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A Framework For Measuring The Value-added Of Knowledge Processes With Analysis Of Process Interactions And Dynamics

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A FRAMEWORK FOR MEASURING THE VALUE-ADDED OF KNOWLEDGE PROCESSES WITH ANALYSIS OF PROCESS INTERACTIONS AND DYNAMICS

by

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ABSTRACT

The most known and widely used methods use cash flows and tangible assets to measure the impact of investments in the organization's outputs. But in the last decade many newer organizations whose outputs are heavily dependent on information technology utilize knowledge as their main asset. These organizations' market values lie on the knowledge of its employees and their technological capabilities. In the current technology-based business landscape the value added by assets utilized for generation of outputs cannot be appropriately measured and managed without considering the role that intangible assets and knowledge play in executing processes. The analysis of processes for comparison and decision making based on intangible value added can be accomplished using the knowledge required to execute processes. The measurement of value added by knowledge can provide a more realistic framework for analysis of processes where traditional cost methods are not appropriate, enabling managers to better allocate and control knowledge-based processes. Further consideration of interactions and complexity between proposed process alternatives can yield answers about where and when investments can improve value-added while dynamically providing higher returns on investment.

Dedicado a mi flaca. Gracias mi amor por ser la persona más importante en mi vida y la que más creyó en mi durante este proceso.

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3D	3-Dimensional
AoA	Analysis of Alternatives
BPR	Business Process Re-engineering
BSC	Balanced Scorecard
CLD	Casual Loop Diagram
COTS	Commercial-off-the-shelf
DBMS	Database Management Systems
DoD	Department of Defense
IAS	International Accounting Standards
IC	Intellectual Capital
IS	Information Systems
IT	Information Technology
ITAA	Information Technology Association of America
JCIDS	Joint Capabilities Integration and Development System
KVA	Knowledge Value-Added
MOC	Matrix of Change
NPS	Naval Postgraduate School
NPV	Net Present Value
NPV	Net Present Value
ODE	Ordinary Differential Equation
OECD	Organisation for Economic Cooperation and Development

PLM	Product Lifecycle Management
QFD	Quality Function Deployment
ROI	Return on Investment
ROIT	Return on Information Technology
ROK	Return on Knowledge
RO	Real Options
ROMP	Real Options Pricing Models
ROP	Return on Process
SD	System Dynamics
SME	Subject Matter Expert
UAV	Unmanned Aerial Vehicles
VCD	Value Chain Dynamics

CHAPTER 1: INTRODUCTION

1.1. Introduction

In contemporary business and product development, managers strive for effective methodologies and processes to improve the tasks and eventual performance of the product being developed. As an example, information systems (IS) managers generally rely on approaches such as financial analysis and cost accounting for planning and controlling processes. Financial analysis and accounting have long been regarded as the basis for decisions aimed at generating higher performance and profits. This is a fact that applies to processes that use knowledge as their basis for output creation like information technology (IT) processes. But financial analysis may not provide measures for all the value that each asset or individual provides to processes and in turn to an organization as a whole.

Problems are encountered when only financial analyses are applied to knowledge processes. Things such as risk, uncertainty, and the intangible benefits become difficult to quantify. The costs of things such as hardware, software and services can be valued by financial models. But these models can only measure and define cost savings from tangible benefits such as reduced growth of expenses from lower resource, labor and vendor expenses. This traditional focus on financial and cost aspects tends to ignore the impacts of intangible benefits and therefore affects the true costs and true benefits of investments in knowledge processes. The main reason for the generalized application of these financial methods may be their use for so long in investments like manufacturing, electricity generation, and telephone services. But these investments are now more than ever completely different from investments such as IT in their rate of technological development. These intangible investments have much shorter life expectancies and higher rates of obsolescence which makes them inappropriate for traditional financial models.

A major intangible asset which is generally overlooked by financial models is knowledge. This is especially true in high-tech organizations such as those involved in software and information systems development which are heavily dependent on knowledge assets to succeed. There are differences in the knowledge required by employees in IT-dependent industries and employees of economies such as manufacturing, where financial models and cost accounting has proven successful. The application and development of information brings about changes in the knowledge of individuals and assets tasked with the implementation and application of tasks or processes. But these knowledge changes cannot be measured with traditional financial and cost accounting techniques. Identifying and accounting for knowledge assets is increasingly seen as critical for information-age organizations, and methodologies have emerged to help firms quantify these intangibles. Knowledge therefore becomes the key factor in determining accurate measures of value added from processes that rely on intangibles.

The dynamic complexity of knowledge-based processes also makes it difficult for managers to make decisions based on the behavior of these processes. Understanding the structure of systems and the behaviors they can produce by using models that simplify calculations and analysis can improve measurement of changes from investments in knowledge-based processes. Analyzing the interactions taking place in the execution of knowledge-based processes can help managers to better link costs and revenues to the knowledge embedded in those processes, improving decision making and asset allocation.

1.2. Impact of Knowledge

Knowledge is a key component of economic survival and success in highly-technological industries. While accounting measurements of economic impact refer to tangibles, technical companies too often attribute economic success to the success of their concepts, innovations, and new ideas. Knowledge has been defined as an "ideational (i.e. conceptual rather than physical) construct generated through the agency of the human mind" (Housel and Bell, 2001). Therefore the economic impact that companies experience from new product creation is derived more from knowledge assets than the tangible assets used to create those products.

The terms "Knowledge Economy" and "Knowledge-based economy" define the use of knowledge to produce economic benefits. This term became better known in the 1990's to describe the contribution to an economy from high-technology businesses and educational or research institutions. Companies that are highly innovative become leaders in their markets as a result of knowledge that makes them more creative than their competitors. An important concept of knowledge-based economies is that knowledge is a productive asset as well as a product that can be sold for a higher rate of return.

Knowledge-based economies are different from traditional economies in that knowledge can be shared and grow with use, unlike tangible resources which deplete or depreciate when applied. Products that have been made better by their knowledge content can carry a higher price tag than products with less embedded knowledge. The high demand for skilled, knowledgeable workers in highly-technological companies tells us that knowledge has a higher value when it is available to us than when it is unattainable or "walking out the door". Ironically few companies report the competency levels acquired by human knowledge capital and rather see downsizing as a cost-avoidance practice.

While many financial analysts are reluctant to include intangibles in their measurements of value-added, companies do not succeed merely on financial capital. Knowledge Capital can account for everything else that is not shown on conventional balance sheets. The effective execution of knowledge capital provides prosperity for a company and this knowledge capital has been calculated by isolating the returns on knowledge capital after paying for financial capital and subtracting that from profits (Strassmann, 1999).

The term "New Economy" describes contemporary developments in business and the economy. The general idea of New Economy is for business to focus on areas critical to success and where there is competitive advantage. It also describes an evolution from a manufacturing-based, wealth producing economy, to a service-based, wealth consuming asset economy. The rise of this New Economy has been justified as being principally driven by information, knowledge, competition, and changing interpersonal activities in businesses. These driving factors have been attributed to the increases in prominence of intellectual capital. The management of knowledge capital has been shown to drive the rise of this New Economy, and this management and measurement of knowledge capital is responsible for the rise of information economies which create "knowledge-based" intangibles. Intellectual know-how and problem-solving capacities have become more important for businesses under intensely competitive markets and strategic adaptation is an ever-more important part of the business. In turn, tangible assets (like equipment and land) diminish in relative business importance (Guthrie 2001).

1.3. The Importance of Measuring Knowledge Value

When the traditional ideas of capital and labor are used to determine the success of a firm, only the productivity of the firm's capital is taken into account. Return on assets and return on investments are examples of this traditional approach which has for long been better suited to long term investments such as manufacturing systems. But knowledge is needed for better use of the firm's capital and therefore a necessary item in any industry and more so in technology-driven companies. As an example, employee knowledge can be based on the accumulation of on-the-job experience along with job-related education that is applied to help the company's goals. Traditional theories claim that only capital assets improve productivity but this is not the case in high-tech businesses. Productivity in highly technological organizations comes from knowledge capital and this is proof of the recent rise in the importance of knowledge management. A good example is the case of an employee with vast experience and education, for who the value of knowledge capital is defined from his or her training and experience which is useful for the company and a determinant of its success or failure (Strassmann, 1998).

Strassmann states that the "two-hundred-year dominance of financial capital in establishing the market value of corporations is now history" (Strassmann, 1998). The importance of information and knowledge management is a reality because we can now manage by planning and controlling knowledge as an input rather than as an investment in technology. The importance of knowledge is now more noticed in the current information technology and information society as changes in technologically-based interpersonal activities take place in today's societies. Along with this, creative and innovative processes are a major factor of competition between organizations and these processes are based on knowledge.

Housel and Bell "make the case powerfully that the measurement and management of knowledge in the new century is of comparable importance to the measurement and management of people and money in the past" (Housel and Bell, 2001). The global tendency in businesses towards increased use of information technology comes from the increasing need to distribute knowledge across business operations. Knowledge and technology have always been key factors in economic development but their importance has been rising at a steady rate in recent years. High-tech industries demonstrate the fastest growing employment levels which convert into higher business outputs (Housel and Bell, 2001).

1.4. Problem Statement

Corporations have traditionally measured success in terms of tangible assets. In highly technical and information-based businesses, the value generated by company processes cannot be measured using cost accounting, which accumulates costs and quantitative data for the purpose of profit measurement. The application and development of processes such as those that use information systems bring about changes in the knowledge of individuals and assets tasked with the implementation and application of the tasks or processes. Investments in information technology can produce value in two ways: through improvement or creation of business processes (to increase efficiency) and through improvement of management decisions by speedier and more accurate decision making (which makes them dynamic).

Firms can therefore attain value from knowledge-based processes but may not be able to account or measure all or some part of that value. While capital budgeting models can measure the value of capital investments, they rely on measures of cash flows. Therefore tangible benefits can be assigned cash values but intangible benefits providing business value cannot be measured under these financial models. Along with this when intangibles are not measured the risks and uncertainty associated with these assets is also overlooked. An important question then becomes where and how can the value of knowledge be measured and reported, within accounting models or as totally separate metrics (Guthrie 2001). Another problem is the difficulty of quantifying intangibles when they are not measured to begin with. Employee knowledge, training requirements, and learning curves are some examples of the very important intangibles a manager can use (if the information is available) for better decision making. Knowledge input is necessary in any business process and the value of knowledge applied to business processes can be used as a measure of value added to the business.

1.5. Research Question

Changes such as information technology investments are implemented in organizations with the purpose of improving processes and reducing costs. Investing in information systems and technology is expected to pay off for companies by supporting core competencies, improving production processes, and boosting commerce and communications for competitiveness. Traditional methods for measuring return on investments or value-added are no longer applicable for current knowledge-based business models. The value earned by executing knowledge processes can be better measured by taking into account the value from knowledge rather than mere monetary tangibles. Previous work has shown the appeal for measuring knowledge as a way to productivity improvement. Knowledge-based processes also interact in dynamic system structures. Therefore reaching a consensus on why, what, and how the dynamic nature of systems affect the measurements of value-added from knowledge processes becomes a new research area. This research will propose to answer the question: Can valuation of knowledge provide an enhanced measure of value-added from processes for use in decision making when aided with process selection and dynamic modeling to provide higher returns on investment?

1.6. Goal of this Research

The goal of this research is to identify and develop a framework to measure knowledge value added that incorporates process complexity interactions and dynamic behavior models. Models are "abstraction of real or conceptual systems used as surrogates for low cost experimentation and study. Models allow us to understand a process by dividing it into parts and looking at how they are related" (Madachy, 2008). Therefore modeling can provide insight into the dynamic behavior of knowledge value variables as part of bounded process wholes. Interactions within a system composed of processes can be modeled and this can be used by managers for improved decision making. A business environment or process with knowledge-value, such as information technology, can be improved by modeling for behavior modes to study effects on value-added. The research aims to provide comparisons of knowledge value at different behavior modes of knowledge processes. Modeling of dynamic behaviors in knowledge processes that generate units of output can demonstrate and further analyze the effects of changes such as information technology modifications.

1.7. Research Objectives

- Development of a framework that measures value-added of processes based on their knowledge complexity.
- Integration of methodologies to analyze process interactions and dynamic behaviors to complement the framework's measurement of value-added by knowledge.
- The ability to compare processes that address knowledge value-added to make decisions on implementation and/or modification of processes.
- Execution of case studies that test the framework to determine its success in analyzing value-added supported by analysis of interactions and dynamic behaviors.

1.8. Research Relevance

The research in this dissertation is relevant to companies where knowledge processes and investments in knowledge assets are keys to performance. Technical companies attribute economic success to their concepts, innovations, and new ideas. In highly-technological companies these innovations and improvements are derived more from knowledge assets than from tangible assets. The complexity and interacting behaviors of knowledge processes may have a large effect on their added value. The behavior of processes based on changes in their sub-processes will be researched to determine if it becomes a discriminator for the value added by knowledge processes.

1.9. Research Contributions

The research will develop and study a framework for decision making that will measure intangible value added, perform alternative selection, and analyze the dynamic behaviors of the selected processes. The framework will provide a way to evaluate and implement improvements in processes based on the value added by knowledge and the interactions that current and proposed alternatives have with each other in dynamic systems. While knowledge is considered a better measure of value from technology-based processes, "effective change management depends on recognizing complements among technology, practice, and strategy" (Brynjolfsson, Renshaw, and Alstyne, 1997). Besides interacting and complementing each other, knowledge processes are dynamic and their dynamic complexity makes it difficult for managers to make decisions based on the behavior of these processes. Like most processes knowledge-based processes exhibit non-linearity that can make decision making difficult because a simple change can produce complicated effects. These complexities imply a need to understand the structures and interactions taking place in knowledge-based systems and the behaviors they can produce by using models that simplify calculations and analysis.

The main contributions from this research come in the form of:

- Valuation of assets based on complexity of knowledge processes that generate common outputs.

- Alternative process selection based on how processes interact with each other – for improved change management based on how processes complement each other.
- Dynamic analysis of proposed system made up of new processes, a combination of existing and new processes, or where no changes are beneficial – for determining the effects of process dynamics and feedback in the overall system.
- Provide a user or manager of knowledge processes a way to measure value added of alternatives and systematically determine how complementary processes are along with the ability to model the dynamics of the processes.

While this research will not contribute answers to the complementarity theory question in mathematical form it will provide a related contribution by the application of a methodology which "detects complementary and interfering practices, and presents an overview of an interlocking organizational system." (Brynjolfsson, Renshaw, and Alstyne, 1997). Analysis of the value added from knowledge assets and processes can be better accomplished by managing the change process since interactions and complements affect the outcomes of processes in a system. In summary, the main contribution of this research will be the measurement of knowledge value added taking into consideration the interactions between processes and the dynamic behavior of chosen alternatives.

1.10. Thesis Outline

This dissertation is organized as follows: Chapter two reviews the existing literature to date as it relates to measuring of intangibles, business valuation and value added of knowledge, the analysis of process interactions in systems, and the existing gaps in the measurement of knowledge value. Chapter three describes the flow of the investigation and the research methodology that the study will apply in order to improve decision making based on valuation of knowledge-based activities. Chapter four integrates the proposed methods into a framework approach and defines the framework's application. Chapters five and six apply the developed framework via case studies. Chapter seven will summarize, conclude and make recommendation on the research results.

CHAPTER 2: LITERATURE REVIEW

2.1. Introduction to Literature Review

Due to the intangible nature of modern-day business processes, value added can be better measured based on the knowledge complexity of process. The complex dynamics involved in knowledge processes also makes it imperative that measurements of knowledge value take into consideration the effects of system interactions and behaviors.

2.2. Measuring Intangibles

Intangible assets are non-monetary assets that cannot be measured physically but require time and effort to be generated. The two general and primary forms of intangibles are legal intangibles (patents, goodwill, and trademarks) and competitive intangibles. Competitive intangibles include knowledge activities as well as collaboration, leverage, and structural activities. These competitive intangibles have a direct impact on the productivity and success of an organization. Human capital is the most significant source of these competitive intangibles in current organizations (Wikipedia contributors, 2007).

According to International Accounting Standards (IAS), intangible assets are expensed based on their life expectancy and have an identifiable (copyrights, patents) or indefinite (trademarks, goodwill) useful life. IAS 38 prescribes the accounting management of intangible assets that are not covered under another accounting standard. Computer software, among others, is an example provided by IAS and can be acquired by purchase or self-creation. Recognition criteria by IAS 38 requires companies to recognize intangible assets only if “it is probable that the future economic benefits that are attributable to the asset will flow to the enterprise” and “the cost of the asset can be measured reliably”. Intangible assets, of which knowledge is an example, are therefore recognized internationally to receive accounting treatment in organizations (IAS, 2007).

The Organization for Economic Co-operation and Development defines intellectual capital (IC) as "the economic value of two categories of intangible assets of a company: organizational ("structural") capital; and human capital” (OECD, 1999). More precisely human capital includes human resources within the organization (i.e. staff resources) and resources external to the organization (namely, customers and suppliers). Often, the term "Intellectual Capital" is treated as being synonymous with "intangible assets". This definition places IC as part of the overall base of intangible assets and the distinction between IC and intangible assets has not been very clear. While intangibles have been labeled “goodwill”, IC is considered a part of goodwill. This lack of a clear distinction has been hampered by traditional accounting methods which have not provided for the classification and measurement of intangibles in companies. Intangibles have simply received no recognition in traditional accounting methods. The limitations of financial methods have brought about the need to measure intangibles especially in current highly-technological and knowledge-based businesses.

The term “Intellectual Capital” has generated different definitions and theories, out of which the “only truly neutral definition is as a debate over economic *intangibles*” (Wikipedia contributors, 2007).   Technology industries are known to use the term intellectual capital more than any other industries. This was in part because the “dotcom bubble” period saw the influence that computer programming had in the stock-market values of newly-established internet companies. There have been many arguments indicating the need for recognizing intellectual capital, ranging from the simple fact that “it matters” to its application for improving efficiency. The early 1980s saw a “general notion of intangible value (often generically labeled "goodwill")” (Guthrie, 2001). But it was not until the late 1990s that the subject of intellectual capital generated publications, conferences, and large projects to encourage academic research on the subject. Figure 2-1 summarizes the milestones of significant contributions to identification, measurement and reporting of Intellectual Capital (Guthrie, 2001).

Figure 2-1: Milestones of significant contributions to identification, measurement and reporting of Intellectual Capital.
(Guthrie, 2001).

Early 1980s	Mid-1980s	Late 1980s	Early 1990s	Mid-1990s	Late 1990s
General notion of intangible value, often labeled "goodwill"	“Information age" takes hold; gap between book value and market value widens noticeably	Early attempts to construct statements/accounts that measure intellectual capital (Sveiby, 1988)	Initiatives to systematically measure/ report on stocks intellectual capital Skandia AFS appoints Leif Edvinsson "Director of Intellectual Capital“; first role of managing Intellectual Capital elevated to position of formal status/ given an air of corporate legitimacy	“The Knowledge creating company“ (Nonaka and Takeuchi, 1995) distinction between knowledge and IC Celemi: •First executive education on importance of intangibles •"knowledge audit" to offer detailed assessment of state of its IC Skandia's "Visualizing Intellectual Capital" focuses on evaluation of stock of IC. (Edvinsson, 1997)	Researchers, conferences, publications. Large scale projects (e.g. the MERITUM project; Danish; Stockholm) to introduce academic rigor into research International symposium in Amsterdam on IC (Organization for Economic Co-operation and Development, 1999; 2000)

Three approaches to reporting of intellectual capital are Intangible Assets Monitor, Skandia Value Scheme/Skandia Navigator, and Intellectual Capital Accounts. These approaches are summarized in Table 2-1.

Table 2-1: Approaches to Reporting Intellectual Capital

Approach	**Description**	**Literature**
Intangible Assets Monitor	Stock-Flow theory, same as traditional accounting theory; Perceives three Intangible Asset Indicators (External Structure, Internal Structure and Competence) as "real" assets.	Sveiby, 2001
Skandia Value Scheme and Skandia Navigator	Models that visualize value components that make up intellectual capital as well as the method of managing them and report on their development.	Edvinsson and Malone, 1997; Edvinsson, 1997.
Intellectual Capital Accounts	Illustrate the scope of the intellectual resources and competencies of a company and the consequences of the management activities to manage and develop these, on the basis of the experiments and experiences with external intellectual capital accounts of ten Danish and Swedish companies.	Danish Agency for Trade and Industry, 1998; 1999.

The valuation of Intellectual Capital has also been proposed by using the "Knowledge Value-Added (KVA) methodology for the valuation of the output from the usage of intellectual capital" (Housel and Cook, 2005). The KVA model describes outputs from processes in common units, and this notion allows for the valuation of intellectual capital and its measurement. Housel and Cook summarize the process for the valuation of IC as shown in Figure 2-2.

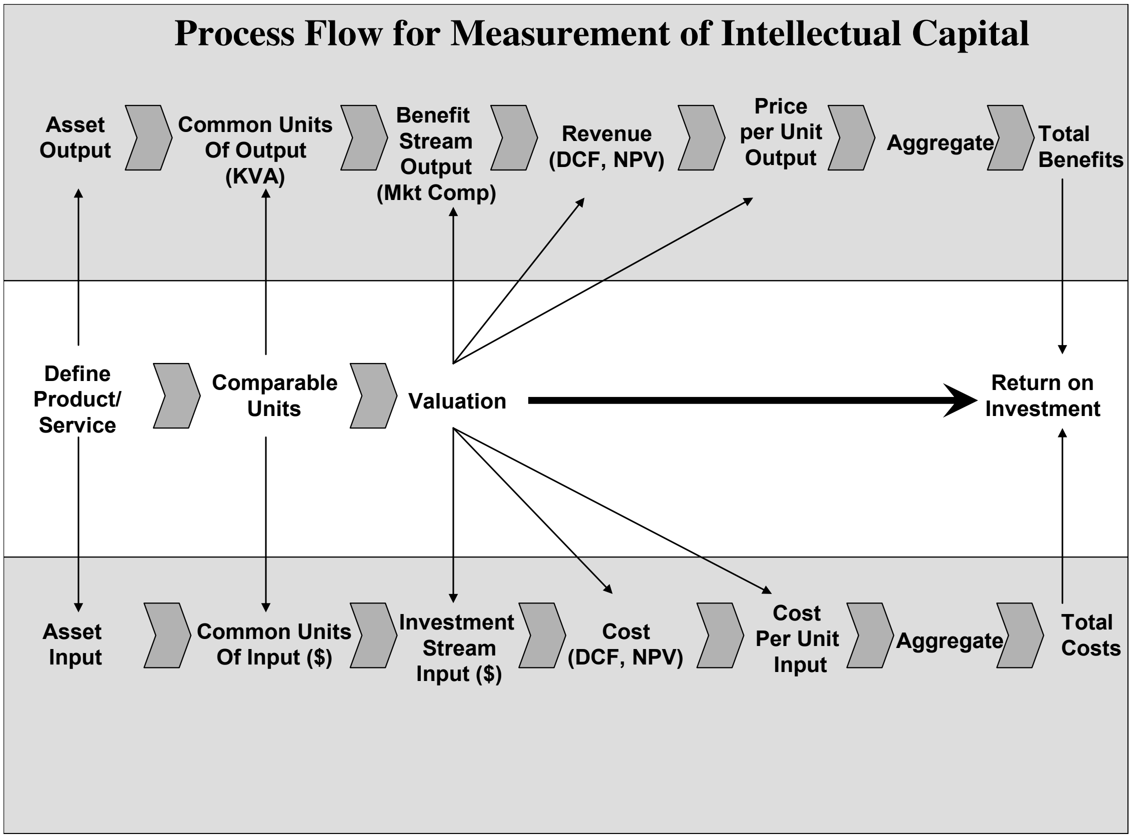

Figure 2-2: Process Flow for the Valuation of Intellectual Capital.

Reprinted from "An Approach to Valuing Intellectual Capital in Defense Processes Using the Market Comparables Approach" by T. J. Housel and G. Cook, IC Conference, 2005. Reprinted with permission.

Business Value Approaches: Capital Budgeting Models

Traditional capital budgeting methods measure the value of investments in projects. Businesses invest in capital projects in order to improve their processes, catch up or stay ahead of the competition, or to simply meet customer requirements. Capital budgeting methods are generally cost-based, and concerned with measuring cash flows and therefore their basic unit of measure is cash (Laudon and Laudon, 2006). These methods are limited when it comes to valuating the intangible benefits that do not come as a direct, clear representation of monetary flow. Some of these approaches are:

- Payback method
- Accounting Rate of Return on Investment (ROI)
- Net Present Value (NPV)
- Cost-Benefit Ratio
- Profitability Index
- Internal Rate of Return

The payback method is simply a measurement of the time required to pay back the investment on a project. It divides the investment cost by the net cash inflow to determine a time period to pay back the original investment. It is a simple method that is useful for projects with undetermined useful lives. But the payback method is not appropriate to determine the profitability of investments, and much less measure the value of intangible assets or their return on investment. Along with the payback method other business value approaches are merely representations of benefits versus expenses. Rate of Return on Investment measure the return on an investment using cash inflows from the investment adjusted for depreciation but it ignores the time value of money. Net Present Value is the amount of money an investment is worth considering the time value of money. Cost-Benefit Ratio is another simple method that calculates capital expenditure returns by dividing total benefits by total costs. Profitability Index can compare the profitability of different investments by dividing present value of cash inflows by the investment cost. Internal Rate of Return takes into account the time value of money to calculate the profit an investment is expected to earn.

