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Performance Management of Tangible Assets within the Balanced Scorecard and Interactive Business Decision Tools

Raymond K. Jonkers

***Abstract*—**The present study investigated approaches and techniques to enhance strategic management governance and decision making within the framework of a performance-based balanced scorecard. The review of best practices from strategic, program, process, and systems engineering management provided for a holistic approach toward effective outcome-based capability management. One technique, based on factorial experimental design methods, was used to develop an empirical model. This model predicted the degree of capability effectiveness and is dependent on controlled system input variables and their weightings. These variables represent business performance measures, captured within a strategic balanced scorecard. The weighting of these measures enhances the ability to quantify causal relationships within balanced scorecard strategy maps. The focus in this study was on the performance of tangible assets within the scorecard rather than the traditional approach of assessing performance of intangible assets such as knowledge and technology. Tangible assets are represented in this study as physical systems, which may be thought of as being aboard a ship or within a production facility. The measures assigned to these systems include project funding for upgrades against demand, system certifications achieved against those required, preventive maintenance to corrective maintenance ratios, and material support personnel capacity against that required for supporting respective systems. The resultant scorecard is viewed as complimentary to the traditional balanced scorecard for program and performance management. The benefits from these scorecards are realized through the quantified state of operational capabilities or outcomes. These capabilities are also weighted in terms of priority for each distinct system measure and aggregated and visualized in terms of overall state of capabilities achieved. This study proposes the use of interactive controls within the scorecard as a technique to enhance development of alternative solutions in decision making. These interactive controls include those for assigning capability priorities and for adjusting system performance measures, thus providing for what-if scenarios and options in strategic decision-making. In this holistic approach to capability management, several cross functional processes were highlighted as relevant amongst the different management disciplines. In terms of assessing an organization's ability to adopt this approach, consideration was given to the P3M3 management maturity model.

***Keywords*—**Outcome based management, performance management, lifecycle costs, balanced scorecard.

R. K. Jonkers is a practitioner in industry with Merlantec Management and Engineering, Halifax, Nova Scotia, B0N 1Y0, Canada (phone: 902-751-1623, e-mail: jonkers.ray@gmail.com).

I. Introduction

PERFORMANCE management is viewed as an integral part to not just program management and evaluation, but to other management and systems engineering disciplines in the effective management of program system assets throughout their lifecycle. Performance management and program evaluation can include review and analysis of program logic models that contain the end-to-end linkages from inputs to outcomes within a program.

Several approaches to outcome-based capability management have been documented while an all-encompassing approach that captures both business management principles and decision-making techniques is not readily apparent. The need for this integrated approach today is premised on a complex and changing environment where resource constraints are ever more present.

The use of quantifiable techniques for performance management can provide structure, meaning and validity to outcome-based capability management and can provide program decision makers with valuable information.

Capability has many definitions and may be viewed as context dependent. From a military perspective, "Capability is the ability to execute a specific course of action" [1]. This may be interpreted as the ability of systems and equipment aboard a ship in providing operational capabilities. Similarly, it may be interpreted as the ability of equipment within a production facility in manufacturing products. From a business management perspective, capability is generally defined as the capacity to carry out business activities. Combined, these definitions point toward the management of activities and projects that support physical assets. These assets may be viewed as being engineering systems, equipment, products, and services that are maintained and utilized in providing capabilities. These definitions also imply that capability may be achieved through the management of both tangible material assets and intangible non-material assets, so as to achieve a desired outcome. Of note, capability may be achieved by one or more systems and the combined effect of multiple system inputs or activities. These inputs may include personnel, collective training, major systems, suppliers, facilities, training areas, support and services, and management [2]. The associated business activities may include staffing, maintenance, project portfolio management, and certification of systems.

II. Outcome-Based Capability Management

Outcome-based management and capability management may be viewed as synonymous in achieving desired outcomes throughout the lifecycle of systems.

Capability management may be viewed as a disciplined approach in planning, implementing, analyzing and sustaining capability, while also maintaining accurate information. In this study, it is proposed that managing the system inputs, as represented by business activity performance measures, and applying a comprehensive management approach will enhance the ability to sustain readiness in accordance with capability requirements. Part of this approach includes the strict capability management discipline, consisting of: requirements generation and management, capability analysis, capability sustainment, and process management of interfaces [1].

Of particular interest to this study, capability analysis includes the aspects of performance, risk, and investigation into potential cost trade-offs in developing optimal, cost-effective, and interoperable solutions [1]. These solutions can involve both material and non-material assets and an appropriate balance of management principles and decision-making techniques. Management disciplines include strategic, capability, program, process, and systems management. It is worthwhile to elaborate on these disciplines where they support a comprehensive approach to outcome-based capability management.

III. Strategic Management and the Balanced Scorecard

The strategic management process allows an organization to adapt effectively to change and deliver effective capability to the customer. This process consists of three stages: strategy formulation, strategy implementation, and strategy evaluation [3].

Developing capability requirements may be viewed as part of the strategy formulation stage where priorities may be assigned to a unique set of capabilities. Moreover, a strategy may be developed to assign priorities to selected systems and their input measures, as aligned with business objectives.

In adopting a structured approach to meeting capability requirements, the use of a balanced scorecard and decision-making techniques may form part of the strategy implementation stage. During strategy evaluation, the degree to which capabilities have been achieved may be captured within the balanced scorecard and adjustments made to business activities and system measures in order to respond to an environment where capability requirements change. During strategy evaluation, alternative solutions may be developed using decision-making techniques such as scenario-based exploration and analysis.

In all three strategic management stages, managers, operations personnel, and systems engineers should be involved in order to validate information, to promote ownership, and to provide all stakeholders with broader insight into organizational and system performance.

