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Value flow mapping: Using networks to inform stakeholder analysis

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Abstract

Stakeholder theory has garnered significant interest from the corporate community, but has proved difficult to apply to large government programs. A detailed value flow exercise was conducted to identify the value delivery mechanisms among stakeholders for the current Vision for Space Exploration. We propose a method for capturing stakeholder needs that explicitly recognizes the outcomes required of the value creating organization. The captured stakeholder needs are then translated into input–output models for each stakeholder, which are then aggregated into a network model. Analysis of this network suggests that benefits are infrequently linked to the root provider of value. Furthermore, it is noted that requirements should not only be written to influence the organization's outputs, but also to influence the propagation of benefit further along the value chain. A number of future applications of this model to systems architecture and requirement analysis are discussed.

1. Introduction

A critical aspect of future space exploration is sustainability. Technical success alone cannot ensure that space exploration will have the continuing societal support necessary over the course of decades to develop enduring and expanding exploration capabilities. We define sustainability using a four-fold approach: valued benefits to all stakeholders, affordability, risk management that communicates residual operational risks to stakeholders, policy robustness to improve the chances of success in a changing political environment [1–3]. In this paper, we focus on modeling the first pillar of sustainability, how value is delivered to a wide range of stakeholders. The exploration enterprise includes the core set of explorers, scientists, and engineers that realize and execute the space exploration campaign. It also includes the extended group of stakeholders who are not directly involved in the exploration campaign, but who are nevertheless crucial in providing support and funding. We assert that all stakeholders must be aware of the benefit derived from the exploration value delivery system and of its delivery mechanism in order for the organization to be sustainable.

Current requirements analysis tends to select architectures based on technical merit, and then build in consideration of stakeholders much later in the design process. We propose that a sustainable exploration value delivery system results from deliberate design decisions, and that those design decisions are best realized through an understanding of the system's stakeholders, their values and needs early on in the process. Once values and

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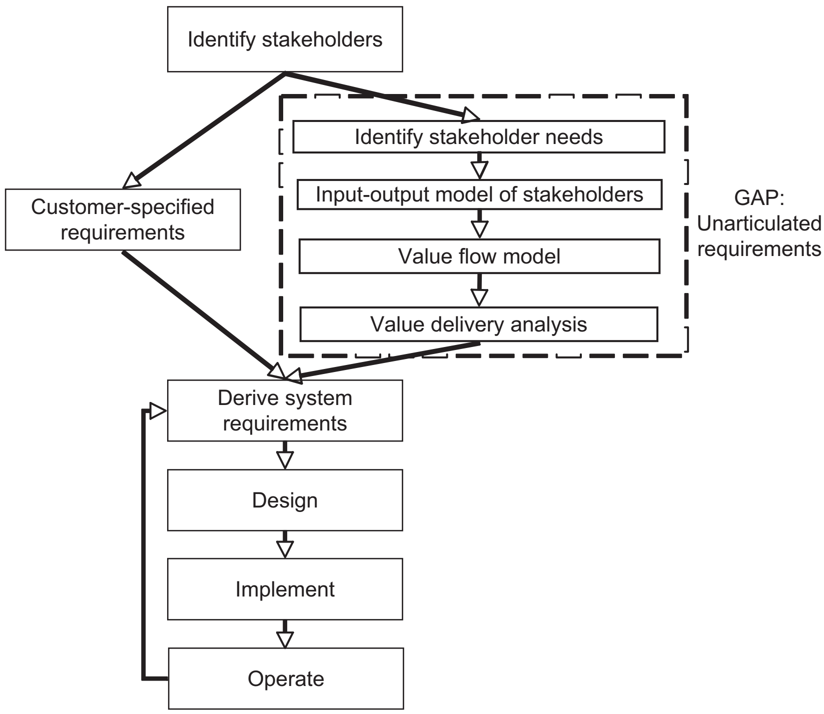


Fig. 1. Stakeholder-derived requirements analysis.

needs are identified, system requirements can be defined, leading to the development of specific architecture choices not only for the exploration technical system, but also for the exploration enterprise and operating concept, as well as its policy environment.

The general objective of this paper is to provide a process for bridging the gap between stakeholders' considerations and requirements analysis for large, complex systems.

The use of stakeholder analysis has grown steadily, diffusing in from rising interest in corporate governance [4]. This reflects a growing sense that the organization should act on the interests *and* values of its stakeholders. While interest on the corporate front centers around whether or not 'maximizing stakeholder value' is an appropriate measure of success, public enterprises are forced to tackle the key issues head-on, given that profit is not an available metric.

