ALFRED P. SLOAN FOUNDATION
Industry Studies
Annual Conference | May 1 - 2, 2008 | Boston, MA
2008
http://web.mit.edu/is08/program

Sustaining the Nation's Aging Infrastructure Systems

Lessons Learned Applying an Asset Management Framework

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Abstract

Infrastructure systems permeate society at both the personal and business levels. These systems are taken for granted, but the implications of system breakdowns are staggering and directly impact our national competitiveness, having both immediate consequences and long lasting effects on the local, regional and national economies. Many of the infrastructure systems found in the United States have been in place far beyond their design lives. How does an organization manage these aging assets given constrained resources?

This paper presents an innovative research and problem formulation method created as part of an effort by the United States Army Corps of Engineers' to develop an Asset Management Framework (AMF) to manage its aging civil infrastructure assets. This paper outlines the development of the framework using an intent-driven command and control approach, grounded by the input from dozens of practitioners, gathered through a series of interviews, surveys, and field studies. The paper describes mechanisms used to bring together economists, biologists, civil engineers, and others to create a robust AMF.

The AMF will be illustrated showing transparent integration of preservation and risk mitigation initiatives, as well as budget and resource allocation processes supporting a lifecycle investment strategy for sustainability across the entire agency. The Framework's scope includes oversight of much of America's watersheds covering 1,000 coastal structures, 800 dams, 250 navigation locks, 75 hydropower plants and other assorted facilities. Lessons learned in developing this system are provided, along with its current status. The implications of this work to other industries and pubic sector agencies will be examined.

I. Systematically Managing Assets: A Case Study

Purpose and Consequences

The United States Army Corps of Engineers (USACE, also referred to as the Corps) serves the Armed Forces and the Nation by providing vital engineering services and capabilities in support

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of national interests across the full spectrum of operations, from peace to war,. The scope of the project described here is limited to the USACE Directorate of Civil Works which is a major component of the USACE. Civil Works programs are organized into eight business lines (Emergency Management, Environment Restoration and Stewardship, Flood Damage Reduction, Hydropower, Navigation, Recreation, Regulatory, and Water supply) that are responsible for achievement of the USACE mission.

Asset Management is at the foundation of the USACE's Civil Works Directorate's effort to manage the nation's watershed assets for the safety of our citizens, the continuation of the Nation's economic viability, protection of the environment, and sustainment of quality of life. Asset management has always been a key priority within the Civil Works Directorate as it directs projects in four broad areas: water infrastructure, environmental management and restoration, response to natural and manmade disasters, and engineering and technical services to the Army, Department of Defense, and other Federal agencies. Recently, Congress and the President have directed the USACE to formalize its asset management process so the USACE can effectively and efficiently achieve its mission.

Asset management decisions include when, at what level, for what period, with what organizational unit, and how to monitor the process of investigating, developing, operating, maintaining and/or decommissioning an asset (or system of related assets). These key asset management terms are defined as follows:

def.: Investigate – a study to determine which, if any, other decision should be made for an asset or a watershed (i.e., a study of a watershed to determine whether an asset should be developed for some purpose within that watershed)

def.: Develop – creation of a new asset or to significantly change the level of service for an asset (i.e., construction of a new lock and dam, or addition of additional lock chambers to an existing lock and dam)

def.: Operate – operation of an existing asset for a purpose at a given level of service (i.e., allocation of the staff and other resources needed to operate a specific lock and dam continuously). Operations included here to ensure total cost of ownership decisions are made while evaluating alternative treatment possibilities.

def.: Maintain – performance of some maintenance action on an asset (i.e., replacement of gates on a specific lock chamber)

def.: Decommission – decommission and removal from inventory of an asset (i.e., drainage of a pool and demolition of the dam structure, or transfer of ownership to another organization)

Sustaining the Nation's Aging Infrastructure Systems

Lessons Learned Applying an Asset Management Framework

Asset management involves the allocation of limited resources over time to investigate, construct, maintain, and ultimately dispose of physical infrastructure in a way that maximizes value. Asset management is a complex process of feasibility and value, trading off, and balancing competing needs for the scarce budget. An asset management framework provides the structure and principles within which asset management decisions can be made

Background

The passage of the Government Performance Results Act of 1993 began a process to improve the results of federal investments and programs. Policies and practices have been reformed to improve procurement processes, accounting processes, human resource management, and federal real property management. In 2003, federal real property management was still identified as an important challenge to the federal government because of significant problems with excess and underutilized property, deteriorating facilities, unreliable data, expensive space, and poor physical security (GAO 2003). In 2007, federal real property management has improved, but it is still an important challenge with many of same issues previously identified in 2003, with the additional issues of competing stakeholder interest and legal and budgetary limitations (GAO 2007a).

The USACE owns and manages a diverse and extensive portfolio of watershed infrastructure assets. The value of USACE water resource infrastructure assets ranks among the top five of all Federal agencies. Under direction of the Federal Real Property Council (FRPC) and the Office of Management and Budget (OMB) and to achieve compliance with their directives, the USACE published its Asset Management Plan (AMP) in 2006. The plan described the Asset Management Framework (AMF) as the next step in providing consistency and transparency in asset management throughout the Civil Works business lines. In early 2007, our team at The University of Alabama's Aging Infrastructure Systems Center of Excellence (AISCE) was chosen to help with this plan.

A high-level illustration of the initial AMF chartered by the 2006 USACE Asset Management Plan is shown in Figure 1. The initial USACE position, based on Office of Management and Budget's (OMB) mandate, included the "garbage can", representing divestment, because a primary aspect of the OMB initiative was to reduce the inventory of federal government "owned" assets.