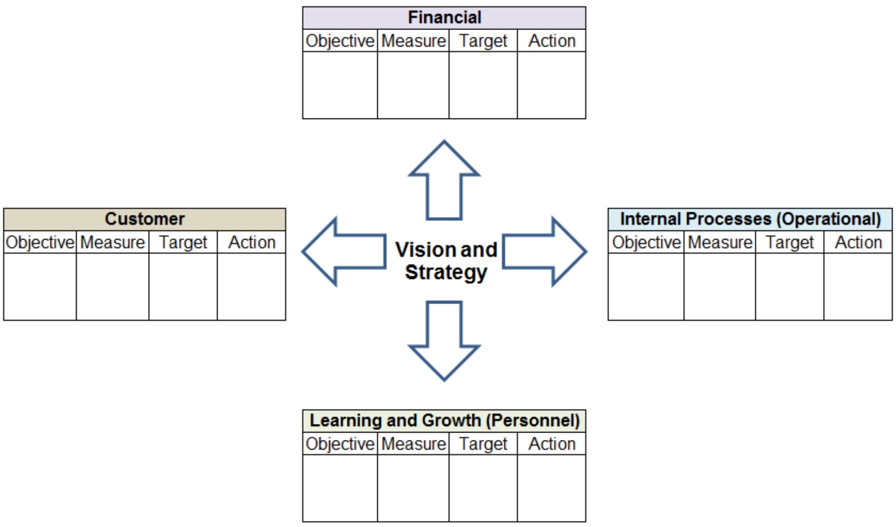

Fig. 1 Balanced Scorecard Quandrants

A key goal for both business and military strategy is to gain competitive advantage within a changing environment. Adopting a holistic management approach and having decision-making tools available early in the process will help to ensure success in achieving capabilities. Traditionally, it was believed that to improve management of intangible assets, measurement of these assets had to be integrated into the management system. This concept extended itself to development of a management tool for describing, communicating and implementing strategy; this tool is called the Balanced Scorecard (BSC) [4]. The BSC consists of four quadrants: financial, customer, internal processes, and personnel. Each quadrant consists of objectives, measures, targets, and actions or plans, as depicted in Fig. 1.

The BSC incorporates business objectives and strategy maps in representing plans to adjust activities within specific

BSC quadrants, and in turn associated performance measures, with an expected causal effect on other quadrant measures. For example, as depicted in Fig. 2, increasing personnel capacity may lead to increased maintenance of systems and certification, thereby reducing project funding that would otherwise be required to enhance or replace aging equipment. On the other hand, increasing project funding to enhance or replace certain equipment may lead to decreased maintenance costs and fewer personnel resources required. These complex linkages within strategy maps make it difficult to estimate casual relationships that will provide positive outcomes and benefits.

The BSC promotes financial metrics as the ultimate outcome measures for company success, but the other three additional perspectives are viewed as important for supporting long-term shareholder value [4]. The traditional BSC approach applies metrics to intangible assets such as knowledge, information, processes, project performance, and customer satisfaction. While this traditional BCS approach has value, it is proposed that a complimentary BSC, using tangible assets, be used where both scorecards together would lead to better predictability of outcomes.

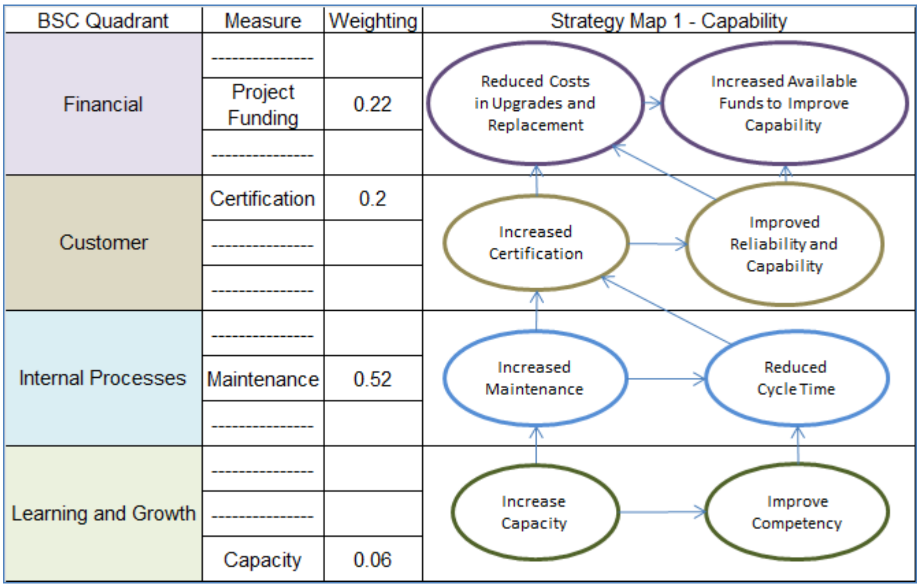

Fig. 2 Sample Balanced Scorecard Strategy Map

Specific measures in support of physical assets or systems are described in this paper within the BCS construct. It is envisioned that there would be a hierarchy of aggregated BSC dashboards, including the traditional BSC that measures the performance of projects within a portfolio that in turn supports and sustains assets. This set of BSC dashboards provides for alignment and consistent reporting throughout the organization with common types of performance measures that aggregate up into a corporate scorecard. This also provides for communication and awareness of program performance throughout the organization [4].

Typically, the weightings assigned to the BSC quadrants stem from top management judgement with respect to the business model and the strategies implemented. The BSC quadrant weightings help in knowing where to start in developing strategy maps in order to be effective in achieving desired outcomes.

It is worthwhile investigating a method to quantify the effect or weighting of the BSC quadrants and their measures. This addresses the need to better understand the casual chains and scenarios for strategy maps associated with the BSC. It is proposed that the weighting of BSC quadrants and system measures can be quantified through use of factorial analysis. Other techniques may be employed to quantify the importance of systems within a network as they affect the management of assets within a program.

IV. Balance Scorecard and Strategy Map Quantifiable Techniques

Factorial experiments are used in situations where there are several ambiguous factors affecting a process [5]. Such experiments are traditionally used for process improvement in the chemical industry where input variables are optimized in an effort to provide maximum yield. In this study, factorial experimental design was utilized to determine the effect of system measures and potential interaction effects across BSC quadrants that result in the optimal level of capability achieved. From this, an empirical model was developed that predicts the desired level of capability.

In this study, the system measures selected for model development were: project funding, maintenance, certification, and material support personnel capacity. In order to develop an empirical model based on factorial experiments, the range for each measure was codified from a low level of –1 to a high level of +1.