Capital Budgeting models encounter many problems when used for information technology investments. One major issue with these financial methods is the measurement of intangible benefits affecting performance and which do not take place up-front, but are rather measured at the time of the analysis. Along with back loaded benefits, constant changes in technology bring about short life expectancies in which knowledge may become obsolete and bring higher risk and uncertainty due to a less-dynamic and less-accurate measurement of investments than accomplished with more *strategic approaches*. As described by Strassmann, "Information-based strategies cannot be developed unless they are linked to measures of performance, yet traditional financial indicators offer little help in this regard." (Strassmann, 1998) Therefore these traditional capital methods cannot bring out explicit measures of performance from knowledge, which are necessary in information technology investments.

Strategic Approaches

Information technology investments can be evaluated under more complex strategic-type considerations which are not covered by the capital budgeting methods discussed previously. One of these is Portfolio Analysis, where different alternatives to choose from can be used to understand where IT investments are being made and allow for selection from alternatives. It is an analysis of the portfolio of potential applications to determine risk and benefits and select information systems alternatives.

Scoring models is another method for alternative decision making based on a rating system that scores selected objectives. It is based on selected criteria from qualitative judgments by the experts who understand the IT investment on which decisions need to be made. Scoring models are mostly used to help back-up and corroborate decisions. Because it is an objective technique, it is rarely used as a sole method for decision making.

Real Options Pricing Models (ROMP) evaluate IT investments with uncertain returns using financial options techniques. By using options valuation derived from financial techniques, ROMP values IT investments similar to stock options by creating a right but not an obligation to invest in a project. By taking into account present value, exercise price, and length of time to defer, ROMP can help managers analyze the volatility of IT investments along with investment timing and cost over time. The disadvantages of ROMP lie on its ability to estimate the key variables that affect the value of the options.

Measuring Returns on IT Investments

Measuring the return on IT investments is important to determine the impact of process improvements and their effect on firm performance. While the previous section discussed budgeting methods for capital projects, more specific approaches to measuring the value of investments in Information Technology and the performance impact these investments can be assessed at the firm and at the process levels (Pavlou, Housel, Rodgers, Jansen, 2005). The most common approaches for measuring return on IT are as follows:

1. Process of Elimination: this technique uses accounting data to account for all costs and then the residual is attributed to knowledge capital.
2. Production Theory: this is a black-box, inputs-outputs approach using regression modeling.

3. Resource-Based View: links outputs to IT resources by considering the uniqueness of those resources.
4. Option Pricing Model: determines the best point to put into effect an investment in IT.
5. Family of Measures: measures indicators to find the contributions of IT at the sub-corporate level.
6. Cost-Based: this is the commonly known activity based costing approach which determines value of IT using cost, and is a Capital Budgeting method.
7. Knowledge Value Added: allocates revenue to IT based on the contributions to the outputs of a process.

These approaches also have their advantages and disadvantages as shown in Table 2-2.

Table 2-2: Approaches to measure return on IT investments.
(from Housel, El Sawy, Zhong, Rodgers, 2001)

Approach	**Advantages**	**Limitations**
Process of Elimination	Uses common financial analysis techniques and existing accounting data	Cannot drill down to effects of specific IT initiatives
Production Theory	Uses econometric analysis on large data sets to show contributions of IT at firm level	"Black-box" approach with no Intermediate mapping of IT's Contributions to outputs
Resource-Based View	Strategic advantage approach to IT impacts	Causal mapping between IT investment and firm competitive advantage difficult to establish
Option Pricing Model	Predicting the future value of an IT investment	No surrogate for revenue at subcorporate level
Family of Measures	Captures complexity of corporate Performance	No common unit of analysis/theoretical framework
Cost-Based	Captures accurate cost of IT	No surrogate for revenue at subcorporate level – no ratio analysis
Knowledge Value Added	Allocates revenue and cost of IT Allowing ratio analysis of IT value-added	Does not apply directly to highly creative processes

The first three methods (Process of Elimination, Production Theory and Resource-Based View) are executed at the corporate or firm level, and most of the literature on the impact of IT investments has shown to improve corporate-level or firm performance. Although the Solow Computer Paradox or “productivity paradox” states that work force productivity does not improve as result of information technology changes, increased information technology investments have been much more agreed on as a path to improvement. The productivity paradox has also been explained to the fact that IT outputs are more clearly seen at the process level than at the corporate or firm level (Pavlou, Housel, Rodgers, Jansen, 2005).

The Option Pricing Model or ROMP as described previously is executed at both the corporate and sub-corporate levels. ROMP has the limitation of assuming projected cash flows due to its use of net present value. But since the outputs of sub-corporate processes are not the final product sold to customers, cash flows cannot be directly tied to sub-corporate processes since they represent corporate-level outputs. Therefore this is more of a corporate level approach and not capable of helping managers at the sub-corporate, process level where they expect their IT investment decisions to make a difference.

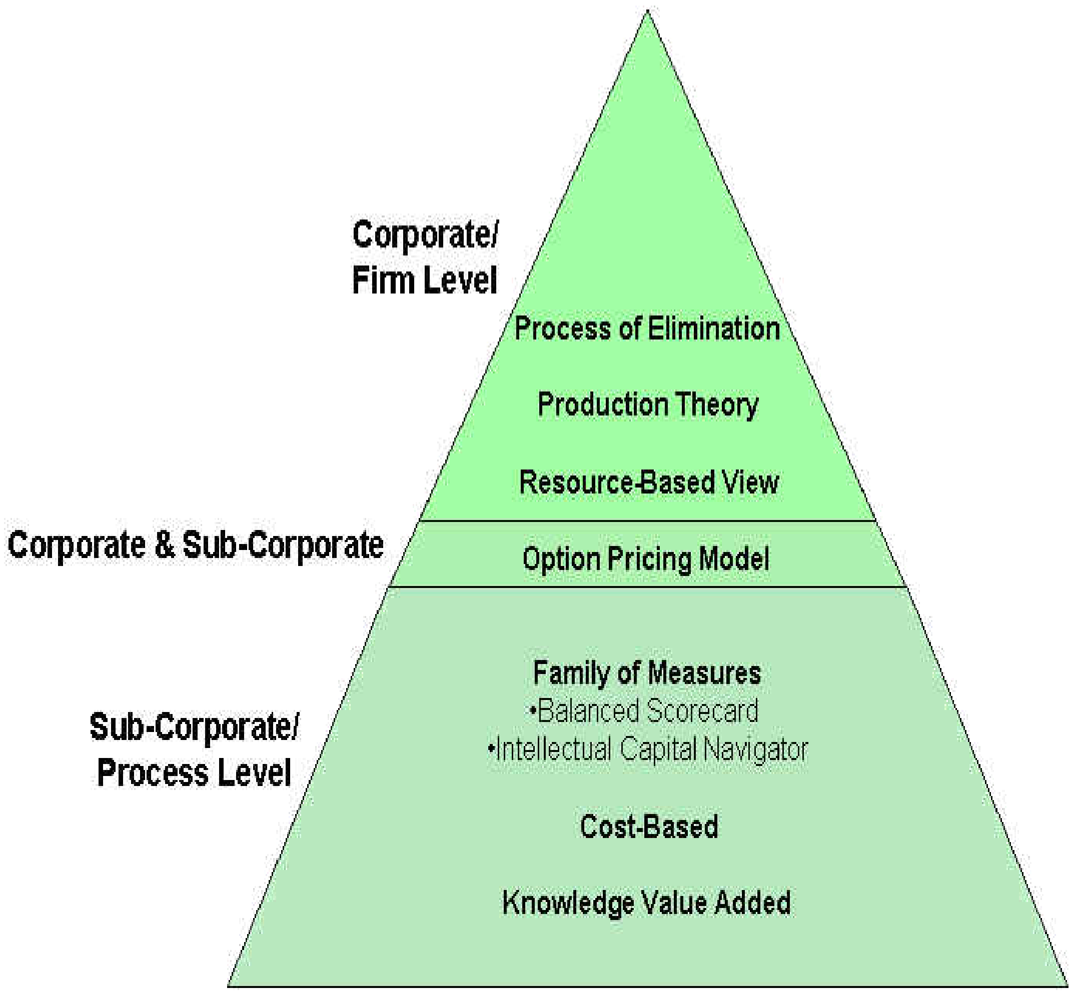

Figure 2-3: Execution Levels of IT-Investment Measurement Models

Family of Measures, Cost-Based, and Knowledge Value Added are executed at the sub-corporate or process levels of the organization to measure the impact of investments on company success. The Family of Measures approaches include Balanced Scorecard (scoring models) and Intellectual Capital Navigator methods. These need to be exercised at the process levels in order for the collected measurements to be meaningful. Family of measures lacks theoretical units of analysis to tie IT investments to firm performance (Bharadwaj, 2000). This brings about subjectivity and does not allow for specifics when it comes to measurements. Cost-based approaches assume savings, such as those coming from process improvements by IT investments, are a reflection value. This is true when there is cost reduction. But in these cases value is not accounted for based on revenue but instead based on savings or expense avoidance.

The KVA approach assumes the possibility of describing outputs in common units via a “knowledge metaphor”. This metaphor uses a common language based on estimates of process knowledge to describe the outputs of the processes in common units. Under the KVA approach knowledge is a requirement either in human or IT form when producing outputs. These units of output, which require knowledge, have a relationship to average time needed to learn how to produce the output. This learning time is based on estimates and can be applied as a surrogate for common units of output. Learning time can also be used to allocate revenues and costs to a firm’s common units of output.

2.3. Information Technology Investments

Information technology is defined by the Information Technology Association of America (ITAA) as "the study, design, development, implementation, support or management of computer-based information systems, particularly software applications and computer hardware" (ITAA, 2009). Information technology covers a wide range of applications of computing and technology to collect, process, convert, store, and retrieve data, information and knowledge. As it relates to knowledge, the use of information technology to perform human tasks has been one of the most important applications when investing in IT. Making decisions regarding what manual or personnel tasks to execute using IT has been a subject of both study and controversy since the invention of computers. Information technology has long been tied to process improvement, increased performance and better value in organizations that make alternative decisions to implement IT to execute processes. But “despite increasing anecdotal evidence that information technology (IT) assets contribute to firm performance and future growth potential of firms, the empirical results relating IT investments to firm performance measures have been equivocal. However, the bulk of the studies have relied exclusively on accounting-based measures of firm performance, which largely tend to ignore IT's contribution to performance dimensions such as strategic flexibility and intangible value” (Bharadwaj, Bharadwaj and Konsynski, 1999). Results on productivity gains from IT investments have been varied. “In spite of remarkable improvements in computing power and the increasing share of IT, empirical research on the economic impacts of IT does not reveal a consistent pattern of enhanced productivity through IT investment” (Lee and Barua, 1999). As also noted for over twenty years by the Solow computer or productivity paradox, these mixed finding have gained major attention from IT researchers.

Information Technology Outsourcing is widely believed to be the best method to cost savings and reduction of expenses, but “there are not many related literatures or studies that would confer each of the procedures after information technology outsourcing, and whether there is any change on its knowledge amount and rate of return” (Wu, Wu, and Yang, 2007). And while vast amounts of literature suggest that IT investments and profitability go hand in hand, mixed findings have also been reported (Bharadwaj, Bharadwaj and Konsynski, 1999).Theoretical and methodological explanations have been provided for these mixed findings; from a theoretical viewpoint IT investments have served not only to increase productivity and value but also to lower entry barriers, eliminate market inefficiencies, and intensify market competition. From the methodological viewpoint, "characteristics of the samples used, measurement errors, and failure to control for other industry and firm-specific factors that influence firm performance have been cited as the primary reasons for the unexpected results" (Bharadwaj, Bharadwaj and Konsynski, 1999).

Knowledge assets that are converted for deployment by IT have shown advantages mostly when applied to simple, repetitive processes or when the knowledge is "volatile and might be lost when employees leave the company" (Housel and Bell, 2001). Complex knowledge systems and their processes do not always prove successful candidates for conversion to IT. Since no process is exactly the same, there is no clear line or rule that denotes when an IT investment will provide improved performance and a higher return on investment. The measurement of the knowledge value and return on investment that originates from specific processes then requires quantitative tools for decision-making regarding the use of IT investments versus other process execution methods.

2.4. Knowledge Value-Added

The addition of value in an organization always begins with the goals of the organization. Fitz-enz explains that "Value can be traced from the inception of data collection through processes to economic results. The values are the economic effect resulting from investment in human capital. Value comes through reduction in expenses as well as through revenue generation, which ultimately lead to profitability and other enterprise goals" (Fitz-enz, 2000).

With value addition and the need for process improvement comes the need to assess and measure the processes in use by a business to better allocate costs and expense. But what has been measured is "not necessarily what is most necessary" (International Engineering Consortium, 2005). Traditional techniques account for dollars as a measure of success, but these dollars did not improve employee creativity, knowledge, or motivation. Therefore the argument is that these known financial approaches do not measure the contribution of knowledge assets in an objective matter.

Knowledge is considered the "fundamental building material of a modern corporation" (Kanevsky and Housel, 2006). But the measurement of knowledge has emerged as recently as the mid-1990s as a way to valuate the knowledge embedded in processes, technology, and employees. "Knowledge is the stock of intellectual assets accumulated through experience, learning, and ongoing practices" (Pavlou, Housel, Rodgers, Jansen, 2005). Business capabilities are defined by the effectiveness of the business when executing its processes. The relationship of knowledge and process capability becomes obvious when we understand that business capabilities are generated or improved by the acquisition of information, the conversion of information into knowledge, and the use of this new or changed knowledge towards more effective activities.

Knowledge Value-Added (KVA) is a methodology, different from traditional capital budgeting approaches, to measure the value of investments in information systems. KVA was developed by Dr. Valery Kanevsky of Agilent Technologies and Dr. Tom Housel at the University of Southern California in the early 1990's to help businesses re-engineer processes by focusing on creating value versus simply reducing costs. This methodology is a "different approach to traditional capital budgeting focusing on the knowledge input into a business process as a way of determining the costs and benefits of changes in business processes in new systems" (Laudon and Laudon, 2006). The main idea behind KVA is to determine, using some surrogate measure, how much knowledge is embedded in each sub-process leading to a specific product or service. It uses "a surrogate measure for intangible value to determine how much each sub-process contributes to the final product or service relative to all the other sub-processes. The methodology then determines value by assessing the cost of each sub-process relative to its overall contribution" (Portugal, 2000).

KVA was developed to "facilitate analysis of value created through business process reengineering" (Walsh, 1998). Business Process Re-engineering (BPR) is a leading approach to improve processes towards improvements in business performance. BPR techniques are geared towards helping companies restructure their processes. These techniques were originally based on principles of downsizing and cost reduction. Now the BPR approach has become extremely important in achieving performance improvements by "the confluence of supply change management, fast response management, and knowledge management" (Cook and Dyer, 2003). Currently BRP creates change for the purpose of improvement under the principle that IT can more effectively use information for competitive advantage.

Derivation of value-added under KVA

KVA focuses on the knowledge input and costs to determine the benefits from a business process. Based on the fact that inputs of knowledge are required to execute processes, KVA measures the value of the knowledge used to generate process outputs. KVA derives value from knowledge starting with information theory which is concerned with the quantification of information. A quantity of information can be defined in relation to individual objects vs. a set of objects (from which individual objects could be selected). The information in an object is the number of bits needed to describe the object and that description is only useful if the full object can be reconstructed from the description. KVA quantifies knowledge like information theory with descriptions of the knowledge needed to execute a process that reconstructs a useful output (could be by learning time, binary measures, or by quantity of instructions). KVA applies the principles of Kolmogorov's Complexity Theory (K-Complexity) as a universal measure of changes in the form of matter and as the universal activity of people including the creation of value in business processes. As K-complexity aims to measure 'information', KVA bases change being proportional to and requiring knowledge on K-complexity theory. Under KVA changes in entropy come from information processes defined from an input (original or unchanged variable) as a variable 0 and output (a changed variable with value added by information) as a variable 1 in the same fashion as Kolmogorov uses the "bit" as the unit of measurement. Businesses, as complex open systems that exchange information with their environments, are capable of adding value via processes by changing inputs into products. The major assumption of KVA is that change, and therefore knowledge, are proportional to value.

KVA has been described as changes in structure that one can measure as changes in entropy and the value-added by a process can be proportionally associated with the change in entropy. This approach assimilates to the language of thermodynamics, where an input (*a*) becomes and output (*b*) via a process (*P*) (Housel, El Sawy, Zhong, Rodgers, 2001). A difference in entropies is proportional to the amount of thermodynamic work needed for the change such that:

$$\Delta E = E(b) - E(a) \tag{1}$$

Applying this parallel or assimilation of a thermodynamics process to knowledge processes, we can depict the process as shown in Figure 2-4.

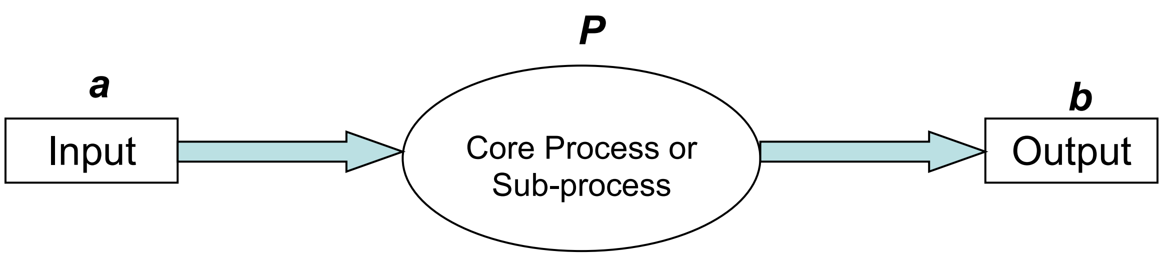

Figure 2-4: KVA Change Representation

A process's output is a function of its input, such that: *P(a) = b*. The process *P* acts on input *a* to produce the output *b*. The following assumptions provide a derivation of how valuation works under KVA's business application of Complexity Theory:

- if a = b, no value has been added, therefore
- value can be added only through changes to input, and
- "changes" can be described, therefore
- the minimum number of changes is equal to the length of the shortest description, so
- "value-added" = "number of changes" = "length of the shortest description"

The differences in the entropies of *a* and *b* are proportional to the amount of processing needed to make the change. In knowledge processes versus a substance in thermodynamics, an information theory bit is proportionate to a unit of "complexity" that is described as a unit of "knowledge".

If a description of *x*, *d(x)*, uses the fewest number of characters it is of minimal length or minimal description. The K-complexity of a variable *x* is the length of the number of characters in its description *d*(x), and is defined as:

$$K(x) = |d(x)| \tag{2}$$

With an amount of “thermodynamic” processing to transform a string *x* into a string *y*, the K-complexity *K(x)* is the length of the shortest description of *x*. When that description of complexity is changed by a process, the change or entropy is a change in K-complexity (where change is the difference between the complexity of input, *K(x)*, and the output *K(y)*:

$$\Delta K = K(y) - K(x) \tag{3}$$

The calculation of value-added in business processes based on K-complexity requires a relationship between business change processes and the descriptions of those processes. KVA states that in a process where change takes place there is always knowledge used to change input into output, change being the value added via the change process. The value is relative to the change via a process and can be measured by the quantity of knowledge needed to generate change. KVA defines knowledge by how much time it takes to acquire the knowledge (or learn how) to execute a process, by the amount of process instructions required to produce an output, or by binary yes/no questions by which outputs are represented as a sequence of yes/no answers, to calculate the length of sequence of yes/no answers for sub-processes. Hence the learning time, process descriptions, or binary query are used as descriptive languages for change measurement.

In terms on process re-engineering, take a process P with an input a and output b, and a modified process M with input x and an output y. Subsequently, if:

> 1) We map a to x in a one-to-one relationship such that a is a set of all inputs possible to process P and x is the set of all possible inputs to process M, and
>
> 2) We also map b to y in a one-to-one relationship such that b is a set of all outputs possible from process P and y is the set of all possible outputs from process M, then
>
> 3) $M(x) = y$ if and only if $P(a) = b$

The changes brought about by a modified process M, for example an information technology investment, are a reflection of the changes. This is because the K-complexity in the investment, as would a string, reflects the structure changes in the inputs from a value-adding process. Value under KVA is an assumption of the changes that knowledge brings about when generating an output. Return on investment (ROI) under KVA is measured based on the knowledge to create outputs and is defined as return on process (ROP) which is calculated similar to ROI by applying value and cost. ROP is what KVA calls its measure of value creation for processes with a predetermined output and is basically a return on investment *in process*. The derivation of ROP under KVA is as follows: the internal performance V of a process is defined as

$$V = I / C \qquad (4)$$

Where I is the amount of information or K-complexity to execute a process and C is the cost to produce the specific amount of K-complexity needed for the process. While this explanation talks about a single process, the performance of compounded processes can also be defined by using weighted averages of component performances.

Along with performance V the necessary relation to an external measure of performance or value to account for the value is described by I (as information, knowledge or complexity). This relates to return on investment where the price of an output accounts for the money gained (or lost) and is the numerator in a ratio against the cost to execute. For example when a business obtains a monetary value from a process output, that value correlates to the complexity of the process that generated the output. KVA derives return on knowledge (ROK) as the ratio of the value that the complexity or knowledge of a process generates and the cost of the process. Return on Knowledge (ROK) is the ratio of revenue allocated to a core area when compared to its corresponding costs. With knowledge as a surrogate for common unit outputs, ROK determines knowledge value to cost ratio for processes.

Limitations of KVA

The KVA approach was designed for application to processes where there is a shortest description of the knowledge needed to change inputs into outputs. These are known as "predetermined output" processes. This limitation is based on the assumption that the average time needed to learn a process that has pre-determined outputs is proportionate to the knowledge acquired, and this knowledge is proportionate to the change produced by the process. This limited application makes it difficult to describe knowledge for complex processes (Pavlou, Housel, Rodgers, Jansen, 2005). This becomes a drawback of the methodology when trying to measure creative processes. Research and development processes are not considered "predetermined output" processes, are therefore unpredictable in nature, and could not be measured under the given KVA assumptions for core processes. In order for highly creative and unpredictable processes to be measured, organizations must introduce or establish those processes into core processes with predetermined outputs so that KVA can apply the transformation of creative outputs into value. From this perspective, "it is possible to use the approach to track the conversion of such creative outputs into value as they are embedded in processes with predetermined outputs" (Housel, El Sawy, Zhong, and Rodgers, 2001).

2.5. The Matrix of Change

BPR efforts frequently fail to attain desired goals due to the need for coordination of technology, products, and strategies. The problems arise from transitions being more difficult than planned and oversight of critical process interconnections. Implementing new technologies without making proper changes in other areas, such as human resources or operating procedures, has often provided no improvements in productivity or quality. Information and knowledge technology investments are associated with increased productivity but complementary processes become a requirement in such organizational change exercises.

The Matrix of Change (MOC) is a tool for business process reengineering (BPR) adopted from Quality function Deployment's "house of quality". It aims to recognize critical process interactions to make decisions on process changes: how fast to implement changes, the order to implement changes, implementation location, and systems stability and coherence. It is based on the idea that successful change management depends on the interactions between components of a system, such as the interdependencies between strategy, practice, and technology. The MOC tool helps in "understanding issues of feasibility (stability of new changes), sequence (which practices to change first), location (greenfield or brownfield sites), pace (fast or slow), and stakeholder interests (sources of value added)." (Brynjolfsson, Renshaw, and Alstyne, 1997).

The MOC studies connections to emphasize interactions and complementary process practices in four steps. The first step provides means to determine the most important practices by i*dentification of critical processes*. It defines goals and identifies existing critical process as well as targeted process and while it can be difficult to identify which processes are most important, once identified the processes are broken up into constituent parts. An example of a target practice can be organizational learning, which can be broken into processes like continuous training, on-the-job training, and cross-training. The practices and their broken-up processes are analyzed using horizontal-triangular matrices in the second step, *identification of system interactions* to identify things like change speed, execution sequence, feasibility, and change location. This step highlights interactions and transition difficulties among practices by identifying the interactions as complementary (reinforcing), competing (interfering), or no interaction using plus or minus signs at the practice intersections in the triangular section of the matrices. A square transition matrix is built in the third step to *identify transition interactions* and determine how difficult it would be to change from current to targeted practices. The last step encourages stakeholder feedback on proposed practices by *surveying stakeholders* to find out standpoints on implementing or keeping practices by using a scale from -2 for rejecting or eliminating a practice to +2 for highly important practices to keep or implement.