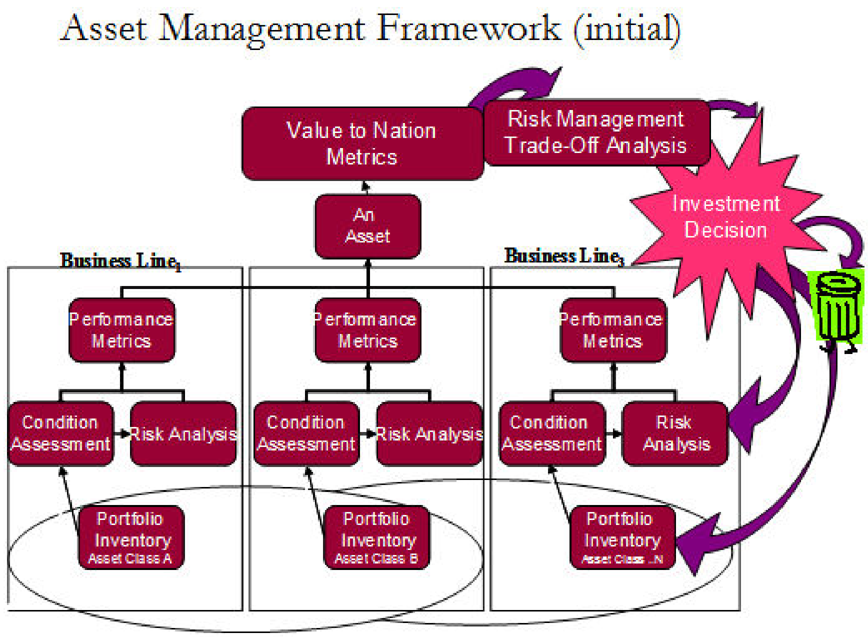

Figure 1: Initial AMF

Our participation in the Asset Management project predates the formation of the AMF team. In August 2005, Dr. David Hale participated in a Joint USACE/U.S. Department of the Interior workshop to identify and prioritize key components of Asset Management. The 150 participants broke into business lines (navigation, hydro-power, recreation, environment, etc.) to brainstorm and select components. In August 2006, the AISCE held a second workshop to verify the prior year's results and to present the Asset Management Plan. Again, over 100 participants broke into business line groups to respond to the AMP, identify a series of issues concerning asset management, and identify principles upon which to build asset management within the Corps.

Data Collection

In January 2007, the AMF team was established, which included members of Corps business line staff, an economist from the Oak Ridge National Labs, and the UA-AISCE team. We performed an initial review of:

- documents describing point-solutions being developed in existing projects,
- issues identified at the August 2005 and August 2006 workshops, and
- the Asset Management Plan.

The goal of our review was to understand the current state of asset management at the USACE and to initiate the formulation of a solution framework. More specifically, the goal of the initial review was to assess current decisions, metrics and data that were available for AMF creation. Based on this review, a gap analysis was performed that mapped current asset management decisions to specific metrics and data sets required to feed each metric. This assessment was then compared to stakeholder issues. Gaps helped identify the investigative areas.

A preliminary AMF was presented for feedback from the USACE AMF steering team comprised of Corps executive leaders. Based on initial findings, site visits were conducted to refine the model and to verify that field execution matched documented processes. In all, we conducted 9 site visits over a period of 18 months. These site visits were supplemented with 14 conference calls, two Corps-wide conference presentations and further supplemented with individual phone calls, emails, and working document exchanges. An electronic document repository was created to manage the information collected concerning business lines, budgeting processes, asset assessment methods, data sources, interview summaries and project risk factors. The participating Corps personnel represented a cross section of executives, managers, and specialists across a diversity of organizational levels, functional tasks, geographic location, and business lines. As a group, they held a wide variety of backgrounds and specialties including: engineering application, economics, real estate, budgeting, engineering research, administration, and science.

The Challenges of Managing Assets: Current State

The USACE is over 200 years old and has been managing its physical assets from conceptualization to retirement for two centuries. We have found that the USACE has dedicated, responsible, highly educated individuals managing USACE assets. Our study reveals the following asset management challenges that need to be addressed in order to more effectively manage its assets and meet the requirements of OMB.

The size of the inventory is large and diverse: The USACE owns and manages a diverse set of watershed infrastructure assets including over 43,000 structures, 285,000 tracts of land and 12,000 buildings. These assets range from 1,000 Coastal Structures and 600 Dams to 2,500 Recreational Areas, 250 Navigation Locks and Dams and 75 Hydropower facilities. USACE assets constructed in a watershed become features of and impact the watershed. These man-made watershed features change the behavior of the watershed system and may provide additional watershed properties such as redundancy (i.e., more than one lock chamber in a lock and dam asset) and cascade (i.e., when the lock is not operational, none of the adjacent upstream or downstream locks can achieve their goals).

Some watershed features not traditionally accounted for as assets: Features of the watersheds have not been on the USACE balance sheet and thus are not ordinarily considered "assets." However, they may become watershed improvements that are needed to achieve the functional goals of the USACE. For example, a river channel that is dredged is modified and measured in order to make it navigable. These measured or modified watershed features are non-traditional assets that should be conceptualized in the asset management domain as lease-hold improvements.

The age of assets is causing increased maintenance costs and performance issue: In recent decades the USACE has shifted from a construction centric organization to an operations and maintenance organization. This shift coupled with assets at or nearing the end of their design life results in USACE' assets that are on the verge of not providing the public with the level of service that the Corps has guaranteed in the past.

The increased pressure to do more with less: The USACE is competing for public resources in a time of constrained revenues and more competing demand for the same federal dollars to fix roads, bridges, fresh water, waste water, estuaries, parks, etc.

The Office of Management and Budget strives to "right-size" Government: As requested by the President, OMB has asked that all agencies review their real assets to determine which of them could be privatized. In most agencies this refers to buildings. However in the USACE, this pertains to dams, levees, power plants, natural areas, etc. Metrics and procedures that apply to office buildings do not necessarily readily transfer to the USACE asset base.

Communication and goal alignment: The diversity of the participants combined with a business unit-centric view of asset management has often created a communication issue for our AMF team. That is, drop-in attendees (e.g., attendees that had not been aware of the AMF project, processes, and prior work) to periodic AMF briefings sometimes left with the belief that the process was either mired in detail or was, at the other extreme, too superficial. Thus drop-in attendee management became critical so that individuals were not so focused on one of the facets of the problem (i.e., process, organizational change, current organizational practices, analytics, objectives and metrics, specific business lines, stakeholders, communications, budgets, etc.) that other important facets were lost. Others were educated to the complexity of the problem space so that they were able to provide feedback on the holistic view that the AMF team was trying to render.

External stakeholder reprioritization: Ultimately, the USACE budget represents political realities. Congress and the executive branch negotiate the final budget based on their beliefs. The USACE is not allowed to lobby Congress.