The key question for public enterprises is therefore how to measure value? We define value as a benefit perceived by the receiving party. Value is always recorded from the perspective of the recipient, in an effort to capture the change in the stakeholder's attribute that is actually related to value. Value is created by the organization in question by using its resources to create an architecture which produces outputs that satisfy the needs of its stakeholders. In this manner, we abstract across a number of different transactions (e.g. goods, services, information, political influence) and disciplines (e.g. systems engineering, science, political science, economics) using the language of value. Identifying which entities are stakeholders shapes the network boundaries, scope, and the types of value that are considered in the analysis. It is therefore important that the choices of stakeholders are consistent with the intended scope of the value flows.

Questions of value and stakeholder analysis are increasingly present in systems engineering analysis. For example, NASA Systems Engineering Handbook of 1995 [5] makes no reference to stakeholders, but a recent NASA study, the Exploration Systems Architecture Study [6], references consulting and communicating with stakeholders tangentially. The most recent version of the NASA Systems Engineering Processes and Requirements document (published March 6, 2006) now requires stakeholder analysis as the first step in the requirements definition process, in order to "elicit and define use cases, scenarios, operational concepts, and stakeholder expectations". [7]

Requirements analysis, however, is well developed as a method for translating opportunities or needs into system requirements [5,8]. In many cases, the identification of requirements is levied from the customer-specified technical requirements or past technical systems, without examining where needs derive from. Furthermore, there is often a selection bias which tends to highlight technical needs because they can be more easily quantified as requirements. Requirements analysis has therefore not mated well with stakeholder analysis in the past, because there are difficulties translating between the output of stakeholder analysis and the inputs for requirements analysis.

The specific objective of this paper is to showcase a modeling technique by which stakeholder analysis produces clear outputs, which can be used to define requirements, particularly for large, complex systems. Large public architectures represent the ideal case study, because they do not have easily derived technical requirements, and the proliferation of non-technical needs forces us to examine the bias in requirements-setting.

While this paper is written using NASA's exploration value delivery system as the primary example, an effort is made to highlight the generic process, given that this process is broadly applicable (Fig. 1).

The paper is structured to mirror the process of value mapping. In Sections 2 and 3, we identify the stakeholders and their needs. In Section 4, we construct an enterprise model of each stakeholder, capturing inputs and outputs. A value flow model is created by linking inputs and outputs in Section 5. This model is analyzed by segregating it into different types of value flows, and by examining common characteristics of the resulting value loops. Organizational and design implications of the analysis are presented at the end, followed by a discussion of future work.

2. Identifying stakeholders

We draw from Freeman's *Strategic Management: A Stakeholder Approach* [9] in defining stakeholders as those entities that have a interest or stake in the value creating organization. Stakeholder theory is intended to answer the question of "How should an organization best be governed, so as to maximize value to its stakeholders?". Freeman summarized his work by stating that stakeholder theory acts to increase an organization's effectiveness by constraining its focus to the relationships that can affect or be affected by the achievement of the organization's purpose. While the origins of this discipline are rooted in management science relating to corporate stakeholders, the work done relating to managing the diverse and competing needs of a broad stakeholder base are relevant to the public sector.

According to Kochan and Rubenstein [10] there are three key criteria for categorizing stakeholders: (1) stakeholders must hold assets that are critical to the enterprise's success; (2) stakeholders must put their assets at risk in the enterprise; (3) stakeholders must have sufficient power to compel influence.

Stakeholders are identified by answering the question: '*who are the stakeholders of the space exploration systems of systems to whom benefit might flow?*' Sources for answering this question were: the Constitution of the United States, the Space Act of 1958 as amended [11], the Vision for Space Exploration (VSE) [12] as well as working group discussions. The eight stakeholders groups, plus NASA, are shown in Fig. 2.

Three of the major groups are explicitly mentioned in the top-level objective in the VSE [12]: *'The fundamental goal of this vision is to advance U.S. Scientific*, *Security*, *and Economic interests through a robust space exploration program'.* The VSE exploration also implicitly notes the *US People* as a benefactor of space exploration: *'A significant human component can inspire us—and our youth—to greater achievements on Earth'.* We broke out *Educators* as a separate stakeholder, to explicitly capture this commitment to youth and training. The *Media* was also added to recognize that there is typically an intermediary between the NASA and the US People, which has the potential to influence value. The *Executive and Congress* were added as the constitutional agent for the US People. Finally, *International Partners* are included for their mention in the Space Act of 1958, which mandates that NASA "shall make every effort to enlist the support and cooperation of appropriate scientists and engineers of other countries and international organizations". In the VSE, international participation is encouraged to the extent that it "further(s) U.S. scientific, security, and economic interests".

