A Generalized System Dynamics Model for Managing Transition-Phases in Healthcare
Environments

By

Javier Calvo-Amodio, M.Sc. BM, BS ISE

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Approved

Patrick Patterson, Ph.D., P.E.
Chairperson of the Committee

Milton L. Smith, Ph.D.
Co-Chairperson of the Committee

James R. Burns Ph.D.

William J. Conover Ph.D.

David A. Wyrick, Ph.D., P.E.

Dominic Cassadonte
Interim Dean of the Graduate School

December, 2012

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ABSTRACT

Learning curve theory, and in particular adaptation function have proven useful to identify organizational learning patterns. Yet they are limited in the information they provide in that they provide a general understanding on how long it will take to reach a desired outcome level. The adaptation function is to be employed to plan a transition-phase, and is capable of helping managers to balance quality, time and resource cost, along with determining periods of instability and of dynamic equilibrium. The adaptation function theory is strengthened by combining it with systems thinking principles and a simulation model based on system dynamics be developed as a result. The purpose of this dissertation is to develop a transition phase management model based on a complementarist approach.

The development process encompasses 1) the analysis of systems thinking, system dynamics and adaptation function characteristics and how they can be combined, 2) the development of the simulation model, 3) extreme values tests (sensitivity analysis) and 4) validation of the model in real world projects.

Healthcare managers can benefit from the model in two ways: 1) the model is developed into a simulation model that possesses a user friendly interface; 2) Managers are able to forecast implementation quality, time and resource costs, identify variables that can be modified to obtain a better outcome by reducing periods of instability or accelerating the learning process.

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CHAPTER I

INTRODUCTION

Simulations provide consistent stories about the future, but not predictions (Morecroft & Sterman, 2000, p. xvii).

History and Background

Frederick Winslow Taylor laid out the road map for the industrial engineering and engineering management professions. He stated that:

It is true that whenever intelligent and educated men find that the responsibility for making progress in any of the mechanic arts rests with them, instead of upon the workmen who are actually laboring at the trade, that they almost invariably start on the road which leads to the development of a science where, in the past, has existed mere traditional or rule-of-thumb knowledge (Levy, 1965; Taylor, 1911, p. 52).

As the 20th century wrapped and the 21st century started, industrial engineering and engineering management practitioners kept developing more and more methods and methodologies to improve the "laboring trade" as Taylor stated. Most industrial engineering and engineering management methodologies were developed after Taylor published his book "The Principles of Scientific Management" (Taylor, 1911).

Engineering Management methods once deployed have demonstrated great levels of efficiency, efficacy, and/or effectiveness. However, as they become more widespread in use and knowledge, the effect that they can have on a problem situation is minimized. As a result, philosophies or toolboxes such as Lean and Six Sigma have been developed. However, the existing methodologies that advocate for the use of many of industrial engineering and engineering management together lack a systemic approach (Calvo, Tercero, Beruvides, Hernandez, 2011).

The approach to understanding a system's behavior can be traced in the western world all the way back to the Greek philosophers. Over the centuries, isolated efforts were made

by philosophers and thinkers alike. Yet, there were no strong advancements to unify the field. The dawn of the twentieth century yielded structured efforts to develop an applied holistic approach –known as systems thinking for better understanding a system’s behavior. Systems thinking as a science arose as the result of the efforts from researchers from varied backgrounds such as biology, sociology, philosophy and cybernetics to explain holistically the systems they studied (Jackson, 2000). Amongst the best known and influential authors we find Ludwig von Bertalanffy, Charles West Churchman, Russell Ackoff, Jay Forrester, Humberto Maturana and Francisco Varela, Stafford Beer, and Peter Checkland.

Applied systems thinking methodologies started to appear as early as the mid-1950s with the early efforts from Russell Ackoff and Jay Forrester. Applied systems methodologies started to be developed to solve particular problems observed or encountered by their authors. Each methodology was developed under particular assumptions that would not necessarily be consistent or commensurable with the others. Robert L. Flood and Michael C. Jackson from the University of Hull in the U.K. recognized this as a problem. They developed a System of Systems Methodologies to help the user match a particular methodology to the problem context they were interested in acting upon. They also developed a meta-methodology called Total Systems Intervention that allows the practitioner to combine incommensurable methodologies together. Flood and Jackson state that problems can be classified in a grid of problem contexts that contains two dimensions: one dimension to evaluate the relationship between the participants in the system; the second dimension to assess the complexity of the system (Flood & Jackson, 1991). Figure 1-1 shows an adaptation of the grid of problem contexts.

Notice how the applied systems thinking methodologies have been classified according to the problem context they are best suited to be used (for more details on the grid of problem contexts refer to chapter 2). The grid of problem contexts provides a very useful

approach to identify within each problem context, which methodology is the best suited to tackle it.

Another contribution by Flood and Jackson is a meta-methodology called Total Systems Intervention (TSI). It allows the user to combine methodologies within or with different problem contexts at the same time. However, there have been no attempts to provide more detailed methodologies to combine particular tools, in a complementary way, into more detailed approaches to modeling.

Relationship Between participants				
		Unitary	Pluralist	Coercive
System Complexity	Simple	Systems Engineering, Operations Research, Statistical Quality Control, System dynamics	General Systems Theory, Social Systems Design, Strategic Assumption Surfacing and Testing	Creative Problem Solving, Critical Systems Heuristics
	Complex	System dynamics , Viable System Model, Socio-technical Systems	Interactive Planning, Interactive Management, Soft Systems Methodology,	Not Defined

Figure 1-1 Grid of Problem Contexts
(adapted from Flood & Jackson, 1991, p. 42)

Traditional industrial engineering and engineering management tools such as statistical process control, design of experiments, operations research, etc., can help engineers identify the current state of a system and develop solutions to potential or existing problems in a particular setting. However, these tools are handicapped in their scope and approach. Their handicap in scope is that they are only effective in a small range of problem types where data is available and the complexity of the system is low. The

handicap on approach is within their logical positivistic nature. These tools are designed to tackle one problem at a time and by nature ignore the emergent properties of the system (in most cases).

Systems thinking on the other hand offers a holistic view of the real world and brings a complementarist approach through creative systems thinking that can benefit the industrial engineering and engineering management practitioner.

Problem Statement

Combining industrial engineering and engineering management tools to improve a particular problem situation in the healthcare industry has proven successful. The use of industrial engineering and engineering management tools (scientific management approach) to improve operation conditions and maximize revenue has been gaining popularity in the health care environment. Examples range from the implementation of the TQM model, to the incorporation of Lean thinking and Six Sigma methodologies. The healthcare industry also is faced with Electronic Health Records systems implementation and constant changes in billing processes. The implementation of these methodologies requires changes in processes, and at times of organizational cultures. The processes through which these changes happen are called transition-phases in this research. Research of transition-phases in a healthcare environment, using a holistic scientific management approach, has received little attention. The estimation of time and resources required to conduct a transition-phase, usually employs “rule of thumb” approaches based on simple calculations– rather than a holistic scientific management method. A systemic approach to manage transition-phases brings a dynamic approach to manage transition-phases during planning and implementation stages.

Research Questions

The management of these transition-phases has yet to be explored under a holistic scientific management perspective. A transition-phase management methodology allows managers to make better use of their resources, and to identify potential problems before they become too costly. A methodology using a complementarist approach that combines the adaptation function theory (Levy, 1965) with system dynamics brings about a suitable model.

While a system dynamics model is unique to the problem context it is developed for, it may share core structures with a broader spectrum of similar problem contexts. System dynamics researchers have identified 11 systems archetypes (Bellinger, 2004) that depict behaviors that repeat within different contexts over time. By considering classification of problems within contexts, and using different applied systems thinking methodologies within contexts (Flood & Jackson, 1991; Jackson, 1990, 1991, 2000, 2003; Jackson & Keys, 1984) then a generalized transition-phase management that measures errors per day can be developed (see Equation 1-1 and Figure 1-2).

$$Q_t = \int_{t_0}^{t_f} (F - a - \mu) dt \quad \text{Equation 1-1. Initial Transition-Phase Management Model}$$

$$\text{Until } |Q_t - P| \approx 0$$

where

Q_t = percentage of errors per day

a = initial efficiency of the process = $f(\text{organizational culture, training, time})$

μ = process rate of adaptation = $f(\text{experience, learning ability, feedback, time})$

F = Damping Factor = $f(a, \mu, \text{forgetting})$

and

$$P = \int_{t_0}^{t_f} B dt + P_0; \text{ where}$$

P_0 = initial desired percentage of errors

$$B = \text{Pressure to Adjust } P = f(|P - Q_t|, \text{time}) \begin{cases} 0 & \text{if } |\dot{P} - \dot{Q}_t| \rightarrow 0, \text{ regardless of } t \\ \geq 0 & \text{if } |\dot{P} - \dot{Q}_t| > 0 \text{ and } (t_f - t) \rightarrow 0 \end{cases}$$

Figure 1-2 Initial Transition-Phase Management Model

First Research Question

Research Question 1: Can a generalized system dynamics transition-phase management model be developed by combining adaptation function theory and system dynamics?

Second Research Question (Experiment 1)

Billing departments in hospitals have to deal with constant changes coming from regulatory agencies, government, insurance companies and electronic health records implementations. Many times, more than one change to the system have to be implemented as different rollout dates are specified to for different areas. Significant resources and time are invested in each implementation.

Research Question 2: Can a system dynamics transition-phase management model provide an efficacious solution to manage short-term multi-phase transition-phases in a healthcare billing department?

Sub-question 2.1: Can the model help billing department managers define policies to better allocate available resources?

Sub-question 2.1.1: Can the model effectively identify deviations from the original plan throughout the transition-phase?

Sub-question 2.1.2: Can the model provide policy modification strategies throughout the transition-phase?

Sub-question 2.2: Can the model provide an accurate depiction of real world behaviors over time with limited access to quantitative data?

Third Research Question (Experiment 2)

The implementation of an electronic health records system in hospital clerical areas requires important changes in procedures. The implementation periods span from one to several months. This process requires careful allocation of resources and policy making.