Managing assets as contributing to a single function: A citizen visiting a dam may see that it provides a pool of water that is used by a city for drinking water and the county as a park, while environmentalists see the estuary that it feeds, and emergency management planners see its use in flood management. But if Congress authorized the Dam for another function, perhaps navigation by barges, the only metrics traditionally and by statute used to determine its priority for repair, rehabilitation, replacement or disposal would be navigation. Multifunctional use across business lines is out of the norm.

Geography v. organization structure: Four levels of the USACE organizational hierarchy exist: Headquarters, Division, District, and Project. Project represents a major asset structure and is the lowest level of funding request. While this is a straightforward and common structure, the organization boundaries do not align with watershed system boundaries. Two or more organizational units may have responsibility for different portions of the watershed making watershed system planning more complex. Additionally, the inter-relationships among the watershed systems cause decisions made by an upstream organization to impact downstream organizations.

The Business Lines v. Organizational Hierarchy v. Watershed: Business lines represent the diverse set of intents which the USACE is striving to achieve. These desired intents systemically interact such that competition cannot be avoided. For example, the need to build a dam to control flood damage, generate hydropower, and to create a water supply must impact the natural ecosystem that is to be stewarded and will impede transportation on the river. The balancing of these intents and dealing with the sometimes incompatible units of measure that they require makes a satisfactory systemic outcome a significant challenge.

Flood Risk Management: One of the elements of the USACE mission is to mitigate and / or be resilient to extreme events. Extreme events may be man-made such as overt aggression (i.e., attacks by terrorists) or accidents (i.e., oil spills); alternatively, extreme events may be natural (i.e., floods, earthquakes, and hurricanes). Some USACE business lines are directed to prepare for or prevent the impacts of extreme events. Thus, although everyday performance is an important aspect of USACE asset management (i.e., navigation, hydropower, water supply, and the environment business lines), risk mitigation, especially with regard to extreme events, is equally, or in some cases more, important (i.e., flood damage reduction and emergency management).

Modeling the Watershed: A watershed is a hierarchical system such that a "large" watershed is comprised of successively "smaller" watersheds that can be further decomposed into watershed features and sub-features. These watershed components are interconnected and interdependent such that an outcome imposed upon a relatively small feature of the watershed can have impacts elsewhere. Modeling these system effects is critical to understanding how to change the watershed behavior in desired ways, but is also very complex due to these interdependencies.

Systems Planning v. Project Execution: Much of the asset management process deals with planning rather than project execution. Planning occurs to secure funding; a routine USACE budget request must be made to Congress three years prior to the acquisition of the funds. Consequently the Corps must anticipate the state of need well in advance of a breakdown. A sensor and monitoring system capable of detecting, identifying, and prioritizing symptoms, pre-cursors, and triggering events is needed. Accuracy is important, precision is much less important. This is contrary to how many of us have been trained as scientists and engineers to produce and use project level data. Similarly, many of the systems used by the USACE rely on generating precise prediction more than showing threshold areas of concern.

Analytics Focused on Amount rather than System Effect: Existing metrics are biased toward large single site problems rather than cascading systems effects. For example, using today's asset management system the replacement of a low-cost hinge at a navigation gate may be critical to prevent cascading and costly failures (due to a lack of redundancy) but will be prioritized below a maintenance task for funding. However, such a hinge failure could shut down barge travel above and below the lock. The opportunity cost of such a shut down is not systematically included in today's budgeting process.

Combining Structural Assessment, Risk of Failure, and Functional Value: Often cited in our study was the need to combine now-isolated metrics of structural condition, consequences of failure, and functional value for continued operations. To create such an index, multiple targets must be assessed and combined in the problem space.

Proposed Solution: Structure the Problem within the Portfolio Management Context

Portfolio Management principles provide the mechanism to address the asset management challenges raised above. Figure 2 provides an overview of the risk and reward matrix that drives portfolio management decisions (Rudd, Clasing et al. 1988). In the context of asset management risk is replaced with feasibility and reward is replaced with value. One key challenge discussed was that of **External Stakeholder Reprioritization.** Specifically, OMB wants to avoid decisions that are narrowly focused, politically motivated, and experience based. The consequences of these problematic decision processes are sub-optimal decisions that prevent the organization from achieving the kind of results that are demanded from their stakeholders (Sanwal 2007). Portfolio management as a mechanism for making asset management decisions has been recommended for a number of organizations within the federal government including the USACE (CBSPCI, BICE et al. 2004; CC, CAUSACEMAPRWRPP et al. 2004; CCCFEAM, BICE et al. 2007; GAO 2007b).

In Figure 2, each project is shown within the matrix according to its normalized value (e.g., reward, as illustrated by the horizontal axis) and a normalized feasibility (e.g., risk, as illustrated by the vertical axis). The project's position on the matrix is determined by the normalized feasibility and value assessment. Each oval represents a project and the size of the oval indicates relative cost of the project when compared to the other projects in the matrix.

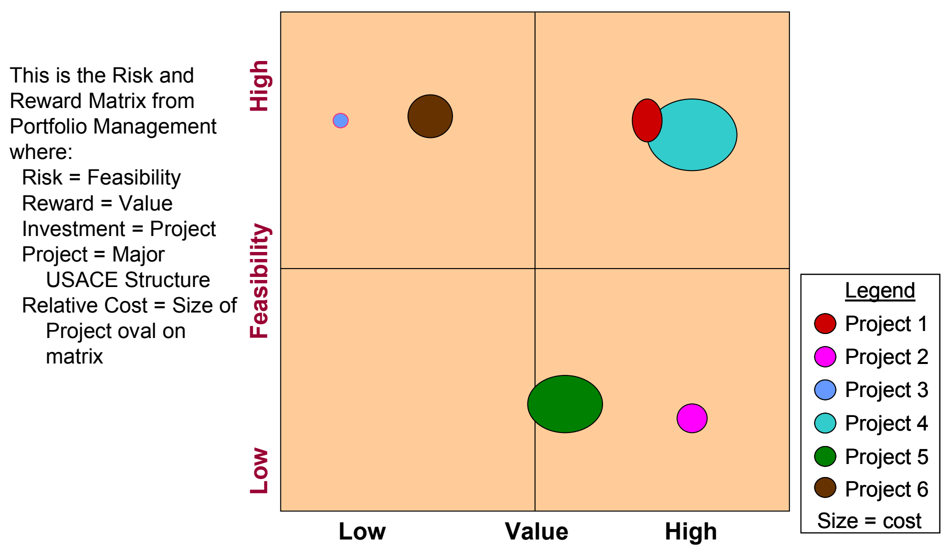

Figure 2: Feasibility and Value Matrices

The last challenge discussed in the prior section, **Combining Structural Assessment, Risk of Failure, and Functional Value**, is illustrated in Figure 3, which displays separate matrix representations for the portfolio management goals that cannot be combined due to differences in unit of measure. For example, Safety is measured in terms of human life and by policy at the USACE; human life cannot be expressed in dollar terms. This means that projects intended to improve Safety conditions cannot be easily compared to projects intended to improve Economic conditions. Likewise, the cost of species loss within the environmental domain is not given a dollar value. Thus, Figure 3 illustrates an asset management scenario encompassing the potential for loss of life (the safety matrix), species loss (the environmental matrix), loss of the public's cognitive "well being" (the confidence matrix) and loss of economic vitality and property (the economic matrix).