Table I lists the natural measure independent variables and their respective codified non-dimensional values. The range of natural variable parameters is decided upon by the user and normalized across the codified parameters.

TABLE I
CODIFIED SYSTEM PARAMETERS

Controlled Variable	Level	Natural Variable (Capability Level)	Non-Dimensional Value
Project Funding x_1	Low	Funding \$ / Demand \$ = 0	-1.0
	High	Funding \$ / Demand \$ = 1	1.0
Maintenance x_2	Low	Preventive Hours / Corrective Hours = 0	-1.0
	High	Preventive Hours / Corrective Hours = 2	1.0
Certification x_3	Low	Actual Number / Required Number = 0	-1.0
	High	Actual Number / Required Number = 1	1.0
Personnel Capacity x_4	Low	Filled Positions / Required Positions = 0	-1.0
	High	Filled Positions / Required Positions = 1	1.0

In this study, the factorial design involved 16 experiments forming a 2^4 factorial design, where four parameters, each at low and high operating levels, were investigated as scenarios where the user would estimate impact on the outcome or capability. With this information and matrix algebra, the resulting overall empirical model incorporates all four independent variables.

$$y = 43.8 + 22.5x_1 + 52.5x_2 + 20.0x_3 + 7.5x_4 + 7.5x_4 + 7.5x_2x_4 + 7.5x_1x_2x_4 \quad (1)$$

where: y = level of capability achieved and x_1, x_2, x_3 and x_4 are codified non-dimensional variables.

From the overall model, three distinct empirical models, each with two independent variables, were developed that visually predict level of capability achieved. The first model is based on the prominent effects of project funding and maintenance on capability.

$$y = 43.8 + 22.5x_1 + 52.5x_2 \quad (2)$$

In this first model, the effect from maintenance (x_2) is higher than for project funding (x_1); there was negligible interaction between these variables.

The second model is based on the prominent effects of maintenance and system certification on capability.

$$y = 43.8 + 52.5x_2 + 20.0x_3 + 5.0x_2x_3 \quad (3)$$

In this second model, the effect of maintenance (x_2) was higher than for system certification (x_3); there was a relatively small interaction effect between maintenance and certification.

The third model is based on the prominent effect of maintenance and to a lesser degree, personnel support capacity.

$$y = 43.8 + 52.5x_2 + 7.5x_4 + 7.5x_2x_4 \quad (4)$$

In the third model, the effect of maintenance (x_2) was significantly higher than for both personnel (x_4) and the interaction effect between maintenance and personnel.

The associated response surface plots for these models are depicted in Figs. 3-5, providing visual interpretation of the parameter effects on the desired capability level.

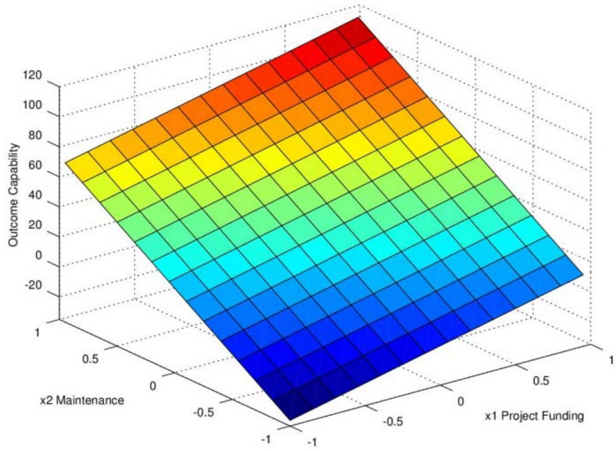

Fig. 3 Surface Response Plot for Project Funding and Maintenance Effects on Capability

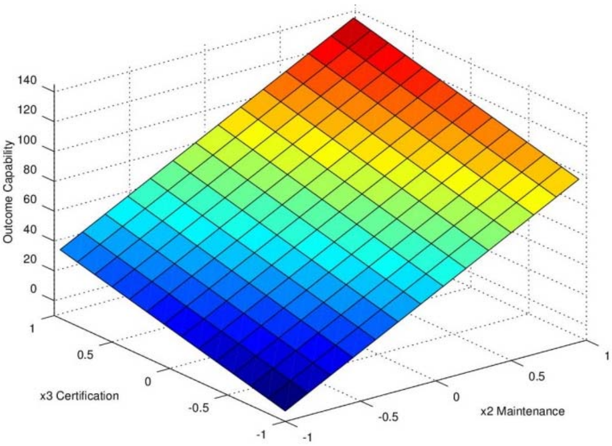

Fig. 4 Surface Response Plot for Maintenance and System Certification Effects on Capability

With empirical models developed for capabilities, the effect of system measures on capability can be better understood. For instance, the measure of maintenance has the highest effect in this study and therefore any adjustments to this measure would be a key focus area. When the actual outcomes as capabilities are measured in the external environment, the overall empirical model can be revisited and revised accordingly as part of an iterative process to improve the model so as to better reflect reality. Also of importance in predicting level of capability achieved is the weighting of physical systems, which may be assessed through systems engineering and a system-of-systems (SoS) approach.

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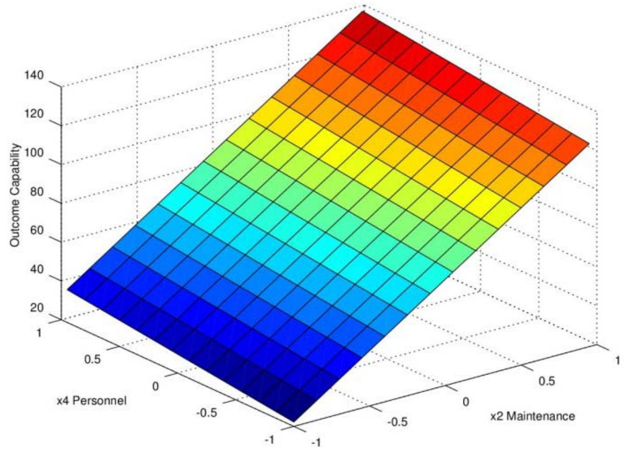

Fig. 5 Surface Response Plot for Maintenance and Personnel Effects on Capability

V. Systems Engineering

Systems engineering is a term for methods used to provide optimally engineered, operationally effective, complex systems. It balances capability, risk, complexity, costs, and technological choices to provide solutions that best meet customer requirements [6]. Systems engineers typically follow the V-cycle, as depicted in Fig. 6. While the later stages in the V-cycle apply to capability sustainment, the earlier stages may have to be revisited when upgrading existing systems, as well as when introducing new systems. In terms of understanding an integrated and enhanced approach to capability management, alignment of other management disciplines to the V-cycle is depicted in Fig. 7.