Research Question 3: Can a system dynamics transition-phase management model provide an efficacious solution to manage transition-phases required by electronic health records system implementation?

Sub-question 3.1: Can the model help health care managers define policies to better allocate available resources?

Sub-question 3.1.1: Can the model effectively identify deviations from the original plan throughout the transition-phase?

Sub-question 3.1.2: Can the model provide policy modification strategies throughout the transition-phase?

Sub-question 3.2: Can the model provide accurate depiction of real world behaviors over time?

In order to answer the research questions, three were performed before the model was validated in real life situations.

Tasks

Task 1:

Develop a pilot study to translate the initial Transition-Phase Management Model (see Figure 1-2 and Equation 1-1) into a stock and flow diagram (will translate into a conference paper).

Task 2:

Further define the model by developing the sub-structures for a , μ , *Damping Factor* and B .

Task 3:

Test the model for inputs limits and validity of outputs (tasks 2 and 3 will translate into a peer reviewed journal paper).

The variable of interest in this research is the percentage of errors per day. A transition-phase is considered to be concluded once the percentage of errors committed by employees reaches the desired or specified level.

Hypotheses

The model developed in tasks 1, 2, and 3 will be used as the template to run experiments 1 and 2, as presented below.

General hypothesis for Experiment 1:

The transition-phase errors per day in a hospital billing process necessary as a result of an electronic health records system implementation can be depicted with the transition-phase management model.

- a) The information available (quantitative and qualitative) to the manager at a local healthcare center is adequate to generate the desired behavior over time.
- b) The model is capable of identifying the path that the percentage of errors per

day will follow during the implementation process

- c) The model is able to identify when and if dynamic equilibrium is reached

General hypothesis for Experiment 2:

The changes to a hospital's clerical processes induced by the implementation of an electronic health records system can be depicted with the transition-phase management model.

- a) The information available (quantitative and qualitative) to the manager at Community Health Center of Lubbock is adequate to generate the desired behavior over time.
- b) The model is capable of identifying the path that the percentage of errors per day will follow during the implementation process
- c) The model is able to identify when and if dynamic equilibrium is reached

Research Purpose

The purpose for this research is to develop a generalized transition-phase management model methodology based on Levy's (1965) adaptation function and system dynamics applicable to healthcare environments. The model will provide healthcare managers with an easy to use tool that does not require historical data to generate future scenarios. The purpose of this dissertation does not include the development of techniques for data collection, or analysis.

Theoretical Purpose

Systemic principles are universal and can be applied within any scientific (von Bertalanffy, 1968) or human activity endeavor. The theoretical purpose of this research is to contribute to the industrial engineering, engineering management, and healthcare fields by enriching their practice with systems thinking concepts with an engineering perspective. This dissertation will also serve bring into engineering practice the use of a

complementarist approach, through Midgley's (1990, 1997) creative methodology design approach by combining adaptation function theory and system dynamics. In particular, it tests the concept that system dynamics can be applied to low-level problems (system dynamics is traditionally applied to macro-level problems).

Practical Purpose

To provide a simple but accurate model for managers capable of evaluating the capacity of an organization's structure and resources to conduct new process implementations. This is accomplished through the development of a generalized methodology to combine system dynamics concepts with industrial engineering and engineering management tools will enhance the practitioner's ability to understand the effects that policies have on transition phases. The development of a generalized system dynamics model with pre-built sub-structures can benefit industrial engineering, engineering management practitioners, and healthcare managers by reducing model development time. In this way, it is possible to justify the use of a simulation model in small-scale process implementations.

The model can also aid healthcare managers to optimize their resources depending on their particular contexts. Examples of possible instances that managers might want to explore are given below:

- a) Minimize the amount of resources to be used to reach the desired state (% errors per day) given a set project completion start time (t_0) and end time (t_f).
- b) Minimize the project completion time ($t_f - t_0$) given a set of available resources and a desired state (% errors per day).
- c) Minimize the potential of shocks and undesirable reactions due to the selection of certain policy levels to reach a desired state (% errors per day).
- d) Maximize the use of the resources available given a desired state (% errors per day) and target end date (t_f).
- e) Evaluate if the target end date (t_f) is feasible with the available resources and

desired state (% errors per day).

- f) Determine periods of instability during an implementation process.

Research Objectives

The main objectives of this research are:

- i. To incorporate system dynamics into industrial engineering and engineering management tools when feedback and time delays have a direct impact in the process behavior.
- ii. To develop a decision-making tool based on system dynamics software (Vensim) to aid healthcare managers manage transition phases.

Limitations

- a. All models will be developed using managers' estimations of the factors (determined by assessments or policies) and compared against historical data from process change projects. Therefore, the expected behavior over time targeted in all hypotheses is measured against historical data.
- b. Accuracy of the model is dependent on the manager's understanding of their own system. At this point there is no methodology to evaluate quantitatively the factors (this is future work – see chapter 8).
- c. The models created are subjected to the best judgment of the researcher.
- d. The generalized methodology is adequate for the problem context it was developed for –healthcare transition-phase management.
- e. This research does not provide an alternative method to Total Systems Intervention; it only used its principles, in particular through the creative methodology design perspective.
- f. The level of detail of the models is dependent on the accuracy reached and data availability.
- g. Model validation is bounded by techniques provided by Barlas (1996).
- h. The analysis of adequateness of techniques required for data collection, and

analysis are beyond the scope of this research.

- i. All data related to staff or personnel provided by the Community Health Center of Lubbock and the Health Sciences Center is codified, and it is not possible to relate an individual with its data.

Assumptions

- a. The data provided by the Community Health Center of Lubbock and the Health Sciences Center is reliable and does not require major adjustments.
- b. All terms and concepts used in this study represent the common usage as found in the related literature, except when specified otherwise.
- c. The model presented in the dissertation proposal does not consider cost variables since financial cost issues are considered outside the scope of the dissertation work and are deferred to future work.

Relevance of this Study

This research is relevant to the systems thinking, industrial engineering, engineering management, and healthcare communities. The user of the transition-phase management model can take full advantage of the power that system dynamics brings in terms of organizational learning and forecasting of effects that policies will have on processes. In particular, the methodology presented in this research, posits that the system under study does not have to possess a high degree of complexity, as traditional system dynamics applications suggest, for it to be worth it to use system dynamics.

Need for this Research

Industrial engineering and engineering management tools have been implemented with success in the healthcare industry (Benneyan, 1996, 1998a, 1998b, 2001; Berwick, Kabcenell, & Nolan, 2005; Callender & Grasman, 2010; de Souza, 2009; Laursen, Gertsen, & Johansen, 2003; Young, 2005). However, the study of transition-phases still

needs to be explored. Using a systems thinking complementarist approach to the implementation of industrial engineering and engineering management concepts into healthcare provides more robust tools when feedback and time delays have a direct impact on the process behavior.

Benefits of this Research

The generalized transition-phase management methodology will provide industrial engineering and engineering management practitioners, and healthcare managers the ability to build decision making models when feedback and time delays have a direct impact in transition phases process behavior.

Research Outputs and Outcomes

- i. A generalized methodology to develop transition-phase management system dynamics models in healthcare environments (tasks 2 and 3, and paper 1).
- ii. A transition-phase management model (in Vensim format) of changes in billing processes at Health Sciences Center as part of experiment 1 (paper 2).
- iii. A transition-phase management model (in Vensim format) of changes in operating processes derived from the implementation of an Electronic Health Records system at the Community Health Center of Lubbock as part of experiment 2 (paper 3).
- iv. One peer-reviewed conference paper, containing the theoretical model, and a pilot study. Target Conference: 2012 American Society for Engineering Management International Annual Conference.
- v. One peer-reviewed journal paper containing the transition-phase management model for the Health Sciences Center. Target Paper: IIE Transactions in healthcare, or a healthcare management journal.
- vi. One peer-reviewed journal paper containing the transition-phase management model for the Community Health Center of Lubbock. Target Paper: the

Engineering Management Journal.

- vii. One peer-reviewed journal paper containing the generalized transition-phase management model methodology for healthcare contexts. Target Paper: the Engineering Management Journal.

CHAPTER II

LITERATURE REVIEW

Introduction

This literature review serves the purpose to provide the basic principles and concepts that will be used in tasks 1, 2, 3, and experiments 1 and 2. An overview of the healthcare industry, learning curve relevant theory, systems thinking relevant theory, and model validation is provided, concluding by introducing the theoretical model for this dissertation work.

Primary Theories and Historical Background

Industrial engineering and engineering management tools in healthcare

The literature mainly points at the use of statistical process control (SPC), total quality management (TQM), six sigma, lean thinking, and simulation as the main industrial engineering and engineering management tools and philosophies employed in healthcare. Many levels of success are reported, but in general, the literature suggests there have been more partial successes and failures in implementing these methods and philosophies than successes in healthcare and reflects on the possible causes. For instance, Benneyan (1996) offers an overview of the possible benefits that SPC could bring to healthcare. He warns about mistakes –such as using the wrong charts and using shortcut formulas –that can be committed if SPC tools and their application are not understood correctly.

Benneyan (1998a, 1998b, 2001) talks about control charts and their potential uses in medical environment providing useful theoretical guidelines on how to implement them, and analyzes their accuracy.

Callender and Grasman (Callender & Grasman, 2010) identify the following barriers to implementation of supply chain management: Executive Support, Conflicting Goals, Skills and Knowledge, Constantly Evolving Technology, Physician Preference, Lack of

Standardized Codes, and Limited Information Sharing. It is possible to extrapolate their reasoning to lean thinking implementation, as they are new or foreign "industrial engineering tools" for the medical community considering that acceptance of new ways is always a challenge. The best practices offered can be lessened by good Lean practices and especially with the electronic health records implementation.

Towill and Christopher (2005) advocate for the analog use of industrial logistics and supply chain management in the National Health Service (NHS) in the United Kingdom. They argue that material flow and pipeline concepts should be applied to the healthcare delivery context to better match demand and the need for a more cost-effective practice.