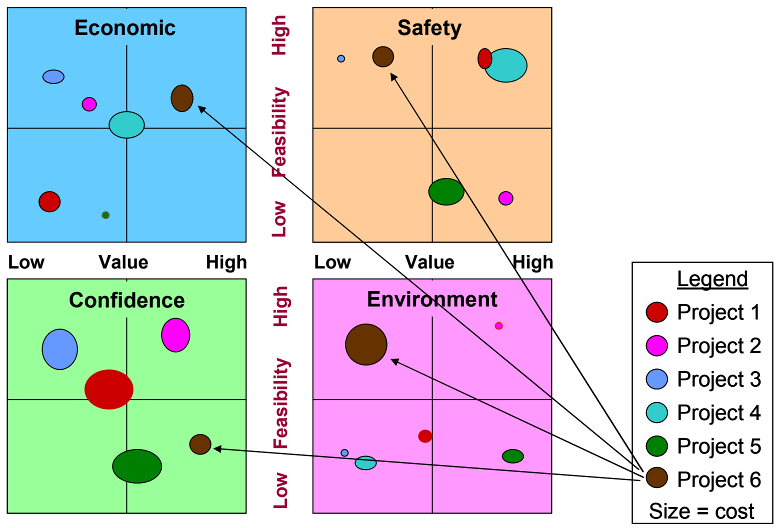

Figure 3: Multiple Perspectives Represented in Asset Management

A similar method is used by the USACE Engineer R&D Center (ERDC) to inform the R&D program of the investment decision process across their Business Areas of Civil Works, Battlespace Environments, Military Engineering, and Installations and Environmental Quality. In the ERDC asset management approach, performance of the "Mission" dimension is based on metrics such as investment in the future, impact, uniqueness of a niche, follow-on opportunities and expertise development. The "Feasibility" dimension is based on the risks associated with technical certainty, resource mix, and transition plan. Expert panels develop weighting for each of the dimensions, and senior leaders within the Corps are then able to view the "portfolio" in a number of ways. An example of the "balance of Risk and Payoff" is shown in Figure 4. Each circle represents a program, each color represents a Business Line, and the size of the circle represents the required dollar investment.

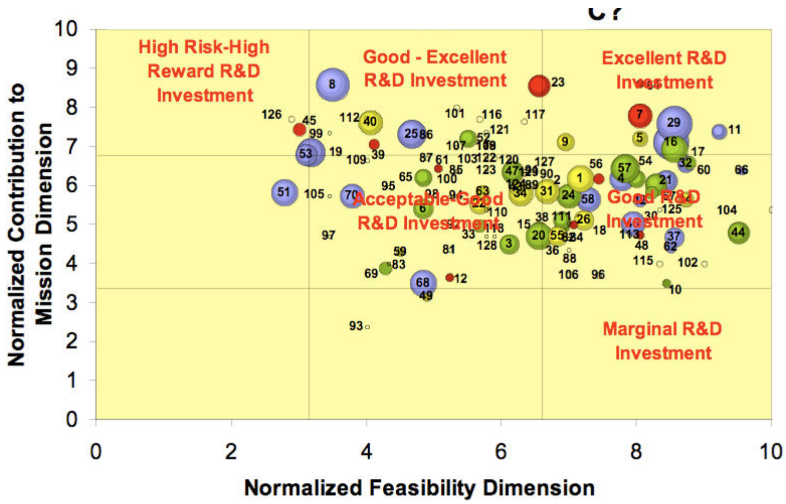

Figure 4: Example Portfolio of R&D Projects

In Figure 5, the pattern of projects appears to be in balance with projects having moderate to high contribution and moderate to high feasibility. The multiple perspectives of the portfolio approach can now be applied to the analysis. In this case, the project being evaluated has low follow-on opportunity value and minor technology impact for future use. Consequently funding for the project was redirected to other projects. A similar approach is planned for infrastructure asset management.