Analysis by the MOC identifies how current and planned business processes interact with each other as characterized by a transition matrix. Interactions between practices, processes and assets are determined with a square transition matrix (third step) by comparing the current and proposed systems. Complementarities of systems are represented by the plus and minus signs used when identifying system interactions. The amount of positive and negative signs describes indicates how difficult a change process can be. The larger the amount of complementary practices and smaller amount of conflicts, the less difficult the change transition. The nature of the interactions, be it by density and strength of positives or negatives, are keys to determine stability and coherence of processes. In relation to system dynamics, "A system of processes with numerous reinforcing relationships is coherent and therefore inherently stable, whereas one with numerous competing relationships is inherently unstable." (Brynjolfsson, Renshaw, and Alstyne, 1997). A basic representation of a matrix of change is shown in Figure 2-5. The proposed process that have a negative interaction with current-state processes are not considered worthy of implementation.

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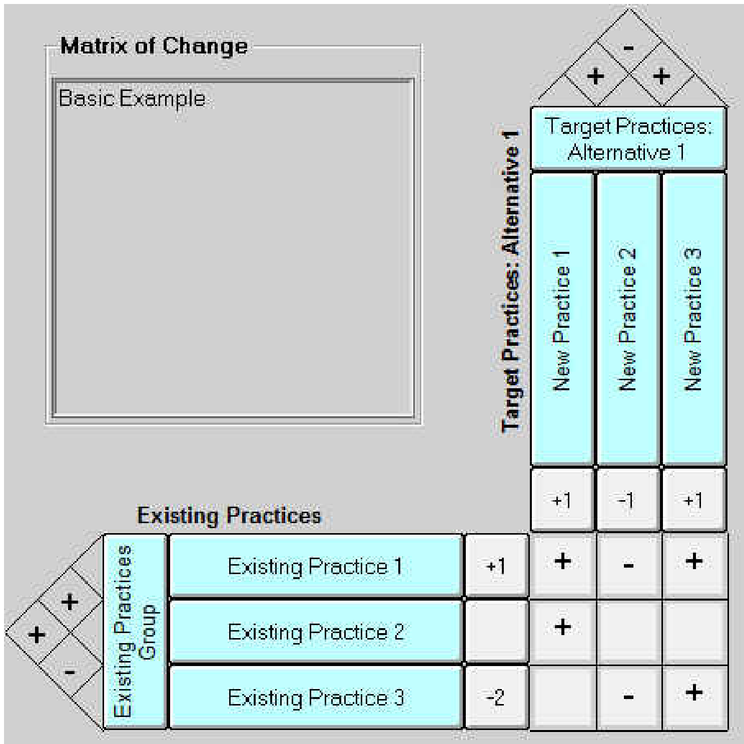

Figure 2-5: Basic Matrix of Change example

2.6. System Dynamics

System dynamics is an approach to model the behaviors of complex systems which usually have interactions with each other over time periods. This approach utilizes a set of specific tools to conceptually understand the structures of complex systems. System dynamics methodologies began use in the 1960s with the creation of the MIT System Dynamics Group and have been applied to business scenarios in the form of dynamic models to experiment alternative business approaches and strategies in a risk-free fashion. "System dynamics is also a rigorous modeling method that enables us to build formal computer simulations of complex systems and use them to design more effective policies and organizations" (Sterman, 2000).

System dynamics is concerned with the dynamic behavior of systems over time. System dynamics modeling helps in identifying behavior patterns exhibited by system variables and build models that can mimic the patterns. This modeling capability can be used for testing process changes to affect system behavior based on desired goals. The use of system dynamics provide "insight and understanding of how the system works and how it will respond to a specific action" (Bennet and Bennet, 2004). This can provide modeling and analysis of behaviors for such complex systems and its application can improve the capacity of decision makers to manage systems.

The tools used by system dynamics to generate models are Causal loop diagrams (CLD) and stocks and flows (Sterman, 2000). CLDs describe variables linked by arrows showing influences of variables on each other. The influences are positive (reinforcing) and negative (balancing) feedbacks. CLDs are "maps showing the causal links among variables with arrows from a cause to an effect" (Sterman, 2000) and can capture the dynamics of a modeled process, but they cannot describe a model's "stock and flow" structure. They are applicable to the capture of hypothesis about dynamics' causes and to demonstrate the feedbacks of a specific process. Stock and flow structures are descriptions of variables with rates or "flows" which can increase or decrease. These flows accumulate into the most important information in a dynamic model as "stocks" which represent system states. Therefore an appropriate system dynamics model requires variables for the state of the system (stocks), for the increase and decrease of these stocks (flows), and variables that can be linked to stocks and flows supporting the description of the model behavior.

2.7. System Behaviors and Dynamic Equilibrium

Dynamic systems, by their nature, exhibit varied and complex modes of behavior. Three fundamental behavior modes are: exponential growth, goal seeking, and oscillation. Exponential growth comes from self-reinforcing or positive feedback, where larger quantities create larger increases which in turn increase quantities leading to faster growths. Goal seeking and oscillation both come from negative feedback but oscillations arise due to time delays in negative feedback loops. Goal seeking negative loops aim at equilibrium and balance in a system to reach a desired state. Oscillation is one of the most common behavior modes in system dynamics and includes types such as chaos. The oscillations arise when actions (such as those taken to affect or eliminate system discrepancies) cause significant delays in negative loops that eventually cause the system to over- and under-shoot a goal state.

When a system's variables remain constant over time the system is said to be in equilibrium or steady state. In equilibrium the variables keep a consistent set of values and in the absence of changes the variable values will remain constant indefinitely. A steady state condition in a model can be found by examining the stocks in the model: if the sum of all inflows to each stock equals the sum of all outflows (and the magnitudes of the stocks do not change over time) the system is said to be in a steady state.

Feedback processes are better understood by taking into consideration the concepts of equilibrium and stability. While positive feedback loops are associated to unstable equilibrium, negative feedback loops are linked to states of stable equilibrium and overall system stability is closely linked to the system's equilibrium state. When a system in equilibrium is slightly disturbed, it tends to return or oscillate about its original equilibrium if it is a stable system. Unstable systems disturbed from their original equilibrium tend to move away from that equilibrium state. System dynamics modeling's main objective is to understand behavior over time.

"Perfect" equilibrium is a dynamic behavior exhibited by few actual systems as a state of perfect balance without needs for change. Equilibrium implies that all state variables in a system have achieved their goals concurrently. While most in the fields of economics and management use models based on the concept of equilibrium, those in system dynamics feel that disequilibrium behaviors are the most interesting behaviors in systems and models that show disequilibrium time paths are more effective. But equilibrium is still extremely useful as witnessed by the practice initially placing models in an equilibrium stated to study their "pure" behavior response to changes.

2.8. Summary and Gaps

The literature review presented the available approaches for measuring intangibles with their applications. The review also demonstrated how complex processes and practices in complex systems can interact and affect each other, making it imperative to know how these interactions influence system goals. This section will summarize the literature review and present the research gaps leading to this research.

The Process of Elimination is a corporate level approach that removes costs of capital and leaves the cost of technology, this remainder as revenue attributed to knowledge or information technology capital. It does not provide and objective, mathematically-derived measure for the cost of the knowledge applied in production capital. At the corporate level, production theory assesses the contributions of inputs or investments to the outputs they produce. It is an economic-theory approach that looks for a relationship between inputs and outputs, but does not reference the actual processes and activities within an organization. Resource-based view is another corporate level approach that cannot provide specifics on units of measurement linking IT and results in performance. Family of measures approaches rely on pre-determined variables to define contributions by IT. Performance indicators or variables are chosen by the organization to account for performance from investment but the determination of importance for each indicator or variable leads to subjectivity issues. Cost-based approaches can measure the impacts of IT investments, but only when under the assumption that costs are reduced and outputs are either constant or improved.

The Intangible Assets Monitor method presents relevant indicators for measuring intangibles depending on the company strategy. It does not present a complete picture of measurable intangibles and does not see this as a possibility. Instead the purpose of this method is “to be practical and to ‘open a few windows’ so managers can start experimenting.” This framework sees the intangible part of a balance sheet as composed of three indicators: individual competence, internal structure, and external structure. Skandia Navigator focuses on a number of areas: backward looking focus areas (financial), present focus areas (process, human, and customer), and future focus areas (renewal and development). These measures are defined locally by managers as an approach to provide the intangibles information missing in financial statements. It uses a process of elimination of tangible capitals until intangible assets are the final balancing value. Intellectual Capital Accounts is a tool to represent the intellectual capital of a company based on companies communicating its values as influenced by intellectual capital both internally and externally. Ten companies which shared some features (but were also different in many aspects) formed the basis for this tool. The measurement of these accounts is made up of a special combination of these factors: human resources, customers, technology, and processes. This tool does not look to raise new capital, but "rather tend to be used to support organizational development by functioning as a communication tool aimed at presenting and maintaining the corporate strategy and vision" (The Danish Trade and Industry Development Council, 1998).

KVA was developed to objectively measure the return on intellectual capital and knowledge assets. KVA provides valuation as it can measure the knowledge in people, information technology, and processes. KVA translates the knowledge applied in core processes into numbers. The main assumption of KVA, for example in the case of knowledge embedded in IT, is that the contributions to output from IT equal the IT value-added. The ability to further analyze this methodology to determine contributions to output and, based on the KVA assumption, the value-added by knowledge, provides a better framework for valuation of knowledge. With these objective valuation measurements managers can model scenarios for comparisons of the core processes and technologies used to create their outputs.

Along with the shortfalls of methods to measure value of knowledge and intangibles, previous applications of knowledge value added have not taken into consideration the interactions between processes that are in place and processes being considered for implementation. A structured analysis of proposed knowledge processes can be accomplished as a preliminary step to determine the stability and coherence of processes. The Matrix of Change provides additional insights into interactions between practices and moreover the interactions and difficulties that take place when making changes from established to proposed process practices.

Knowledge is clearly one of the most important strategic resources to remain competitive and firms need to both create it and manage it. But effective decision-making in environments of dynamic complexity requires expanded mental models that can describe these complex behaviors. "Accelerating economic, technological, social, and environmental changes enhance the dynamic complexity of the same systems, making difficult for managers to fully understand the behavior of such systems, and so the knowledge management" (Iavernaro, 2006). System dynamics can model closed systems which are based on actions that feedback onto themselves. Actions can be highly influential and highly dependent on each other, allowing analysis of interactions between related activities such as hiring, training, task execution, testing, etc. This approach is widely recognized as a tool for decision making in dynamic environments where management actions affect the outcomes of processes. An important application of system dynamics has taken place over the last twenty years when "system dynamics modeling has been applied in software organizations to help compare process alternatives and to support project planning" (Kellner, Madachy, and Raffo 1999). Kellner et. al. presented a review of work on the field which does not specify an application of SD to measure knowledge. It "identifies the questions and issues that simulation can be used to address ("why"), the scope and variables that can be usefully simulated ("what"), and the modeling approaches and techniques that can be most productively employed ("how")" (Kellner, Madachy, and Raffo 1999).

Stevenson and Wolstenholme presented "Value Chain Dynamics" (VCD) as a convergence of system dynamics and "value thinking". Their support methodology "is a project-based approach that establishes the interdependence of SD and value thinking as a means to assess the value implications of all kinds of change" (Stevenson and Wolstenholme, 1999). The authors outline opportunities coming from "semi-systemic" management thinking and significant developments that have increased the need for system dynamics. These developments include value-based management, knowledge management, intellectual capital, asset management, human capital management and balanced scorecards. The paper supports the idea that the application of system dynamics can be greatly enhanced by linking SD and semi-systemic resource-based thinking or "value thinking" in business.

Value-based management "starts from the proposition that companies and business strategies should be judged by the economic value they can create for shareholders, i.e. by future cash flow-based economic valuations rather than historic accounting measures" (Stevenson and Wolstenholme, 1999). With value now being accepted as the most important management concept, system dynamics complements the value movement with the development of resource-based understanding of critical business resources. Most current approaches in knowledge management are only concerned with "explicit" knowledge, and system dynamics can model the business activities that help reflect and share "tacit" knowledge. Intellectual capital needs to be managed interdependently over time and system dynamics is a proven approach that can describe intellectual resources and model both the creation and destruction of intellectual capital (Stevenson and Wolstenholme, 1999).

Nielsen and Nielsen applied system dynamics modeling to the use of Balanced Score Cards with the reasoning that "one of the main difficulties of balanced scorecard (BSC) is to foresee the time lag dimension of different types of indicators and their combined dynamic effects" (Nielsen and Nielsen 2008). They point out the fact that several top companies have been applying system dynamics to address critical decisions such as diffusion of technologies and business cycles. While one of Nielsen and Nielsen's main goals was to address time lag issues related to the dynamic environments being measured by BSC, they wanted to "demonstrate the benefit of using SDM for a concept like BSC, and to shed some light on the formulation of the timing aspects pertaining to the cause-and-effect relations between BSC means and measures" (Nielsen and Nielsen 2008). In that study the time delay problems and their cause-and-effect behaviors are considered explicitly in order to make BSC a more appropriate method for predicting financial results. The application of SDM to a family of measures approach like BSC, which operates at sub-corporate process levels just like knowledge value added, provides a basis for a similar application of system dynamics to KVA.

The literature to date does not provide specific applications of system dynamics modeling of the KVA methodology. A notable and knowledge-related application is entitled "system dynamics for knowledge-based decision making". The focus of this knowledge-based decision making is on "organizing knowledge derived partially from the target situation-related personnel's cognitive models" (Kim, Yim, and Kwak, 2000). The goal is to improve competitiveness by modeling, with system dynamics, the personnel's knowledge on variables such as productivity, customers, and pricing strategies. This study falls under the category of a more common application of system dynamics rather than an application of SD to measure and manage knowledge.

A significant publication on system dynamics is provided by R. J. Madachy's emphasis on the coupling of technical factors with simulation tools as a means for process improvement. "The purpose is to improve decision making about projects and organizational policies by being better informed about the dynamic consequences of decisions. Decisions may involve setting project budgets and schedules, return-on-investment analysis, tradeoffs between cost/schedule/quality or other factors, personnel hiring, risk management decisions, make/buy/reuse, process improvement strategies, etc" (Madachy, 2008). As a synthesis of previous work on software process simulation and system dynamics, it presents findings in the field of software process modeling with system dynamics and how the principles of system dynamics have been used to analyze and improve organizational processes. The publication does not include any applications of system dynamics to measure knowledge value-added.

The literature agrees that the application of system dynamics allows the modeling of systems where there are tradeoffs. While simple systems have objectives that can be accomplished without bad consequences, complex systems can result in undesirable consequences after short-term goals are maximized. The modeling of tradeoffs from short to long term goals is possible by identifying the problem and developing hypothesis to then build computer models of the system in question. Testing the model to ensure it accurately represents the system's behavior then allows its use to model alternatives. In the case of a knowledge-based system the alternatives will come from different applications or uses of knowledge processes. Dynamic decision making and process re-engineering is made possible by the use of system dynamics modeling.

More recently system dynamics and KVA were combined in "System Dynamics Modeling for Improved Knowledge Value Assessment: A Proof of Concept Study" (Ford, Housel and Dillard, 2010). This study generated system dynamics models of the movement and tactical use of weapons in which the accumulation of weapons and hitting of targets, respectively, are stocks. Moving weapons to desired locations and hitting desired targets takes knowledge and time and subsequently generate value when the expected outputs are obtained. These "operationalized" benefits were then divided by costs for each process to obtain return on knowledge metrics and compare the processes' value-added based on KVA calculations.

System dynamics has been applied to software processes to support software development projects and for dynamic modeling of software processes. "Value Chain Dynamics" uses value thinking and system dynamics to assess the impact of changes and defines the importance of managing by modeling intellectual capital over time. Balanced scorecards have been modeled with system dynamics to address the time issues encountered in dynamic environments. The KVA methodology has yet to interact with system dynamics to provide a dynamic framework to analyze knowledge value-added. Analysis of the behavior and stability of processes selected for use can be a further discriminator of knowledge value. Since proposed alternatives have not been applied like current processes have, modeling the proposed alternatives for dynamic behavior becomes a tool for decision making before committing to investments.

This research aims to investigate the application of three theories to analyze proposed processes for increased value-added from intangibles and model the selected alternatives in terms of knowledge-value added. With modern organizational processes relying on intangibles assets (knowledge) for process outputs, changes to improve the outputs of those processes can be analyzed using the Matrix of Change as a first-pass to determine feasibility, stability, and difficulty of making changes based on process interactions. With new process alternatives selected for implementation against a current environment, system dynamics can then be used to model the proposed processes for their system behavior and stability. The measure of knowledge-value added becomes a main determinant in decision making.

The available literature has presented KVA as a way to “measure the value of knowledge assets deployed in core processes objectively” (International Engineering Consortium, 2005). This measure of value of knowledge embedded in company processes, technology and human assets takes place through return on knowledge (ROK) and return on process (ROP). The use of knowledge assets and processes in general could also be modeled to determine the improvements and value added from the use of knowledge.

KVA has been exercised using available, collected data to measure the value added of knowledge from specified processes. But the available literature has not accounted for interactions and dynamics between knowledge processes under KVA-based measurements. Literature examples measure the outputs of knowledge and compare the return on knowledge (ROK) ratios of functional areas such as sales, marketing, customer care, finance, and human resources. A specific area is determined to produce the highest ROK, and management uses this information to make decisions that promote the applicable area over the other functions due to its higher ROK.

Investing in the latest information technology available is highly regarded as a sure way to improve processes, but does it always result in increased value? Changes in information technology processes will affect intangibles but the value added from knowledge is variable. Effective decision making in knowledge-based processes that rely on information technology requires models that expand beyond simple business structures. Decision makers in knowledge and technology-intensive organizations have to deal with complex dynamic systems and how these complex structures behave. The fact that process changes such as information technology are not always a solution for higher productivity and process improvements implies a need for studying the causal and interactive effects of process changes. Since "the effect of information technology in a company's shareholder's value has been largely unpredictable" (Gardner, 2000), the quality of the information utilized to measure returns on investments becomes critical to decision making. “Amidst the increasing quantity of available information, the quality of information becomes a crucial factor for the effectiveness of organizations” (Eppler, 2006). The consideration of dynamics between process aims to improve the quality of the KVA measurements from modeling of systems applying knowledge. Dynamics thinking introduces awareness of “what the systems are, what characterizes them, and their general properties” (Bennet and Bennet, 2004). The problem stated by this research is the need for measuring the value added by the use of knowledge taking into consideration the dynamic interactions inherent in knowledge-based systems.

Table 2-3 presents a synopsis of the reviewed literature and the research gaps as related to measuring the intangible value of knowledge-based processes. The table summarizes the availability of accounting and tangible-asset methods (Capital Budgeting Models described in section 2.2) and the Strategic approaches (Portfolio Analysis, Scoring models, and Real Options Pricing Models) that cannot provide measures of intangibles or even less knowledge value.

Table 2-3: Literature Gaps

	Value of Investments	Intangibles' Value of Investments/ Information Technology	Information Technology Knowledge Value	Analysis of critical process interactions	System Dynamics	Dynamic measure of Knowledge Value	Authors
Capital Budgeting Models[1]	X						Laudon and Laudon, 2006
Strategic Approaches[2]	X						Laudon and Laudon, 2006
Process of Elimination	X	X					Strassmann, 2000
Production Theory	X	X					Brynjolfsson & Hitt, 1996
Resource-Based View	X	X					Jarvenpaa& Leidner, 1998
Family of Measures	X	X					Kaplan & Norton, 1996
Cost-Based	X	X					Johnson & Kaplan, 1987
Intangible Assets Monitor	X	X					Sveiby, 2001
Skandia Value Scheme & Navigator	X	X					Edvinsson and Malone, 1997; Edvinsson, 1997
Intellectual Capital Accounts	X	X					Danish Agency for Trade and Industry, 1998; 1999
Measuring the Return on Information Technology	X	X	X				Pavlou, Housel, Rodgers, Jansen, 2005
Software Process Dynamics	X				X		Madachy, 2008

	Value of Investments	Intangibles' Value of Investments/ Information Technology	Information Technology Knowledge Value	Analysis of critical process interactions	System Dynamics	Dynamic measure of Knowledge Value	Authors
Value Chain Dynamics	X				X		Stevenson and Wolstenholme, 1999
System dynamics modeling for a balanced scorecard	X				X		Nielsen and Nielsen 2008
System dynamics for knowledge-based decision making	X				X		Kim, Yim, and Kwak, 2000
System Dynamics Modeling for Improved Knowledge Value Assessment	X	X	X		X	X	Ford, Housel and Dillard, 2010
KVA/MOC/System Dynamics	X	X	X	X	X	X	Cintrón and Rabelo, 2013

[1] Capital Budgeting Models include: Payback method, Accounting Rate of Return on Investment (ROI), Net Present Value (NPV), Cost-Benefit Ratio, Profitability Index, and Internal Rate of Return.
[2] Strategic Approaches include: Portfolio Analysis, Scoring models, and Real Options Pricing Models.

CHAPTER 3: RESEARCH METHODOLOGY

This chapter describes the research methodology. The research methodology to be applied is defined with a description of the research flow that will be utilized in this research.

3.1. Methodology Introduction

The literature review demonstrates that the measurement of value added from knowledge processes can be accomplished by using complexity as the basis for value when executing processes that convert inputs into outputs. Different from measuring value from tangible cost and cash earnings, valuation of knowledge based on Kolmogorov complexity principles can be used to calculate return from investments. The application of knowledge valuation will focus on measuring the returns on investment and comparing the obtained metrics for decision making. The development of a framework that takes into consideration more than just valuation metrics can greatly increase process selection and decision making. This investigation will propose that considering process interactions and complements as well as dynamic behavior of systems provides a significant improvement to decision making that is based on value added from knowledge. The focus of the research will be the development of a framework for process analysis and decision making. The investigation will present a structured approach to analyze and measure value based on process complexity along with process interactions and dynamic behavior.

Valuation of investments has been based mostly on measures of cash flow but in modern information and technological processes the use of cash flows and tangible assets is not as effective. The major contribution of using knowledge to measure value added is the application of process complexity in relation to converting inputs into outputs, therefore accounting for change of inputs via processes. With available alternatives that may improve value added, the ability to anticipate complex interrelationships surrounding change becomes significantly important. Merely introducing changes that may increase value added would be incomplete without understanding things such as stability of changes, sequence and pace of implementing change, and stakeholder opinions. There is a need for analyzing the interactions that processes have within their systems and the applications of knowledge valuation to date have not considered this. Systems demonstrate behaviors based on processing of inputs to generate outputs and these behaviors can complement or affect each other. Merely comparing value added metrics does not achieve comprehensive decision making.

3.2. Methodology Description

The investigation begins with a statement of the research question. The research to be conducted starts with a recommendation for improving process selection based on measures of value added. Decision making and process selection in knowledge processes and information technology is a complex process that can benefit from structured analysis approaches. To implement and execute effective processes, change management must take into consideration the interactions that processes in a system have among them. The investigation asks the question: can combining a methodology for process alternative selection and modeling of dynamic behaviors improve the results from investment valuation based on knowledge complexity? This question will be researched by studying three methodologies in an integrated framework that aims at calculating return from knowledge processes. The potential contribution is the structured combination of alternative selection and dynamic modeling to analyze valuation from knowledge processes. For the purposes of this research, systems consist of processes that interact and are executed as part of systems that generate value when processing inputs into outputs. This research will then answer the question: Can knowledge provide better measures of value-added from processes for decision making when aided with process selection and dynamic modeling?

The research is introduced for decision making based on process change interactions and feasibility and adding a major contributor in modeling processes for effects and stability (Chapter 1). The literature review in Chapter 2 compares methods to answer the research questions and describes units of analysis derived from process complexity that will become the mathematical basis for alternative selection and process modeling in the proposed framework. These units of analysis will be the pre-cursor to developing the framework, which starts with baseline (current) and proposed (alternative) system processes for structured process selection and eventual dynamic modeling (Chapter 4). Case studies will be executed to put the framework into practice (Chapters 5 and 6). An analysis of the framework based on case study results will summarize the completion status of the research (Chapter 7). The research methodology is depicted by Figure 3-1.