Young (2005) proposes simulation as a tool to re-structure healthcare delivery on a macro-level by researching patient flow, as the big hospitals go against Lean thinking principles by promoting big queues. Young also suggests that system dynamics and theory of constraints could work together since system dynamics is well suited to identify bottlenecks in a process (p. 192).

Lean in healthcare

De Souza (2009) proposes a taxonomy of the application of Lean thinking on healthcare through a literature review. De Souza divides the lean healthcare literature into two categories: case studies and theoretical, concluding that lean healthcare appears to be an effective way to better healthcare organizations. He argues that lean is a better fit to healthcare as it is more adaptable in healthcare settings than other management philosophies, the potential it has to empower staff along with the concept of continuous improvement. He states that it "is believed that lean healthcare is gaining acceptance not because it is a 'new movement' or a 'management fashion' but because it does lead to sustainable results" (p. 122). Lean healthcare is a relatively new concept, as can be seen in the history of lean thinking in a Figure De Souza adapted from Laursen et al. (2003, p. 3) (Figure 2-1).

Figure 2-1. The appearance of lean healthcare.

As can be observed in Figure 2-1 (de Souza, 2009, p. 123), lean healthcare is relatively a new practice and research area. As would be expected, there is still much work to be done. Berwick, Kabacoff, & Nolan (2005) mention that lean healthcare, although it is on the right path, still has a long way to go to be comparable with mainstream applications of lean thinking.

De Souza concludes that the majority of the literature is theoretical, with 30% being speculative and less than 20% being methodological in nature, and expects the field to grow in the near future.

Complementary use of methodologies with lean thinking

Several attempts to combine methodologies, such as managerial philosophies like total quality management, six sigma, theory of constraints, reengineering, and discrete event simulation (de Souza, 2009, p. 125) to overcome their inherent limitations have been attempted, all arising from the authors' observations that single methodologies are rarely a one-size-fits-all solution. Yasin et al (Yasin, Zimmerer, Miller, & Zimmerer, 2002)

conducted an investigation to evaluate the effectiveness of some managerial philosophies applied into a healthcare environment. The authors report that "it is equally clear from the data that some tools and techniques were more difficult to implement than others" (Yasin et al., 2002, p. 274), implying that many of the failures were due to inadequate implementations or lack of understanding of the scope. From a systems thinking perspective, these two types of failures in implementing a methodology are explained by the methodology's inability to deal with very specific problem situations. This supports the point that a complementarist industrial engineering and engineering management - systems thinking approach can be explored by taking an atypical approach by tackling ""small"" problems, instead of large and complex problems. This approach should convince management of the effectiveness of a complementarist managerial philosophy using systems thinking.

Lean Six Sigma

Consider the case of the Lean Six Sigma (LSS) philosophy as an example of a methodology that was built to enhance its constituent methodologies strengths and further their scope. On one end we have a six sigma focus on the "lowest hanging apples" (Arnheiter & Maleyeff, 2005, p. 12), which may not be the best place to start. On the other end, lean thinking focuses on waste reduction from the consumer perspective, without consideration of quality or stability of processes. The complementarist Lean Six Sigma approach suggests that Lean organizations can gain "a good balance between an increase in value of the product (as viewed by the customer) and cost reduction in the process [as] an outcome of combining Lean and SS" (Arnheiter & Maleyeff, 2005, p. 16). The authors suggest that an organization that follows the Lean Six Sigma philosophy would possess key characteristics belonging to both philosophies, as stated in Table 2-1 (Arnheiter & Maleyeff, 2005)

Table 2-1 Organizational Lean Six Sigma Characteristics

Lean	Six Sigma
(1) It would incorporate an overriding philosophy that seeks to maximize the value-added content of all operations.	(1) It would stress data-driven methodologies in all decision making, so that changes are based on scientific rather than ad hoc studies.
(2) It would constantly evaluate all incentive systems in place to ensure that they result in global optimization instead of local optimization.	(2) It would promote methodologies that strive to minimize variation of quality characteristics.
(3) It would incorporate a management decision-making process that bases every decision on its relative impact on the customer.	(3) It would design and implement a company-wide and highly structured education and training regimen.

The authors also posit how a LSS approach would balance value and costs as perceived by the customer and producer respectively (see Figure 2-2 (Arnheiter & Maleyeff, 2005, p. 16).

Figure 2-2 Nature of competitive advantage.

Socio-technical systems - lean thinking

Joosten, Bongers and Janssen (2009, p. 344) take a socio-technical systems approach to lean thinking. They suggest that value in lean thinking “is not seen as an individual level concept, but as a system property. According to lean, a system has an inherent, maximal value that is bounded by its design, rather than by the will, experience or attitude of individual members”. They state that socio-technical systems can provide a framework to improve healthcare delivery by complementing the intrinsic operational approach of lean thinking with the social aspect of implementations.

Action Research

Action research “results from an involvement with members of an organization over a matter which is of genuine concern to them” (Eden & Huxham, 1996, p. 75). Action research was developed for research in management sciences. However, it should also provide a great tool for industrial engineering and engineering management research where a significant part of the focus on research is on problem solving applications. Action research is adequate for situations when the application of some knowledge (new or existing) into a particular problem context can have wider research consequences that are worth investigating. A practitioner can apply an industrial engineering and engineering management tool to a particular system. However, without a systemic thinking mode, the solution may end up causing some undesired effects within the same system and/or on a seemingly unrelated system. This can bring a methodological debate between practitioners and researcher as to how to address such vicissitudes.

Rosmulder et al (2011) explore the use of simulation models while conducting action research. They conclude that “the design of the simulation model would play a crucial role in the AR experiment” (p. 400). They stress that in order to have all the stakeholders

willing to take action during the action research process; they should accept the model and have confidence in the structure and outcomes it generates.

Learning Curve

Basics of Learning Curve

The organizational learning curve was first explored by Wright-Patterson (1936), who observed that unit labor costs in air-frame fabrication declined with cumulative output. From Levy (1965), Newnan, Eschenbach, and Lavelle (2004), and Yelle (1979) the general form of the learning curve model is extracted and presented in Equation 2-1:

$$T_N = T_{Initial} \times N^b \quad \text{Equation 2-1}$$

where
$$b = \frac{\log(\theta)}{\log 2.0}$$

and T_N = time requirement for the Nth unit of production
 $T_{Initial}$ = time requirement for the initial unit of production
 N = number of completed units (cumulative production)
 θ = learning rate expressed as a decimal
 $1 - \theta$ = The progress ratio

Relevant learning curve theory to this research work

Argote and Epple (1990) identified that organizational forgetting, employee turnover, transfer of knowledge across products and organizations, incomplete transfer within organizations, and economies of scale are factors that produce variability in learning curves across organizations.

Wyer and Lundberg (1956; 1953) propose that the learning curve slope is affected by the amount of planning put forward by management. Adler and Clark (1991) propose a model that focuses on single -traditional experience variables and double loop learning -

two key managerial variables (engineering change and training). The authors conclude that the learning process can vary significantly between departments and that learning can be intensive in labor and capital intensive operations. Adler and Clark (1991) first proposed and Lapré, Mukherjee, & Van Wassenhove (2000) confirmed that induced learning can facilitate or disrupt the learning, stressing the importance that management involvement has.

Adler and Clark (1991) posit that the “human learning process model begins with the relationship between experience and the generation of data driven by that experience” (p. 270). As more data is generated, it is processed by the organization leading to the creation of new knowledge, which in turn leads to a change in the production process. Part of this new knowledge directly affects single-loop learning based on repetition and on the associated incremental development of expertise. This learning helps workers or direct laborers be more effective at their jobs. The other part of the knowledge generated will affect the double loop learning process. Here, the learning takes place in the management environment, where decision rules, data interpretation and data generation are adapted to be in line with newly acquired knowledge to increment output. The authors caution that even though a double loop-learning model is certainly a facilitator of learning, it can disrupt knowledge either temporarily or permanently depending on management’s understanding of the learning system. It is worth noting that Adler and Clark’s model is consistent with the double loop-learning model presented in section 2.2.5.

Formal training and equipment replacement illustrate how managerial decision making is improved due to a better understanding of past behavior (Yelle, 1979, p. 309), as a result of double loop learning. Adler and Clark also express that training time should lead to improvement in worker performance concluding that experience is also affected by training. Learning in management is prompted by the problems encountered throughout the production process. The new policies generated by management should result in

improved productivity. Figure 2.3 presents Adler and Clark's (1991, p. 278) learning process model.

Figure 2-3 Learning Processs Model

Adaptation Function Learning Model

Levy (1965) believes that the planning process can be improved through a better understanding of how the individual worker, as well as the firm, have historically adapted to past learning situations. Furthermore, Levy posits that the lack of a goal seeking behavior in traditional learning curves is not realistic. For that reason, Levy proposes an alternative to the traditional learning curve model:

$$Q(q) = P[1 - e^{-(a+\mu q)}] \quad \text{Equation 2-2}$$

where

$Q(q)$ = the rate of output Q after q units have been produced

P = desired rate of output

a = initial efficiency of the process

μ = process rate of adaptation = $f(y_1, y_2, y_3, \dots, y_n)$

q = cumulative number of units produced

We suggest that the firm's cumulated experience or stock of knowledge on a particular job at a specified time can be summarized in the stock of the product it has produced up to that time. Thus, as the firm produces more and more of a given product, it increases its stock of knowledge on that product and is able to come closer to the desired rate of output (Levy, 1965, pp. B-137).