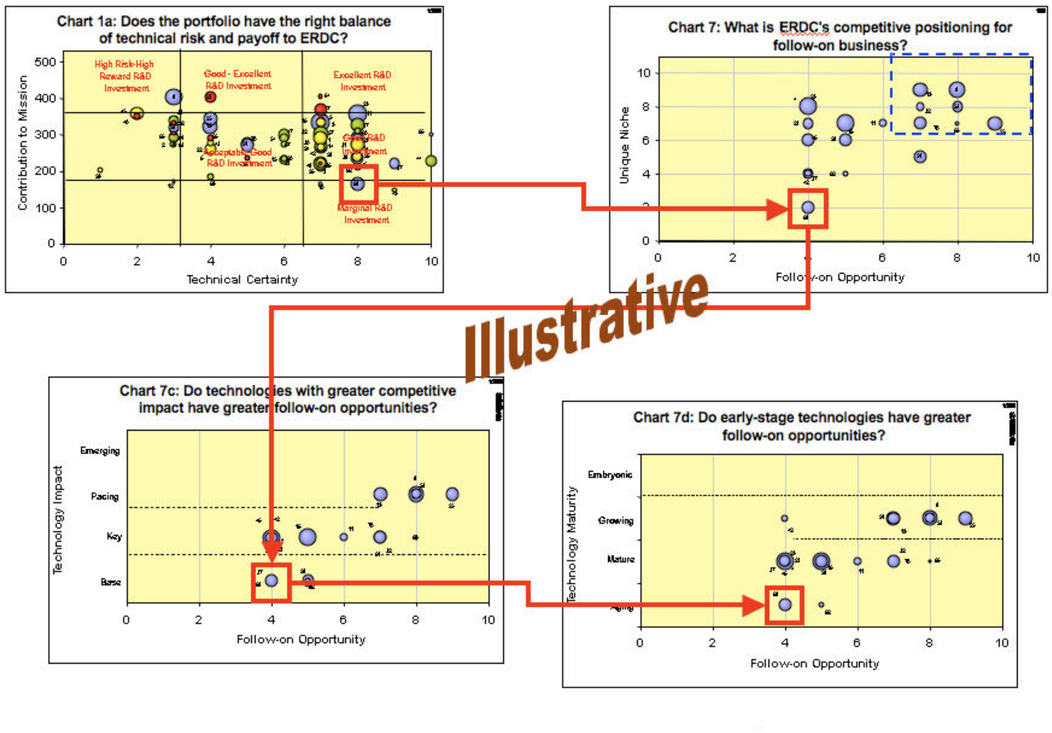

Figure 5: Multiple Visualizations of the Portfolio of Projects

Portfolio management allows decision makers to visualize the complex trade-offs associated with allocating resources among asset investigation, construction, operations, maintenance, and decommissioning projects. Recognizing and analyzing such complexity and interdependency is key to overcoming the challenges listed in the prior section. The project tradeoff visualization provides a communication vehicle that is sophisticated in its ability to analyze a situation, yet can be cognitively grasped by individuals from many disciplines.

II. Innovative Method: Intent-Based Problem Formulation

Arriving at the use of portfolio management as the approach to examine the trade-offs and interdependencies associated with the Corps' mission to management the nation's waterway infrastructure has been a journey of innovation and intense industry interaction. Along the way, we have had to develop new structures to maintain the complexities of the problem space related with concepts, interrelationships and resulting incongruences. The product is an intent-based problem formulation model that meets the needs of the nation and is grounded in theory. While not visible in the above discussion of the proposed portfolio management solution, the intent-based problem formulation model enabled the viability of the asset portfolio management approach within the USACE environment.

Purpose and Scope

We propose that the Intent Resource Agent Architecture (IRAA) approach provides a problem formulation method for industry studies that require a repeatable, rigorous, and generalizable problem domain formulation approach. IRAA supports a fractal approach to problem solving (Witte 1972; Bahill, Bentz et al. 1996) by formulating the problem based on its structure. The structure needed to formulate problems using IRAA are: Intent, Resource, and Agent. These structures are related in predetermined ways. The structure is recursive and each recursion can be viewed as an independent problem domain formulation.

"Intent" is a hierarchical structure that identifies the goals, objectives, measures, and target metrics that define success in a time frame. This structure is identified at the USACE within their eight business lines. These business lines know their agents, or stakeholders, and manage their expectations based on this intent structure. A partial intent structure example is shown in Figure 6.

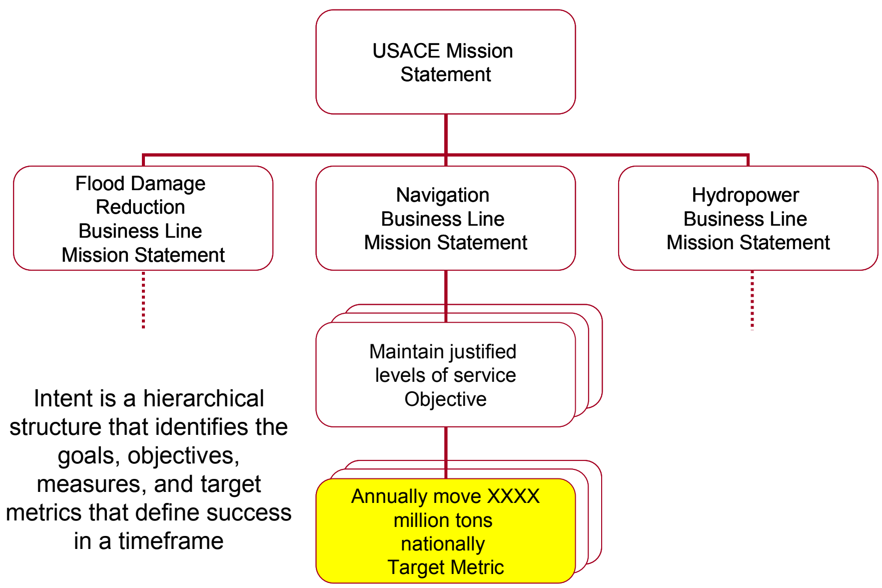

Figure 6: Intent Structure Example

"Resource" may be a hierarchical structure, or a networked structure, that identifies the resources within the system that produce the results measured by the intent. Watersheds are the systems managed by the USACE. Watersheds are identified and broken down hierarchically into systems, sub-systems, and features. Assets are the resources within the watershed system that produce the results measured by the intent structure and assets are identified as features within the watershed that are then decomposed into components. A partial resource structure example is shown in Figure 7.