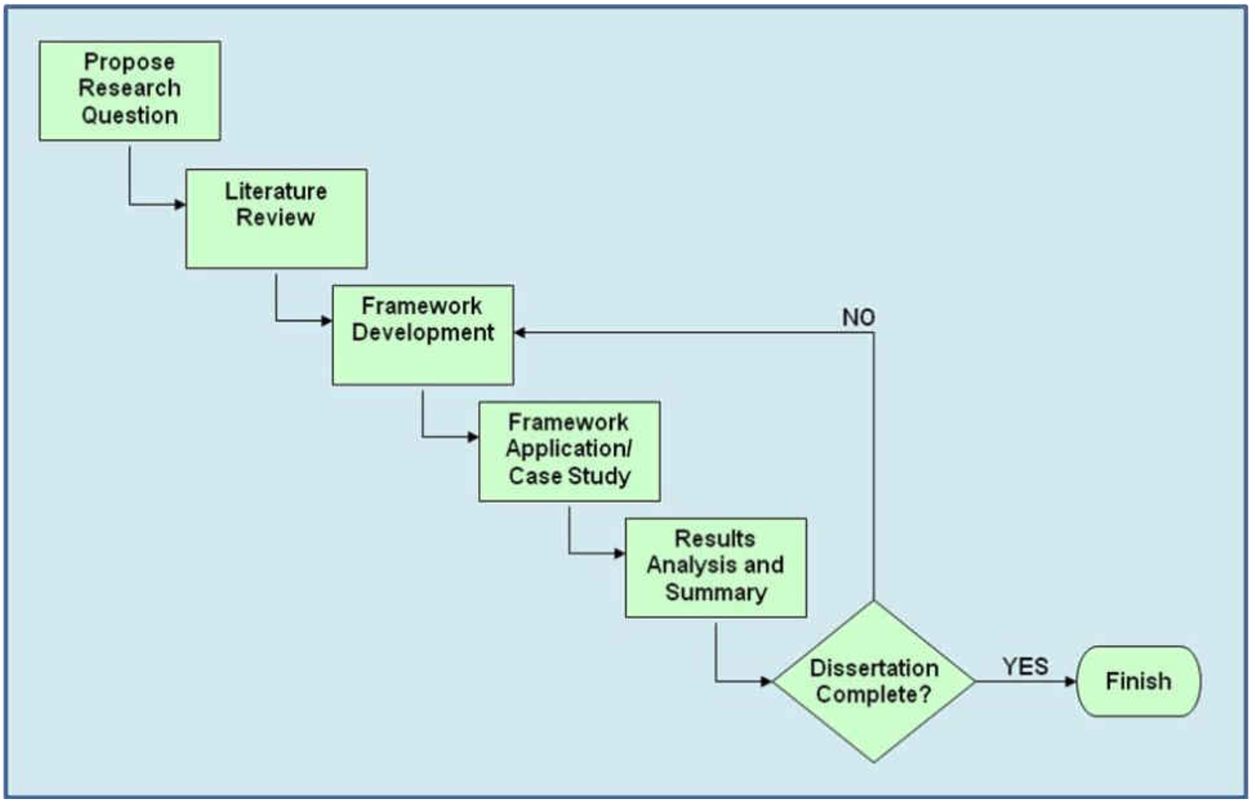

Figure 3-1: Dissertation Methodology

3.3. Propose Research Question

The research methodology starts by stating the research question. This investigation begins with an inquiry of the need for improving process change selection based on knowledge. The research begins by asking: does investing and concentrating on specific sub-process because they provide higher value affect the overall knowledge and value-added of a system? How does investing in changes affect knowledge value from processes? These questions lead to the main research question: Can the knowledge value-added methodology be improved for process selection by the introduction of methods for interaction evaluation and dynamic modeling?

3.4. Literature Review Summary

The literature review showed knowledge value-added as a methodology for valuation of knowledge assets and processes. Generation of process outputs in knowledge-based systems is better accomplished by using process complexity as the basis for measuring returns on investments. The literature review also described the need for managing the change process so that managers can identify critical interactions among processes to anticipate how to implement change, in what order changes can take place, and if the proposed changes are stable and coherent. Along with the need for management of change the behaviors of processes functioning as systems need to be considered after changes are implemented. The review and analysis focuses on intangible value measurement and dynamic interactions between processes.

3.5. Framework Development

From the literature review it can be concluded that the following steps need be considered to accomplish the goals of the proposed question:

1. When considering alternatives for improving returns on investment, define systems composed of output-generating processes that are measured by their knowledge.
2. Obtain value metrics based on process complexity to determine the individual value-added of each process.
3. Analyze process interactions for how complementary and stable the processes are when combined as part of a system.

4. Model the behavior of the system to determine cause and effect of processes in a working environment and study the dynamics of system process changes.

3.6. Framework Application

The developed framework will be used to demonstrate, by the application of case studies, the framework's functionality. The case studies will apply and exercise the framework to show how the framework performs the proposed objectives. For systems that require a defined amount of processes to generate outputs, all processes (baseline and alternative) need to be analyzed for how they function together. The next step then studies cohesiveness and interactions between all processes. The framework will use this as a preliminary "filtering" of processes to determine if further consideration should be given. The analysis will allow decisions that can range from no changes (to maintain overall higher value) to changes on all processes (to increase value). The interaction analysis will yield processes to compose a modified system which could be made up of any combination of baseline (current) processes and proposed (alternative) processes. After process are selected by studying how complementary processes function in a system, the newly defined system is studied for how processes behave with each other. This part of the case studies will provide modeling of the selected processes to determine functions and dynamics over time. The framework application phase of the research methodology will take place as shown in Figure 3-2.

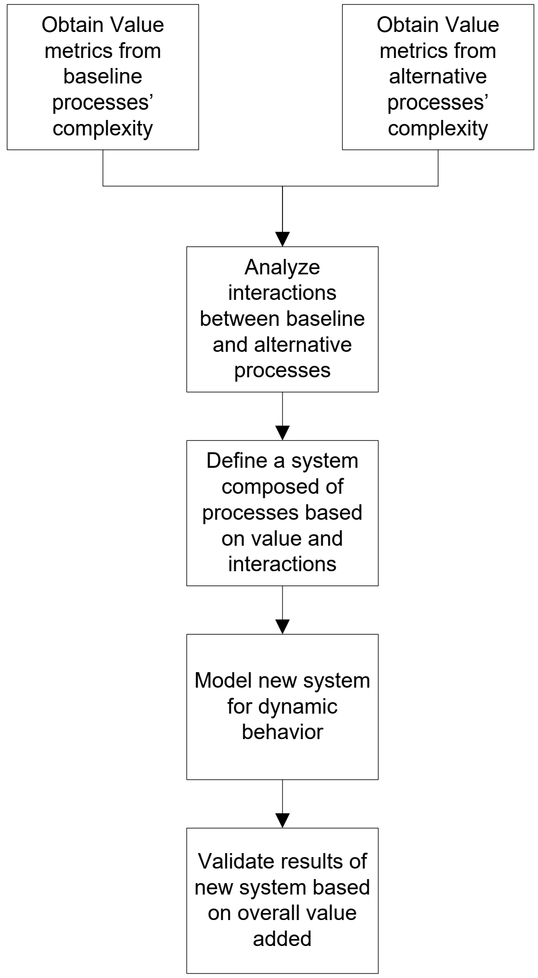

Figure 3-2: Framework Application Flow

3.7. Case Studies

The metrics to be applied on the case studies will be collected from knowledge-based processes. After the boundaries of the system and its core processes are defined the metrics to be collected will require, at a minimum, process costs of execution and process complexity from knowledge application. Therefore the metrics will be based on knowledge of the processes along with costs for each process under both baseline and alternative systems. The interactions study will consider complementarity between processes apart from valuation metrics. The system modeling will consider the processes' dynamic behavior and their valuation changes. The goal of the case studies is to compare baseline processes with the implemented alternative processes in terms of value added. Value metrics will be measured for a baseline state and for a state where changes/improvements are made to processes. The analysis that follows will compare the baseline and alternative systems, reviewing results for accuracy and refining the framework for repeat case studies as required from analysis findings. Figure 3-3 depicts the three major phases that the case studies will undergo.

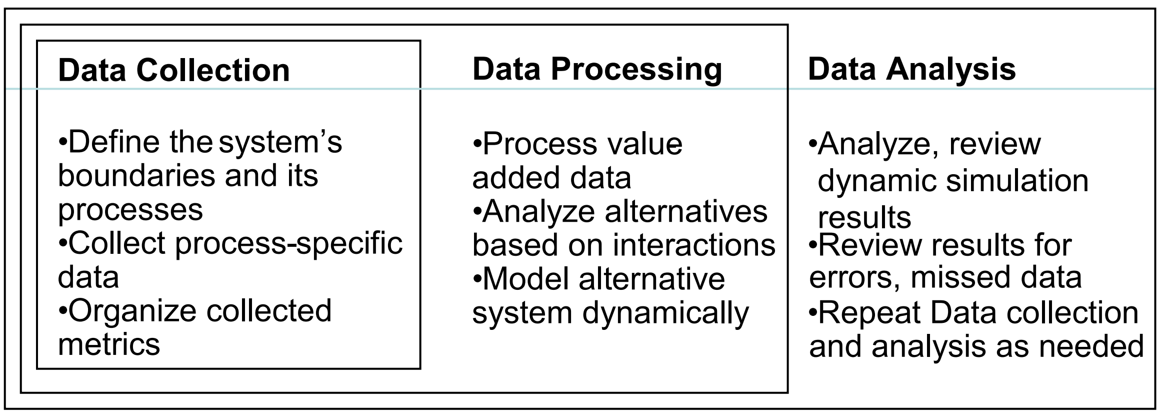

Figure 3-3: Phases for Case Studies

3.8. Results Analysis and Summary

An analysis of results (with possible need for framework revision) will describe the findings from the study of the new processes selected using the framework. If the results cannot be validated, the framework will require revisions to reattempt reaching the expected goals. The proposed framework starts with the use of knowledge complexity as a more appropriate method to measure the value of intangible knowledge processes. From there it can provide analysis of process alternatives based on their interactions, feasibility and the stability of a system with modified and/or new processes. The framework then models the structures and feedbacks that take place in processes while applying a knowledge valuation methodology as its mathematical basis. The existing literature does not analyze interactions of knowledge processes before changes are made and neither does it model the resulting systems in a dynamic fashion for the purposes of controlling and comparing process variables. In order to meet the dissertation goals the framework will be exercised on case studies of knowledge-based processes to test the framework's validity. This validation will provide the ability to assess intangible benefits to provide better allocation of resources for productivity and value.

The framework will methodologically select candidate processes, study their interactions, and dynamically model the value added by knowledge for alternative decision making. The framework will be designed from existing methodologies with the goal of discovering how process investments affect value-added while dynamically providing return on investment.

CHAPTER 4: FRAMEWORK

4.1. Introduction

This chapter describes the framework by integrating methods that will accomplish the goals defined in Chapter three into the research approach and by defining the framework's application. The research will use process knowledge complexity as the method by which processing of inputs is measured for value and introduce decision making based on process change alternatives and dynamics of processes. The goal of this research is to combine methodologies in a structured and ordered process for a framework that analyzes value-added based on knowledge with process change selection and further modeling of dynamic behavior. The framework will improve the process of alternative selection using knowledge as the base measure of value added and supplement it with analysis of processes interactions prior to changes and the dynamics taking place after process changes.

4.2. Framework Justification

The framework is being developed to provide improved decision making based on value added from processes. The literature review has demonstrated a need in the current technical- and technologically-based business landscape to account for the impact of intangible assets. The researched topics on valuation from intangibles established knowledge management as a necessary aspect of organizational decision making. With the agreed-upon importance of measuring the impact of processes by knowledge management, different methodologies have emerged to quantify the effects of intangibles and knowledge. Some of the reviewed methods identify knowledge as some remainder after tangible capital has been accounted for; others use subjective means and assumptions. But the reason processes are executed is to bring about changes to generate an output. In the case of knowledge processes, how much change takes place on inputs by using knowledge is then considered the most important aspect of executing these processes. In other words the activities that take place in a system which changes inputs and converts them to outputs in a modified state is what the framework wants to measure.

The literature survey has described that the amount of change to an input by using knowledge can be measured by how much knowledge is used to make the change. This statement is based on both thermodynamic entropy and Kolmogorov complexity, and can be summarized as follows: the required energy or complexity to generate or describe a process output is a measure of change. A framework of value-added from knowledge must then measure how much change a process has when generating outputs as follows: the more knowledge used the more change that can take place, and the more value that is generated. With an established method for measuring the value added from knowledge as described, what other aspects must be considered for a framework to provide a structured and systematic method for alternative decision making? When alternatives are available how can one determine how changes or added alternatives would function together in a system? Moreover, what behaviors may take place and how can we know if selected alternatives will affect system stability?

When a system composed of processes is under study for the purpose of modifying or selecting alternative processes to current processes there must me a consideration of how new processes interact in the current system. As an example the replacement of one process in a system made up of three processes must first be evaluated for how the new process functions with the two remaining ones. There must be a way to determine things like how processes interact, how feasible they are, and how difficult they are to introduce.

After the value-added of a process has been found to provide higher returns on investment, implementing the process can be pursued. In the proposed framework the next logical step is to analyze if the process will interact well with others. This step in the framework will take those processes that have been selected based on value added and further "filter" them by how they interrelate with other processes. To accomplish this, an organized and structured method that takes into account various criteria shall be used. The general goals of this phase of the framework are to identify how critical process are (more than merely adding more value), how they interact (do they reinforce or interfere as part of a system), are they difficult to implement, and how do stakeholders feel about them. An alternative system would now being analyzed not just by one main driver - value added from intangibles - but by applying educated methods to determine if they should be considered at all. In this phase the framework would define if progress is adequate before it is too late.

A proposed system generated based on value added from knowledge and on how well the processes function in a system would benefit from an analysis of system stability and dynamic behavior before any implementations. The framework's next phase will model the behaviors of a proposed systems because the processes are expected to interact over periods of execution. Since the proposed system processes have never been executed, modeling would enable the identification of behavior patterns as a way to test the process changes. The system behaviors can then be studied before implementation. With knowledge as the most main resource to manage in the framework, effective decision-making can be achieved by accounting for the complex behaviors that a new system may exhibit. Without any available metrics the proposed actions to implement new processes can only be modeled to address why and how a system will behave. This final phase of the framework will complete actions required for a systematic and informed analysis of knowledge-based alternatives.

4.3. Framework Overview

The framework begins with the consideration of processes that can be modified or replaced with the expectation that they can add more value. The decision on modifying the processes or selecting alternative processes start with the assumption that the processes are knowledge-based and their complexity determines how much value they add (as derived from Kolmogorov-complexity). With the processes' value defined from the knowledge they require to produce their expected outputs, knowledge value metrics are obtained for both current and proposed processes. The resulting system to be further analyzed can range from not doing anything (keeping all current processes), to a combination of current and proposed processes, to a completely new system composed of all new processes. With an alternative system determined, modeling to analyze the dynamics of feedback and time delays between the processes acting as a system becomes the last major step of the framework. This determines how the processes behave over time and execution periods in order to further analyze the actions taken for effectiveness, with the capability of testing the process changes to affect behavior based on desired metrics of value-added. Figure 4-1 demonstrates the framework in general terms based on these steps to accomplish process selection.

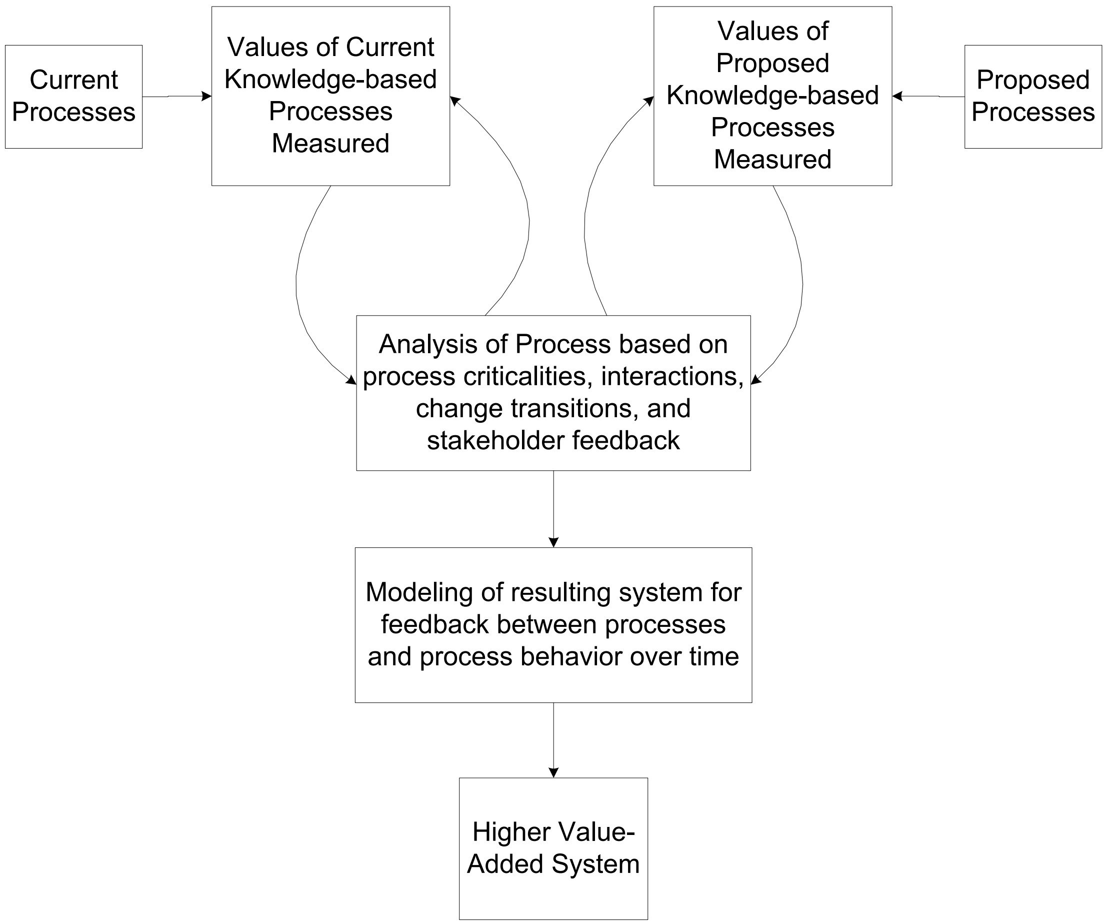

Figure 4-1: Framework Flow Description

4.4. Framework Description

The framework's starting point includes current systems with defined processes that are under consideration for improvements to increase their value-added, which is measured using process complexity. The processes will be evaluated for fittingness to measure the value they add based how much knowledge is required to produce outputs. This part of the analysis models an "as-is" state for data collection. In a similar fashion, proposed processes will be analyzed with the only difference being that the data may come from expert opinions and estimates. The next step in the framework will be to evaluate the current versus proposed changes by recognizing complements between the processes' technologies and practices. Since interactions can make it impossible to successfully implement new, complex processes, this analysis has the goal of anticipating complex interrelationships that surround system changes. During this phase of the framework decisions are made taking into account interactions among all components of an alternative system.

After complement analysis, the review of results will yield a proposed "to-be" system that the framework will model to understand the behavior over time of a new and complex system. This analysis will be based on complex systems being governed by both the influences that the system's processes have on each other along with the time delays taking place during execution of processes. Since so many different parameters can become particularly important to the stability of systems they become major determinants when they affect the feedbacks that processes have on each other while acting together in a complex system. These complex behaviors can therefore impact value added from knowledge processes over time. This phase of the framework will analyze the stability and behavior by modeling. With an analysis of feedbacks, time delays, and stability of a new system, the framework provides details on how the value added from knowledge processes will behave. Complex behavior modeling becomes a way to discover effects on value added and modification of inputs and processes can be used to study the behavior of a complete system.

4.5. Analysis of Value Added from Knowledge

The framework begins with processes under consideration for change or replacement to improve value added. The current system shall qualify as one with knowledge process that can be measured for their complexity rooted on the Kolmogorov concept of information as a way to describe changes. In this phase of the framework the complexity of a process determines how much value a process adds and the requirement is to measure value added based on how much change a process brings. In the case of organizational processes this quantification takes the form of the creation of an output, as a changed variable, by an amount of knowledge that can be measured.

As previously presented under section 2.4 the valuation of knowledge as the means to measure value added from process changes can be accomplished quantitatively and by different means. KVA uses quantitative measures of the complexity (in this case knowledge, equivalent to measuring information in K-Complexity theory) that proportionally define change from a process. Based on Kolmogorov's consideration of the "bit" as a measurement of information, the measurement of knowledge is derived from the random-variable idea of "0" and "1". Information obtained from actions like experiments or processes can be described by a "0" for no data and a "1" for a change in information. In these basic terms the quantification of knowledge in the framework defines "0" as an input and "1" as a variable changed by information which in this case takes the form of knowledge.

The quantification of value added from knowledge is therefore derived by measuring information. When inputs are changed to generate expected outputs the knowledge required to successfully generate an output is described in terms of information. The term "successfully generating an output" is a key to providing a measure of knowledge. Since the method is concerned with the information needed to specifically change a variable from 0 to 1, the measurement is derived from the knowledge to execute the process "successfully".

As previously defined the systems under study are capable of changing inputs into outputs via processes and add value when the changes take place similar to the basic description of entropy. Change from knowledge under KVA is proportional to value and the output b is a function of input a.

$$P(a) = b$$

Valuation under KVA is such that:

If P(a) =b and a = b after P has been executed, no value has been added

If P(a) = b and a ≠ b after P has been executed, change has taken place

Knowledge value added only occurs when there is change and the difference between the entropies of an input and an output (*a* and *b*) is proportional to the how much change is needed to convert *a* into *b*. Knowledge being proportional to entropy can be derived from thermodynamics:

$$\Delta E = E(b) - E(a) \quad (5)$$

Similarly, "entropy" from information in KVA is the difference between the complexity of input, *K(x)*, and that of the output *K(y)* as:

$$\Delta K = K(y) - K(x) \quad (6)$$

The calculation of value-added based on complexity and entropy uses the relationship between business change processes and the descriptions of those processes. When a baseline process *P* with an input *a* and output *b* can be performed as a modified process *M* with an input *x* and an output *y* such that

$$M(x) = y \text{ if and only if } P(a) = b \qquad (7)$$

since *a* maps to *x* as the full set of inputs to processes *P* and *M* respectively, as *b* maps to *y* as the full set of all outputs from processes *P* and *M* respectively. The knowledge complexity of the processes *P* and *M* reflect the structure changes to the inputs as a value-added.

With KVA as the method established to measure value added, a means to measure the knowledge required by value-generating processes is provided. Under KVA the value created is relative to the change on the input and that change can be measured by the quantity of knowledge needed to generate change. KVA can accomplish this by describing change in different forms provided that common units are used. Describing change in terms of units proportional to process complexity, a major aspect of the KVA method is how it measures knowledge complexity based on processing of inputs by three methods that provide common units:

1) Time to acquire the knowledge to execute a process – learning time.
2) Amount of process instructions to produce an output – process descriptions.

3) Binary yes/no questions that represent possible outputs from yes/no answers - binary query.

Under a learning time method the knowledge metrics come from the amount of time it takes an average individual to learn how to perform a given process and successfully execute it. When process descriptions are utilized the number of instructions (e.g. number of words) necessary to execute a process and produce an output can provide knowledge metrics. The third method applies a binary query from comprehensive yes/no decisions that break processes into binary or "bit" questions representing the outputs.

With value measured based on knowledge, KVA lastly provides a return on knowledge measure by describing a return on investment in process (ROP) calculated using process cost data. This derivation of return on process defines the internal performance V of a process by the amount of knowledge complexity to execute a process (I) and the cost to produce the specific amount of knowledge complexity needed for the process (C)

$$V = I / C \qquad (8)$$

This equation follows the return on investment (ROI) model by accounting for the cost of executing a process against value from complexity when KVA defines return on process (ROP) as a ratio of the value that process knowledge generates versus process. Value added from process knowledge is not accurately or complete without taking into account costs to execute the process. Therefore the measurement of value added from knowledge is further quantified by the calculation of a rate of return. Similar to the ROI financial method, a ratio of return is derived from the knowledge process (value-added amount) relative to the cost of the process (invested amount). This index called Return on Knowledge (ROK) is the index used to measure the knowledge within a process by implying that an organization will use personnel and assets that apply the company's knowledge to generate process outputs. "Because time is money and money has value then the value of that knowledge can be measured" (Cook and Dyer, 2003). ROK is then a ratio to allocate revenue to the knowledge used, as in the knowledge embedded in IT to produced outputs. ROK can be calculated when all the knowledge needed to successfully execute the process is identified. Knowledge becomes the numerator while cost is the denominator of the equation:

$$ROK = \frac{Knowledge}{Cost} \tag{9}$$

The described ratio allocates revenue to the knowledge used, as in the knowledge embedded in IT to produced outputs. A return on knowledge can be calculated when all the knowledge needed to successfully execute the process is identified; the valuation of knowledge processes is then a ratio of knowledge value to costs.