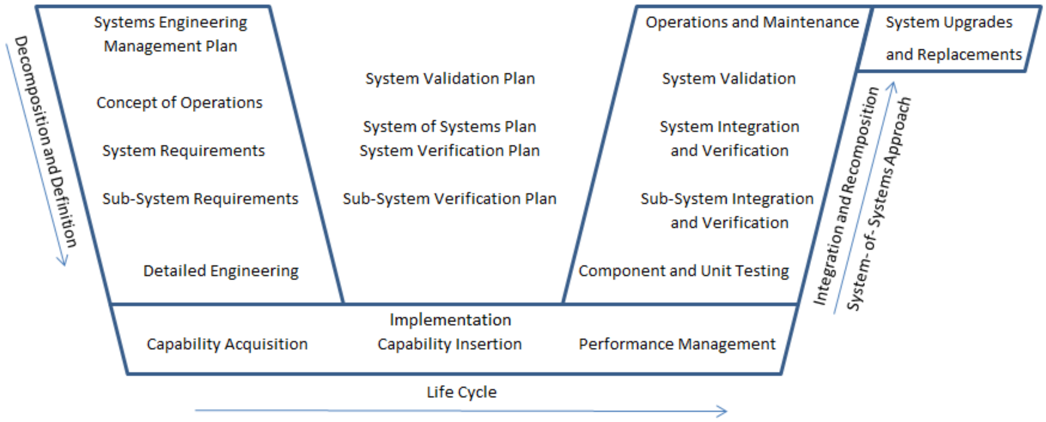

Fig. 6 Systems Engineering V-Cycle

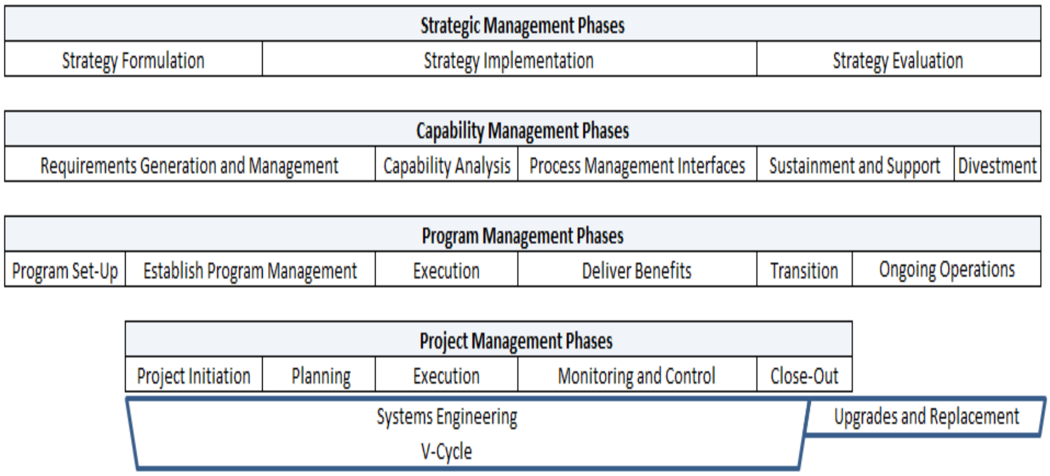

Fig. 7 Alignment of Management Disciplines in Relation to The V-Cycle

The relative importance of systems within the BSC may be assessed through pair-wise comparisons where system interdependency weightings are assigned. This is typically developed in the form of a N^2 chart, as depicted in Fig. 8, with the dependency of systems on one another estimated on a scale from 1 to 5, from lowest to highest dependency. The values in this chart may be used as input into interdependency software where resultant metrics may be applied to the BSC. As depicted in Fig. 8, the electrical and machinery control systems may be viewed as critical, in that the electrical system provides multiple inputs into the other systems while the machinery control system receives multiple inputs from the other systems. This leads to the concept of quantifying the relative importance of systems.

VI. Asset Quantifiable Technique and System-of-Systems Approach

In this study, system relative importance was determined through the use of interdependency matrices and Inflow™ software, with the degree of interdependency depicted in Fig. 9. The centrality of system nodes and the thicker lines stemming from key systems indicate systems of high importance or power.

The interdependency of systems is this study is viewed as analogous to the interdependency of nodes within a social network. Extensive work in social network analysis and metrics is of value to the current study.

High Pressure Air	4	3					
	Electrical System	5				5	
2	5	Machinery Control	2	1	2	4	
	5	5	Steering System		2		
	2	2		Fresh Water			
	4	3		2	Heating		
5	3	4		5	2	Diesel Generator	
	4				2		Cranes

Fig. 8 System Interdependency N^2 Chart

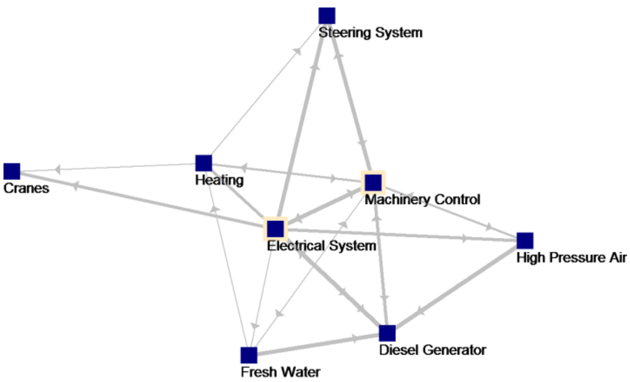

Fig. 9 System Interdependency and Power

The metrics of "Betweeness" and "Closeness" reveal a node's advantage within a network. "Betweeness" measures the control of flow of information that a node has in a network and is related to how often it may be in the path between other nodes. "Closeness" measures how easily a node can access all other nodes in a network. The combination of these two measures provides the "Power" of a node. A node with complete control and access to other nodes has perfect "Power" with a value of 1 [7]. These key metrics are summarized in Table II. Of note, the "Power" metric is used in this study to provide system weightings within the BSC.