The model assumes that there is a known, or expected, level of performance $P = \text{desired rate of output}$. It also assumes that the process will start at an unwanted or initial rate of output $Q(q)$ with $q=0$. As q starts to increase, $Q(q)$ will approach P at a rate determined by a and μ . Levy suggests that the initial efficiency of the process (a) is an estimation of the amount of training provided to the worker. The process rate of adaptation (μ) is a function of different variables that influence the rate at which an organization can learn. The process rate of adaptation then is influenced by the experience the worker has in similar job functions. That is, the more experienced a worker is, the faster he/she will be able to identify problems with the process and find solutions. With that, Levy suggests that learning can happen in three different ways: autonomous learning, planned or induced learning, and random or exogenous learning. Induced learning is influenced by pre-planning activities such as mock runs, pre-production models, tooling determination, etc, and by industrial engineering tools such as time and motion studies, and control charts after the process starts. Random or exogenous learning happens when the firm gains knowledge of the process from unexpected sources such as new materials characteristics, suppliers, government, etc. Finally, autonomous learning happens as the worker gains more experience with the actual process and identifies ways to improve or make more efficient his/her tasks.

Carrillo and Gaimon (2000) introduce a dynamic model to maximize profit in a process change strategy. The model seeks to identify optimal process rate change (and when the change should start – rate and timing for investment in process change) subject to the ratio of cost to marginal contribution of preparation/training times to effective capacity, cumulative knowledge, and marginal revenues produced by the new process. The authors

state that the input parameters can be adjusted to run different scenarios to select the appropriate process change alternative.

Knowledge Production as a Control Variable

Dorroh, Gulledge, and Womer (1994) state that at the beginning of a new process implementation, education and training are the primary tasks performed by the worker, and as the project advances then production becomes dominant (p. 947). Their model is different from a learning-by-doing model because “knowledge is produced independent of production experience” (p. 952). Dorroh, Gulledge, and Womer (1994) state that higher levels of knowledge allow for easier knowledge production, resulting in more resources allocated for learning, and a faster rate of knowledge production –or a sharper learning curve. They conclude that knowledge creation is a managerial decision, and that the rate of knowledge production is a control variable (p.957). As the process implementation advances, the need to generate more knowledge (knowledge value) decreases, reducing the resources devoted to knowledge generation (Dorroh et al., 1994, p. 955; Epple, Argote, & Devadas, 1991, p. 65).

According to Epple, Argote, & Devadas (1991), learning from the experience of others can benefit an organization. It is worth noting that knowledge acquired through learning will depreciate at a relatively fast rate. Epple, Argote, & Devadas (1991) also state that when learning caused by the use/implementation of new technologies, then learning will transfer –at least partially from one department to another, from one shift to another as long as that technology is used within.

For further reference, read Yelle (1979) and Levy (1965) for reviews of the learning curve literature.

Learning Loop Model

Sterman (Senge, 2006; 1994, 2000) introduced an idealized learning loop model (Figure 2-4).

Figure 2-4 Idealized learning loops.

The validity of the model Sterman introduces is that it provides a good justification for the use of simulation models as learning tools. By simplifying reality and putting it into a virtual world, it is possible to perform experiments within it. Policies and approaches can be challenged without having to wait for feedback from reality, which can be expensive.

Learning Curves and System dynamics

Carrillo and Gaimon (2000), and Morrison (2008) mention that productivity in early stages suffers even if the new process is supposed to improve productivity, and that it is strictly related to the learning curve process. That process is also congruent with the system dynamics principle which states that when there is an intervention on a system it can get worse before it gets better (Sterman, 2000). Morrison (2008) also states that cumulative production is a reflection of knowledge of the process, and that according “to learning curve theory, the accumulation of experience increases productivity, or alternatively reduces costs” (p. 1184). Thus identifying characteristics that are shared with system dynamics simulation models can bring better light to the study of learning curves. Morrison proposed the following model shown in Figure 2-5 (Morrison, 2008, p. 1185) of learning under constraints:

Figure 2-5 A model of learning by doing under constraints.
Extracted from

The model stresses that the learning process is enhanced by the amount of time spent with a new skill, which in turn increases the cumulative experience. Morrison posits that forgetting is an intrinsic part of learning, but that enough time spent with a new skill will offset the effects of forgetting.

Systems Thinking

Formalized systems science theory, and applied methodologies date back to the middle of the 1900's with the strong contributions by Ludwig von Bertalanffy's general system theory, Jay Forrester's system dynamics, Russell Ackoff's, Churchman's and Maturana and Varela's autopoiesis.

The Engineering Management practice is teleologically oriented. That means that the focus on the development of theories and their application is goal-seeking or purposeful. Systems thinking is also teleologically oriented. Engineering management and systems thinking are oriented to provide solutions for systems that can display choice of means and/or ends.

[The systems age] is interested in purely mechanical systems only insofar as they can be used as instruments of purposeful systems. Furthermore, the Systems Age is most concerned with purposeful systems, some of whose parts are purposeful; these are called social groups. The most important class of social groups is the one containing systems whose parts perform different functions, that have a division of functional labor; these are called organizations. Systems-Age man is most interested in groups and organizations that are themselves parts of larger purposeful systems. All the groups and organizations, including institutions, that are part of society can be conceptualized as such three-level purposeful systems. There are three ways in which such systems can be studied. We can try to increase the effectiveness with which they serve their own purposes, the self-control problem; the effectiveness with which they serve the purposes of their parts, the humanization problem; and the effectiveness with which they serve the purposes of the systems of which they are a part, the environmentalization problem. These are the three strongly interdependent organizing problems of the Systems Age (Ackoff, 1973, p. 666).

When healthcare managers embark on the implementation of a EHR, or a new billing procedure –large purposeful systems, change management is a key element of such purposeful system.

Critical Systems Thinking

Critical systems thinking embraces five major commitments by seeking to demonstrate critical awareness, showing social awareness, dedication to achieve human emancipation, commitment to the development of complementary and informed development of systems thinking methodologies at the theoretical level, and commitment to the complementary and informed use and application of methodologies (Flood, 2010, p. 279; Jackson, 1991, pp. 184-187).

System dynamics

System dynamics creates diagrammatic and mathematical models of feedback processes of a system of interest. Models represent levels of resources that vary according to rates at which resources are converted between these variables. Delays in conversion and resulting side-effects are included in models so that they capture in full the complexity of dynamic behaviour. Model simulation then facilitates learning about dynamic behaviour and predicts results of various tactics and strategies when applied to the system of interest (Flood, 2010, p. 273).

System dynamics was developed by Jay W. Forrester to model feedback loops in systems where non-linear time dependent interactions are present. System dynamics presents a powerful approach to modeling complex systems in accordance to what their internal structure and interactions actually are, and not in accordance to what statistics and/or mathematical models suggest alone. Feedback is present in non-linear systems where its components sustain complex interactions and that emergent properties arise from such interactions. With the use of level and rate variables, it is possible to model the interactions and feedback loops between system components. Dynamic modeling can help identify lack of understanding of a process or system, and to identify what are the most important variables in a process or system (Hannon & Ruth, 2001, p. 10).

Senge (2006) advocated for the use of systems thinking as the quintessential tool to enhance the efficacy of managerial endeavors. As Forrester's disciple, Senge's approach is focused on the use of system dynamics, and causal loop models.

The foundation blocks, or the common structures that describe all systems are the level and rate equations (J.W. Forrester, 1961, 1968; 1971). Level equations result from integrations of flows proceeding from rate inflow equations minus the integration of rate outflows equations over time (see Equation 2-4). In its simplest form, a rate equation depends on the state of the level variable. A rate equation regulates, depending on the state of the level variable the flow rate (see Equations 2-3 and 2-4).

$$Level_t = \int_{t=0}^n Inflow\ Rate - \int_{t=0}^n Outflow\ Rate \quad \text{Equation 2-3}$$

$$Rate_t = \frac{dLevel}{dt} = Inflow\ Rate_t - Outflow\ Rate_t \quad \text{Equation 2-4}$$

There are two graphical tools to represent the relationships expressed in Equations 2-3 and 2-4: Causal Loop Diagrams, and Level and Rate diagrams. A causal loop diagram is a graphical representation of the interactions between the level and rate variables in the system. In Figure 2-6 we can see the graphical representation of Equations 2-4 and 2-5. The state of the level is determined by the inflow and outflow rates. The arrows connecting the variables indicate the nature of the relationship (feedback) between them. A positive feedback means that the rate change will be in the same direction as the change observed in the level. A negative feedback means that the rate change will be in the opposite direction of the change observed in the level. For instance, if the state of the level increases, the inflow rate will decrease.

Figure 2-6 Causal Loop Diagram

Figure 2-7 shows a Level and Rate diagram where the rate of flow and stock of goods, materials, money, information, etc. is represented by valves and stock components. The valves (Inflow and Outflow Rates) are controlled by the feedback received from the stock variable (Level).

Figure 2-7 Rate and Level Diagram

A system dynamics model is constructed using, according to Forrester (1971; 1961, 1968) from the use of mental, written, and numerical databases (see Figure 2-8). Different components of the model are extracted from these databases allowing the model to replicate the real system characteristics accurately.

Figure 2-8 Mental Data Base and Decreasing Content of Written and Numerical Data Bases

Barlas (1996) presents a guideline on generalized steps employed to develop a system dynamics model:

1. Problem identification
2. Model conceptualization (construction of a conceptual model)
3. Model formulation (construction of a formal model)
4. Model analysis and validation
5. Policy analysis and design
6. Implementation

The construction of a conceptual model is generally aided by the use of causal loop diagrams.

Causal loop diagrams as mental models

Systems thinking authors such as Peter Checkland (1979a, 1979b, 1981, 1985, 1988, 1999, 2000; Checkland, Forbes, & Martin, 1990; Checkland & Scholes, 1990) and Forrester (1961, 1971a, 1971b, 1980, 1987a, 1987b, 1991, 1992, 1994, 1995, 1999; J. Forrester, Low, & Mass, 1974; J. Forrester & Senge, 1980) advocate for the use of mental models to better understand, or learn about the system at hand. “The real value of modeling is not to anticipate and react to problems in the environment, but to eliminate the problems by changing the underlying structure of the system” (Sterman, 2000, pp. 655-656). Causal loop diagrams help the practitioner to uncover the underlying structure of the system.