Interestingly, the Space Act of 1958 explicitly identifies Mankind as a stakeholder: "for the benefit of all mankind", but Mankind is not mentioned in many recent documents, including the VSE.

These eight stakeholder groups are classified into four types, identified by color in Fig. 2: public (gray), security (pink), economic (green), science (yellow). These types were created to explicitly identify that some stakeholders, such as educators and media, are intermediaries in the process of delivering value to the US People.

The level of aggregation chosen for stakeholder groups decides the level of detail of the remainder of the model. Given that the number of possible links in the system scales quadratically with the number of nodes,

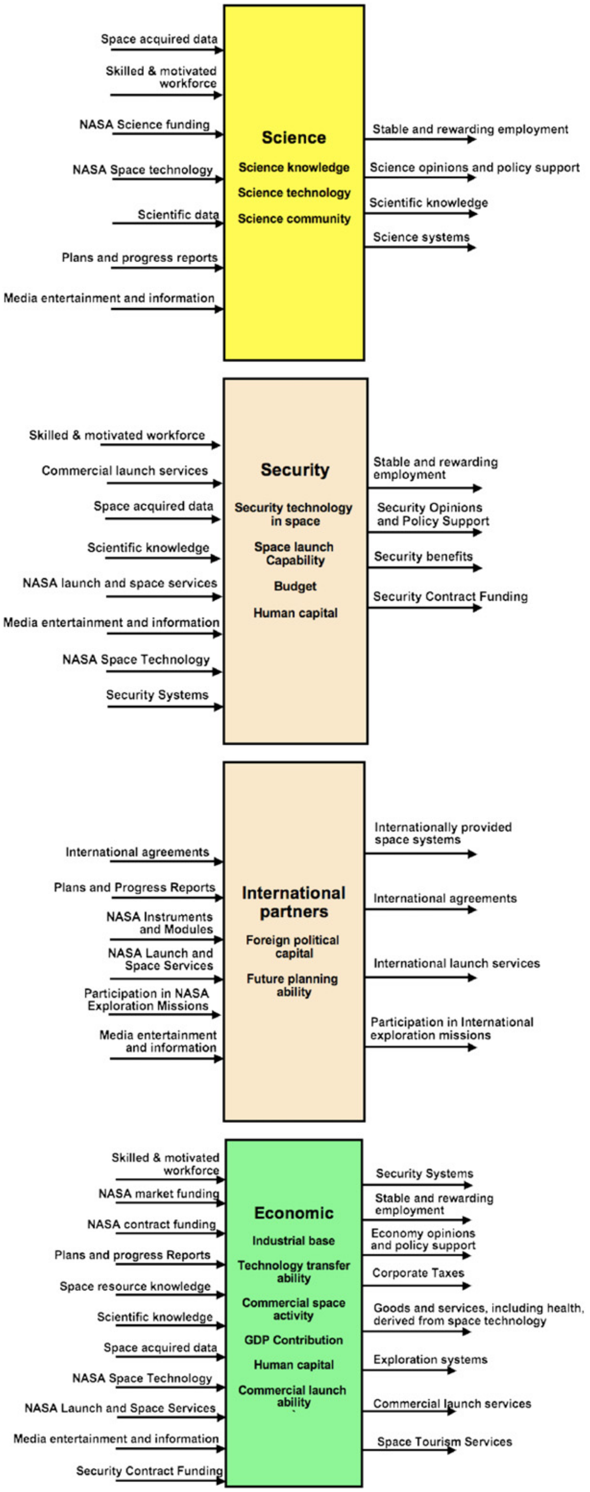
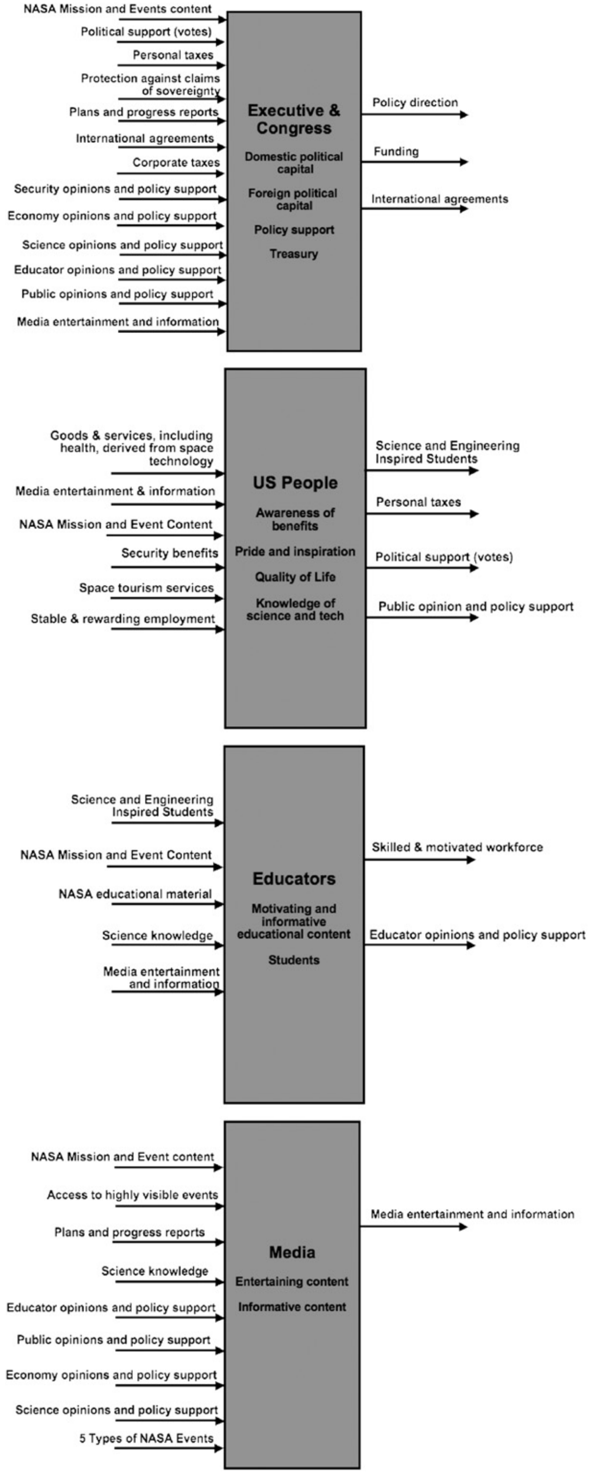