System-of-systems (SoS) is a methodology that groups systems with similar attributes together where interdependent relationships are considered [8]. In this study, systems with similar attributes pertain to those sharing common outcomes or capabilities. This methodology is applied to the BSC in forming system groups with aggregation of respective measures.

TABLE II
System Network Metrics

System	Betweeness	Closeness	Power
Machinery Control	0.46	0.88	0.67
Electrical System	0.13	1.00	0.57
Heating	0.08	0.70	0.39
Fresh Water	0.00	0.64	0.32
Diesel Generator	0.05	0.58	0.32
High Pressure Air	0.00	0.54	0.27
Steering System	0.00	0.50	0.25
Cranes	0.00	0.14	0.07

Improvement techniques for the design and acquisition of complex systems also include adherence to the V-cycle, a SoS approach, and use of model-based engineering. This has been proposed in the optimization of ship design and in capability planning [9]. This mainly occurs in the beginning and intermediate stages of the V-cycle.

While the V-cycle is typically used for new systems, the management of existing in-service systems and the introduction of system upgrades or replacements can also follow the V-cycle as part of a comprehensive and structured management approach.

With weightings determined for BSC quadrants and relative levels of power determined for systems, the BSC can be enhanced to provide performance management of the system measures and the translation of these measures into impact on associated outcomes or capabilities.

VII. Performance Management

The performance reporting cycle in an organization includes planning, implementation, and evaluation; this cycle also includes reporting and the utilization of results to adjust strategic objectives. Fig. 10 depicts a model where organizations can integrate strategic planning, program and policy design, implementation, and evaluation into the performance management cycle [10].

In relation to Fig. 10, the alignment of management disciplines is elaborated upon in this study. The stages of performance management and reporting and real consequences are also presented in this study through an enhanced BSC with quantifiable elements, and through a proposed outcome-based capability control system.

Activities and associated measures in this study were selected based on perceived availability of accurate data, ease of translation of measures into costs, and applicability to the management of systems.

Fig. 10 Performance Management Cycle

The goal of managing outcomes may be viewed as ensuring the organization will realize and sustain benefits from investment in the program. For systems or physical assets, this investment typically includes acquisition and through life support costs. As supports costs can be significant after transition of systems into in-service, this study is focused on the use of the BSC in the operational environment where system measures may be represented in terms of the cost of supporting projects and activities.

Fig. 11 illustrates the relative cost involved in supporting systems throughout the lifecycle. The 70:30 "golden ratio" of operations and support costs to acquisition costs is typical for a majority of weapon systems [11]. This ratio is of importance in this study in working toward measures of program cost-effectiveness and the concept of system total cost of ownership.

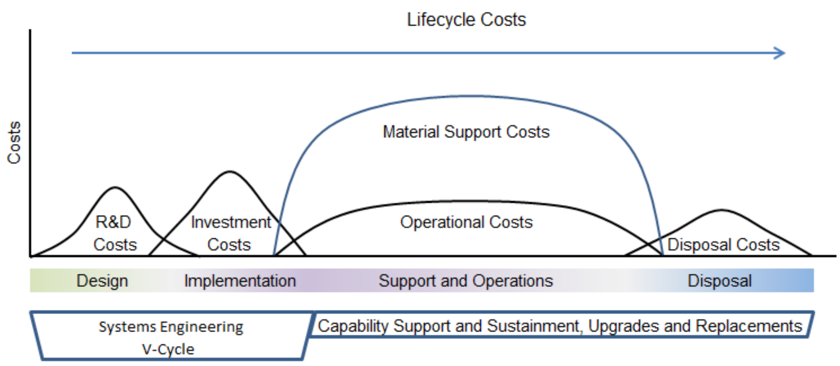

Fig. 11 System Costs of Ownership

Should objectives be verified as correct, this study proposes that the BSC system performance measures be adjusted in order to enable required changes to the program and to better realize desired outcomes and benefits. For instance, these adjustments may include reallocation of resources and reprioritization of system supporting activities. This adjustment to system measures within the BSC may be provided through the use of interactive controls.

VIII. Interactive Controls for Capability and Program Management

The interactive controls for measures presented in this study are based on priority of capabilities, BSC quadrants, systems, and constraints such as resources. As described, weightings for these measures and their respective BSC quadrants can be determined through development of empirical models. Fig. 12 describes the financial quadrant of the BSC model, including interactive controls for adjusting the measure of project funding to predict and strive to achieve a required level of capability. This is conducted in balance with other measures within the BSC for system maintenance, certification, and personnel capacity, as representative measures for the other quadrants within the BSC

The intent behind interactive controls is to adjust pertinent system measures so as to achieve a balanced approach in optimizing the capability of interest, while recognizing that some systems and measures are weighed more heavily in terms of effect on the capability. User defined capability readiness thresholds for each measure are indicated by a red-amber-green dashboard, where adjusted measures and impact on capabilities are dynamic.

While the proposed BSC represents the capability baseline for measures and current capability requirements, interactive controls provide the ability to proactively adjust system measures in response to changes in the environment. These changes can take the form of changes in policy, objectives, capability goals, priorities, and regulatory requirements. New capability goals may be described in strategic capability roadmaps and, along with suitable BSC dashboards, used to identify capability gaps.

Using a SoS approach, systems are aggregated into groups sharing common capabilities, as indicated in Fig. 13. The weighted system impact of the financial measure on capabilities is dynamic and changes through interactive controls, thus providing for scenario-based exploration.