Efficiency, efficacy, and effectiveness of a model

When creating any model, the purpose, objectives, and benefits expected—or ends—and the resources available – or means—must be clearly stated. Proper allocation of means and ends can be balanced through their efficient, efficacious, and effective use within a model. Efficiency refers to the ratio between resources used and their product (or what

the outcome is). A system is efficient if the value of the outcome or the benefit is perceived to be higher than the value of the resources employed to produce/generate it.

An efficient model should minimize efforts while maximizing the value of outcomes. Unfortunately when special attention is paid to the means to achieve the ends a paradox arises. This contradiction takes place because as more resources are invested to increase the value of the benefits, those resources become more costly, making it impossible to reach a superior model, leading to a compromise in end quality so that the feasibility of a model is maintained (see Figure 2-9)

Equation 2-3 Efficiency in model development

$$Efficiency = f(value) = \frac{\sum Benefits}{\sum Resources} \text{ where:}$$

Resources = time allocated, personnel, money invested

Benefits = accuracy, completeness, robustness

Efficiency < 1 (ideally should be ≥ 1)

Figure 2-9 Ratio relationship between Resources and Benefits to achieve efficiency

Efficacy refers to the ability a system has to perform as and/or do what it is designed to do. That is, the ends are what matters, regardless of the means employed. It is then, as

presented in the previous section, that achieving efficacy in a model results in a paradox, but nonetheless is a highly desired characteristic.

Effectiveness refers to the alignment of what the system actually does and what the system is supposed to do. That is, it questions the adequateness of the outcome produced by the system. A system may be efficient and/or efficacious within its own design but still fail to perform as desired, not effective¹. Hence, a model is only effective if its performance –regardless of its complexity—is aligned with what it is expected to do.

Thus, efficiency, efficacy and effectiveness, can be used to validate a model.

Procedure depends on the purpose, so the procedure presented here is valid within that premise.

Model Validity in a System dynamics Model

C.I. Lewis (1924), states that knowledge is probable only if our experiences and/or interpretations of the object (what we are studying, a model for instance) and the a priori (knowledge of the real world) –through our senses are in accordance to each other. Also that empirical truth is possible through conceptual interpretation of the given, hence we can have an empirical object, an imaginary construct of a reality extrapolated from our own past experiences – an a priori. Hence, a model is a valid construct to depict a system, a selected set of parts, interactions, and characteristics of a particular given.

Validity means “adequacy with respect to a purpose” (Barlas, 1996, p. 188). Thus, if a model is efficient, efficacious, and effective, it is valid. However, the process of model validation has to use semi-formal and subjective components (Barlas, 1996, pp. 183, 184). For instance, a white-box model –a system dynamics model, is built to reproduce/predict the real world behavior, and to explain how the behavior germinates.

¹ It is important to note that defining efficiency and efficacy carefully is important to approach the expected behavior of the model.

Ideally, the model should also suggest ways of changing the existing behavior (Barlas, 1996, p. 186).

System dynamic models are built to assess the effectiveness of alternative policies or design strategies on improving the behavior of a given system. Therefore, “a valid model [is] one of many possible ways of describing a real situation” (Barlas, 1996, p. 187).

Barlas (1996) presents a summary of activities that can be used to validate a system dynamics model based on a literature review (see Figure 2-10).

The structure confirmation test, requires comparison of the form of the equations of the model against the real system (J. Forrester & Senge, 1980) as part of the mental database and correspondence with the numerical database (as presented in Figure 2-8). The comparison to the written database is called a theoretical structure test. It is conducted by comparing the model equations with knowledge found in the literature (Barlas, 1996, p. 190).

The information used to validate the structure of the model is qualitative in nature, a process similar to the validation of computer models in that the structures and data flows are compared to the real world. It is important to test individual expressions to extreme conditions and see if they still behave in a manner that could be expected in the real world. Structural tests should be applied to the whole model and to subsections of the model through simulation of normal and extreme conditions. With these tests, the sensitivity of the model is to be uncovered, changes can be made, or at least unreliable operation conditions are uncovered.

Figure 2-10 Overall nature and selected tests of formal model validation

System dynamics in healthcare

Homer (J. Homer & Oliva, 2001) has advocated the use of system dynamics in healthcare environment. In particular, Homer advocated the use of System dynamics as a tool to identify and control chronic illness underlying structures (J. B. Homer & Hirsch, 2006).

Electronic Health Records (EHR)

The Electronic Health Record (EHR) is a longitudinal electronic record of patient health information generated by one or more encounters in any care delivery setting. Included in this information are patient demographics, progress notes, problems, medications, vital signs, past medical history, immunizations, laboratory data, and radiology reports. The EHR automates and streamlines the clinician's workflow. The EHR has the ability to generate a complete record of a clinical patient encounter - as well as supporting other care-related activities directly or indirectly via interface - including evidence-based decision support, quality management, and outcomes reporting (http://www.himss.org/ASP/topics_ehr.asp).

Miller and Sim (2004) present some barriers to the implementation of an electronic health records system. Their research showed that high initial financial costs, slow and uncertain financial payoffs, and high initial physician time costs are barriers to implementing electronic health records. They add that difficulties with technology, complementary changes and support, electronic data exchange, financial incentives, and physicians' attitudes are also underlying barriers.

Yoon-Flannery et al (2008) identified six themes that are important to an EHR implementation: 1. communication, 2. system migration, 3. technical equipment, support and training, 4. patient privacy, 5. efficiency, and 6. financial considerations.

Communication must be fluid between executives, practitioners, and vendors; with clear leadership, and communication of performance expectations. System migration must be smooth and avoid loops or gaps in information access, as these could be critical in treating patients. Technical equipment, support, and training are viewed as a pivotal element of an EHR implementation. Support is vital to help practitioners, for instance, equipment must be available at all times; if that is not possible, contingency plans must be in place to minimize potential problems. Patient privacy is considered to be a priority

and there is a belief that it can help increase patient privacy; however there is a concern that the electronic health records system may be vulnerable to unauthorized access to patients data. Since the implementation of the electronic health records requires some changes to be made to the workflow and processes, there is a concern of whether the efficiency will be affected negatively by its implementation. Finally, expenses to install and operate the system, and how the new system will affect the personal incomes must be clarified to the users.

Zandieh et al (2008) report that communication with patients and access to more complete data to make more knowledgeable diagnoses, is an advantage of an electronic health records system. They also report that a more streamlined process can be a result of an EHR implementation after a period of 4-6 months of inefficiency (specifying 2-3 weeks of disastrous inefficiency).

Adler (2007) suggests that successful electronic health records system implementations are influenced by three dimensions: teams, tactics and technology. He posits that teams may suffer in large or small organizations because it is hard to form synergy and in small organizations they may suffer due to lack of experience. Regarding tactics, he says that they affect both large and small organizations due to planning, workflow redesign, data entry, interfaces, training, going live, and big bang versus phased type implementations. Technology also has an impact if networking, speed of data transfer, IT support, and maintenance are not properly catered for.

McGowan, Cusack, and Poon (2008) state that the system selection in an electronic health records system implementation should be driven by organizational issues and the desired outcomes. These desired outcomes should be incorporated into a formative evaluation plan. They define formative evaluation as “an iterative assessment of a project’s viability through meeting defined benchmarks, can mean the difference between

success and failure in EHR implementation” (p. 297). This effort aligns with lean thinking’s continuous improvement approach.

Lo et al (2007) conducted a time and motion study to evaluate whether an electronic health records system would add time to practitioners’ activities compared to traditional paper forms. They concluded that there is a non-significant increase in the overall time practitioners spend given enough time (they mention 9 months of learning). They also found that there is no need to develop particular versions of the software for specialists (cardiologist, ophthalmologists, etc.) since a generalized version will perform as well. Pizziferri et al (2005) conducted a time motion and study in an oncologist setting and concluded that an EHR system will not take more time than the traditional paper records keeping method.

Terry et al (2008) state that finding the time to train, practice and learn the EHR is the biggest problem physicians identified. The authors also mention that the level of computer literacy has an effect on how fast of the user will transition to the new system.

Yoon-Flannery et al (2008) report that improved access and completeness of patient records is an advantage of EHR use. Another advantage to the use of EHR is the capability to record more data that can lead to better reports and population analyses, all of which will help with compliance with regulations and can help increase quality of healthcare.

Complementarist Approach

Midgley (1990, 1997) introduces an evolution of total systems intervention, called creative methodology design. The premise is to identify the problem context, revise suitable methodologies, and select all, or parts of the methodology that fit the problem context. Many methodologies are comprised of parts that may each be suitable separately

to different problem contexts. However, it is possible to use commensurable² methodology parts to create an ad hoc methodology that fits the problem context of interest. This approach will be employed in the development of the theoretical model. The approach will also serve as the foundation for the remainder of this work.

Theoretical Model

In this chapter, relevant theoretical foundations to build the proposed theoretical model have been presented. It is the intention of this section to provide the theoretical foundations to the methodologies to be presented in chapter III, and used in chapters IV, V, VI, and VII. Systems archetypes provide generalized structures that describe common behaviors over time on a wide array of contexts and settings. Levy's adaptation function (1965) introduces a goal-seeking behavior to the learning curve body of knowledge. Equation 2-4 is adapted from Equation 2-3 to include errors per day as the variable of interest.

$$Q(t) = P[1 - e^{-(a+\mu t)}] \quad \text{Equation 2-4}$$

where

$Q(t)$ = *percentage of errors per day at time t*

P = *desired rate of output expressed in errors per day*

a = *initial efficiency of the process expressed in percentage of errors*

μ = *process rate of adaptation expressed in percentage of errors*

t = *cumulative time*

Equation 2-5 generates an exponential decay goal-seeking behavior until the initial percentage of errors per day reaches the desired percentage of errors per day. Figure 2-11 presents the expected behavior over time as expressed by Equation 2-6.

² Commensurable refers the compatibility that a methodology has with a problem context. In the context above: A section of a methodology may be commensurable to a different problem context than the parent methodology; and different commensurable parts of methodologies can be used to create a new ad hoc methodology. See Midgley (1990, 1997) and Wilby (1997) for details.