Fig. 2. Stakeholder input–output diagrams.



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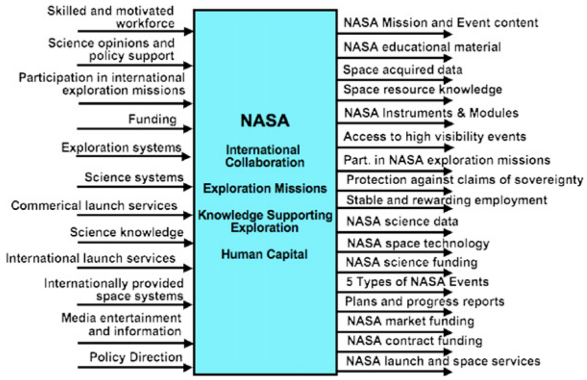

Fig. 2. (*continued*).

one should chose the minimum number of stakeholders that will capture the important outflows of the value creating organization. For example, we abstracted the military space interests as "Security", despite the fact that it is made up of the three branches of the military plus associated agencies, because they all have similar needs from the NASA perspective. The key is to converge on a level of detail that is uniform through the system, and that communicates the important concepts.

It is important to make the distinction between stakeholders and beneficiaries. Beneficiaries are those parties that receive benefit from the organization, but do not contribute resources or hold a stake in the organization. A beneficiary for NASA could be the Department of Agriculture, which may use the results of in-space terrain mapping, but is not dependent on NASA in order to accomplish its mission, nor does it contribute to NASA's mission. It is desirable to exclude beneficiaries who are not stakeholders in this analysis, because they will never close the value loop back to the value creating organization. Beneficiaries often form a superset of stakeholders—we took the approach of identifying all beneficiaries, and then culling the list to remove those that are not stakeholders, using the filters mentioned above.

Having identified the stakeholders, the next step is to capture their needs, in order to determine how value is created.

3. Discovering stakeholder needs

In this section, we determine the needs of all stakeholders. This process will help identify conflicts between stakeholders, to the extent that their needs conflict or are synergistic. Additionally, needs form the true metric by which an architecture's value to stakeholders is determined.

We used three techniques to elucidate needs.

First, we asked "Which inputs were required by the stakeholders?". For example, scientists clearly require science data, and commercial launch providers (within the economy stakeholder group) need customers in order to generate revenue.