System	System Interdependency Power	Capability	Demand vs Project Funding	Interactive Adjustment to Project Funding	Demand vsAdjustment to Project Funding	Increase/ Decrease in Funding	Increase/ Decrease in Funding
High Pressure Air	0.27	Operability	A		A	-$4,000	
Electrical System	0.57	Operability	A		G	$10,000	
Machinery Control	0.67	Mobility	G		A	-$32,500	
Steering System	0.25	Maneuverability	A		G	$15,200	
Fresh Water	0.32	Habitability	G		A	-$3,450	
Heating	0.39	Habitability	A		A	-$2,240	
Diesel Generator	0.32	Operability	A		A	-$45,000	
Cranes	0.07	Operability	R		A	$50,000	
Total			A		A	-$11,990	

Fig. 12 System Mapping to Capabilities and Interactive Controls for Project Funding

System Group	Weighted Systems Current Project Funding Impact on Capability	Aggregated Capability	Demand vs Project Funding	Weighted Systems Adjusted Project Funding Impact on Capability	Demand vs Adjustment to Project Funding	Increase/ Decrease in Funding	Increase/ Decrease in Funding
1	82%	Operability	A	90%	A	$11,000	
2	100%	Mobility	G	87%	A	-$32,500	
3	80%	Maneuverability	A	95%	G	$15,200	
4	94%	Habitability	G	77%	A	-$5,690	
Total			A		A	-$11,990	

Fig. 13 Aggregated Systems Into Distinct Capabilities for Project Funding

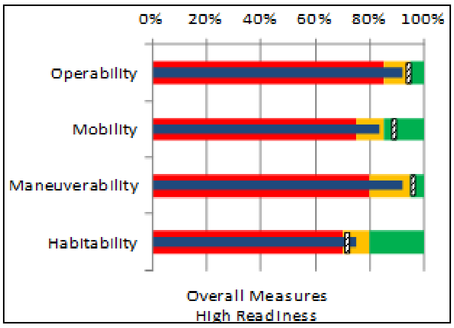

Fig. 14 Weighted Overall Effect of All Measures on Capabilities

The remaining three system measures are captured within similar dashboards and all four weighted results are aggregated. The overall effect of adjusted system measures on capabilities for one scenario is depicted in Fig. 14; several other scenarios may be explored. Of note, integration of the four BSC quadrant measures and translation into capability impact is achieved through applying the overall empirical model at (1). Improvement to this model is made by assessing actual capability achieved and revisiting factorial experimentation. This leads to the need for a process and feedback loop that considers actual outcome or capability achieved and adjustment to the program.

IX. Program Management

There are several definitions to describe program management. Program management may be defined as "a group of related projects managed in a coordinated way to obtain benefits and control not available from managing them individually" [12]. This definition has similarities with that for SoS methodology where the focus is on system groups and shared attributes.

The difference between project management and program management may be explained in that "*projects produce deliverables, whereas programs deliver benefits and capabilities that the organization can utilize to sustain, enhance, and deliver organizational goals*" [13]. This definition is relevant to both systems engineering and the SoS approach where systems and their attributes are mapped to outcomes. It also highlights the aspect of capability sustainment within an integrated management structure.

Of particular relevance to this study, program management may be viewed as carrying out the coordinated organization, direction and implementation of a portfolio of projects and transformation activities to achieve outcomes and to realize benefits of the program [8]. This view recognizes the need to reconcile competing demands for resources, providing control for projects and their funding within the program.

This study suggests representation of competing demands through output measures captured within the BSC for both asset supporting projects and activities. This enhanced BSC will connect outputs to outcomes, provide strategic context, and incorporate performance management in order to better plan, execute, control and monitor, and take corrective action.

Factors such as strategic benefits, coordinated planning, shared resources, optimization of costs, risks, and interdependencies contribute to determining whether multiple projects should be managed as a program. The SoS approach can be adopted to help group projects and their systems under a capability categorized program portfolio.

The value in realizing strategic benefits and capabilities from projects is that they continue on after projects close, and they support the long term strategic goals. This was depicted in the V-cycle and management alignment diagrams above, where capability sustainment and program management continue well after project close. The return on investment for each project may not always be clear. The example shown in this study for project funding, and the interactive control thereof, is a technique to help better realize the impact on capability and the return on any investment. Similarly, the deliberate adjustment of other system measures may contribute to the potential overall return on investment

In order to be effective, consideration should be given to stakeholder engagement, the management disciplines discussed in this study, and use of decision-making tools.

While program effectiveness may be gauged through adjustment of system measures and optimized capability, other program evaluation techniques are available.

X. Program Evaluation

One of the key questions in program evaluation is whether the program was effective in achieving desired outcomes. The cost-effectiveness of a program may be expressed as the program costs per unit outcome [10]. In this study, the program costs may be captured within the BSC in terms of output measures and costs. The cost related activities in support of these outputs or assets include project funding, maintenance, system certification, and staffing of personnel support. These lifecycle support costs represent a significant portion of program material asset support costs. The mapping of physical assets to outcomes and the use of the enhanced BSC and interactive controls provides for estimation of outcome unit level improvement or degradation. For instance, a program monetary value may be estimated for a 5% improvement in outcome, measured against an established benchmark. This benchmark may be derived from the previous year, from revised objectives, or from external benchmarks as they relate to the output measures. In this study, several cost-effectiveness ratios may result in terms of individual outcomes and the respective associated program supporting costs.

The enhanced BSC may be used to benchmark current outcome performance, as well as to forecast outcome performance based upon purposeful adjustment of the output measures in accordance with outcome targets. The outcomes can be investigated in terms of near-term, intermediate, and long-term capability requirements.

The elements of capability management and techniques discussed in this paper may be further described in terms of an outcome-based capability management control system, including feedback loops.

XI. Outcome-Based Capability Management Control System

In Fig. 15, an outcome-based capability management control system is proposed that considers decision-making techniques and key program and capability management elements.

At the heart of this system is performance measurement and adjustment to BSC measures within the program. The adjustment of measures act on system supporting activities and over time results in a change in output measures. When compared to the desired outputs, additional adjustment to measures may be required.

A. Outcome-Based Capability Management Control System

The system outputs are translated into outcomes or capabilities, which are also measured. Similar to the outputs, predicted and actual outcomes are compared and adjustments through performance management are made where required.