The framework will perform analysis of value added from knowledge on both current and proposed processes. The processes under consideration for improvement undergo a similar process in the framework as the current processes in which they are analyzed for their value added. The initial analysis for the proposed change process differs from the current process analysis part of the framework since the data comes from estimates. Subject matter experts and process executioners are utilized to obtain the metrics that will provide the metrics for the proposed processes. The framework's main measurements are the returns from knowledge which itself is a complex and dynamic process and "notoriously difficult because there are many factors that will influence the outcome" (Curley, 2004). This difficulty provides a justification to apply the second major phase of the framework described in the next section.

4.6. Change Analysis

Stand-alone measurement of value added from knowledge cannot provide a comprehensive basis for decisions on replacement or modification of processes. While new processes may deliver higher rate of return from knowledge than a current one in generating an output, processes need to properly interact and complement each other within their systems. Successful change management must incorporate customer and technology requirements. As an example quality improvements are better achieved when requirements and expectations are introduced in the early phases of a design or project. Drawing from Quality Function Deployment (QFD), the proactive definition of activities needed to meet requirements "permits quality and customer needs to be designed into the product, not added on" (Richardson, 1997). The QFD methodology applies mechanisms that analyze relationships and correlations by which customer requirements are translated to successfully meet requirements. This is accomplished by a matrix that illustrates relationships between performance and requirements. Along with customer requirements, effective management of change requires recognition of the critical role of interactions. Interactions "can make it impossible to successfully implement a new, complex system in a decentralized fashion. Instead, managers must plan a strategy that takes into account and coordinates the interactions among all the components of a business system" (Brynjolfsson, Renshaw, and Alstyne, 1997).

QFD has proven successful in change management by early evaluation of requirements and customer expectations. QFD uses a tool which graphically represents relationships between customer needs and capabilities of a firm, processes, or products. The proposed framework can relate this idea when it shows a need or a "what" (value added from knowledge) with a "how" (process changes). QFD uses a matrix called the "House of Quality" which applies values and priorities to the relationships between needs and requirements. The proposed framework will apply the underlying concept of QFD to evaluate more than just customer requirements. Due to the complex landscape of knowledge processes, the goal of improving value added in the framework will require identification of criticalities, system interactions, and transition interactions along with stakeholder feedback.

A structured and systematic procedure can be used to emphasize interactions among the processes under study and the transition difficulties from an established to an alternative system. The goal is to identify reinforcement and interference between the processes that will make up a new system. Similar to the house of Quality this phase of the framework will collect current and desired processes into a transitional state that bridges the two collections of processes. The first step on this analysis identifies that business objective of the change: to increase value added. Current and proposed processes are identified for analysis in a matrix that will identify interactions based on reinforcements and complements when transitioning to a new system. In the last step stakeholders are surveyed for their feelings on maintaining current processes and implementing proposed ones. The analysis resulting from such change matrix tool addresses the following:

- Feasibility: system coherence, stability, and transition difficulty.
- Process Execution Sequence: where to begin change and how it affects value added.
- Location: are new processes implemented within the existing or new systems?
- Pace and Nature of Change: Speed and order of change implementation
- Stakeholder Evaluations: all-inclusive stakeholder involvement and use of the best feedback sources.

The management of change based on the importance of process interconnections and considering that system optimization requires cohesive processes can be accomplished using the Matrix of Change (MOC). MOC provides effective change management as it recognizes complements between technology, strategy, and practice by anticipating complex relationships that come from change. These issues in question include stability under new changes, sequence of processes, pace of change, implementation in new or available locations, and the sources of value added from the interests of stakeholders. MOC analysis provides support for process design in a systematic and formal fashion and was selected as the second step of the framework because it provides the interaction analysis needed to determine if process changes are worthy of consideration for implementation. The MOC analysis is accomplished in four steps: three matrices (current practices, desired practices, and transitional state bringing current and desired practices together) and an evaluation by stakeholders to identify the importance to stakeholders of process activities.

The first of the four MOC steps is to identify critical processes. The purpose and objective of change in this framework is identified as creation of value added. While MOC can be used to identify high-level goals and the practices needed to accomplish them, this study will use the MOC for specific and detailed process changes. This MOC step identifies practices that are broken down into “constituent parts” or the processes expected to meet or improve practices or goals. In this framework the target practice is to maximize value added, and the constituent parts are the knowledge processes that make up the system under study.

The second MOC step is the classification of system interactions by matrices that identify processes as ones that increase returns on processes they complement (reinforcing) or ones that decrease returns on processes it competes against (competing). A grid based on Quality Function Deployment’s “House of Quality” starts in this step in the way of triangular matrices: a horizontal for existing processes and a vertical for proposed processes. These “interference matrices” use grid signs at the process junction locations: plus signs (+) for reinforcing, minus (-) for competing, and no sign for weak or no interactions. The plus and minus signs can be determined in different ways as many times it can be self-evident but other formal theories can be used as well as empirical methods and surveying of personnel. Figure 4-2 summarizes steps one and two of the MOC.

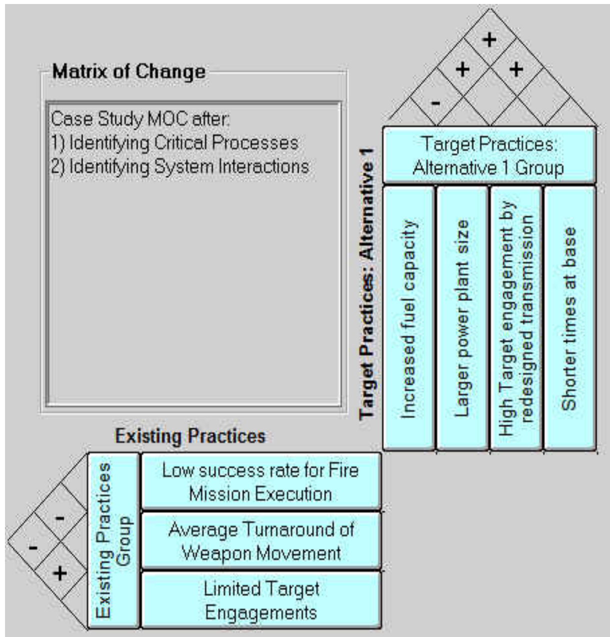

Figure 4-2: MOC System Interactions

Step three in the MOC identifies interactions of transitioning by implementing proposed processes by combining the horizontal and vertical matrices from step two into a matrix to determine interactions between existing and target practices using the plus and minus signs configuration previously applied.

The fourth and last MOC step surveys stakeholders on how they perceive current and target processes in terms of building a better system, output, or value-added. Those surveyed will use a five-point Likert scale as follows to rate each process:

- +2: Extremely important practice/process
- +1: Important, but no essential practice/process
- 0: Indifference
- -1: Some but not essential desire to change or reject a practice/process

- -2: Strong desire to change or reject a practice/process

The measure of business value evaluated from stakeholder's perspective for the purposes of this framework will apply the quantifiable units of knowledge value-added as the basis for this step of the MOC. It answers the MOC question: what are the greatest sources of value? Figure 4-3 demonstrates MOC analysis of transition interactions.

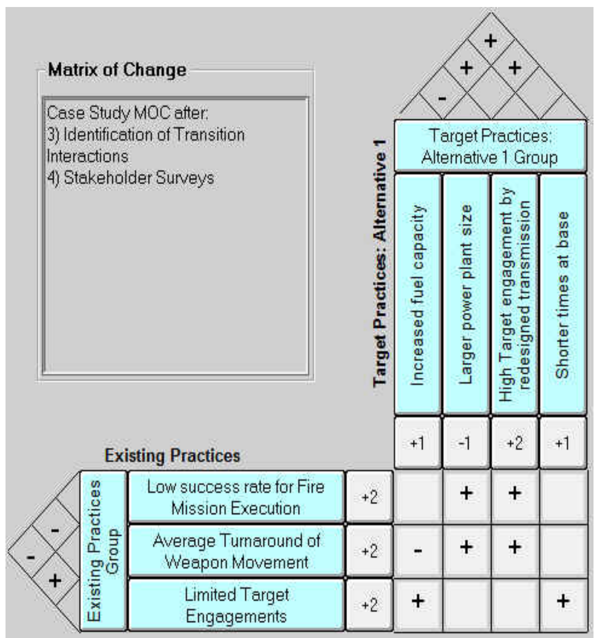

Figure 4-3: MOC Transition Interactions

The change process has a higher chance of success by the identification of complementary structures and analysis of interactions between processes provides the most important tool for decision making without the significant commitments that change would otherwise incur. Such analysis also provides a smooth transition into the next phase of the framework that will model the proposed systems for behavior and stability during process executions over time.

4.7. Dynamic Modeling Application

Complex systems encounter activities and changes that affect their behavior. The structures of systems are characterized by influences on their behavior and literally any system that is dynamic can be affected by interdependences, feedbacks, interactions and the effects of time causality. This stems from relationships between system processes which can cause dependencies, delays, reinforcements, or circular references among other possible behaviors. The term "system" implies an interdependent group of organized and patterned items and as such the systems under study in this framework are composed of processes. These systems (as all systems) have a structure with patterns of behavior from which events take place. The new or modified systems under this research can be made up different combinations including processes that have never been executed before and/or processes previously executed within other systems. But even when all the processes in a newly proposed system have been previously executed, this research inquires on the behavior of processes proposed to function as a whole new system. With a proposed system composed of processes generated from the first two major phases of the framework, the last major phase of the framework will model the system for system behavior over time. This last phase will help frame and understand complex issues and problems that arise from dynamic behaviors.

The objective of this analysis by the framework is to dynamically simulate proposed systems over time periods. By applying a behavioral view of system dynamics the framework can focus on system (and process) characteristics that may "make or break" the complete system. This analysis will consider the system as composed of processes interconnected by information feedback loops and circular causality. Formulation of a behavioral model will provide reproduction of the dynamic system under consideration before any change commitments. This behavioral model can be formulated as a simulation model expressed by nonlinear equations. The implementation of changes then becomes a product from the insights gained during the dynamic simulation modeling. The basis for modeling the behavior of process that make up a complex system is the recognition that system structures are as important as the individual processes, while there are properties of a complete system that cannot be explained or even recognized by the behavior of individual processes.

The methodology to accomplish this is called System Dynamics (SD). The SD approach is unique in its study of the feedback and stock-and-flow dynamics to display what could be severe non-linearity in systems that may appear simple. A main application of SD for understanding dynamics of complex systems has been managerial policy analysis and change among many others. A major assumption and application is that the systems researched in this framework are composed of knowledge processes that move inputs among them to generate outputs. SD can study the behavior of these complex systems for their non-linear processes. The mindset for this understanding of complex systems requires the inclusion of factors such as feedbacks, flows, and accumulations in processes and these factors are at the heart of the SD modeling approach.

System dynamics provides modeling environments that incorporate equations formulated from continuous quantities, interacting in information feedback loops and “circular casualty”. These continuous quantities are expressed in the form of “stocks”, “flows”, and “feedback loops”. SD defines problems dynamically over time analyzing the endogenous behaviors of systems. This approach allows systems thinking and analysis to provide system insights and understanding for model-based decision making. More specifically the SD approach uses visual representations of the information feedback and circular causality that conceptualize the structure of complex systems, in turn communicating model-based insights. Feedback loops are present when information from an action (e.g. a knowledge process) moves through a system and can influence the system's behavior.

The continuous view of SD does not track system events or actions individually but instead as an aggregate to compose the system. This can be described using differential equations and differs from discrete modeling which does not usually provide insight into system inter-connections and feedbacks. SD combines events, actions, or activities (such as processes) to form infrastructures which can be modified for the purposes of modeling. A mathematical formulation of SD simulation modeling can be described as coupled, non-linear, first-order differential or integral equations:

$$\frac{d}{dt}x(t) = f(x, p) \tag{10}$$

With *x* as a "vector of levels" or stock variables that describe the state of the system and are represented by the levels; *p* as system parameters; and *f* as a non-linear vector-valued function. For these time-based models, these means that SD simulations partition time into discrete events of length *dt* which are integrated as a simulation advances to represent the state variables (levels) *x* as time steps thru the system. This mathematical approach partitions the modeled time into discrete intervals of length *dt* and steps the system through time one discrete interval at a time.

All state variables (stocks) are computed from previous values during simulation modeling as a rate of change $x'(t)$ described as:

$$x(t) = x(t - dt) + dt * x'(t - dt) \qquad (11)$$

Where the interval *dt* "is selected small enough to have no discernible effect on the patterns of dynamic behavior exhibited by the model" (System Dynamics Society, 2011). This formulation can also be used in integral form to describe the inflows and outflows of levels at time intervals *t* with a parameter of time increments *dt* during system simulation

$$level = level_0 + \int_0^t (inflow - outflow)dt \qquad (12)$$

where *level* can be computed at any time during a simulation and *inflow* and *outflow* are flow rates in and out of the level.

The formulation of system dynamics simulation on proposed systems composed of knowledge processes can be derived as follows:

$$process = process_0 + \int_0^t (inputs - outputs)dt \qquad (13)$$

Where *process* are the stocks that convert *inputs* into *outputs* at time intervals during simulation modeling of a proposed knowledge-based system.

System dynamics and its mathematical representations can more specifically be described by an engineering discipline called control systems engineering which applies control theory for the purpose of designing systems with desired behaviors called out. Control engineering defines a "state space representation", the mathematical model of a system as a set of inputs, outputs and state variables that are related by first-order differential equations. This state space representation is a method to conveniently model and analyze systems that have multiple inputs and outputs. Complex systems as dynamical systems are made up of state spaces (or phase spaces) with coordinates that describe system states at time instants. Dynamical system rules specify the instant future of state variables based on the present values of those same state variables. These dynamical systems can be considered models to define their sequential evolution as systems.

Similar to Kolmogorov complexity as a descriptive method to represent the units of data that specify an object, state variables under the state space representation are the smallest set of variables $\{q_1, q_2, \ldots q_n\}$ such that the knowledge of the variables at a time $t = t_0$along with the knowledge of the input for $t \geq t_0$can completely determine the behavior of a system, as the value of the state variables, for a time $t \geq t_0$. This set of all possible states is called the state space, where a common class of mathematical models for dynamical systems is an ordinary differential equation (ODE) written as the differential equation

$$\frac{dx}{dt} = f(x) \tag{14}$$

(called an autonomous system because there are no external influences) to describe the rate of change of a state as a function of the state itself and $x = x_1, x_2, \ldots x_n$ as a vector of real numbers describing the current state of the system. When modeling the effects of disturbances or forces on a system, the equation becomes a forced or controlled differential equation

$$\frac{dx}{dt} = f(x, u) \tag{15}$$

with u representing the controlled forces or external influences. This modeling implies that a state's rate of change can be influenced by adding the input $u(t)$ which provides a model to examine how external disturbances influence a system. In the cases where input variables can be controlled, this equation is useful to analyze how a system can be influenced from a point in the state space to another through input choices. This *n*-dimensional space called state space, consisting of coordinate axes $\mathrm{x} = \mathrm{x}_1, \mathrm{x}_2, \dots \mathrm{x}_n$ can also be represented by an *n*-dimensional state vector of components with state variables describing the system completely. In all dynamical systems the state space remains unique but state variables are not unique. The general form of a state model representing an autonomous, time-invariant nonlinear dynamical system can also be described by a state vector *x* as:

$$\dot{x} = f(x)\ (\equiv f(x(t))),\ x = \begin{pmatrix} x_1 \\ x_2 \\ \cdot \\ \cdot \\ \cdot \\ x_n \end{pmatrix},\ f(x) = \begin{pmatrix} f_1(x) \\ f_2(x) \\ \cdot \\ \cdot \\ \cdot \\ f_n(x) \end{pmatrix} \qquad (16)$$

The previous description applies to systems that are independent of time shifts and do not have inputs. Dynamic systems with inputs can be described by an independent time variable *t*, a dependent output variable y(t), and an input u(t) with a state space form as:

$$x = \begin{pmatrix} x_1 \\ x_2 \\ \cdot \\ \cdot \\ \cdot \\ x_n \end{pmatrix} = \begin{pmatrix} y \\ dy/dt \\ \cdot \\ \cdot \\ \cdot \\ d^{n-1}\, y/dt^{n-1} \end{pmatrix} \qquad (17)$$

And a state space equation:

$$\frac{d}{dt}\begin{pmatrix} x_1 \\ x_2 \\ \cdot \\ \cdot \\ \cdot \\ x_{n-1} \\ x_n \end{pmatrix} = \begin{pmatrix} x_2 \\ x_3 \\ \cdot \\ \cdot \\ \cdot \\ x_n \\ -a_n x_n - \cdots - a_1 x_n \end{pmatrix} + \begin{pmatrix} 0 \\ 0 \\ \cdot \\ \cdot \\ \cdot \\ 0 \\ u \end{pmatrix},\quad y = x_1 \qquad (18)$$

A more general dynamic system can be described with the output as a linear combination of system states, such as:

$$y = b_n x_1 + b_{n-1} x_2 + \cdots + b_1 x_n + d_u \qquad (19)$$

These linearly-independent state variables can and must collectively describe a complete dynamic system in state space. Such system can be modeled in state space as:

$$\frac{d}{dt}\begin{pmatrix} x_1 \\ x_2 \\ \cdot \\ \cdot \\ \cdot \\ x_{n-1} \\ x_n \end{pmatrix} = \begin{pmatrix} 0 & 1 & 0 & \dots & 0 \\ 0 & 0 & 1 & \dots & 0 \\ \vdots & & & \ddots & \\ 0 & & & & 1 \\ -a_n & -a_{n-1} & \dots & & -a_1 \end{pmatrix} x + \begin{pmatrix} 0 \\ 0 \\ \vdots \\ 0 \\ 1 \end{pmatrix} u, \quad y = (b_n b_{n-1} \dots b_1) x + du \qquad (20)$$

System dynamics modeling as the last phase of the framework will analyze the dynamic behavior of alternative processes in terms of their behaviors during process executions to produce desired outputs. The modeling of alternatives would simulate processes as continuous steps in a system that begins with an input and finishes with an output. Revenue and cost are used for knowledge valuation based on KVA methods, and the knowledge processes make up the stocks. System dynamics modeling can be used to influence inputs, value-added, cost metrics, cycle times, and outputs generation.

Figure 4-4 summarizes all three major methodologies used in the framework in terms of the tasks that the framework will accomplish.

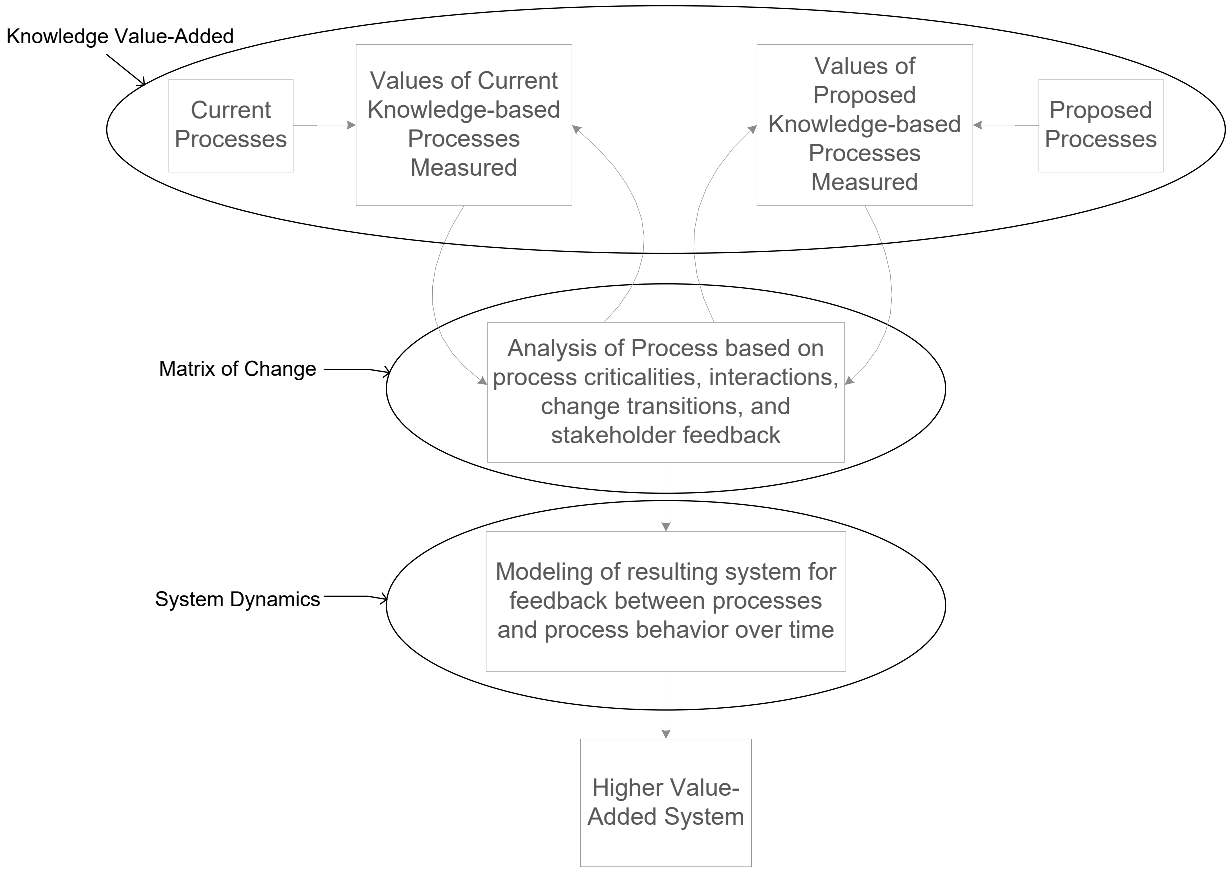

Figure 4-4: Methodologies to accomplish the Framework's objectives

CHAPTER 5: CASE STUDY OF UAV ACQUISITION PROGRAM

5.1. UAV Acquisition Program Introduction

The first case study to exercise the framework will be based on previous research on Department of Defense (DoD) acquisition programs. "System Dynamics Modeling for Improved Knowledge Value Assessment: A Proof of Concept Study" (Ford , Housel , and Dillard, 2010) looked to improve the use of benefits in analysis of alternatives (AoA) by making a system dynamics model of a military operation and integrating it with KVA in order to improve the accuracy of KVA estimates in AoA processes.

The main problem identified by the Naval Postgraduate School (NPS) performing this research was measuring the benefits of alternatives. AoA became difficult due to alternative diversity, metric selection and performance measurement among other factors. Along with cost estimates pre-dominating the AoA, the research arose from the difficulty of incorporating benefits from materiel since many important benefits were intangible in nature. The goal of the research was to include benefits in AoA in terms of common units, to enable better comparisons among alternatives based on value instead of merely cost.

5.2. UAV Acquisition Case Study Background

The US DoD acquisition program starts with a Joint Capabilities Integration and Development System (JCIDS), one of three decision systems for war fighting capability to provide requirements "top down" and work along with planning and budgeting to reach tactical from strategic. When a materiel solution is needed, AoA is used to meet criteria and reach decisions. When needs are derived in an area that can only be met by new materiel, AoA helps comparison of options (for example manned or unmanned aircraft vs. a missile, chemical vs. kinetic energy kill mechanisms, etc.).

The NPS research was brought on from lessons learned on a Javelin anti-tank weapon system concept which had three different missile technology alternatives in order to award a development contract. The chosen alternative was selected based on a capability which was not a stated requirement and therefore it was not criteria originally established to provide value to the stakeholders. While there were lessons on requirements, bureaucracy, and technology readiness, perhaps the best lesson learned on analyzing alternatives is that a single undefined and qualitative factor of performance (gunner survivability) ultimately drove the chosen alternative. A parameter of technology which promised the most of what was impossible to quantify became the main factor when selecting alternatives and the process failed in reaching a final solution faster and more directly due to insufficient articulation of benefits in the AoA process.
The Javelin program showed a need for common units of benefit estimates in AoA, leading to inclusion of units of benefit along with cost.

Weapon acquisition programs typically conduct AoA to select material solutions based on viability and costs to make decisions regarding further development and production. Concepts are then analyzed as part of a material solutions analysis by which various cost estimates are generated from cost comparisons. Several system performance and keys system characteristics are selected to quantify differentiation points. But costs dominate the analysis even when operational and performance risks should be included in the analyses because the costs of these systems are highly substantial. This emphasis on costs becomes even greater when further considerations like operating costs, maintenance and training are included. In reality, all costs from procurement to support and maintenance are a requirement for major acquisition programs to move into development and demonstration, as well as into production and use.

The emphasis on costs in the early stages of acquisition should not become the main (and even less only) criteria for alternative selection. This practice caused a feeling of disparity between costs and benefits from effective operations. The main problem area that the NPS research looked to improve was the estimation of benefits, but more importantly in common units. Benefits were considered from cost savings and this type of alternative analysis led directly to alternatives with the low costs instead of the highest benefits.