Second, we asked "What are the outputs of the value creating organization, and who they are provided to?". The question then becomes, what needs are these outputs satisfying? For example, NASA is charged with inspiring the American youth to pursue science and engineering careers [12], which suggests that the American people have a need to be inspired by exploration. However, it is important that needs are not created simply to match outputs. Those outputs that do not link to true needs do not deliver value—these are an important output of the analysis, and will be treated separately.

Third, we combinatorially paired stakeholders other than the value creating organization, and asked whether there are relevant transactions that play out between them. Understanding which transactions are relevant becomes clearer once the value loops have been identified and labeled, but at this stage, it is best to err on the side of discovering more needs.

Typically, the difficulty is not in listing needs, but rather in culling the list of needs for the independent and salient entries, such that they can reasonably be mapped to stakeholders. Our process generated 81 stakeholder inputs, for a total of 48 distinct needs, ranging from 'protecting against foreign claims of sovereignty' to 'attract a skilled and motivated workforce'. These were recorded in input–output diagrams centered on each stakeholder (and the value creating organization), shown in Fig. 2.

Each of these needs represents a possible requirement on NASA's architecture. In order to downselect to the requirements that will be satisfied, we have to determine how needs are related to value, which will be accomplished by modeling stakeholders.

4. Modeling stakeholders

Having documented all of the needs of stakeholders, the question becomes 'How are needs related to value delivery?'. We postulate that the delivery of value is often related to the core objective(s) of each stakeholder—the next step is therefore to model the objectives of stakeholders. Our aim here is to explain how and why each stakeholder transforms the inputs they receive (according to their needs) into outputs they produce.

We model each stakeholder using three attributes:

To: An objective function or purpose.

To attain life, liberty and the pursuit of happiness

By producing outcomes, and other outputs, including:

- Science and engineering inspired students
- Tax revenues
- Political support for Executive and Congress (voting)
- Policy support for NASA (enabled by knowledge of the assets derived from NASA)

Using the following assets directly or indirectly derived from NASA

- Goods and services, including health, derived from space technology
- Media entertainment and information
- NASA mission and event content
- Security benefits
- Space tourism services
- Stable and rewarding employment

Fig. 3. To–By–Using for the US People.

By: A listing of processes and outputs used to accomplish the purpose.
Using: A listing of transferable assets and inputs required to execute the processes

This model has several key ideas embedded in it. First, all stakeholders have different goals, as embodied in the 'To' statements. The outputs of the value creating organization are used to satisfy a range of different stakeholder goals. Second, each stakeholder can be measured relative to their ability to produce the outputs of the processes listed under 'By'. Third, 'Using' highlights the transferable assets and inputs that stakeholders require NASA to provide. These transferable assets and inputs then help define the requirements for NASA's architecture.

For example, we represented the Objective of the US People as 'To attain life, liberty, and the pursuit of happiness'. This suggests that somehow, each input should be related to the objective. For example, 'life' suggests that health must play a role, which reminded us that significant physiology research is conducted by NASA, and should somehow provide value to the US People. An example of a 'To–By–Using' model is provided in the Fig. 3.

The 'To–By–Using' model is clearly related to the input–output diagrams of Section 3. The added complexity provided in the 'To–By–Using' is an exercise provided to help discover additional inputs and outputs, by providing a logical model that links the inputs to the outputs within a stakeholder. We captured part of this input–output connectivity by listing 'internal assets' for each stakeholder on the input–output diagrams (Fig. 2). Each internal asset represents a measure of the satisfaction of a stakeholder objective. For example, we list 'Quality of Life' as an internal asset for the US People, which is derived from the objectives 'Attain Life' and 'Pursue Happiness'.

5. Value flow: connecting outputs to inputs

Having modeled each stakeholder individually, the next step required is to connect the stakeholders together, using the inputs and outputs that have been discovered.

At this stage, many of the output-to-input (stakeholder to stakeholder) connections have already been formulated in the mind of the modeler, and are easy to connect. For example, having listed 'Science knowledge' as an input to the educators, it is clear that this derives from an output of the Science stakeholder. The value of this step comes when the modeler discovers inputs that have no matching output, or outputs that do not connect to an input. Given the criteria we used to identify stakeholders, it is not desirable to have unterminated value flows. This dynamic reinforces the iterative nature of this modeling process, where inputs and outputs are deleted and created. This approach represents a systematic process that can help identify areas where value delivery is poorly understood or executed in the systems being modeled.