The actual performance of capabilities may be measured in terms of system operational deficiencies or mean time between failures, both affecting system availability. Another measure affecting actual outcomes or capabilities may be derived from the results of system tests and trials, as a measure of system performance. This can also be described through factorial analysis in the form of an empirical model.

$$y = 31.5 + 15.6x_5 + 9.4x_6 + 9.4x_5x_6 \qquad (5)$$

where: y = actual level of capability achieved, and x_5, and x_6 are codified non-dimensional variables for system availability and system performance, respectively.

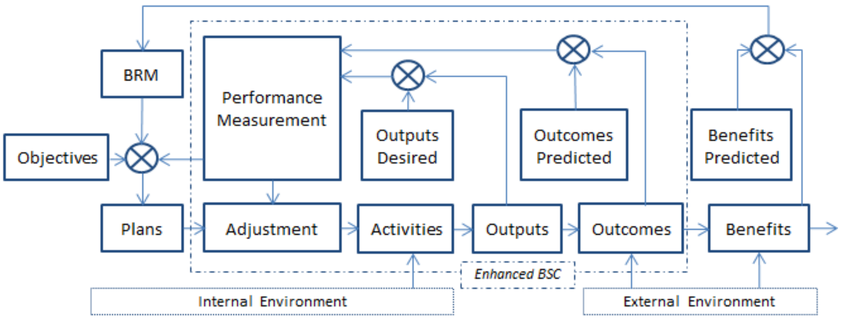

Fig. 15 Outcome

The associated response surface plot for this model is depicted Fig. 16, providing visual interpretation of the parameter effects on the actual capability level achieved. The actual outcome or capability, as a result of program adjustment, may be compared to the baseline outcome illustrated in Fig. 14. The gaps between baseline and actual outcomes or capabilities are illustrated in Fig. 17. This provides for measures of outcome unit improvement or degradation, and can include the adjusted program system support costs incurred as quantified through the output measures. The resultant program outcome cost effectiveness measures are illustrated in Table III, which are based on a defined time period.

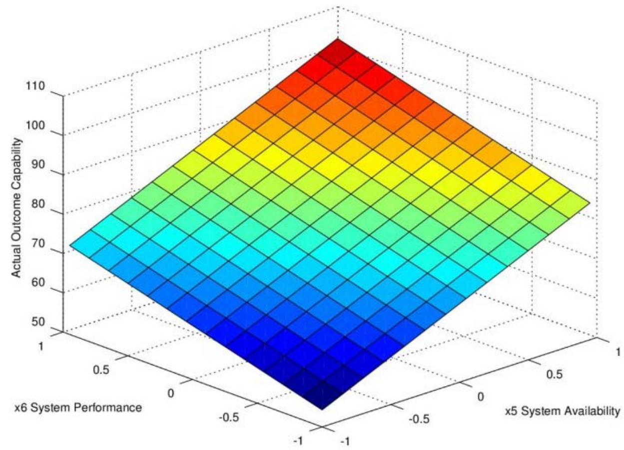

Fig. 16 Surface Response for System Availability and Performance on Actual Outcome Capability

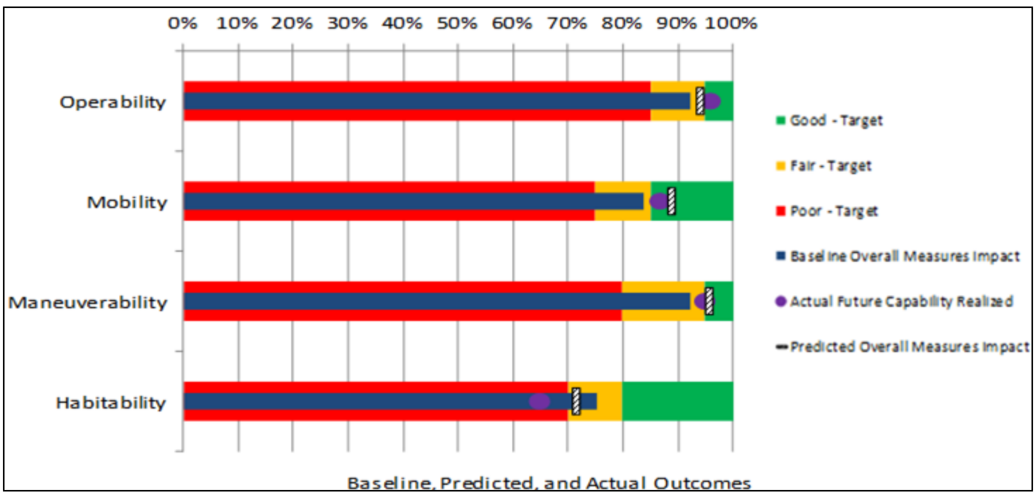

Fig. 17 Gaps between Baseline, Predicted, and Actual Outcomes

The program outputs operate in the internal program environment while outcomes operate in the external operational environment. This external environment can be where the client, as end-user, is located. As the changing environment can impact success of the program, it is worthwhile for the program management team to continually scan the environment for possible disturbances to the program system.

External factors that may influence and require changes to the program include economic, cultural, political, and technological forces [10].

Internal factors may represent an organization's strengths and weakness and can stem from the functional areas of management, financial, production, operations, research and development, and information systems [3].

TABLE III
PROGRAM OUTCOME EFFECTIVENESS MEASURES

Outcome/ Capability	Outcome Improvement/ Degradation	Adjusted Increase/ Decrease in System Support Costs	Program Outcome/ Capability Cost Effectiveness Measure
Operability	10%	$300,000	$30,000/Outcome Improvement Percent
Mobility	5%	$200,000	$40,000/Outcome Improvement Percent
Maneuverability	5%	$100,000	$20,000/Outcome Improvement Percent
Habitability	-10%	-$150,000	-$15,000/Outcome Degradation Percent

As depicted in Fig. 13, the outcomes or capabilities may be translated into benefits. Translation of outcomes into benefits may be viewed as directly related to the program objectives and therefore a feedback loop is incorporated into the system.

Best practice in program management may be viewed as achieving alignment of everything towards satisfying strategic objectives and realizing benefits where the success of a program may be judged by its ability to realize benefits [14].