The main problem stated by the NPS research was the difficulty of defining common metrics to measure performance in order to account for benefits from alternatives. This need arises from a typical emphasis on costs and the fact that the alternatives under study are intangible in nature and cannot be measured by monetary costs as with tangibles assets. The measure of intangible benefits was accomplished based on information theory's Kolmogorov complexity. This method used the complexity of executing a task as a proportional determinant of the change (entropy) that a process can effect. Benefit then comes in the form of a process or task's ability to generate change and this measured but the complexity of executing the process. Such Kolmogorov complexity-based approach satisfies the need for common units to measure benefits, since information can be measured equally among alternatives. This measurement of benefits from complexity was then integrated with dynamic modeling of a weapon system for Unmanned Aerial Vehicles (UAVs) to make decisions on upgrading the system. The modeling uncovered synergies between the UAV weapon system processes which (while being measured using common units) increased the amount of alternatives to analyze. The research concluded that this measurement of benefits along with modeling of the dynamics of the system's alternatives was a major improvement from decisions made using costs of alternatives (Housel and Cook 2005; Housel and Bell 2001; Housel et al. 2001).

Figure 5-1: A Predator UAV firing a HELLFIRE missile.

5.3. UAV Acquisition Case Study Description

This first case study being proposed by this dissertation will apply the framework using the findings from the NPS research and more importantly improve on decision making by integration of common measurement of benefits from intangibles (included in NPS research but done after dynamic modeling), alternative decision making based interactions and complementarities between alternatives (not included in NPS research), and dynamic modeling to analyzed changes in benefit values after a new system has been defined (modeling used in NPS research, but before any complexity/benefit metrics were calculated).

The NPS proposed as an item for further investigation the ability to indicate the sub-processes that improve the alternatives. As an example, while it was thought that increasing the "fuel capacity "alternative was the reason a sub-process called "fire mission development" was improved, it was discovered from the modeling that the actual cause for the improvement was an increase in "vehicle range" because this alternative reduced the chance of losing a target if it was missed (versus not being able to re-acquire a missed target and needing more time, fuel use, etc.). This will be researched in this dissertation under the alternative decision making phase of the framework, which will provide a method to identify if changes are to be implemented.

Another suggestion for future work presented by the NPS study was the use of the model to generate forecasts of performance during acquisition, "comparing those forecasts with actual operations, and using the results to improve the model fidelity with the system. The improved model can then be used to analyze proposed changes or replacement of the system throughout its lifecycle" (Ford, Housel and Dillard, 2010). The proposed framework will utilize dynamic modeling of the selected alternatives to analyze behaviors from time delays and the feedbacks and interactions between those alternatives. The goal of the NPS research on Department of Defense (DoD) acquisition programs was to include benefits in AoA in terms of common units, to enable better comparisons among alternatives based on value instead of merely cost.

5.4. UAV Case Study KVA Metrics

The first step of the framework uses the KVA metrics derived by the NPS study, in which KVA and SD are integrated and tested for their ability to improve AoA. A generic structure of a mobile weapons system was developed with SD and KVA estimates were operationalized in a SD model that was calibrated for four weaponized UAVs. Results were analyzed for the model's ability to estimate benefits using KVA in terms of value added of system capabilities. The generic model was composed of three sectors: weapons movement, target evolution, and KVA analysis. Weapons movement simulates position and movement of weapons assuming total number of weapons remains constant (an assumption that can change with modeling of a specific asset). This is a sub-process that adds value, requires operator learning time to accomplish, and requires processing time to accomplish. The completed moving of weapons to the station and back to the base is an output of the sub-process and an input to the KVA analysis. In the NPS model, two movements, "assets arrive at station rate" and "assets arriving at base rate" represent the accomplishment of the vehicle movement sub-process. Figure 5-2 describes these processes.

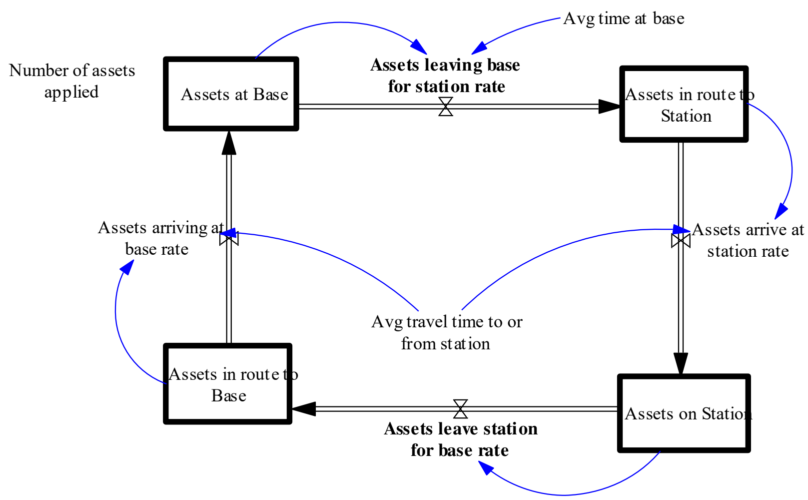

Figure 5-2: Positions and Movement of Weapons during Operations

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The weapons sector defined weapon movement rates as the number of weapons preparing to leave or arrive a base or station and the average time in a preceding accumulation as follows: Average "Assets leaving base for station" = number of assets at the base / average time weapon spends at base between trips to the station. The Target Evolution Sector simulated the development of targets by five sub-processes: acquire target, fire support coordination, fire mission development, engage target, and battlefield assessment. The SD model presented accumulated targets sequentially into stocks affected by movement rates between system conditions. Both weapon movement and target evolution sectors are composed of sub-processes that add value and first require time to learn and then time to process. They are outputs from the sub-processes and become the inputs to the KVA analysis.

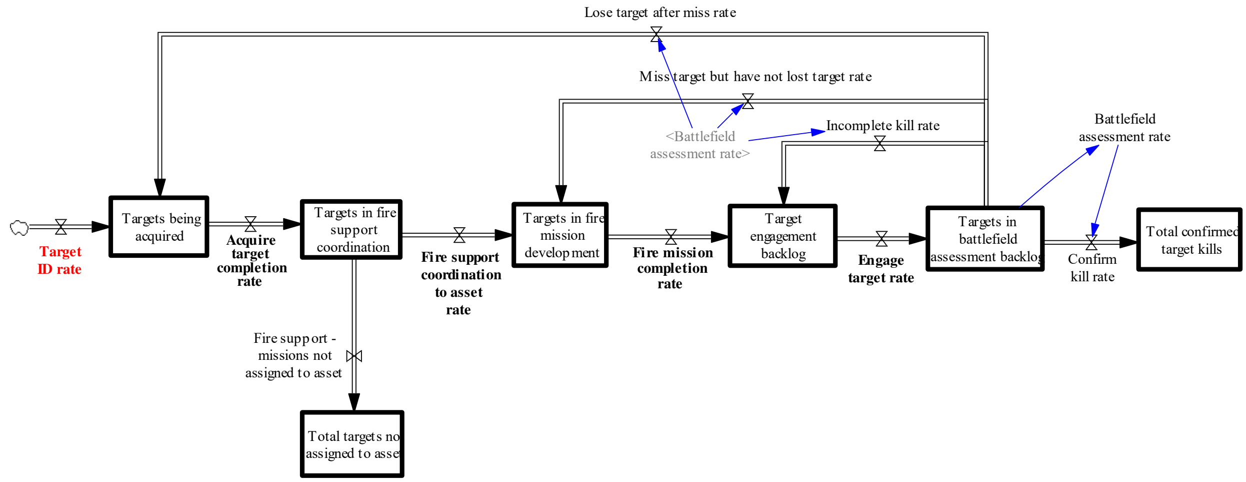

Figure 5-3: Accumulations and Movements of Targets in Weapon System Operations

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Along target flows, the targets sector modeled three mission failures: hitting target without destroying it, missing the target, and missing the target and losing target location to re-engage it because it moved. Figure 5-3 shows the model of these scenarios and how the weapons re-flow is based on each one with rates for movement of targets defined by number of targets in sub-process stocks and time to perform the sub-processes dependent on the particular sub-process or weapons abilities to destroy, hit, and not lose targets. These abilities were represented by probabilities: hit but do not destroy target: P(kill if hit); missed: P(hit); and lost: P(not lose). Or more specifically:

$$p(\text{kill}) = f_k(\text{Payload / Lethal payload}) \tag{21}$$

$$p(\text{hit}) = f_h(\text{Dash speed / Target speed}) \tag{22}$$

$$p(\text{not lose}) = f_{nl}(\text{Range / Target distance from base}) \tag{23}$$

where:

p(kill) - probability of destruction if the target is hit with the ordinance (24)

p(hit) - probability of the weapon hitting the target with ordinance (25)

p(not lose) - probability of not losing the target if it is missed with the ordinance (26)

The KVA Sector used information from the weapons and target sectors and generated value metrics for each sub-process as a productivity ratio reflecting an output/input by dividing benefits by the costs to generate the benefits in common units. This included both monetized and time-based KVA metrics. The monetized metrics came from the benefits generated by a weapon system as an estimate of the value (in monetary terms) of destructing a target (estimated by the cost the government would pay an entity to perform the same task without using a weapon system). These were directly proportional to the learning time of the sub-process and the equations to estimate the benefits of a sub-process are:

Unit sub-process benefit fraction = Sub-process learning time / Total of all sub-process learning times (27)

Unit sub-process benefit = Unit sub-process benefit fraction * Unit benefit for entire process

Rate of sub-process generating revenue = Sub-process processing rate * Unit sub-process benefit

Sub-process benefits generated to date = $\sum$(Rate of sub-process generating benefits) * dt (28)

The KVA denominators were sub-process costs or as the time to perform the sub-process times the average cost per hour of performing the sub-process, calculated as:

Rate of spending time on sub-process performance = Sub-process performance rate *Time required to perform the sub-process (29)

Sub-process work time spent to date =$\sum$ (Rate of spending time on sub – process performance) * dt (30)

Sub-process processing time generated to date = Sub-process work time spent to date * Hourly performance cost (31)

In each time period the benefits and costs are combined into KVA productivity ratios.

Sub-process productivity = Sub-process benefits generated to date / Sub-process processing time generated to date (32)

Non-monetized common units of output were used for simplicity using only time units to learn to produce the outputs, as the numerator for the output (units of learning time)/input(cost to produce outputs) productivity definition. These calculations of time-based KVA metrics uses the same approach as monetized metrics but using learning time to quantify benefits and touch time for costs instead of money:

Sub-process learning Time accumulated to date = $\sum$ (Rate of sub-process operation * Sub-process unit learning time) * dt (33)

Sub-process touch time accumulated to date = $\sum$ (Rate of sub-process operation * Sub-process unit touch time * dt (34)

Sub-process Productivity = Sub-process learning time accumulated to date / Sub-process touch time accumulated to date (35)

Four UAVs were used for model calibration and testing, with estimated data collection which included vehicle range, total mission time, time on station, dash speed, and payload: Predator, Sky Warrior, Reaper and X-47B. “These estimates were rough but adequate for this proof-of-concept study, which sought to determine if the model was capable of reflecting differences in characteristics in KVA parameters, not whether it was capable of predicting actual outcomes" (Ford, Housel and Dillard, 2010). The SD model was tested with standard SD tests for similarity to reality and reasonable behavior to inputs values and found to be similar to typical. There were no backlogs and no operations performed at scenario starts and when targets appeared both backlogs and rates increase by weapons moving thru the system with increasing that eventually reached a "steady state".

The operational scenario included other info such as targets at five per minute, target distance from base 400-1100nm; target speeds of 50 to 250nm; payload to destroy if hit 400 to 1000lbs. KVA productivities for the six sub-processes under the four UAVs are shown below that represented benefits (output) per unit cost (input) and can be interpreted as a measure of return on the investment in percent. For example, the fire mission development ration for predator of 943 is calculated as 79,684 learning time hours divided by 84.5 processing-time hours. This and the other productivity ratios in the Table 5-1 are accumulated learning times divided by accumulated processing times. The paper explains as the dynamic part of the evaluation that "In the simulated steady state operations this accumulated learning time hours increases at a rate of 301 learning-time hours per minute (the product of the estimated 500 learning-time hours per fire development operation and an average fire development rate of 0.6 targets developed per minute) and the processing-time hours increases at a rate of 0.3 hours per minute (the product of the estimated 30 minute processing time to develop a fire mission and the same average fire development rate of 0.6 targets developed per minute)" (Ford, Housel and Dillard, 2010).

Table 5-1: KVA metrics collected from four weaponized UAVs.

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		Weaponized UAV			
		Predator	**Reaper**	**Sky Warrior**	**X-47B**
Subprocess Productivity	**Acquire targets**	377	377	377	377
	Fire support coordination	189	189	189	189
	Fire mission development	943	3122	1222	3962
	Move weapons	50	23	44	607
	Engage targets	5094	70761	15212	254736
	Battlefield assessment	377	377	377	377
	Weapon	705	907	954	1067

For this research's case study a new version of the Predator UAV is being developed to engage enemy UAVs in which stakeholders value payload, dash speed and range differently and want recommendations on different improvements to select only one of the improvements. The alternatives for improvement were increasing size of power plant, redesign transmission, increase fuel tank size, and reduce time required at base between trips to station. The previous study's AoA suggested that the increasing of fuel capacity by 100% is the alternative that improves the system the most. If there are inadequate resources to implement this alternative fully, then increasing fuel by 50% can be attempted (since it will still bring the highest improvement). The ones that do not improve performance (last three with negative change from base case) can be eliminated from consideration. Table 5-2 summarizes the KVA metrics of the framework's first step and is included in the next section that defines the framework's second step.

Table 5-2: Predator Upgrade Alternatives Results

		Sub-process KVA ratios			Weapon System	
		Develop Fire Mission	Move Weapons	Engage targets	KVA ratio	% Change from Base Case
	Predator Base Case	943	50	5,094	705	0.00%
Improvement Alternatives	Increase fuel capacity 100%	**1,886**	50	5,094	**951**	34.90%
	Increase fuel capacity 50%	1,415	50	5,094	831	17.90%
	Increase power plant 100% for payload	849	50	7,641	771	9.40%
	Increase power plant 50% for payload	849	50	7,641	771	9.40%
	Redesign transmission for 100% faster dash speed	943	**100**	**10,188**	741	5.10%
	Redesign transmission for 50% faster dash speed	943	75	7,641	727	3.10%
	Increase power plant 100% for dash speed	849	**100**	**10,188**	717	1.70%
	Increase power plant 50% for dash speed	849	75	7,641	702	-0.40%
	Reduce time at base 50%	943	52	5,094	699	-0.90%

5.5. UAV Case Study Matrix of Change

Under the NPS research a new version of the Predator UAV was being developed to enable it to engage opposing UAVs. Only one improvement alternative was to be selected to improve three options which stakeholders value differently: payload, dash speed, and range. The current practices are providing low mission execution success rates, average turnaround movement of weapons and limited target engagements. The correct alternative changes implemented correctly from payload, speed and range could improve the current practices. The study's analysis focused on value compared to cost in terms of the capabilities of the systems. KVA was integrated with SD to investigate how modeling weapon systems can improve the accuracy of KVA ratios. Assuming a new version of the predator UAV is being developed to engage enemy UAVs, an example improvement can be an increase in the fraction of targets missed because UAVs are faster, more agile (than land targets), and have longer ranges for missions. There is access to only some limited resources to improve performance. Stakeholders value payload, dash speed and range differently and want recommendations on different improvements to select only one of the alternatives. The alternatives will be compared using MOC based on different characteristics and effects on the weapon system:

- Increase size of power plant: can increase the vehicle's payload, dash speed, or combination of both; requires an increase in fuel capacity to not reduce range.
- Redesign transmission: will increase dash speed.
- Increase fuel tank size: will increase range but decrease dash speed unless power plant increased.
- Reduce time required at base between trips to station: increases time the vehicle is on station and available for missions.

The operation of the system with each potential alternative was simulated in the original study to calculate KVA productivity ratios for sub-processes and for the whole system (the three sub-processes that are impacted by the characteristics of the vehicle). Referencing Table 5-2, the AoA suggested increasing fuel capacity by 100% or by 50% since either would bring the highest overall improvements.

This research proposes a MOC analysis before system dynamics modeling (the NPS research performed SD in the beginning) where the alternatives are analyzed against available practices or goals. For the NPS study this proposed framework will perform a MOC analysis on the alternative practices against the system sub-processes. MOC will analyze the practices of increased power plant size, increase fuel capacity, redesign transmission and reduce time at base against fire mission execution, weapons movement, and target engagements. The stakeholders' interest in payload, dash speed, and range will influence their view of target practices differently.

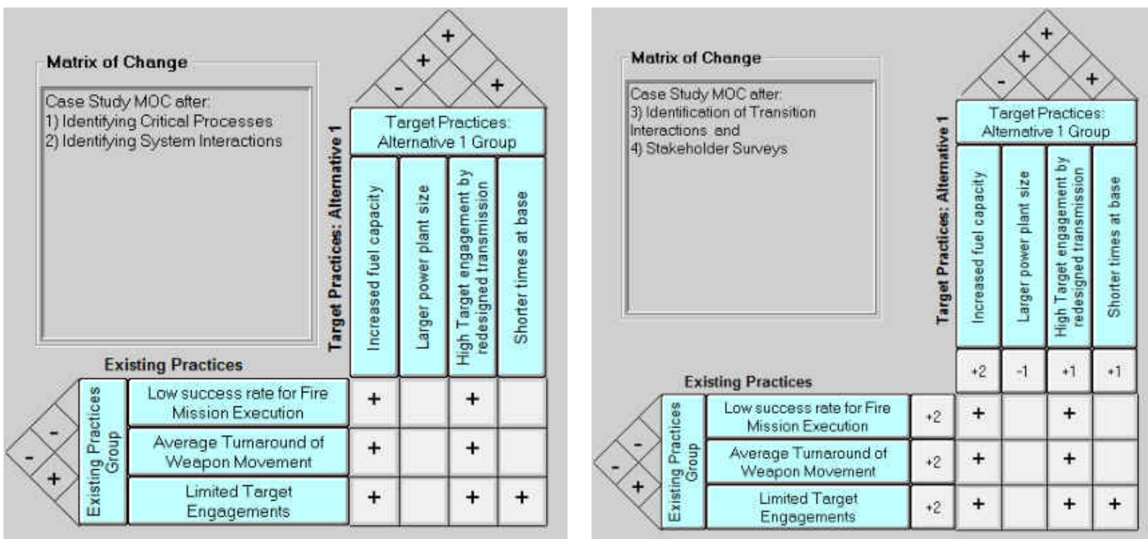

Figure 5-4: MOC Steps 1 through 4 for NPS Study

The MOC analysis shown in Figure 5-4 provides insights into complementarities of practices (and assets) by the interaction signs in the matrix. In step 2 of the MOC shown on the left side of Figure 5-4, increased fuel capacity and redesigned transmission are practices with two reinforcing interactions and which reinforce each other while a larger plant has no reinforcing relationships with one that is conflicting. The questions of feasibility, sequence of execution, location, pace/nature of change, and stakeholder evaluations offer guidelines on how, when, and where to implement changes. Step 3 of Figure 5-4 shows the difficulty of transitioning to the alternative processes defined by +/- signs in the cross-sections for existing and target processes. This MOC analysis will initially consider the "larger power plant size" alternative non-important based on its neutral interactions on the complete system and more because of its negative importance to stakeholders. The remaining three practices become ones to keep under consideration and to receive attention for investing, with “increase fuel capacity” and “redesign transmission” demonstrating the easiest transition but “increase fuel capacity” showing the strongest importance to stakeholders (+2). From this we infer that increasing fuel capacity reinforces execution of missions, weapon movements, and engaging targets because more fuel allows the UAV more time in missions, with more weapons on board, and less time at base since less re-fueling is needed. Redesign transmission is another reinforcing practice which will be a focus of attention in the dynamic modeling taking place in the next step of the framework. Fuel capacity alone was the main practice in the original study but this study’s MOC and SD analysis has found redesign transmission to be of similar importance for consideration of future investments.

5.6. UAV Case Study Dynamics Modeling

After decisions on implementing new processes, system dynamics can dynamically model the resulting proposed system. SD has two main tools: causal loop diagrams (CLD) and stocks and flows. CLDs show causal links among variables capturing dynamics of processes and applicable to the capture of hypothesis about dynamics’ causes and to demonstrate the feedbacks of a specific process. Stock and flows structures are descriptions of weapon movement and execution rates or “flows” which can increase or decrease. These flows accumulate into some other important information variables in this framework application, knowledge and cost, in the dynamic model as “stocks” representing system states. An appropriate system dynamics model for measuring knowledge value requires variables for the state of the system (stocks), for the increase and decrease of these stocks (flows), and variables that can be linked to stocks and flows supporting the description of the model behavior. The resulting system from the selected alternative processes in the MOC analysis is now put into this SD model to simulate the complete system processes of moving weapons and acquiring a target under the NPS study. The modeling of alternatives would simulate processes in a system that begins with an input and finishes with an output. Revenue and cost are used for knowledge valuation based on KVA methods, and make up the stocks for each of the processes (these stocks are considered return on knowledge stocks). System dynamics modeling would be used to influence inputs, value-added, and cost metrics. This modeling allows graphing of stocks of value-added to provide the KVA metrics to be analyzed for results in the framework. Figure 5-5 demonstrates the CLD of the alternative system from the processes selected in the MOC analysis. This is the final phase of the framework aimed at providing (by modeling before implementation) insight on the behavior of the complex dynamics of a knowledge system over time. Figure 5-6 represents the SD model for this case study.