Figure 2-11 Levy's Adaptation Function seen as behavior over time graph

The initial approach to link the adaptation function behavior over time to a system archetype is to look at the 'balancing loop' structure and its corresponding behavior over time (see Figure 2-12). The action causes the current state to move towards the desired state.

Figure 2-12 'Balancing Loop' Causal Loop Diagram and Behavior Over Time Graph

At first glance, the ‘balancing loop’ appears to be a good fit to the behavior over time described in Figure 2-11. However, in reality a transition-phase will not occur without glitches or inconsistencies. For instance, the balancing loop ignores the effects of factors like forgetting, employee absenteeism, different levels of experience, varying learning abilities, pressure to manage resources, and pressure to complete the project on time.

The ‘drifting goals’ archetype can model the pressure generated by any deviations from the original plan, which may result in changes on deadlines, or target state. Figure 2-13 presents the ‘drifting goals’ archetype using causal loops.

Figure 2-13 ‘Drifting Goals’ Causal Loop and Behavior Over Time Graph

Notice how the lack of convergence from the current state concerning the desired state generates pressure to adjust either the target percentage of errors per day or the deadline.

The current state may differ from the desired state due to errors in planning that cause unintended consequences. The ‘fixes that fail’ archetype would be the option. Figure 2-14 presents the ‘fixes that fail’ archetype in causal loop format.

Figure 2-14 ‘Fixes that Fail’ Causal Loop and Behavior Over Time Graphs

The ‘drifting goals’ and ‘fixes that fail’ archetypes provide more complete solutions than the ‘balancing loop’ archetype alone. However, if used separately they provide an incomplete solution. Figure 2-15 presents the combination of the ‘balancing loop’ with the ‘drifting goals’ and ‘fixes that fail’ archetypes. This new structure is called the adaptation function causal loop.

Figure 2-15 Adaptation Function Causal Loop Diagram

The adaptation function causal loop introduces the generalized structure that a transition-phase management system dynamics model should follow to replicate the behaviors over time presented in Figures 2-13 and 2-14. The current state is then influenced by the initial efficiency of the process ‘ a ’ which is defined by initial and ongoing training, and organizational culture. The process rate of adaptation ‘ μ ’ is affected by individual employee learning rates, employee level of experience, and frequency of practice (mean time between entries). To fit Equation 2-3, Figure 2-12 is adapted as follow:

Figure 2-16 Balancing Loop incorporating equation 2-3

It becomes clear that the action expression $1 - e^{-(a+\mu q)}$ in Figure 2-16 is not a suitable mathematical expression. Note that q is no longer an adequate variable in the model, hence it is substituted by t (days). Therefore, the causal loop diagram is modified in Figure 2-17.

Figure 2-17 Adapted balancing loop

Following this logic, and after changing q for t (days), Figure 2-15 translates into Figure 2-18:

Figure 2-18 Initial Transition-Phase Management Model

The expression in Equation 2-6 has to be adjusted to fit the adaptation function conceptual model. Equation 2-7 shows the new general mathematical expression:

$$Q_t = \int_{t_0}^{t_f} (F - a - \mu) dt \quad \text{Equation 2-6. Initial Transition-Phase Management Model}$$

$$\text{Until } |Q_t - P| \approx 0$$

where

Q_t = percentage of errors per day

a = initial efficiency of the process = $f(\text{organizational culture, training, time})$

μ = process rate of adaptation = $f(\text{experience, learning ability, feedback, time})$

F = Damping Factor = $f(a, \mu, \text{forgetting})$

and

$$P = \int_{t_0}^{t_f} B dt + P_0; \text{ where}$$

P_0 = initial desired percentage of errors

$$B = \text{Pressure to Adjust } P = f(|P - Q_t|, \text{time}) \begin{cases} 0 & \text{if } |\dot{P} - \dot{Q}_t| \rightarrow 0, \text{ regardless of } t \\ \geq 0 & \text{if } |\dot{P} - \dot{Q}_t| > 0 \text{ and } (t_f - t) \rightarrow 0 \end{cases}$$

P is a variable that determines the desired percentage of errors per day set at an expected completion time or t_f , therefore:

$$P = f(\text{desired percentage of errors}, t_f) \quad \text{Equation 2-5 Desired State}$$

Pressure to Adjust P (B) is a dimensionless function based on the relationship between time remaining to complete the project ($t_f - t_{obs}$), a time determined by manager's policy to start evaluating the progress (*Panic Time*) and the difference between the percentage of errors per day and the desired state at time t ($Q_t - P$).

$$B = f(t_f - t_{obs} < \text{Panic Time}, (Q_t - P) > 0) \quad \text{Equation 2-6 Pressure to Adjust}$$

Where

$$\begin{aligned} t_f - t_{obs} &> 0 \\ t_0 &\leq \text{Panic Time} \leq t_f \\ Q_t - P &> 0 \end{aligned}$$

The model is capable of providing the following alternatives as objective functions (Figure 2-19).

Figure 2-19 Objective Function for Transition Phase Management Model

Balance between vertices in the triangle means that in order to optimize one apex, one of the two remaining vertices cannot be optimized.

It is hypothesized then that the model is capable of helping healthcare managers to:

1. Maximize the quality of a new process implementation through the balance of resource cost allocation and time to complete the project.
2. Minimize the use of resources through the balance of time to complete the project and quality.
3. Optimize the time required to complete the project through balancing quality and use of resources.

Section 8.1 presents the conclusions on how to Figure 2-19 relates to the work presented in this dissertation.

CHAPTER III

METHODOLOGY

Introduction

The purpose of this chapter is to provide an outline of the research methodology used in this research. The chapter provides details on how the research methodology will be divided into three tasks and two experiments. The chapter explains how the tasks and experiments are allocated into one conference paper and three different peer reviewed journal research papers.

Rationale

The rationale for this research is to increase the understanding of the dynamic interactions that occur during transition-phases in healthcare projects.

Research Design

Barlas (1996, p. 185) provides a list of six major steps typically followed in the construction of a system dynamics model.

1. Problem identification
2. Model conceptualization (construction of a conceptual model)
3. Model formulation (construction of a formal model)
4. Model analysis and validation
5. Policy analysis and design
6. Implementation

This dissertation will focus on steps one through four as specified in Table 3-1 as steps 5 and 6 are left for the healthcare managers that will use it.

Table 3-1 Research Design Steps

Step	Research Scope	Design Overview
1. Problem identification	Chapter 1	Described through problem statement, research questions, and hypotheses.
2. Model conceptualization (construction of a conceptual model)	Theoretical Model presented in section 2-3.	Developed after adaptation function, and system dynamics theories. The model will be included in a conference paper.
3. Model formulation (construction of a formal model)	Task 1	The generalized model formulation after the theoretical model in section 2-3 will start with a pilot study presented in a conference paper. It will develop sub-structures in paper one and will be validated with real world data in papers two and three.
4. Model analysis and validation	Tasks 2 and 3 Experiments 1 and 2.	For paper 1, a double loop learning process will be followed. For papers 2 and 3, the process presented in Figure 2-10 will be employed.
5. Policy analysis and design	Outside the scope of this dissertation. Future work.	
6. Implementation	Outside the scope of this dissertation. Future work.	

This dissertation follows a four-paper format. The theoretical model presented in section 2-3 will serve as the starting dynamic structure from which tasks 1, 2 and 3 are derived.

The recognition of the problem is stated in section 1-2, and it reads:

Combining industrial engineering and engineering management tools to improve a particular problem situation in the healthcare industry has proven successful. The use of industrial engineering and engineering management tools (scientific management approach) to improve operation conditions and maximize revenue has been gaining popularity in the health care environment. Examples range from the implementation of the TQM model, to the incorporation of Lean thinking and Six Sigma methodologies. However, research of transition-phases in a healthcare environment, using a holistic scientific management approach, has received little attention. The estimation of time and resources required to conduct a transition-phase, usually employs “rule of thumb” approaches based on simple calculations– rather than a holistic scientific management method. A systemic approach to manage transition-phases will bring a dynamic approach to manage transition-phases during planning and implementation stages.

Task 1 will conclude as a conference paper presented in chapter 4. Tasks 2 and 3 will result in a peer reviewed journal paper and will be included in chapter 5. Experiments 1 and 2 will result in two peer reviewed journal papers and will be presented in chapter 6 and 7 respectively. Chapter 7 will present general findings applicable to the dissertation, and chapter 8 will introduce conclusions and future work analysis derived from chapter 7.

Type of Research

The research type followed in this research follows the standard approach to system dynamics model development as presented by Barlas (1996) and Sterman (2000) but can be best exemplified by a matrix presented by Dr. Simon Hsiang³ in his design of experiments class as he proposed the following model for model validation:

³ From IE5342 Design of Experiments class, Fall 2011.

Table 3-2 Model Validation Matrix

Verification Stage \ Characteristic	Order of first run	Input	Model	Output
System Identification	1	Known	Unknown	Known
Simulation	2	Known	Known	Unknown
Control	3	Unknown	Known	Known

The process is iterative and non-linear, as with any simulation model. For illustration purposes, the first iteration is described. The first step is to develop the dynamic hypotheses (identify expected behaviors over time) through the system identification. The first attempt is presented in section 2-3 as the theoretical model. The second step requires the translation of the theoretical model into a simulation model in a pilot study form. The pilot study will then lead to step three, where the identification of inputs will aid the data collection for experiments 1 and 2. After that point, steps one through three will alternate until a validated structure, within the parameters defined in the testable hypothesis, are rejected, or fail to be rejected.

Research Focus

The creative methodology design approach to total systems intervention is based –as specified in section 2-3, on Levy’s adaptation function. The adaptation function is interpreted as behavior over time under a system dynamics framework. The focus in this dissertation is to develop a transition-phase management system dynamics model that is capable of replicating real world behavior over time in a healthcare transition-phases.

Research Hypotheses Restated

In chapter I, three tasks and two general research hypotheses were stated. Each of these hypotheses belongs to one experiment. This dissertation follows the three papers format, hence tasks 2 and 3, and experiments 1 and 2 will result in research papers.