Benefits may not be realized for some time after outputs have been delivered and supporting activities carried out. When they are realized, Benefits Realization Management (BRM) is viewed as part of strategic and program management in assessing benefits and adjusting the program as required. BRM may be defined as “the process of organizing and managing, so that potential benefits, arising from investment in change, are actually achieved” [15]. A benefit may be defined as “an outcome of actions and behaviors that provide utility to stakeholders” [13]. In this study, benefits may be viewed in terms of: optimization of resources, reduced overall support costs and ability to fund other needed areas, having the right level of supporting projects and activities being worked on by sufficient personnel, and reliability of systems operating in the external environment. This requires a holistic management approach.

There are several program governance themes that support benefits realization. The themes relevant to this study include: stakeholder engagement, planning and control, business case analysis, and risk and issue management. The development of a benefits realization strategy and plan will support these themes and provide a framework for identifying, prioritizing and achieving benefits [14].

While BRM and its governance themes are key elements to both strategic and program management, there are several key cross functional processes amongst the other management disciplines that contribute toward a holistic approach to outcome-based capability management.

B. Integrated Management Disciplines and Cross-Functional Processes

The international standard, IEEE 15288:2008 [12], groups system life cycle activities into four process groups: agreement processes, project processes, technical processes, and organizational project-enabling processes. This last group of processes includes project portfolio management, human resource, and quality processes. While these processes are viewed as important to capability management, there are several processes that interface across the different management disciplines, systems engineering, and SoS functions, Table IV highlights cross functional processes that are relevant to the current study.

The approach in this study is to take advantage of the management approaches and methods in other disciplines in ways to optimize program and capability management.

The ability of an organization to adopt aspects of several management disciplines, and the associated cross functional processes, may be evaluated through the use of maturity models similar to P3M3® models.

The P3M3® model typically covers project, program and portfolio management disciplines and processes [16]. This model may be augmented to assess management disciplines and processes discussed in this study, as highlighted in Fig. 16. This revised model shows how the project, program and portfolio seven process areas can span across the strategic management, capability management, systems engineering and SoS functions to represent an integrated outcome-based capability management approach. Six additional key cross-functional processes are depicted at the bottom of Fig. 18.

TABLE IV
MANAGEMENT CROSS FUNCTIONAL PROCESSES

Strategic Management	Capability Management	Program Management	Systems Engineering	SoS Functions
Formulation	Requirements	Benefits	Requirements	Translating Capability Objectives
Formulation	Requirements	Scope	Requirements	Developing and Evolving an SoS Architecture
Formulation	Requirements	Scope	Interface Management	Understanding Systems and Relationships
Implementation	Requirements	Quality	Verification and Validation	Monitoring and Assessing Changes
Implementation	Requirements	Risk	Risk	Understanding Systems and Relationships
Implementation	Capability Analysis	Portfolio	Decision Analysis	Assessing Performance to Capability Objectives
Implementation	Requirements	Benefits	Design Solutions	Addressing Requirements and Solution Options
Implementation	Capability Sustainment	Portfolio	Integration	Orchestrating Upgrades to SoS
Evaluation	Capability Analysis	Risk	Risk	Assessing Performance to Capability Objectives

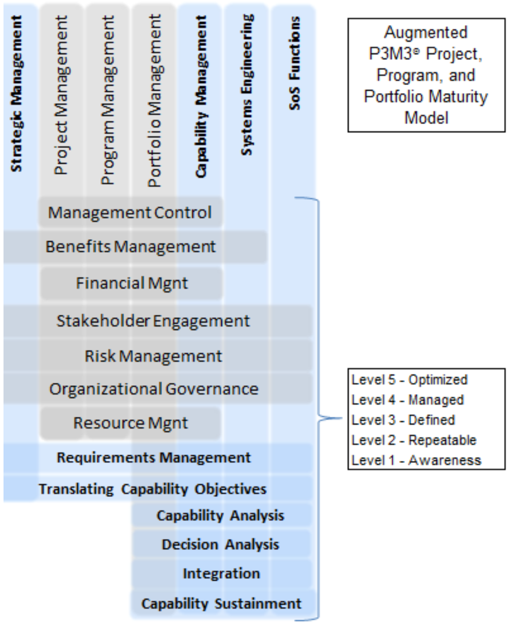

Fig. 18 Outcome-Based Capability Management Maturity Model

XII. Conclusions

The current study presented a holistic management approach to outcome-based capability management within the BSC framework, with the ultimate goal to achieve optimally supported capabilities through management of system variables and measures.

In this study, three strategic decision-making techniques were adopted to enhance an all-encompassing capability management approach. Use of the factorial experiment methodology provided an empirical correlation between system control measures and capability performance. This was visualized through surface response plots that depict system measures and optimal level of capability achieved. The second technique quantified system power within a network using system interdependency matrices and Inflow™ software. The third technique introduced interactive control of system measures within the BSC. This enhanced BSC, with systems as assets mapped to outcomes and the use of interactive controls for output measures, can be viewed as a practical technique to help in evaluation of program effectiveness and its outcomes.

Elements of capability management and the techniques discussed in this paper were described in terms of an outcome-based capability management control system, including essential feedback loops. The measurement of actual outcomes compared to baseline outcomes provided for program outcome or capability cost effectiveness measures. In this holistic management approach, several cross-functional process interfaces were highlighted as important to effective outcome-based capability management. The P3M3® model may serve as a tool in helping an organization adapt additional management disciplines, including associated cross-functional processes.

XIII. Recommendations

It is recommended that there be continued investigation into the BSC as a framework for managing system measures as capability and outcome drivers for a broader range of applications within industry.

There should be further identification of system measures that address total cost of ownership throughout the system life cycle as appropriate to achieving desired outcomes; this should include a measure for material costs.

The measurement of program outcomes may be a challenge since data and resources may be limited. This supports using readily available accurate data for a pilot program when implementing the approach proposed in this paper.

Lastly, it is recommended that the enhanced BSC, V-cycle and the revised P3M3® model be customized to suit the specific requirements of the user in achieving effective outcome-based capability management.

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