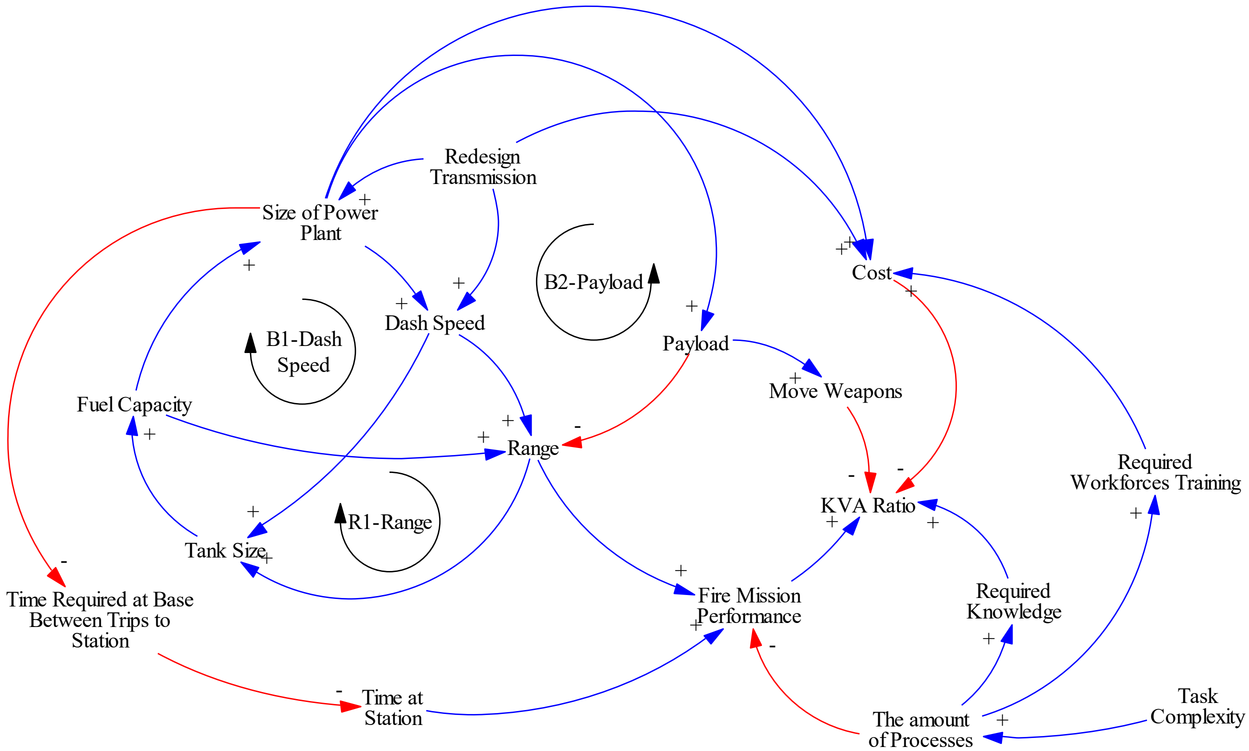

Figure 5-5: Causal Loop Diagram of UAV Weapons System

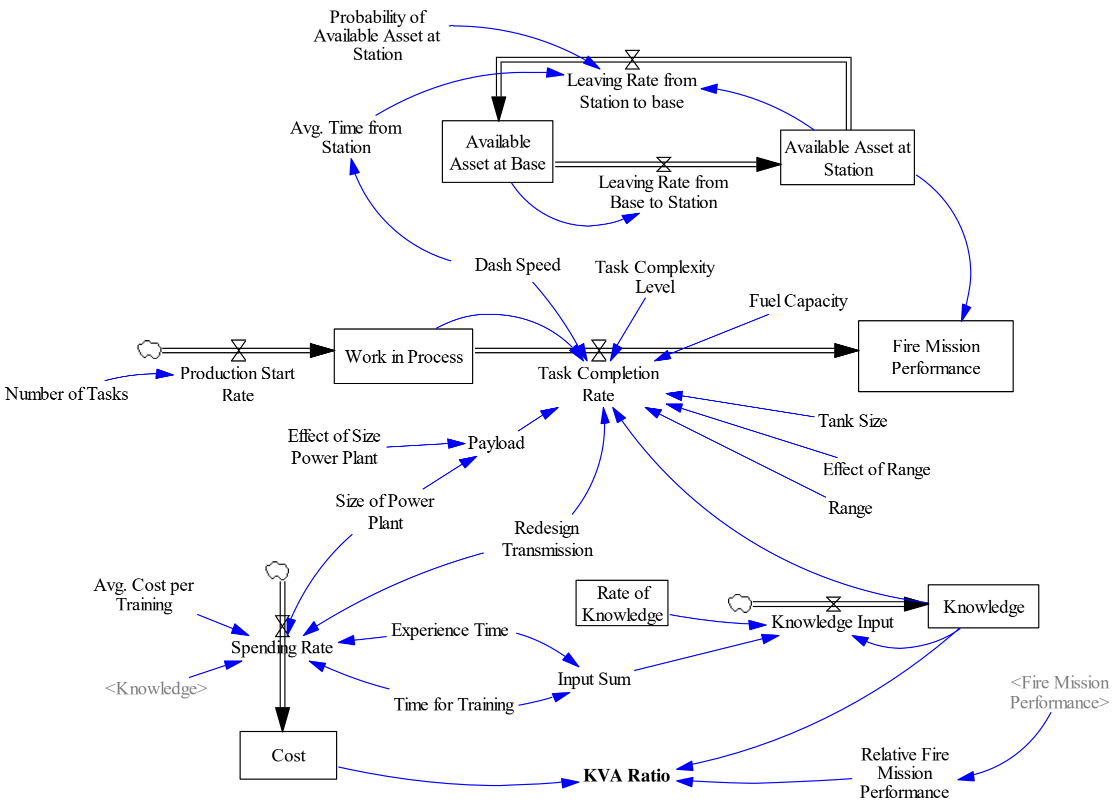

Figure 5-6: System Dynamics Model of UAV Weapon System

The dynamic modeling took into account all applicable variables (payload, tank size, range, knowledge and cost rates, etc.) in order to simulate a complete proposed system in the interest of viewing the behavior of asset work-in-process, weapon movement, mission performance, etc. The model showed that "fire mission performance" was the level that provided the highest return on investments to achieve completion of the system's tasks. This stock was more affected by the fuel capacity variable by allowing completion of missions from longer mission campaigns. Increased fuel capacity and redesigned transmission were identified as the most reinforcing practices in the MOC analysis and became the focus of the SD model. The behavior of the model demonstrated a balanced system capable of successfully competing tasks over time without adverse impacts on overall mission performance, thus a system with complementary processes as seen in the MOC analysis. Additional analysis is shown in the next section.

5.7. UAV Case Dynamic Model Optimization

As an additional step on the modeling part of the case study, the optimization option within the Vensim (Vensim DSS 2003) system dynamics modeling software provides an efficient tool for policy analysis. An efficient Powell hill-climbing algorithm searches for the best set of policy parameter values to maximize the objective function. The Powell hill-climbing algorithm was developed by Michael J. D. Powell and it is an optimization approach that searches the objective in a multidimensional space by repeatedly using single dimensional optimization. The method finds an optimum in one search direction before moving to a perpendicular direction in order to find an improvement. The main advantage of this algorithm lies in not requiring the calculation of derivatives to find an unconstraint minimum from a function of several variables (Powell, 1964).

With the purpose of reducing the current level of Work in Process (WIP) inventory (see Figure 5-7), we apply policy optimization to the parameters that affect the “Task Completion Rate” (see Table 5-3). This rate initially starts increasing until it reaches a peak and then stabilizes. The objective will be to maximize the “fire mission performance”.

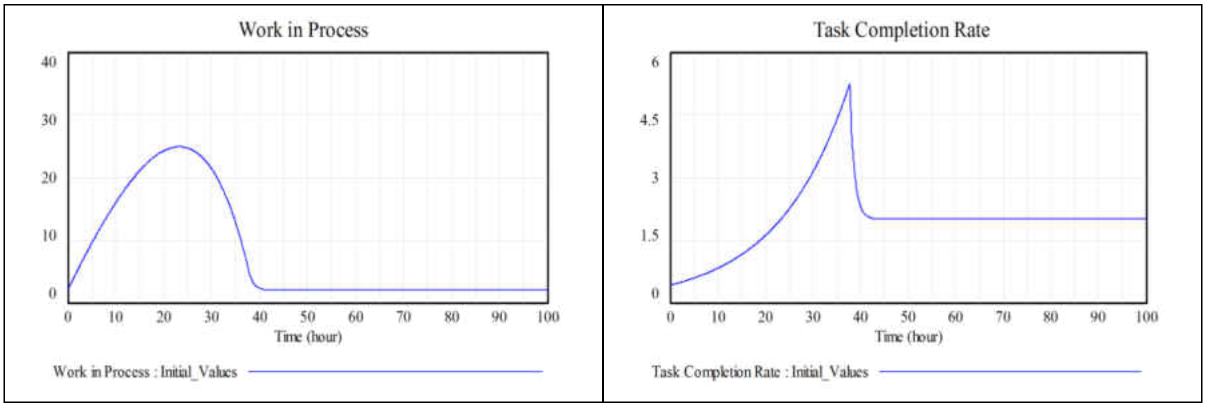

Figure 5-7: Work in Process Inventory, Task Completion Rate before optimization

Table 5-3: Comparison of new parameter values with the original values

	New values from the optimization	**Original values of the model**
Fuel Capacity	1	1.02
Tank Size	1	1
Redesign Transmission	1	1
Size of Power Plant	1	1
Effect of Range	0.85	0.85
Effect of Size of Power Plant	1	1
Task Completion Rate	4	4
Range	2	2
Dash Speed	1	10

From Table 5-3 and Figure 5-8 we can conclude that although fire mission performance remains almost the same, increasing dash speed significantly it is possible to reduce and stabilize the work in process inventory. The other parameters remain unchanged.

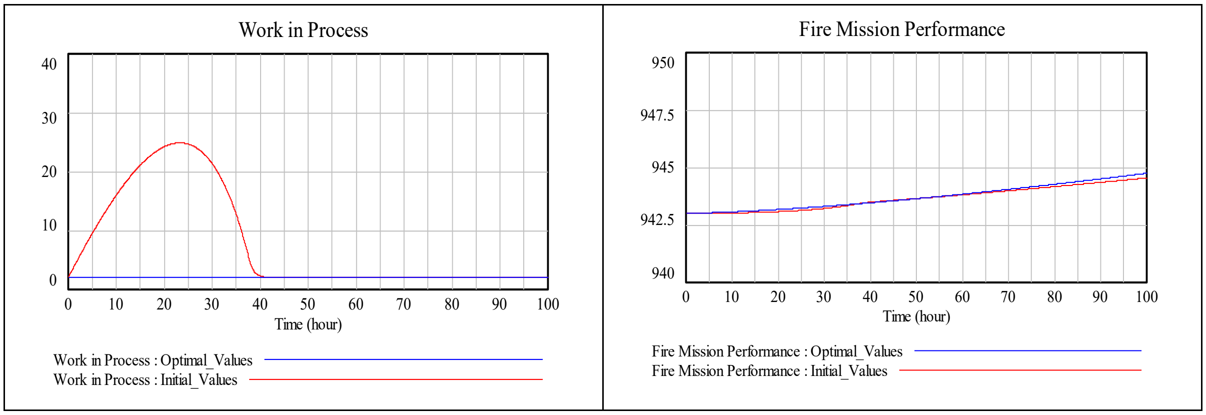

Figure 5-8: Comparison of Work in Process inventory and Fire Mission Performance before and after the optimization

5.8. UAV Case Study Summary

The matrix of change provided analysis of what was necessary for stakeholders and decision makers in the alternative scenario, showing fuel capacity and redesign transmission as reinforcing practices desired in the dynamic modeling that followed in the framework. The SD simulation results with model optimization showed that knowledge and KVA ratio started increasing at 50 hours exponentially. An increase in knowledge enhanced fire mission performance over periods of time. Therefore the level of knowledge is a significant factor for improving fire mission performance, with KVA ratio having a positive relationship with fire mission performance. While the original NPS study selected only fuel capacity as the improvement alternative this MOC and SD analysis showed both fuel capacity and redesign transmission as the two processes to invest in. Model behavior demonstrated a stable system over time with no unfavorable impacts on performance and resulting in a system composed of complementary processes as expected from the MOC analysis.

CHAPTER 6: CASE STUDY OF SHIPYARD PLANNING PROCESS

6.1. Shipyard Case Study Introduction

The DoD spends about 14% of its annual budget ($63 billion) throughout the world on major depots, shipyards, and organizational units to support approximately 280 ships, 14,000 aircraft, 900 missiles and 330,000 vehicles (Komoroski, Housel, Hom, and Mun, 2006). In order to obtain maximum benefits, measurement of alternative projects requires definition of value and comparison of processes benefits, costs, and revenues. From a need for analytical quantification of risks and value from these naval acquisitions, the Naval Postgraduate School (NPS) developed a KVA plus Real Options (KVA+RO) valuation framework to evaluate and select projects for Department of Defense (DoD) maintenance programs aimed at maintaining US Armed Forces modernized. The combined KVA with RO analysis applied option valuation methods to make decisions on capital budgeting. Real options valuation or real options analysis views an option as a right, not an obligation, to undertake initiatives like expanding, staging, deferring or completely abandoning an alternative. Real options are different from conventional monetary options because these options cannot be or involve assets that can be traded as financial securities.

6.2. Shipyard Case Study Background

Shipyards are facility locations that build, maintain, and modernize ships. American naval shipyards declined to four public and six private shipyards in the 1990s. The Norfolk Naval Shipyard in Portsmouth, Virginia, is the oldest and largest Navy-owned facility and one of the largest shipyards in the world while the Puget Sound Planning Yard in Washington State services ships and submarines from the West Coast and those stationed in Japan. Planning yards are responsible for collection and management of job data for end-users like the shipyard itself, private-sector shipyards, or other organizations independent of planning yards and shipyards. Shipyard planning activities require seven sequential processes (all involving several sub-processes): issue tasking, interpret orders, plan for ship check, conduct ship check, report assembly, revise schedule and generate drawings. These core processes take place for all naval vessels when they reach their "shipyard availability" period.

Figure 6-1: Aerial view of Puget Sound Naval Shipyard in Bremerton, Washington.

Navy leadership defines work schedules and locations using dates far in advance of needs, which are affected by budgets and priorities. Output products from planning yards include ship compartments areas, equipment movement routes, and materials documents in the form of 2-dimensional (2D) AUTOCAD drawings. The Navy was considering implementing a 3D laser scanning technology along with improving communication and collaboration between parties involved in the planning processes (Komoroski, Housel, Hom, and Mun, 2006).

6.3. Shipyard Case Study Problem Description

The NPS study focused on the implementation of two new Commercial-off-the-shelf (COTS) technologies to increase ROI by applying the KVA+RO Framework. These technologies were aimed at cost reduction by the use of 3-dimensional (3D) laser scanning technology and by a collaborative Product Lifecycle Management (PLM) solution versus current two-dimensional CAD drawings and outdated data management technologies. The KVA+RO analysis was designed to support IT acquisitions by providing performance and scenario analysis by deriving ROI using KVA to then evaluate investment decisions with Real Options analysis. The analysis considered the following risk areas: identification, quantification, valuation, mitigation and diversification. The study began with the need for portfolio investment measurements, followed by performance tools. Core concepts of the KVA+RO Valuation Framework were presented in the naval maintenance process called Planning Yards to study the alternative use of COTS technology. Three scenarios were analyzed: “As Is,” potential “To Be,” and potential “Radical To Be.”

The NPS case analysis indicated that 3D laser scanning with PLM and database management system (DBMS) could reduce maintenance costs by expediting work, improve fleet utilization, and reduce inventory requirements via reduced cycle-times. The study identified cost savings and areas of process improvements and conducted Real Options analysis for valuation of the three options using KVA as a platform.

This research will utilize the KVA data from the NPS Shipyard study to execute the KVA, MOC, and SD framework. The NPS study demonstrated the ability of selection based on value for the 3D, DBMS, and PLM technology alternatives, technologies which proved beneficial to the naval shipyard processes. The application of KVA and RO methodologies resulted in decisions to implement the technologies to yield solutions that will reduce costs and improve utilization and productivity. The NPS study recommended applying the KVA+RO methodology using a larger sample to better asses impact of the alternative technologies on other applications, implementing KVA+RO software to perform analysis real-time, and creating a common repository of 3D images to serve all levels of shipyard operations and not just planning. This research will not look to perform these recommendations but rather utilize the KVA data from the original study to exercise this research's framework.

6.4. KVA Analysis for Shipyard Case

The KVA+RO Framework began by gathering data from subject-matter experts (SMEs) supplemented with historical data, and along with additional research the study's data-gathering yielded the following:

- Learning time method used for sub-processes KVA estimates.
- Seven major processes; SMEs defined inputs, outputs, and execution frequency.
- System process details:

- 10 ship checks accomplished per year (40 among 4 shipyards)
- 100 SHIPALTS (orders that direct ship changes) per each ship check
- Work days: 230 days/year, 20 days/month. 5 days/week. 8 hours/day.
- Minimum five drawings created for each SHIPALT.

The “To Be” assumptions defined costs for IT including laser scanning equipment. KVA was applied for three scenarios: a current “As Is,” a “To Be,” and a “Radical To Be.” The “To Be” scenario introduced the 3D laser scanner system and 3D data-capture technology that would introduce more precise process outputs in the form of 3D digital images and models (different from static installation drawings delivered on paper under the “As Is” scenario). The “Radical To Be” scenario introduced a completely enhanced 3D and collaborative IT system with laser scanners, 3D digital imaging, data warehousing, database management system (DBMS), and collaborative PLM environments. The KVA values demonstrated major cost reductions from the 3D and collaborative technologies for the seven major processes. ROI from KVA analysis also yielded improvement in both the “To Be” and “Radical To Be” scenarios as shown in Table 6-1. Cost savings were seen in both alternative scenarios for the plan ship check, conduct ship check, and generate drawing processes (processes 3, 4, and 7). The “Radical To Be” scenario showed additional extreme savings in processes 2 and 5, interpret orders and report assembly. The “To Be” scenario yielded $36.8 million in savings and the “Radical To Be” $40.2 million. Implementing the 3D technology was expected to reduce total work days in the “conduct ship check” process (“As Is” = 286, “To Be” = 145, “Radical To Be” = 113) and “generate drawings” (“As Is” = 3960, “To Be” = 521, “Radical To Be” = 256). Generate drawings in the “As Is” scenario required manual paper and pencil sketching sub-processes. The alternative to-be scenarios would reduce the amount of manpower for the labor-intensive generation of drawings by the use of digital 3D capture technologies that translate into drawings via automated processes.

With cost savings possible in up to five of the seven processes, returns on investments for these processes in turn showed considerable percentage increases as shown in Table 6-2. The KVA metrics that will be used in applying the framework for alternative comparisons will be the "As Is" and the "Radical To Be" ("To Be" will not be used). The KVA metrics showed two processes (conduct ship check and generate drawings) having the highest returns on investments. Availability of these metrics will lead into the framework's next step.

Table 6-1: Knowledge and Cost values for selected "Radical To Be" alternatives.

	Process	RADICAL TO BE Benefit (by Knowledge)	RADICAL TO BE Costs	RADICAL TO BE ROK
1	ISSUE TASKING	35,984	$173,500	0.21
2	INTERPRET ORDERS	2,142,000	$328,000	6.53
3	PLAN FOR SHIP CHECK	14,676	$374,500	0.04
4	CONDUCT SHIP CHECK	36,013,580	$1,041,000	34.60
5	REPORT ASSEMBLY	1,383,240	$122,000	11.34
6	REVISE SCHEDULE	1,288,144	$131,000	9.83
7	GENERATE DRAWINGS	71,346,000	$2,319,000	30.77
	TOTALS	112,223,624	$4,489,000	25.00

Table 6-2: Shipyard cost reductions and KVA ROI summary
(from Komoroski, Housel, Hom, Mun, 2006)

	Process Title	"AS IS" Costs	"RADICAL TO BE" Costs	*"RADICAL TO BE" Cost Savings*	"AS IS" ROI	"RADICAL TO BE" ROI
1	**ISSUE TASKING**	$173,500	$173,500	***$0***	***-69%***	***-68%***
2	**INTERPRET ORDERS**	$520,000	$328,000	***$192,000***	***518%***	***1168%***
3	**PLAN FOR SHIP CHECK**	$1,655,000	$374,500	***$1,280,500***	***-99%***	***-92%***
4	**CONDUCT SHIP CHECK**	$2,604,500	$1,041,000	***$1,563,500***	***552%***	***2530%***
5	**REPORT ASSEMBLY**	$235,000	$122,000	***$113,000***	***783%***	***1601%***
6	**REVISE SCHEDULE**	$131,000	$131,000	***$0***	***1375%***	***1373%***
7	**GENERATE DRAWINGS**	$39,386,000	$2,319,000	***$37,067,000***	***-37%***	***4515%***
	TOTALS	**$44,705,000**	**$4,489,000**	***$40,216,000***	***N/A***	***N/A***

6.5. Matrix of Change for Shipyard Case

The KVA+RO analysis defined four major changes from the alternative scenarios. Improved performance came from the "conduct ship check" and "generate drawing" processes. The ROI for the overall system, composed of seven main processes, was optimized with the use of the more efficient technologies. Reductions in cycle time in the planning processes would allow more time for other naval activities and reduced fleet sizes since ships would be more available. The matrix of change application in this study will identify reinforcement and interferences among current practices and the target practices from introduction of the 3D, DBMS, and PLM technologies.

Identification of critical processes begins with the general MOC suggestion of "starting with the end in mind". The objectives of the shipyard study are to maximize naval readiness, reduce costs, and increase efficiency. The seven processes in their current state yield low productivity and performance from labor-intensive processes with manual measurement and drawing methods, extensive cycle times for planning fleet maintenance and development, high execution costs, and constrained capabilities and large inventories. The “To-Be” introduction of 3D scanning along with data capture and storage is expected to enable reuse of information, reducing re-engineering needs and in turn expanding the system’s capabilities. The “Radical To-Be” scenario looks to add major cost reductions from optimal efficiency which reduces fleet cycle times and inventories. From current and alternative scenarios a MOC is developed as shown in Figure 6-2.

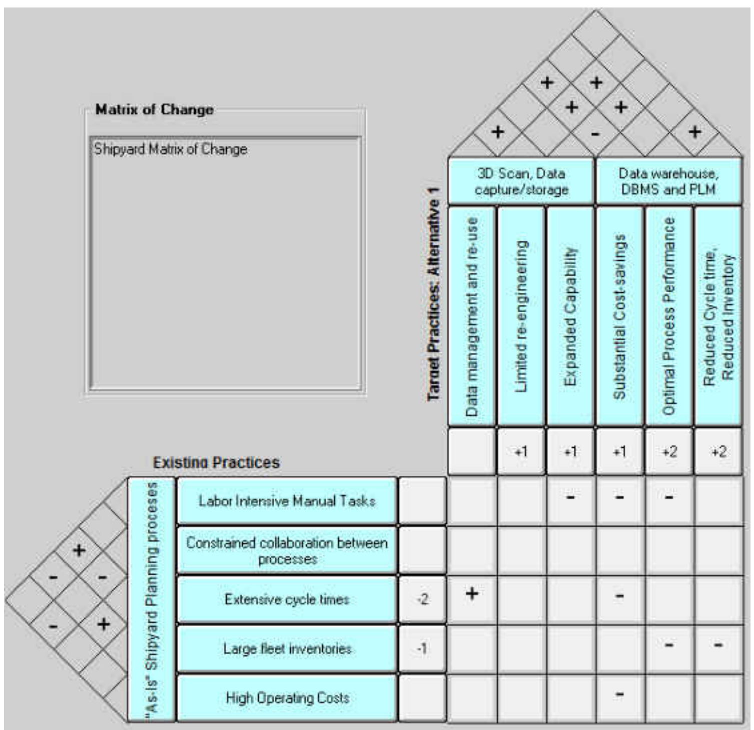

Figure 6-2: Shipyard Matrix of Change

In the MOC analysis the existing practices from the “As-Is” scenario were interfering for the most part since they augment each other in maintaining an inefficient, high cost shipyard planning system. The MOC analysis demonstrates that the target practices virtually do not interfere within them, but mostly interfere with the existing practices. The alternatives that stakeholders value the most were defined to be optimal performance and reduced cycle times and inventories. These are tied to obtaining reduced operational costs and increased fleet availability. These target practice come from use of 3D scanning, DBMS and PLM technologies to specifically provide better collaboration, more accurate and precise drawings, shortened planning process durations and eventually lower in-work inventories for higher fleet availability. This MOC analysis provides evidence to consider implementation of all the target practices into the next framework step.

6.6. System Dynamics Model for Shipyard Case

The dynamics analysis will model the seven major processes in the shipyard planning system by executing them in sequence. The system executes 10 planning yard process (ship checks) per year and each of these executions is composed of 100 ship alterations (SHIPALTs). One ship checks took 61 working days in the "As Is" scenario and 40.85 days under "Radical To Be". With all the improvement alternatives being selected for implementation from the MOC analysis, the seven sequential processes will be modeled for their cycle time durations defined in Table 6-1. The goal is to determine system stability and simulate the new processes with their execution times. This resulting system from the "Radical To Be" processes selected in the MOC analysis will simulate the seven-step system that starts with issue tasking and completes sequentially with drawing completions which in turn denote completion of ship checks as system outputs. Figure 6-2 represents the CLD describing the influences of variables on each other and capturing the dynamics of the proposed system.

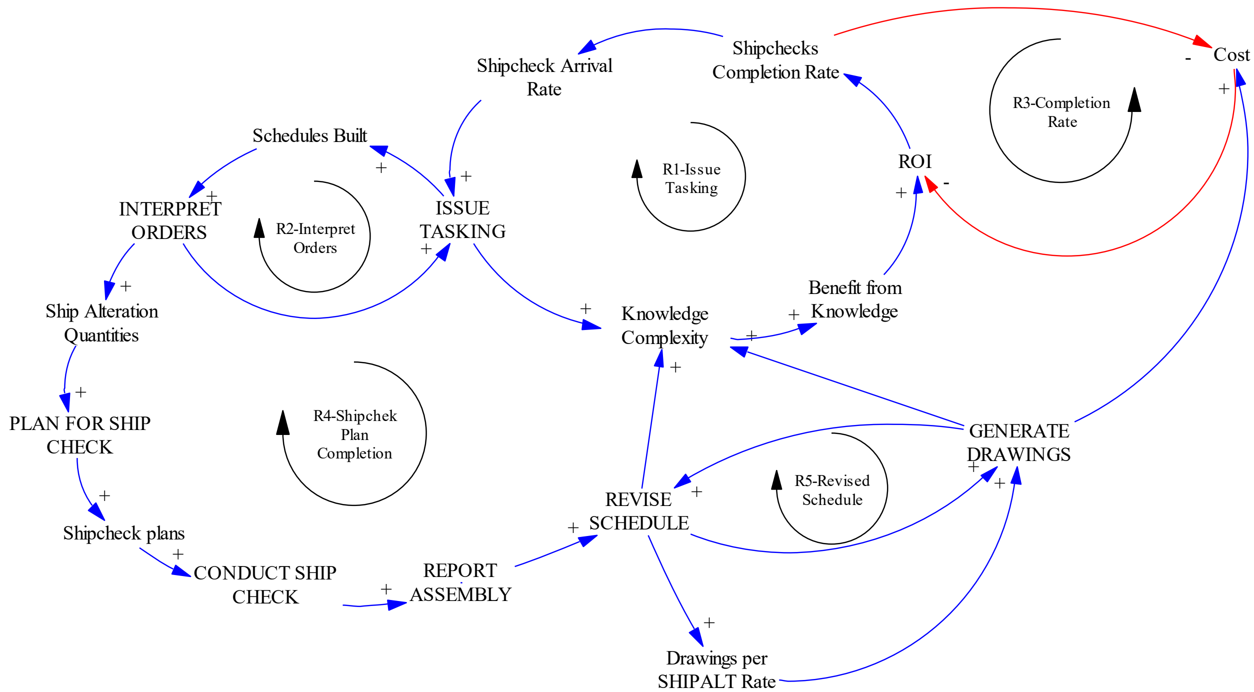

Figure 6-3: CLD for Shipyard "Radical To Be" System

While the case study in Chapter 5 included many variables by virtue of not being a strictly sequential system (different scenarios for output generation could take different paths to complete a UAV mission), this shipyard planning model is required to always perform the seven processes in the same order. The dynamic model for this case study will execute 10 ship checks per year over a total 230 working days a year. This data along with the process execution times (in days) for each process in both the "As Is" and "Radical To Be" scenario shown in Table 6-3 will be the main variables that the system dynamics model will simulate. The goal is to determine how the seven processes acting as stock functions accumulate and move forward the shipyard planning work in process tasks while performing as a new dynamic system.