Table 3-3 Outputs and Target Publications

Activity/Test	Output	Target Publication
Task 1	Conference Paper	2012 ASEM International Annual Conference
Tasks 2 and 3	Peer Reviewed Journal Paper	Engineering Management Journal
General Research Hypothesis 1	Peer Reviewed Journal Paper	IIE Transactions in healthcare, or a healthcare management journal
General Research Hypothesis 2	Peer Reviewed Journal Paper	Engineering Management Journal, or System Dynamics Review

Tasks

Task 1: Develop a pilot study to translate the initial Transition-Phase Management Model (see Figure 1-2 and Equation 1-1) into a stock and flow diagram (will translate into a conference paper).

Task 2: Further define the model by developing the sub-structures for a , μ , *Damping Factor* and B .

Task 3: Test the model for inputs limits and validity of outputs (tasks 2 and 3 will translate into a peer reviewed journal paper).

Hypotheses

The model developed in tasks 1, 2, and 3 will be used as the template to run experiments 1 and 2, as presented below.

General hypothesis for Experiment 1:

The transition-phase errors per day in a hospital billing process necessary as a result of an electronic health records system implementation can be depicted with the transition-phase management model.

- d) The information available (quantitative and qualitative) to the manager at a local healthcare center is adequate to generate the desired behavior over time.
- e) The model is capable of identifying the path that the percentage of errors per day will follow during the implementation process
- f) The model is able to identify when and if dynamic equilibrium is reached

General hypothesis for Experiment 2:

The changes to a hospital's clerical processes induced by the implementation of an electronic health records system can be depicted with the transition-phase management model.

- d) The information available (quantitative and qualitative) to the manager at Community Health Center of Lubbock is adequate to generate the desired behavior over time.
- e) The model is capable of identifying the path that the percentage of errors per day will follow during the implementation process
- f) The model is able to identify when and if dynamic equilibrium is reached
- a) the expected effects that the feedback structures have on errors per day.

Tasks 1, 2 and 3, and experiments 1 and 2 serve to generate a model that will facilitate the double loop learning process in an organization (see Figure 2-4) by reducing the time to develop a virtual world and providing a reliable structure to analyze the real world. According to these general hypotheses and Table 3-3, the general hypotheses that deal with model validity are presented in Table 3-4. Table 3.5 presents specific testable hypotheses for experiments 1 and 2.

Table 3-4 General Testable Hypotheses Matrix

Tests for	Hypothesis	Hypothesis	Proposed Test
Task 3	1	H_0 : The μ substructures have no effect on the percentage of errors per day for all t : $H_0 : \mu_{t_0} = \mu_{t_1} = \mu_{t_2} = \dots = \mu_{t_f} \approx 0$ $H_a : \mu_t = 0$ for all t	1. Extreme values test using built in sensitivity analysis in Vensim using uniform and triangular distributions 2. Data sub-set Variance Plot
	2	H_0 : The a substructures have no effect on the percentage of errors per day for all t : $H_0 : a_{t_0} = a_{t_1} = a_{t_2} = \dots = a_{t_f} \approx 0$ $H_a : a_t > 0$ for all t	
	3	H_0 : The F substructures have no effect on the percentage of errors per day for all t : $H_0 : F_{t_0} = F_{t_1} = F_{t_2} = \dots = F_{t_f} \approx 0$ $H_a : F_t > 0$ for all t	
	4	H_0 : The B substructures have no effect on the percentage of errors per day for all t : $H_0 : B_{t_0} = B_{t_1} = B_{t_2} = \dots = B_{t_f} \approx 0$ $H_a : B_t > 0$ for all t	
Experiments 1 and 2	5	H_0 : Percentage of errors per day (Q_t) model generated data replicates the behavior of the real world percentage of errors per day (Q_{Rt}) for short, mid and long-term projects: $H_0 : Q_t = Q_{Rt}$	1. Paired Two Sample for Means R^2 2. Histogram of Differences $Q_{Rt} - Q_t$ 3. Graphical comparison between Q_t and Q_{Rt}
	6	H_0 : Percentage of errors per day (Q_t) model generated data predicts the path of the real world percentage of errors per day (Q_{Rt}) for short, mid and long-term projects: $H_0 : Q_t = Q_{Rt}$	

Collection and Treatment of Data

Two sources of data were employed: a local healthcare clinic's clerical processes and a local healthcare center's billing department. The data used is historical in nature, aiding in the validation process for the models.

Data Collection

Quantitative Data

Per Internal Review Board (IRB) requirements, all quantitative data were to be retrieved by personnel from each organization, and any identifiers were to be coded, so that no individuals' data could be traced back (see appendix A for IRB proposal). System dynamics model-building strategies suggest starting with simple structures and increasing complexity gradually until the desired levels of accuracy are reached. In the case of this research two levels of resolution were deemed sufficient.

Qualitative Data

System dynamics models allow the use of qualitative data when quantitative data is not available, or when it is necessary to define some behavior over time parameters.

Collection of qualitative data followed the same process described in section 3.4.1.1, with the distinction that the data was recorded directly from informal interviews with the managers.

Simulation

Model calibration followed Table 3-3. Once the parameters replicated the expected behavior over time after goal programming-style calibration, a sensitivity analysis of all variables was conducted through the built in sensitivity function in the simulation package (Vensim Professional) and are presented in chapter 5.

Case Study

A pilot study was developed –and presented in chapter 4 using the theoretical model presented in section 2-3 to complete task 1. Parameters were adjusted based on mental and written databases (see Figure 2-8) following a goal programming approach. The pilot study’s objective is to observe if the structure replicates the expected behaviors over time of the initial transition-phase management model structure. Tasks 2, and 3 propose specific structures for efficiency of the process, process rate of adaptation, and Damping Factors substructures introduced in task 1. The objective is to produce a model that can be applied within a healthcare context when managing changes brought by electronic health records system implementation and changes in billing procedures are of interest.

Treatment of Data

The data obtained was utilized “as is” to compare it versus the model. Some outlier data points were removed due to special circumstances such as capture errors or data generated under special circumstances such as holidays or weekends. The justification to minimize as much as possible data treatment follows two points:

1. The data collected is the data managers work and make decisions with.
2. System dynamics can help detect errors in data collection if the expected behavior over time cannot be replicated. In that case, what needs to be treated is the data collection method, not the data.

Methodological Issues

Reliability

Reliability is the accuracy of the research, its efficacy, and effectiveness. It refers to how well the model will yield certain expected results as long as the entity being measured does not change. Reliability in this research is given in two steps. The first one is achieved in experiments 1 and 2 through the validation of their substructures in hypotheses. The second one is obtained through the cross-validation of their

substructures. In both cases, the reliability will follow the process delineated in Table 3-2, and expanded in Table 3-5.

Validity

Model validity depends on the non-linear process of identifying the system's structure, performing simulation to calibrate its output (or outputs), and controlling the inputs, with regards of level of detail and nature –qualitative, quantitative or a mix of both. Table 3-5 presents a detail depiction of the model validation process to be used in this dissertation. Table 3-5 is based on Table 3-2.

Table 3-5 Detailed Model Validation Matrix

Characteristic Verification	First run order	Input	Model	Output	Product	Hypotheses from Table 3-4
System Identification	1	Known	Unknown	Known	Conference Paper	Theoretical Model Task 1
					Paper 1	Tasks 2, and 3
Simulation	2	Known	Known	Unknown	Paper 1	Task 3
					Paper 2	Hypothesis 1
					Paper 3	Hypothesis 2
Control	3	Unknown	Known	Known	Paper 1	Hypothesis 1
					Paper 2	Hypothesis 2

Each validation step, followed an iterative three-step process based on Total Systems Intervention (Flood & Jackson, 1991): A Creativity phase, and Choice Phase, and an Implementation phase. For instance, the system identification step requires the use of creativity to generate the structures required to duplicate the expected behavior over time. It requires the researcher in conjunction with the managers to choose the right structure that mimics the real world structure. The implementation of the structure is done through the pilot study, where this initial structure is tested. The simulation step requires

creativity to select the best parameters to produce the expected output(s). The control phase requires creativity to expand the original structures and to identify what type of information can be used to increase the model's validity. Figure 3-1 presents the validation structure followed.

Figure 3-1 Model Validation Process

Thus, the combination of the mental, written, and numerical databases (see Figure 2-8) will yield the structures for efficiency of the process, process rate of adaptation and damping factors structures and parameter estimations needed in each validation step.

Replicability

Replicability will be addressed mainly in experiment three (paper three). The objective of paper three is to produce a generalized transition-phase management model, which relies on replicability within a healthcare change environment.

Bias

As with any simulation model, there exists inherent bias because of the simplification of the real world resulting from the abstraction and modeling process.

Representativeness

This research is representative of transition-phase projects in healthcare contexts.

Research Constraints

The main purpose of this research is to produce a generalized transition-phase management model for healthcare contexts. For that reason, *ad hoc* methods to collect data and validate data will not be developed. In addition, the expected variables measured and outputs are bounded by the requirements that the healthcare clinic and center selected have at the time this research is conducted.

Model Development, and Validation

This dissertation is structured to follow a four paper route. Therefore, instead of following a more conventional approach with a chapter dedicated to data collection, analysis and discussion and another one for conclusions, one chapter is dedicated to present the theoretical model (based on section 2.3), one chapter addressing Hypotheses 1-4, and one chapter addressing hypotheses 5 and 6 (Table 3-4).

Validation of the model (Figure 3-5) is conducted in accordance to the schedule presented in Table 3-6..