The key to resolving many of the output–input discrepancies revolves around the level of detail created in the model. We chose a low but uniform level of detail for this initial effort, analogous to a crude macroeconomic model of the US economy. In this manner, we represent the steady state conditions, rather than enter into the complexity of an event-driven model. For example, International Partners provide 'International Space Systems' to NASA, rather than providing the 'Leonardo Module' for a specific flight to the International Space Station. This also facilitates the connection to exploration architectures, in that it recognizes that all architectures should provide the same type of outputs to their stakeholders, and obviates a need to create separate value network models for different architectures. In this sense, the model we have created enables a realistic representation of both the Apollo- and Shuttle-era architectures, net of differences in scope between these two and the current VSE.

The resulting value network is illustrated in abbreviated form in Fig. 4. A select group of value flows is illustrated, as the full set containing 81 links is too complex to illustrate on a small diagram.

It is useful at this stage to clarify some of the terminology used. We use the term *Value Flow* to mean the connection of an output to an input in the model—it is the provision of value from one stakeholder to another.

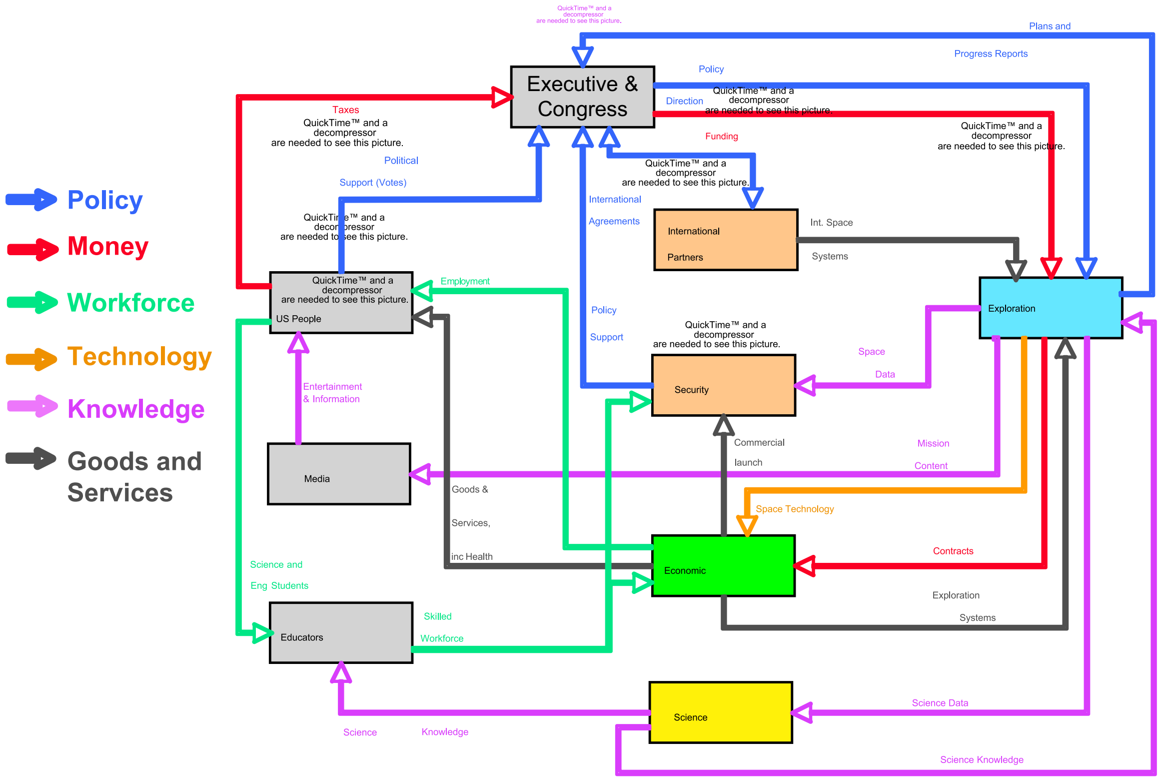

Fig. 4. Condensed value map (not all links shown).

An individual value flow is uni-directional, and does not necessarily imply a return transaction.

The term *Value Chain* will be used to mean a collection of Value Flows, connected by stakeholders. For example, "NASA provides Science Data to the Science community, which provides Science Knowledge to Educators" would be a value chain starting at NASA and ending at Educators. Typically, in doing so, we are implying some sort of causality, in that participants in the chain have a responsibility or objective to propagate value. A well-formed value chain should be explainable in terms of an obligation or incentive connected to the 'To' statement of the stakeholder at that link in the chain. For example, the reason Science creates science knowledge from science data is related to Science's objective 'To create new scientific knowledge and thought'.