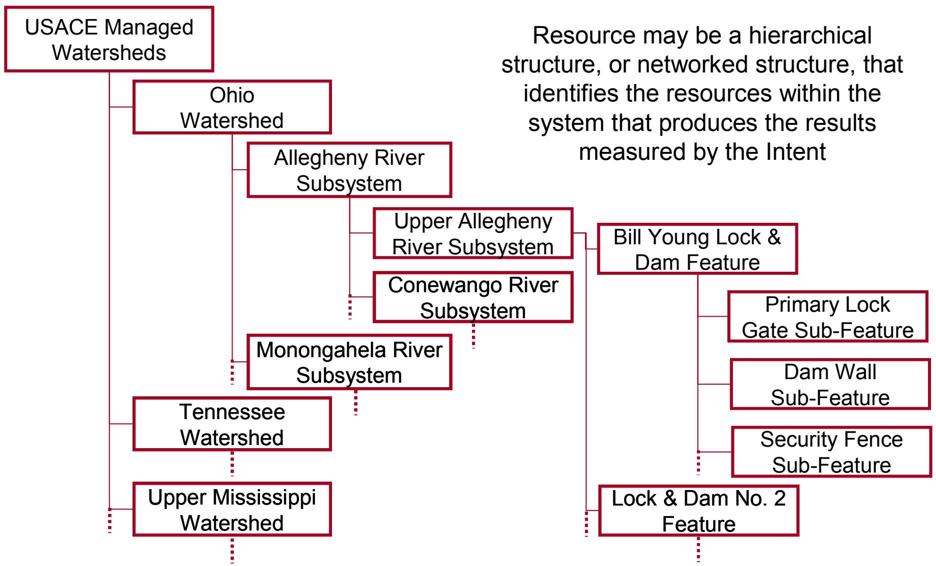

Figure 7: Resource Structure Example

"Agent" is a container class that contains the hierarchical structure that identifies the organizational units that are responsible for intent achievement. The agent structure in the case of the USACE decomposes from Headquarters into Divisions, Districts, and Projects. A Project identifies a major asset, such as a lock and dam, which is the lowest level of funding request. The agent structure is related to the resource structure through a relationship that specifies that the organizational unit is responsible for the performance of the related resource. At the USACE, watersheds, systems, sub-systems, and features are assigned to a Division or District. Assets and their associated components are assigned to the Project level of the structure which is the lowest level of this responsibility assignment. A partial agent structure example is shown in Figure 8.

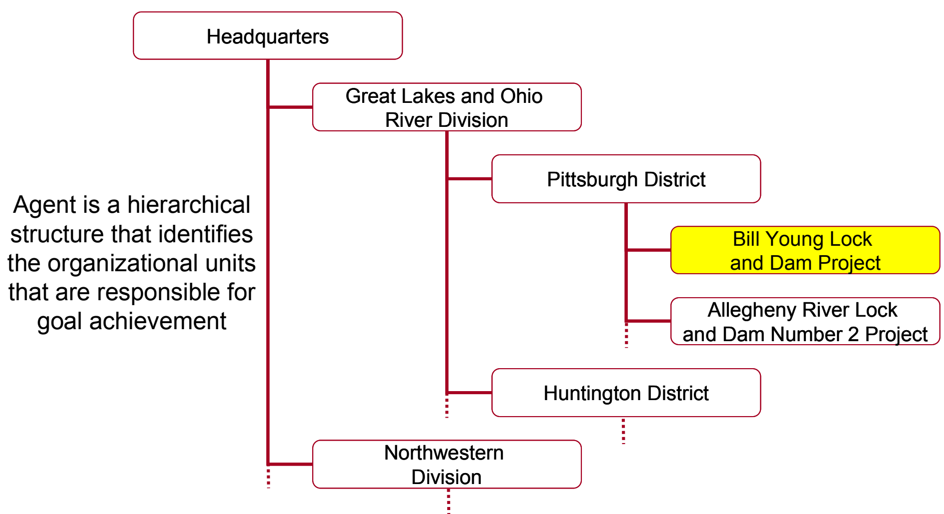

Figure 8: Agent Structure Example

The resource structure is related to the intent structure through an assignment relationship. For example, a USACE lock and dam may be allocated a portion of the total annual transportation tonnage target metric and all USACE levees may be assigned a target metric for ability to withstand a 300 year rain event. The agent structure is related to the intent structure through the agent resource responsibility relationship and the fact that the resource has an assigned target metric. The resource structure is further related to the intent structure through the identification of the required resource condition necessary for target metric achievement. For example, a lock gate condition must be 75% or more of its designed service level to meet the annual tonnage target metric and levee condition must be 70% of their designed service level to meet the 300 year rain event target metric. A partial example of the interaction relationships are shown in Figure 9.

Intent, Resource, and Agent structures interact based on the relationship between Intent and Resource, and between Agent and Resource.

Agent Structure			Watershed Structure	Intent Structure
Division	District	Project		Target Metric Annually move XXXX million tons nationally
Great Lakes and Ohio River Division			Ohio River Watershed	Annually move XXX million tons
	Pittsburgh District		Allegheny River	Annually move XX million tons
			Locks and Dams	
		Bill Young Lock and Dam	Bill Young Lock and Dam	Annually move X million tons
			Lock Structures	
			Lock Walls	
			Land/Middle/River Walls	=> 60% of designed service level
			Guide and Guard Walls	=> 60% of designed service level
			Utility Culverts (X-overs)	=> 60% of designed service level
			Esplanade	=> 60% of designed service level
			Sheet Pile Cells	=> 60% of designed service level
			Mitre Gates and Operating Equipment	
			Gate Structure, Seals & Bearings	
			Primary Lock Mitre Gate 1	=> 75% of designed service level
			Primary Lock Mitre Gates 2	=> 75% of designed service level
			Auxiliary Lock Mitre Gate 1	=> 75% of designed service level
			Auxiliary Lock Mitre Gates 2	=> 75% of designed service level
			Emergency Mitre Gates	=> 75% of designed service level

Figure 9: Interaction Relationship Example[5]

Theoretical Grounding

IRAA is based on the notion of Intent. Our definition of Intent is in alignment with Searle's definition: "intentionality is that property of many mental states and events by which they are directed at or about or of objects and state of affairs of the world" (Searle 1983). We also propose that Intent is the same as Pierce's definition of *Thirdness*. "First is the conception of being or existing independent of anything else. Second is the conception of being relative to, the conception of reaction with, something else. Third is the conception of mediation, whereby a first and a second are brought into relation" (Peirce 1891). This also justifies our formulation of Intent at the nexus of Resource and Agent, as Intent is a mental mediation that directs an Agent's attention to some Resource (Sowa 2000).

We also propose the notion of "required condition" is the same as the notion of Condition of Satisfaction (COS). We propose Searle's definition of a Condition of Satisfaction (COS) that is

[5] In the Intent Structure column the "Annual movement of from XXXX to X tons" is an illustration of a target metric allocation to various units within the Watershed Structure. The symbol "X" is a placeholder for an actual target metric where "XXXX" represents the largest target metric and "X" represents the smallest target metric.

defined within the context of intention. "Intentionality is not an ontological problem (what is a belief really?); the answer has to be given, at least in part, in terms of the logical properties of belief: a belief is a propositional content in a certain psychological model, its mode determines a mind to world direction of fit, and its propositional content determines a set of conditions of satisfaction" (Searle 1983).

We also propose that the recursive structure fulfills the requirements of Simon's definition of purpose (Intent). Fulfillment of purpose involves the relationship between the purpose, or goal, the character of the artifact, and the environment in which it operates (Simon 1996). Whereby, purpose is our Intent, "character of the artifact" is the "required condition", and environment is fulfilled by the structure's recursiveness.

