.TUCK.DARTMOUTH.EDU/SPREADSHEET/PRODUCT_PUBS_FILES/LITERATURE.PDF
20. KRÖTZSCH, M., MORPHISMS IN LOGIC, TOPOLOGY, AND FORMAL CONCEPT ANALYSIS. MASTER'S THESIS, DRESDEN UNIVERSITY OF TECHNOLOGY, (2005) RETRIEVED FROM HTTP://CITESEERX.IST.PSU.EDU/VIEWDOC/DOWNLOAD?DOI=10.1.1.59.8052&REP=REP1&TYPE=PDF
21. WIKIPEDIA, & CONTRIBUTORS. (2015), GRAPH THEORY. RETRIEVED FROM HTTPS://EN.WIKIPEDIA.ORG/W/INDEX.PHP?TITLE=GRAPH_THEORY&OLDID=667682086
22. GANTER, B., STUMME, G., & WILLE, R. (2005). *FORMAL CONCEPT ANALYSIS: FOUNDATIONS AND APPLICATIONS (LECTURE NOTES IN COMPUTER SCIENCE / LECTURE NOTES IN ARTIFICIAL INTELLIGENCE)* (2005 ED.). SPRINGER. RETRIEVED FROM HTTP://WWW.AMAZON.COM/FORMAL-CONCEPT-ANALYSIS-APPLICATIONS-INTELLIGENCE/DP/3540278915%3FSUBSCRIPTIONID%3D0NM5T5X751JWT17C4GG2%26TAG%3DSONNYSOFTWARE%26LINKCODE%3DXM2%26CAMP%3D2025%26CREATIVE%3D165953%26CREATIVEASIN%3D3540278915