Finally, we use the term *Value Loop* to denote a Value Chain that returns to the starting stakeholder. Value loops are at the heart of this mapping exercise, in that they illustrate which stakeholder needs are satisfied by strong feedback loops, and which needs are not well satisfied. An example of a loop is "NASA provides inspiration to the US People, who provide political support to the Executive and Congress, who rewards NASA with funding". By building the model up from a series of value flows, the process fosters creativity in loop identification, in that we can examine many possible chains of value flows to determine if they help explain real behavior. For example, by combining value flows we created the loop: "NASA provides launch contracts to the Economic community, which provides launch services to the Security community, who in turn could provide support for NASA to the Executive for NASA funding". This stimulated the idea that that the Economic community has a commercial launch industrial base, such that NASA purchasing launch services indirectly helps the Security community's need for launch services. However, not all combinations of value flows yield realistic value loops. An example of a less useful loop would be "NASA provides Space Technology to the Security community, which as a result, provides Security Contracts to the Economy", because there is not a causal link between Space Technology and Security Contracts.

We categorized individual value flows into six categories, in order to examine whether most value loops are constituted of similar flows. The six categories represented in our model were:

(1) Policy—Flows that relate to the motivation or transaction of policy decisions. Ex. Political Support, International Agreements.
(2) Money—Flows that represent funds changing hands. Ex. Corporate Taxes, NASA Market Funding.
(3) Workforce—The flow of employment and job-related expertise between different stakeholders. Ex. Skilled Workforce, Stable and Rewarding Employment.
(4) Technology—Sharing of technology between stakeholders. Ex. Space Technology flowing from NASA to the Economy.
(5) Knowledge—The transmission of knowledge from one stakeholder to another. Ex. NASA provides Space Resource Knowledge to the Economic community.
(6) Goods and services—The transaction of actual technical goods and services. Ex. International Space Systems.

We observed that the majority of the value loops are composed of several types of flows. This implies that there are several conversion steps that happen within a stakeholder to transform, for example, a skilled workforce input into exploration system output. These transformations are accomplished by the organization's business and cultural processes—we simply observe that connections between stakeholders are less tangible when there is a conversion of flow type.

In the process of creating the model, a number of modeling decisions were made to simplify value loops, in order to make the model easier to understand. The key decisions are described below.

We abstracted the workforce flows by asserting that the US People are the source of science and engineering inspired students. These students are provided to the educators, and then become the source of a skilled workforce. We chose to represent the body of experience within the educators, because it is simpler than representing skilled workforce flows between all actors, and because the educators are the only stakeholder for whom educating the workforce is a central goal. When we add to this the value chain that describes the Economy and Science support for NASA funding in response to stimulating students, we create a value loop termed the "Inspiration Loop". The build up of the industrial base is then captured separately within the Economy.

Universities are cleaved into the research function, which is stored under Science, and the education function, which is stored under Educators. Science knowledge is then passed from Science to Educators, in order to enforce the connection.

Science missions are lumped under NASA, rather than under Science. We show a flow of a Science Funding to the Science community, which returns Science Systems through to NASA. NASA then operates all science missions, return Science Data to Science, who then return Science Knowledge and Science Opinions to NASA.

We show reciprocal international agreements being transacted between the International Partners and the Executive and Congress, rather than directly between the International Partners and NASA. We then require that the Executive provides policy direction to NASA related to these agreements. However, actual Systems are transacted directly between NASA and the International Partners, such as International Space Systems and NASA Instruments & Modules.

6. Discussion and conclusions

6.1. Observations

The central observation derived from this exercise is that many important value loops have long paths to closure. For example, the "Inspiration Loop" moves through five stakeholders, and contains six separate value flows. The "Commercial Launch" loop, whereby NASA helps stimulate a commercial launch industry for the benefit of the Economic and Security communities, in return for funding support, contains three stakeholders. Indeed, the vast majority of the loops that end with NASA Funding are circuitous at best. This contrasts strongly with typical business transactions, where money is exchanged directly for goods and services.

The length of these loops implies that value delivery is often an indirect process. We postulate that the probability of a loop breaking scales with the number of links in the chain. One could also make a reasonable inference that the number of stakeholders in a loop will increase either the probability of failure, given the difficulty of coordinating several actors, or the extent of the resources that must be dedicated to preserving the function of that loop.

Additionally, we observe that there are many pathways that can lead to the same end result. For example, many of the stakeholders in the model provide Opinions and Policy Support for NASA to the Executive. There are therefore a number of policy avenues NASA can pursue to increase support for its programs. A more nuanced approach, however, might suggest that a minimum base of support from each is required.