Usage

An important concept when using IRAA is to recognize the duality associated with problem formulation. As shown by the recursive structure, there is a duality in problem formulation such that each domain interacts with at least one other problem domain. In the case of the Corps' Asset Management initiative, the asset management plan included a list of governing principles. A close look at the governing principles identified three problem domains that must be formulated. The first domain was the watershed domain for which there were goals defined by the business lines, the second domain was the asset domain whereby the goals were for the asset conditions to support the watershed domain goals, and the third domain was the budget domain where the goals were to get the most value for the every dollar spent. These were recursive domains in the order presented. The duality is that two problem domains are often worked at the same time. In this case, the watershed domain and the asset domain were worked together and the asset domain and the budget domain were worked together.

Flow

Once the problem domains are identified, the next step is to identify intents, resources, and agents. This is an iterative process that will be top-down, bottom-up, and ink spot in nature, depending on the information currently available. The goal is to fill all the information gaps in the structure. A problem domain is formulated when the following conditions have been met:

- Identify
    - the system resource that produces the results
    - the agents that need results from the system
    - the intents that represent the required agent results
- Decompose
    - responsible agents into an organizational hierarchy
    - intents from goals to target metrics
    - the system resource into component parts
- Relate

- resources necessary to achieve a target metric to an intent using a required condition
- resources to their responsible agent

Typically, the process starts top-down. The system resource that produces results and the agents that need those results are identified. Intents from each agent are identified and the process of decomposition begins for intents, resources, and responsible agents. As intents, resources, and agents are identified in the "middle" of the decomposition, the structure gains detail. This detailing is more of an ink spot process that links lower level intents, resources, and agents to higher level ones and decomposes the lower level intents into additional intents, resources, and agents. As low level intents, resources, and agents are identified, they are linked to, or identify new, higher level ones in a bottom-up process. While the process typically starts top-down, it quickly becomes fractal with the same components and relationships being identified and defined at multiple levels simultaneously.

Completeness

Completeness of the problem formulation using IRAA is indicated by four factors. A primary indicator of completeness is that each intent is associated with the agent who has the intent and a resource system that achieves the intent. Another primary indicator of completeness is that each intent fully identifies the required resource conditions such that when each resource condition is achieved the intent is achieved. Other indicators of completeness entail verifying that each agent has at least one responsibility relationship to an intent or a resource and that each resource has at least one assignment relationship to an intent with a required condition identified. Additions of intents for a resource system expand the scope and are not considered a problem formulation completeness issue. Once these indicators have been verified the problem formulation is complete.

Innovation

The underlying method used here is unique in its ability to support hierarchical problem domain specification and then view the problem domain as a network to uncover incongruences. It is these incongruences that are often the source of organizational challenge. Incongruences are misalignments between intents, resources, and agents. These misalignments cause organizational challenges in areas of common understanding and management of expectations.

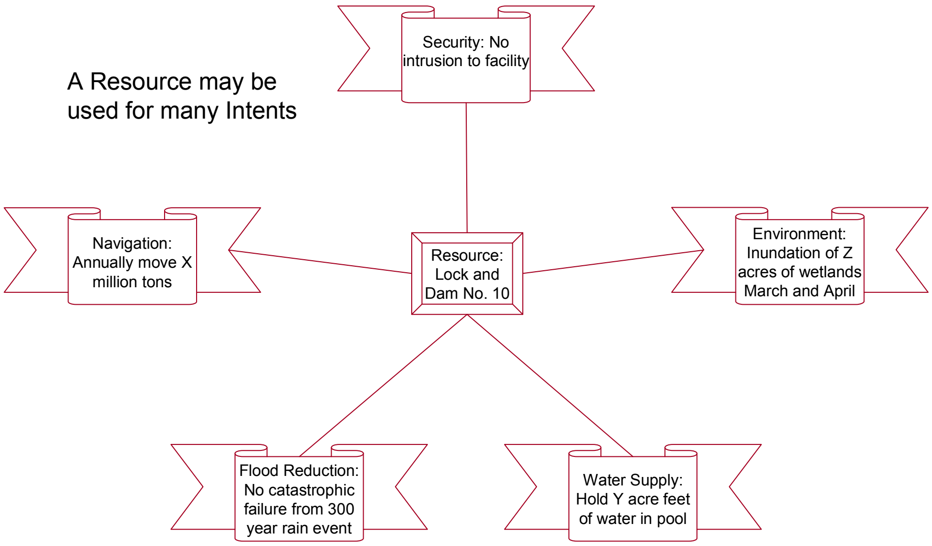

Figure 10: Network View of a Resource

The network view is obtained by identifying a resource of interest within the resource structure and then identifying its uses through its connection to all of its intents. An example of a resource network is shown in Figure 10. By superimposing the definition of the resource based on intent requirements, the various definitions of the resource can be identified and compared, as illustrated in Figure 11. This illustration shows resource incongruence, in that a single name has more than one definition. This resource incongruence may cause agent incongruence in that the agents who receive value from the resource may have a different understanding of the responsible agent's responsibilities.

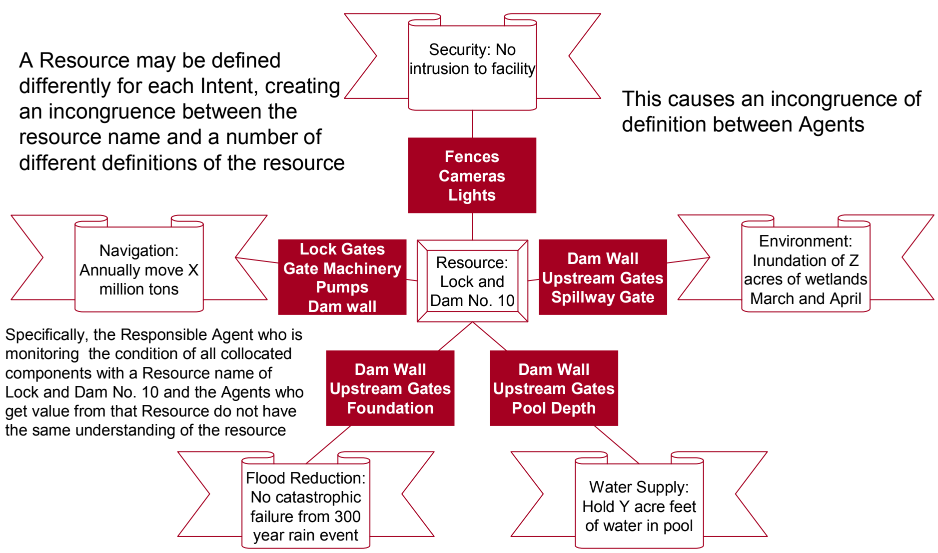

Figure 11: Resource Definition Incongruence

Exposing incongruences can help researchers find the root cause of the organizational challenges that they are often asked to study and for which they are often asked to propose solutions. Understanding the root cause of the challenge makes solution identification and acceptance easier. We believe this approach to identification and communication is an innovation in industry studies methods.