Table 6-3: Cycle Times for "As Is" and "Radical To Be" scenarios.

	Process	AS IS Cycle time (days)	RADICAL TO BE Cycle time (days)
1	**ISSUE TASKING**	8	8
2	**INTERPRET ORDERS**	10	3.5
3	**PLAN FOR SHIP CHECK**	6	2.95
4	**CONDUCT SHIP CHECK**	10	11.9
5	**REPORT ASSEMBLY**	6	1.5
6	**REVISE SCHEDULE**	3	3
7	**GENERATE DRAWINGS**	18	10
	TOTALS	61	40.85

The system dynamics model is show in Figure 6-4. Introduction of all alternative technologies was decided from MOC analysis as they would offer desired outcomes from reduced execution times and accuracy of outputs. Dynamic modeling was constructed to analyze the cycle times from Table 6-3 to compare each process stock for their improvement or reduction in completing their outputs in terms of work in process. This comparison will be between the shipyard planning inventories of the "As Is" and "Radical To Be" systems. The model was generated describing the sequence of seven processes adding up to completed ship-checks. Different from the case in Chapter 5, this model did not demonstrate the same characteristics of process outputs able to feed into a variety of other possible processes based on system behavior (for example where a process does not perform as expected). Instead this model's behavior is one of time delays when a process is not capable of successfully providing its intended output.

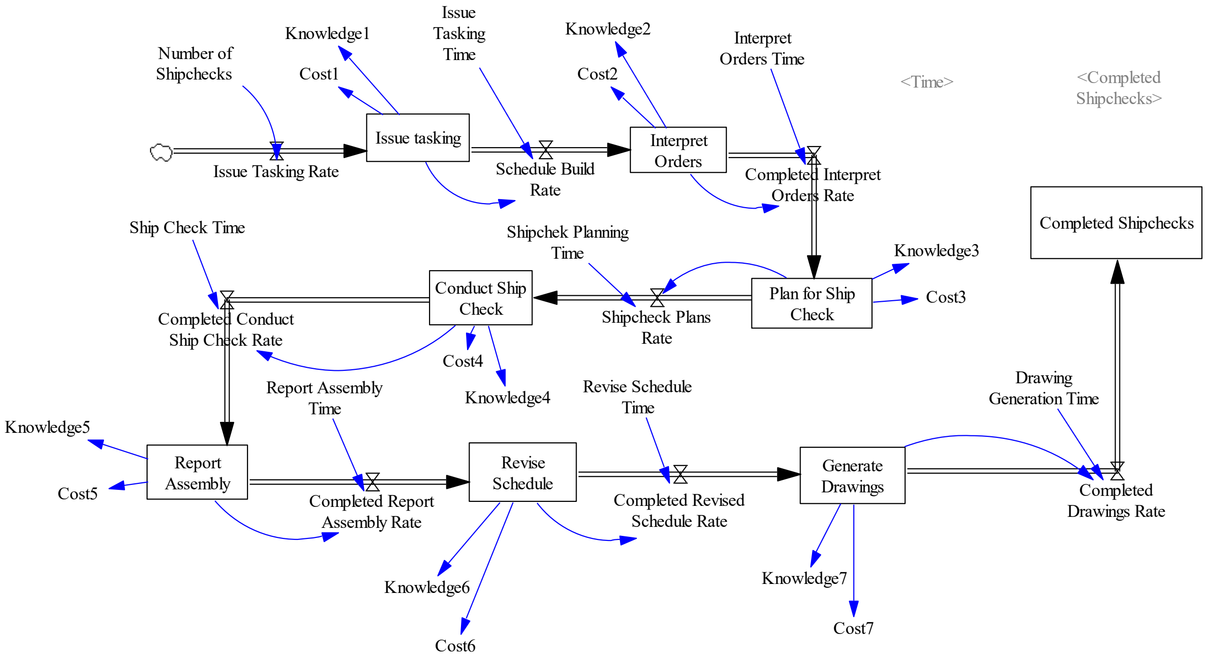

Figure 6-4: System Dynamics Model of Shipyard Planning System

The modeling demonstrated that the proposed alternatives will provide reduced WIP inventories in a system that can successfully execute the shipyard planning outputs. Comparisons for all seven processes' stocks between the "As Is" and "Radical To Be" systems are shown in Figure 6-5. The reduction in cycle times allowed the "Radical To Be" system to maintain lower WIP inventories than the "As Is" system in six out of the seven processes. While conducting ship checks (step 4) required an additional 1.9 days in the Radical scenario than in the original, the simulated proposed system would complete 10 ship checks with an approximate 10.5% reduction in total cycle time. The "Radical To Be" process cycle times were better than or equal to the "As Is" model in all but the "conduct ship check" process as shown in Figure 6-5.

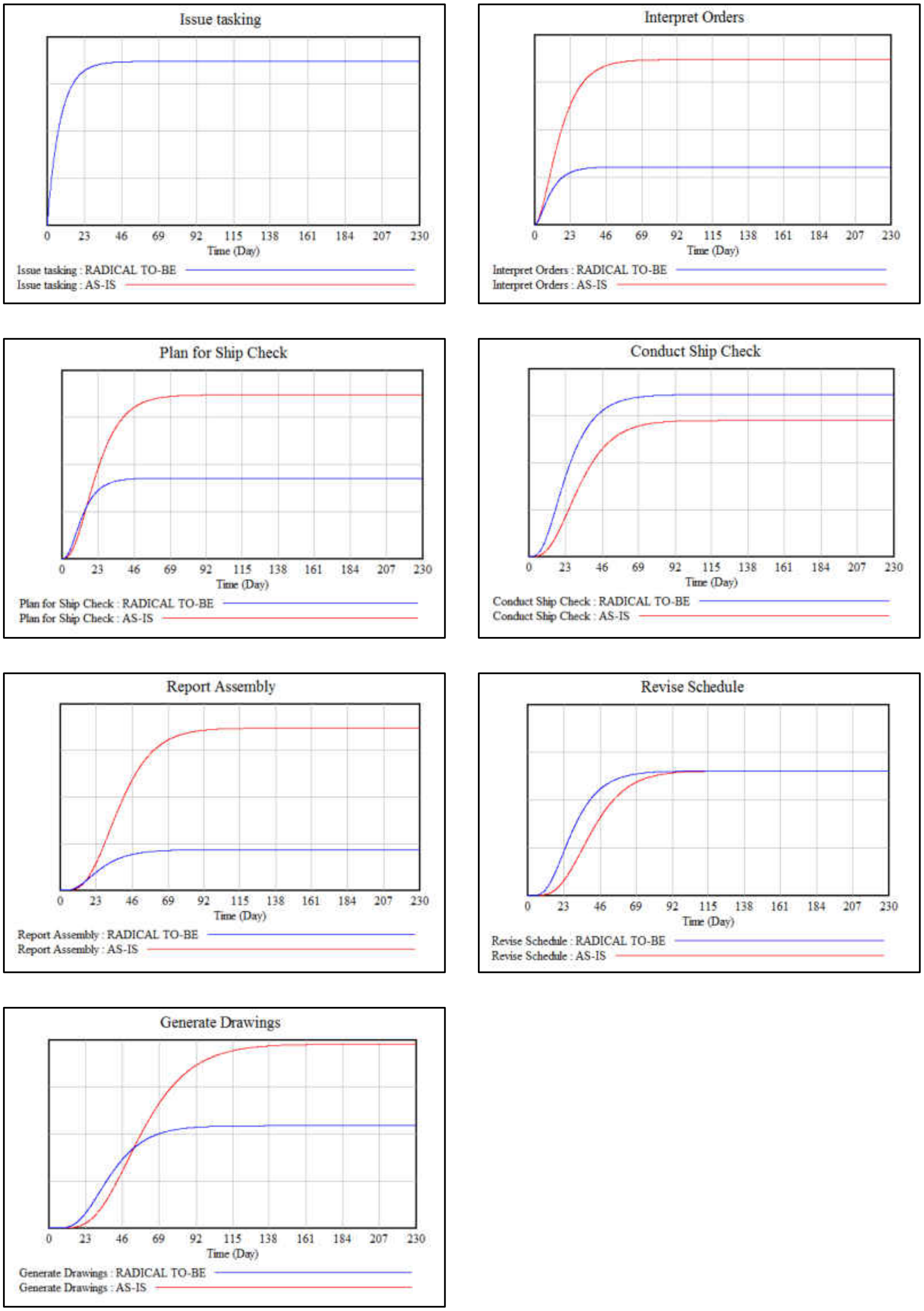

Figure 6-5: Process stocks comparisons between the “As Is” and “Radical To Be” simulations

6.7. Shipyard Case Study Results

This shipyard case selected all alternative practices and used system dynamics to determine which practice(s) provided the greatest system impact when completing the shipyard planning system's processing of ship checks. The reduction in cycle times confirmed what the original NPS study presented and all proposed alternatives can be suggested for implementation into a new system. This case study application of the framework demonstrated use of complexity and knowledge to determine value matched with dynamic behavior analysis. The NPS shipyard study identified conducting ship checks and generating drawings as the highest value-added processes and the framework's analysis deduced that those practices would in fact benefit from implementation of the new alternative technologies (3D, DBMS, and PLM). The framework's analysis inferred that the new alternative system with such optimized processes would benefit from the major reduction in costs from cycle time reductions in these high-value processes. The major reductions in processing hours along with more accurate outputs were able to provide stable value-added in a dynamic system while successfully producing outputs.

CHAPTER 7: CONCLUSIONS, CONTRIBUTIONS, AND FURTHER RESEARCH

7.1. Conclusions

The Knowledge Value-Added plus Matrix of Change plus System Dynamics framework has been presented with its utilization of knowledge as a determinant of value from execution of processes. This dissertation developed and presented the framework for improved decision making based on the intangible value-added that execution of processes generate.

This research began by introducing the real-world status of intangibles and the difficulties in measuring the returns that these kinds of investments provide to organizations. Financial and accounting models were shown to be inadequate for measuring intangibles such as knowledge-based activities. Modern-day business activities rely more than ever on information and knowledge activities which are complex by their nature. The execution of such processes to generate outputs demonstrated the need for measuring how these processes provide benefits with the goal of making educated business decisions. The importance of measuring and managing knowledge was coupled with the complex nature of knowledge activities that do not function in the same manner as, for example a repeatable manufacturing process. The measuring of value from investments that use knowledge also demonstrates a need for analysis of complex process behaviors.

The literature review looked at intangibles and knowledge management, starting with the evolution of intellectual capital into the current information-based business landscape. Intellectual capital can come from both organizational and human assets while the ability to generate the same outputs can in many cases be achieved either by structures or by people. The research demonstrated that traditional capital budgeting methods were designed for depreciable and tangible assets. All the methods reviewed for measuring intangibles came with shortcomings. Among these the Knowledge Value Added method was found to provide measures down to sub-process levels with its main limitation being inapplicability to creative tasks that do not have pre-determined outputs. The current business landscape where obsolete technologies and processes are being replaced with knowledge-based processes requires measuring value by considering that the same output can be obtained from alternative technologies while accounting for differences in cost. Replacement of process to generate the same output took into consideration that the same knowledge may be required while differences in time, cost, and success in execution make knowledge management a necessary aspect in decision making. After KVA was demonstrated as the method to account for complexity and the knowledge needed to produce the change(s) required for output generation, the research stated a case for improving KVA decision making.

The research presented how complexities and interactions in the current technologically-driven marketplace apply to organizational systems down to sub-process levels. This introduced the need for methods that would complement the KVA methodology to analyze interactions and complementarities between system processes. This requirement proposed the Matrix of Change as the tool to recognize process interactions between alternatives for change management and selected this tool to study interdependencies between strategies and technologies. Coordination of current and proposed practices in order to generate alternatives that yield higher rates of return from intangibles was shown to be analytically achieved by MOC analysis. While value added from knowledge may provide measures for higher returns, successful change management requires that processes properly interact. The MOC incorporated customer and technology requirements by depicting relationships and critical interactions. This made it possible to plan and strategize by taking into account all the components of a business system. After the MOC analysis was shown for its ability to yield systems from alternative and current practices the research presented the need and applicability of modeling complex systems never before executed. Modeling was introduced at this point for the ability to obtain insight and understanding of complex system behaviors where tradeoffs can result in undesirable outcomes. Modeling was a natural choice to simulate for change effects before commitments, and since the framework is based on complexity to measure value System Dynamics was the selected tool for modeling the resulting proposed systems.

Chapter three outlined the methodology which began by proposing the research question and describing the need for measuring added value from knowledge, analyzing interactions and modeling complex systems. This led to a literature review which presented previous studies and available methods to answer the posed question. The methodology then developed the framework which presented the select methods to achieve the research goals. Case studies put the framework in practice followed by conclusions and recommendations to complete the dissertation.

The framework was constructed in Chapter four using what was presented by the research question and learned by the literature review. Starting with collection of knowledge value-added metrics, the framework first compared KVA data between current and proposed practices to initially make decisions on what changes to take into considered for implementation. With KVA as a key to the framework's objectives, knowledge value data became the first requirement to determine what was needed to begin a decision-making analysis. From there it was possible to combine practices and targets expected to generate improvement on a system composed of processes under consideration. Since knowledge value metrics were a major requirement but not considered to meet all needs for decisions making, the framework then analyzed interactions between the processes and practices selected in alternative systems. With value-added as a major consideration for alternative decision making, the framework introduced a method to study processes functioning together as part of a system.

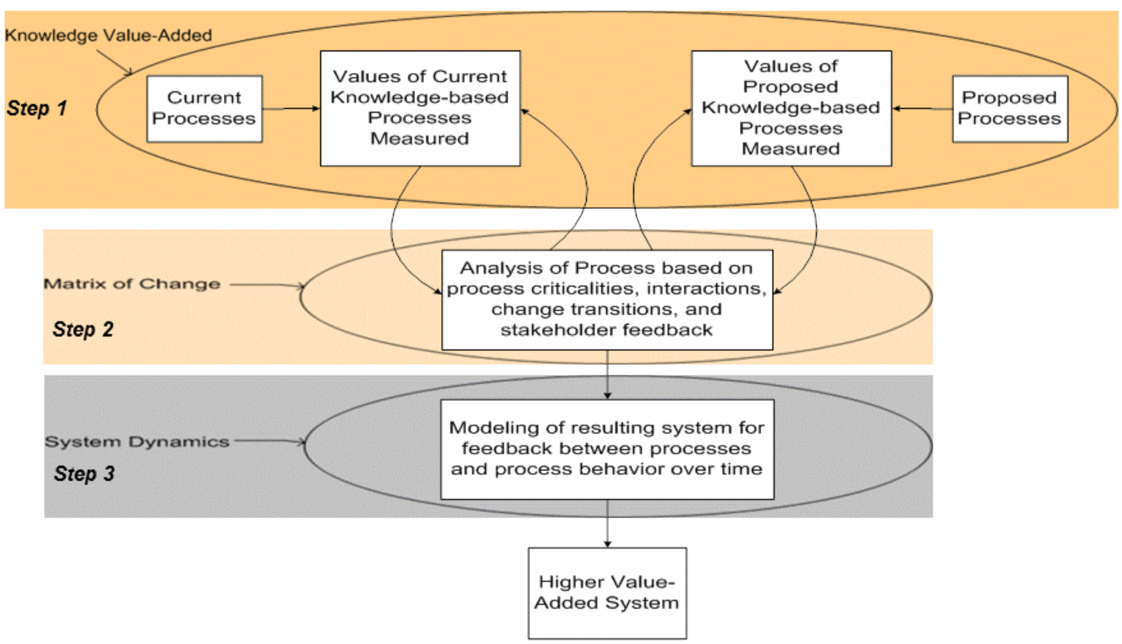

Figure 7-1: Framework Summary Description

The Matrix of Change analysis provided insight into how critical and necessary a current or alternative practice might be, and following KVA analysis the MOC execution provided a means to analyze alternative and current processes for compatibility when generating an alternative system. This determined how the selected practices complemented (versus negatively interacting with) each other. At this point the framework had made use of two essential analysis tools for process selection: process value-added and process-system interactions. In its last analysis step, the framework re-stated modeling as a practical scientific tool to study systems before commitments. Because of the risks and uncertainties presented by the complex processes that the framework was designed for, system dynamics was selected to simulate the alternative systems generated. With system dynamics the framework showed the effects of time, feedback, and modifications in the variables affecting system outputs. This took into account that complex systems behave in complex ways and over time may perform differently. System Dynamics served as a method to model alternative systems, simulating process behaviors and allowing insights before investments are made. Causal loop diagrams and dynamic modeling provided depictions of alternative system structures and analysis of behavior based on interdependences and interactions in time. This provided modeling of a selected system for how knowledge and costs along with all other possible variables can behave. This last step of the framework closed the loop in a systemic, structured, and comprehensive analysis of alternatives.

With the two case studies the dissertation demonstrated that higher complexity and knowledge coupled with lower costs of process execution can provide business opportunities for higher value-added. Both case studies were able to apply and demonstrate the framework in its entirety by selecting practices for consideration based on return on knowledge, then studying those selections for how they interact. Once the alternative new systems were constructed they were modeled for execution of their processes and analysis of cost and knowledge data. In both case studies the framework showed that some processes provided higher returns which made them worthy of more attention. Both case studies used learning time for the KVA metrics needed for the first step of the framework and the metrics used were obtained from the leading experts of the KVA methodology. The UAV case in Chapter 5 contained three major process changes (out of nine total) with considerably higher return on knowledge investments based on more efficient process executions even when cost savings were not a major factor. The shipyard case (chapter 6) began with five out of seven processes having increases in value-added by both cost savings and improved system processes performance but the dynamic modeling emphasized cycle times for output completions as a conclusive factor when the simulations were completed.

The UAV case in Chapter 5 generated a dynamics model for a system where stakeholder desires for improving the system's performance (payload, fuel capacity, etc.) were considered against the parameters they affected (assets at base, mission performance, etc.). In this first case fire mission performance was found to provide the highest returns and was more affected by fuel capacity as a reinforcing practice. The second case study on shipyard planning simulated sequential process, in contrast with the UAV system in which the completion of missions was more dynamic and sequence of executions was more affected by the model's variables. This shipyard case would be heavily dependent on the execution times, because of its sequential nature, after knowledge benefits and complementarity of the proposed system (which implemented all alternatives) suggested a comparison between the current and proposed systems.

7.2. Contributions to the Body of Knowledge

This dissertation contributed to the research and use of the Knowledge Value-Added methodology starting with the consideration of KVA as a proven and quantitative way to measure intangibles. The use of KVA for selection of alternatives also contributed to demonstrating that complexity and change in output creation are objective determinants of value-added. Another major contribution came in the form of analysis of interactions and complementarities between knowledge processes that are complex and dynamic by nature. These complexities called for studying structures and behaviors by system dynamic models. The dynamic simulations contributed simplified calculations and analysis for investment decisions.

The main contributions from this research came in the form of:

- Valuation of returns from investments based on the knowledge complexity needed to successfully generate predetermined outputs.
- Selection of alternatives based on how processes interact among themselves while being executed in a system, including analysis of how processes complement each other.
- Dynamic modeling of proposed systems that can be composed of all new processes or a combination of existing and new processes, providing information on how process dynamics and feedback behave in a system.
- Provided a way to measure value added from intangibles, a systematic way to determine what to and what not to change, and simulation of proposed systems for stability and behavior.

7.3. Recommendations for Further Research

The presented research demonstrated the integrated use of KVA, Matrix of Change, and System Dynamics to improve investment decision making. Opportunities for additional research include the following:

1. The case studies demonstrated the application of the framework for defense projects. These studies made use of the best available KVA data and studied systems mostly sequential in nature where output generation required execution that followed predefined sequences. These studies also had many possible alternatives and these desired alternatives were based on both their value added and how they worked in a system. Some recommendations from this are to apply the framework in non-defense areas and investigate how to tailor it to non-sequential or less-structured systems. Most importantly the framework can be applied in areas where there may not be alternatives for all processes in the system and moreover the framework could be used to identify those processes that, if modified, will yield the best value-added options. In other words, can the framework identify, without available higher-KVA alternatives, which processes to put emphasis on and possibly research for change?

2. On a more insightful matter related to the KVA method, questions on cost, compensations, and investments as functions of how much knowledge a process applies can be raised. Drawing from KVA's use of complexity for measuring change, this research proposes investigating a parallel to KVA where measurement of compensation (salaries or hourly pay rates) may be based on how much knowledge an individual

possesses versus how much that person is compensated. While this would be part of cost under the KVA model, the question becomes one of complexity in terms of the return (pay) an individual receives. For example, does becoming a brain surgeon or physicist require so much more knowledge than a manually laborious profession such as a machine operator or fast food restaurant worker? While some professions are generally compensated more in comparison to others, can pay rates be a function of the existing knowledge applied to perform a job? Is talent considered a form of knowledge accumulation such that accomplished musicians and artists earn higher returns for producing outputs not executed with the same success by others?

3. Relating to learning curves, experience time and knowledge rates, this research did not introduce any changes to what was already established on the KVA methodology which measures and utilizes knowledge (e.g. learning time) and generally keeps complexity values steady (numerator of ROI). On the other hand costs may be easier to recalculate based on execution of processes. Therefore the KVA methodology could benefit from researching how complexity and learning may change with differences in how processes are executed and not merely using base measurements of knowledge complexity. The research question being posed here is: with complexity as a measure of value, do things like learning curves and changes in process executions have an effect on KVA calculations, otherwise introducing a consideration of differences in knowledge?

4. While MOC provided analysis as presented in the framework, change can take place over time in terms of interactions and even stakeholder preferences and system goals. Just as knowledge and complexity can change over time the decisions taken under the MOC

analysis could achieve progress or setbacks. This can be true as analysts, decision makers, and stakeholders obtain different understandings and if forces external to the systems in question affect original MOC practices. With complex interactions and interdependencies between processes being of critical importance under MOC these same items cannot be overlooked over time. Can MOC be improved by developing predictions on things like practice changes, stakeholder needs, or even management expectations that can come from organizational changes?

APPENDIX: PERMISSION FOR USE OF REPRINTED MATERIAL

RE: KVA+MOC+SD Status

To see messages related to this one, group messages by conversation.

Thomas Housel 7:03 PM
To: Jose Cintron
Cc: Luis Rabelo

I just saw the citation in the dissertation. But, don't recall seeing it in the article. Anyway, you have permission to use all the sources you have cited. Glad to see that they are providing something useful for your research.

Tom

From: Jose Cintron [mailto:jrcintrong@hotmail.com]
Sent: Wednesday, September 25, 2013 6:18 PM
To: Housel, Thomas (CIV)
Cc: Luis Rabelo
Subject: KVA+MOC+SD Status

Hello Dr. Housel,

Hope all is well and you are doing great. Sorry about the very long time since you last heard from me. I have continued in the same job and working on my PhD where I am now in my graduation semester.

My dissertation made major use of previous KVA data that you provided me. While we did not change or presented anything new in terms of the KVA methodology, we utilized the KVA data since one major goal was to present KVA's applicability. We then added the use of the Matrix of Change and System Dynamics.

I believe Matrix of Change was not yet part of my research the last time we talked. Since we last talked I also submitted to a couple of conferences and publications and got approved by ISERC 2013 where I presented the attached final paper and presentation.

I have also attached the lasted draft of my dissertation, where I am presenting tables and figures for which I would like formal your permission to use in the dissertation. This is a list of those items:

Figure 2.2-2
Figure 5.5-1
Figure 5.5-2
Table 5.5-1
Table 5.5-2
Table 6.5-1

I also listed equations that described how knowledge data was generated, for example the equations for the UAV case study (section 5.5). If you think permission is needed for those also please let me know.

Sorry about giving you all this info at once instead of logically keeping you updated often as things happened. Please let me know if you would like to talk soon at your convenience so we can catch up and I can answer any questions you may have. My cell phone number is still 407-761-7551, or I can call at a time of your choosing.

Thank you, and hope to talk with you very soon.

José Cintrón

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