Our analysis suggests that benefits are not always clearly linked to the root provider of value. At the level of abstraction used in this modeling effort, we observe that each stakeholder group employs a number of complex processes to convert their inputs to outputs. We also noted that value chains often modify flow types. To make matters less traceable still, value delivery to a given stakeholder is primarily focused on the immediate input they receive, rather than the value chain that leads to that input. We believe that enhancing traceability and awareness of benefits derived from NASA are therefore central to NASA mission and survival. Each flow within a loop represents an opportunity to interact with stakeholders to improve NASA branding and value delivery.

Finally, we return to the end goal of value analysis: satisfying stakeholder needs. While the value decomposition that we have pursued here suggests that individual value flows are independent, this is not necessarily the case. Indeed, the process of rationalizing and culling needs brought out several reference modes. They are:

(1) common needs,
(2) synergistic needs,
(3) conflicting needs,
(4) orthogonal needs.

Common needs are the easiest to recognize—for example, both NASA and Security have a need for a skilled workforce. Synergistic needs result when the satisfaction of one need acts to help satisfy another, or when the same action acts to satisfy different needs. Synergistic needs often result when two stakeholders are connected to each other—for example, satisfying the media's need for 'Access to high visibility events' helps satisfy the US People's need for 'Entertainment and Information'. Another example of synergistic needs occurs when launching a spacecraft satisfies both the Economic community's need for 'Contracts' as well as the Science community's need for 'Science Data'. Conflicting needs are significantly more difficult to recognize, because they often result from an external constraint—such as the conflict between 'Gather science data' and 'Test new technology in space' under the constraint of fixed funding. Orthogonal needs are needs that are not influenced by the satisfaction of other needs—for example, we can say that the US People's need for goods and services derived from space technology is independent of their need for stable and rewarding employment. The reality is in fact that relatively few needs are actually orthogonal, as the satisfaction of a need by an architectural feature often has some implication for cost, schedule, performance, or operational risk.

6.2. Organizational implications

Having mapped out the observations about our network model, we can ask what the organizational implications of this work is.

First and foremost, identifying value loops can help an organization discover who helps in the provision of its inputs.

Second, reducing the number stakeholders and value flows between the organization and the end beneficiary will almost universally improve traceability.

Third, organizations should be aligned to deliver value—that is to say, the valued outputs created by the organization should be clearly traceable to responsibilities, processes, and incentives within the organization. Recognizing that these outputs constitute the totality of the organization's impact on its environment highlights their importance. Given that these are the products by which the organization will be judged, responsibilities should be clearly delineated and monitored over time.

Fourth, facilitating important delivery paths at stakeholder nodes may provide opportunities to reinforce or amplify the organization's role in delivering value.

Fifth, building common understanding *among* stakeholders can help reinforce key messages in a distributed fashion. For example, reinforcing a message that NASA provides health benefits to the population, and strengthening communications opportunities among relevant stakeholders, may eventually lead to a conventional wisdom that "NASA does life science research", at which stage stakeholders will form a distributed communications network for NASA. Likewise, the value of reinforcing aspects of NASA's work that are already in the conventional wisdom may not prove to be high-leverage activities.

In addition to building awareness of benefits, we believe this work has implications for the derivation of requirements for a value creating organization. By enumerating all of the possible needs, and then illustrating how the dynamics between needs can be represented using a network, we have defined the full space of considerations that the requirements will need to capture. We have also illustrated how needs can be represented by outcomes and transferable assets. The corresponding requirements are then easy to write—produce the necessary transferable assets and inputs. Additionally, by pre-processing for conflicting needs well before they become conflicting requirements, we believe significant waste can be eliminated in the design process. The process of requirements writing embodies a number of decisions on which needs to satisfy—it is our belief that if these decisions are informed by a broader base of information, then the architecture will be better prepared to operate in a sustainable fashion.

6.3. Future directions

While holistic analysis of this type is useful for gaining a sense of how value is created and transmitted, we hope that in the future it will be possible to overlay architecture models on this framework, and then compute which needs are best addressed by different architectures using sensitivity analysis. A system of proximate metrics to link architectural parameters to value delivery will be required. While this is not outside the scope of current capabilities, proximate metrics would benefit greatly from additional study. Furthermore, there are important gains to be made by combining more network theory with value maps, for computation of shorter paths, pruning opportunities, and maximum flow problems. Lastly, we believe that this work could be extended to include a more structured analysis of 'policy options' available to a given stakeholder in the model, with which one could investigate how the diversity of stakeholders and the length of value chains affect end value delivery.

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