III. Generalizability

We believe that IRAA is a repeatable, rigorous, and generalizable approach to formulate problem domains for industry studies. We will continue our work using IRAA with the USACE as an illustrative case study of the approach, specifically by extending, testing, and refining IRAA on this and other infrastructure systems. We also intend to continue development in practice by applying IRAA to new industry studies that are in various stages of initiation.

USACE Plans, Challenges, and Our Role

The USACE work presented is a interim proposal in an ongoing study. It is expected the asset management project will continue for a number of years into the future. We currently have a report under review that presents asset portfolio management based on the IRAA problem formulation approach. We expect to continue work in the asset capability domain using IRAA to formulate an asset capability portfolio management to be used in making investment choices with regard to metrics, analytics, organization, process, principles, integration, and tools. The greatest challenge continues to be managing the diversity of participants and needs in order to create a holistic identification and definition of asset management capabilities that provides the greatest value to the USACE. Our role as we see is to provide the external holistic view that permits integration of all the key assets that USACE manages into a formulation that both recognizes the outstanding capabilities that they do have and identifies, justifies, and builds business cases that permit them to continue to provide the level of service and safety that we have come to expect in our national water resource infrastructure.

Research Implications

We have asserted repeatability, rigor, and generalizability and these are propositions that must be tested in future research. Testing of the repeatability assertion will be focused on measuring how consistently the approach results in the same problem formulation. Rigor is tested by measuring completeness in the problem formulation. Generalizability will be tested by measuring the number of different kinds of problem formulation domains IRAA can rigorously model and identifying which of those domains that IRAA is determined to be useful.

While this paper focused on the underlying hierarchical structures associated with problem domain formulation, we propose that the interaction of those hierarchies result in a network. For example, each intent has a relationship to each resource required to achieve the intent, each resource has a relationship to each intent for which the resource can be used, and each agent has a relationship to each resource for which they are responsible. These inter-relationships form a network. Further research is needed to understand the form and functional implications of this resulting network.

We believe that the inter-relationships between problem domains as modeled using the interacting hierarchies have significant implications to the practice of command and control in organizations. For example, understanding what it means to have a mission such as transporting some number of tons of cargo on a watershed system and then understanding what it means to properly fund those activities in a budget management system is a complex process that we believe is critical to the command and control process. Future research is needed to better understand these implications.

Practical Implications

IRAA's implications to practice are to provide a starting point pattern for problem formulation. While we have already discussed the need to research the generalizability of the approach, we will also use these tests as practical application of the approach. We have several real world problems in various stages of initiation on which the approach will be applied.

References

Bahill, A. T., B. Bentz, et al., Sandia National Laboratories (1996). "Discovering System Requirements." July 1996. SAND96-1 620 " UC-706

CBSPCI, BICE, et al., Committee on Business Strategies for Public Capital Investment, Board on Infrastructure and the Constructed Environment, Division on Engineering and Physical Sciences, National Research Council, The National Academies Press (2004). "Investments in Federal Facilities: Asset Management Strategies for the 21st Century." 0-309-08919-0 http://www.nap.edu/catalog/11012.html.

CC, CAUSACEMAPRWRPP, et al., Coordinating Committee, Committee to Assess the USACE Methods of Analysis and Peer Review for Water Resources Project Planning, Water Science and Technology Board, Ocean Studies Board, Division on Earth and Life Studies, National Research Council, The National Academies Press (2004). "U.S. Army Corps of Engineers Water Resources Planning: A New Opportunity for Service." 0-309-09222-1 http://www.nap.edu/catalog/10975.html.

CCCFEAM, BICE, et al., Committee on Core Competencies for Federal Facilities Asset Management 2005-2020, Board on Infrastructure and the Constructed Environment, Division on Engineering and Physical Sciences, , National Research Council, The National Academies Press (2007). "Core Competencies for Federal Facilities Asset Management Through 2020: Transformational Strategies." 0-309-11397-0 http://www.nap.edu/catalog/12049.html.

GAO, United States General Accounting Office (2003). "High Risk Series: Federal Real Property." GAO-03-122 www.gao.gov/cgi-bin/getrpt?GAO-03-122.

GAO, United States Government Accountability Office (2007). "High Risk Series: An Update." January 2007. GAO-07-310 www.gao.gov/cgi-bin/getrpt?GAO-07-310.

GAO, United States General Accountability Office (2007). "Report to the Committee on Armed Services, U.S. Senate: Best Practices, An Integrated Portfolio Management Approach to Weapon System Investments Could Improve DOD's Acquisition Outcomes." GAO-07-388 www.gao.gov/cgi-bin/getrpt?GAO-07-388.

Peirce, C. S. (1891). "Review of Principles of Psychology by William James." Nation **53**: 32.

Rudd, A., H. K. Clasing, et al. (1988). Modern portfolio theory : the principles of investment management Orinda, CA.

Sanwal, A. (2007). Optimizing Corporate Portfolio Management: Aligning Investment Proposals with Organizational Strategy. Hoboken, NJ, John Wiley and Sons, Inc.

Searle, J. R. (1983). Intentionality, an essay in the philosophy of mind Cambridge [Cambridgeshire] ; New York : Cambridge, University Press.

Simon, H. (1996). The Sciences of the Artificial. Cambridge, Massachusetts, The MIT press.

Sowa, J. F. (2000). Knowledge Representation: Logical, Philosophical, and Computational Foundations. Pacific Grove, CA, Brooks/Cole Thomson Learning.

Witte, E. (1972). "FIELD RESEARCH ON COMPLEX DECISION-MAKING PROCESSES - THE PHASE THEOREM." International Studies of Management & Organization **2**(2): 156-182.