Table 3-6 Model Validation - Chapter Relation

<div>Characteristic</div> <div>Verification</div>	First run order	Input	Model	Output	Chapter	Hypotheses from Table 3-4
System Identification	1	Known	Unknown	Known	Chapter V	Theoretical Model Task 1
						Tasks 2, and 3
Simulation	2	Known	Known	Unknown		Task 3
						Hypothesis 1 Hypothesis 2
Control	3	Unknown	Known	Known	Chapters VI and VII	Hypothesis 1
						Hypothesis 2

CHAPTER IV

A PROPOSED CONCEPTUAL SYSTEM DYNAMICS MODEL FOR MANAGING TRANSITION-PHASES IN HEALTHCARE ENVIRONMENTS

Abstract

Engineering management practice and research has gained popularity since the dawn of the new millennium. Efforts in development and application of lean thinking and six sigma into the healthcare industry have been steadily increasing. In addition, the healthcare industry is faced with changes in regulations, whether small –changes in billing procedures or large –implementation of electronic health and medical records systems. These challenges require processes to be modified, whether on a small or large scale, or in a superficial or deep way. Yet, little attention has been paid to the management of these transition phases using a scientific management approach. The purpose of the work presented in this paper is to introduce a conceptual transition phase management model. The model is based on system dynamics principles, and borrows concepts from change management and learning curve theories. Engineering managers can benefit from the model in two ways: 1) the model can be employed to conduct qualitative behavior over time analyses and 2) the model possesses the potential to be developed as a simulation model.

Key Words. System Dynamics, Healthcare Management, Change Management, Complementarism, Total Systems Intervention.

Introduction.

The healthcare industry is under increasing expectations to implement electronic health records and electronic medical records systems. This pressure is placing a burden on available human resources in healthcare institutions during implementation phases. healthcare managers are confronted with the challenge to balance workloads, ensure

transitions from old to new systems, and minimize the time it takes to implement the new systems. In this paper, the authors present a conceptual model of a generalized transition-phase management model for health care institutions.

The model is built using a complementarist approach to bring together Ferdinand Levy's adaptation function (1965) and Jay Forrester's system dynamics. The methodology draws on complementarism concepts introduced through Totals Systems Intervention (TSI) by Robert Flood & Michael Jackson (1991) and Gerald Midgley (1990, 1997). The rationale behind TSI is that to build *ad hoc* robust methodologies, the strengths of individual methodologies with respect to the problem context can be combined.

Background

Frederick Winslow Taylor laid out the road map for the industrial engineering and engineering management professions. Most industrial engineering and engineering management methodologies were developed after Taylor published his book "The Principles of Scientific Management" (Taylor, 1911). In his book Taylor stated that "[it] is true that whenever intelligent and educated men find that the responsibility for making progress in any of the mechanic arts rests with them, instead of upon the workmen who are actually laboring at the trade, that they almost invariably start on the road which leads to the development of a science where, in the past, has existed mere traditional or rule-of-thumb knowledge" (Taylor, 1911, p. 52).

With the ever increasing specialization and increased requirements on knowledge workers, Taylor's statement re-gains importance. As the 20th century closed and the 21st century dawned, industrial engineering and engineering management practitioners kept developing more and more methods and methodologies to improve the "laboring trade" as Taylor stated. Engineering Management methods once deployed have demonstrated great levels of efficiency, efficacy, and/or effectiveness. However, as they become more widespread in use and knowledge, the effect that they can have on a problem situation is minimized. As a result, philosophies or toolboxes such as Lean and Six Sigma have been

developed. Yet, the existing methodologies that advocate for the use of many of industrial engineering and engineering management together lack a systemic approach (Calvo-Amodio, Tercero, Hernandez-Luna, & Beruvides, 2011).

The approach to understanding a system's behavior can be traced in the western world all the way back to the Greek philosophers. Over the centuries, isolated efforts were made by philosophers and thinkers alike. Yet, there were no strong advancements to unify the field. The dawn of the twentieth century yielded structured efforts to develop an applied holistic approach, known as systems thinking, for better understanding a system's behavior. Systems thinking as a science arose as the result of the efforts from researchers from varied backgrounds such as biology, sociology, philosophy and cybernetics to explain holistically the systems they studied (Jackson, 2000). Amongst the best-known and influential authors, we find Ludwig von Bertalanffy, Charles West Churchman, Russell Ackoff, Jay Forrester, Humberto Maturana and Francisco Varela, Stafford Beer, and Peter Checkland.

Applied systems thinking methodologies in the management sciences started to appear as early as the mid-1950s with the early efforts from Russell Ackoff and Jay Forrester. Applied systems methodologies were developed to solve particular problems observed or encountered by their authors. Each methodology was developed under assumptions that would not necessarily be consistent or commensurable with the others. Robert L. Flood and Michael C. Jackson from the University of Hull in the U.K. recognized this as a problem. They developed a System of Systems Methodologies to help the user match a particular methodology to the problem context they were interested in acting upon. They also developed a meta-methodology called Total Systems Intervention that allows the practitioner to combine incommensurable methodologies together. Flood and Jackson state that problems can be classified in a grid of problem contexts that contains two dimensions: one dimension to evaluate the relationship between the participants in the

system; the second dimension to assess the complexity of the system (Flood & Jackson, 1991, p. 42). Table 4-1 shows an adaptation of the grid of problem contexts.

Notice how the applied systems thinking methodologies have been classified according to the problem context they are best suited to be used (for more details on the grid of problem contexts refer to Flood & Jackson, 1991, Jackson 1984, 1990, 2000). The grid of problem contexts provides a very useful approach to identify within each problem context, which methodology is the best suited to tackle it.

Another contribution by Flood and Jackson is a meta-methodology called Total Systems Intervention (TSI). It allows the user to combine methodologies within or with different problem contexts at the same time. However, there have been no attempts to provide more detailed methodologies to combine particular tools, in a complementary way, into more detailed approaches to modeling.

Table 4-1 Grid of Problem Contexts

		Relationship Between participants		
		Unitary	Pluralist	Coercive
System Complexity	Simple	Systems Engineering, Operations Research, Statistical Quality Control, System dynamics	General Systems Theory, Social Systems Design, Strategic Assumption Surfacing and Testing	Creative Problem Solving, Critical Systems Heuristics
	Complex	System dynamics , Viable System Model, Socio- technical Systems	Interactive Planning, Interactive Management, Soft Systems Methodology,	Not Defined

Traditional industrial engineering and engineering management tools such as statistical process control, design of experiments, operations research, etc., can help engineers identify the current state of a system and develop solutions to potential or existing

problems in a particular setting. However, these tools are handicapped in their scope and approach. Their handicap in scope is that they are only effective in a small range of problem types where data is available and the complexity of the system is low. The handicap on approach is within their logical positivistic nature. These tools are designed to tackle one problem at a time and by nature ignore the emergent properties of the system (in most cases).

Systems thinking on the other hand offers a holistic view of the real world and brings a complementarist approach through creative systems thinking that can benefit the industrial engineering and engineering management practitioner.

Methodology

In this section a brief overview of the adaptation function and system dynamics theories is presented.

Adaptation Function.

Levy (1965) believes that the planning procedure of a process change can be improved through a better understanding of how the individual worker, as well as the firm, have historically adapted to past learning situations. Furthermore, Levy posited that the lack of a goal seeking behavior in traditional learning curves is not realistic. For that reason, Levy proposed an alternative to the traditional learning curve model as shown in Equation 4-1:

$$Q(q) = P[1 - e^{-(a+\mu q)}] \quad \text{Equation 4-1 Levy's Adaptation Function}$$

where

$Q(q)$ = the rate of output Q after q units have been produced

P = desired rate of output

a = initial efficiency of the process

μ = process rate of adaptation = $f(y_1, y_2, y_3, \dots, y_n)$

q = cumulative number of units produced

The objective is to maximize $Q(q)$ given the initial efficiency of the process, desired rate of output and the process rate of adaptation within a given number of units produced.

The model suggests that cumulated experience and knowledge on a job at a given time can be summarized in amount of products or repetitions at that time. Therefore, as more experience is gained, the gap to reach the desired rate of output is reduced (Levy, 1965, pp. B-137).

System Dynamics.

Jay Forrester created system dynamics as a special case of control theory to model feedback structures in systems where non-linear time dependent interactions are present. System dynamics presents a powerful approach to modeling complex systems in accordance to what their internal structure and interactions actually can be at different times and levels of interactions. Feedback is present in non-linear systems where its components sustain complex interactions and that emergent properties arise from such interactions. With the use of level and rate variables, it is possible to model the interactions and feedback loops between system components. Dynamic modeling can help learning about a system and what are the most important variables in a process or system (Hannon & Ruth, 2001, p. 10). In addition it can be used to delineate policies to achieve a goal.

Operational Definitions

To bound the problem context, three operational definitions are required.

Problem Context.

A situation where operational change is expected in a healthcare environment, requiring the implementation of a new process or processes that entail staff training and learning by doing. When their efficiency is measured as percentage of errors per day, healthcare managers are decision makers, and the healthcare institution is subject to locally available resources such as staff, money, and training.

Generalized Model.

A model applicable to situations that align with the problem context requiring minimal or no adjustments necessary.

Transition-Phase Management.

An operational change that is focused on minimizing the percentage of errors per day, seen as a process done through learning by doing. It is the result of the implementation of big scope methodologies like Lean thinking and Six Sigma, or electronic health records. The implementation of these methodologies requires changes in processes, and at times, of organizational cultures

Transition-Phase Management Model (TPMM)

A TPMM combines the three operational definitions provided above. Carrillo and Gaimon (2000), and Morrison (2008) mention that productivity in early stages suffers even if the new process is supposed to improve productivity, and that it is strictly related to the learning curve process. That process is also congruent with the system dynamics principle which states that when there is an intervention to improve the condition of the system, the condition can get worse before it gets better (Sterman, 2000). Morrison (2008) also states that cumulative production is a reflection of knowledge of the process, and that according “to learning curve theory, the accumulation of experience increases productivity, or alternatively reduces costs” a behavior that can be replicated with system dynamics simulation models.

Consider Equation 4-1 as a goal seeking behavior representation of a system. Equation 4-2 adapts Equation 4-1 into the problem context replacing $Q(q)$ - the rate of output Q after q units have been produced by Q_t – percentage of errors per unit of time.

$$Q_t = P[1 + e^{-(a+\mu t)}] \quad \text{Equation 4-2 Modified Adaptation Function}$$

where

Q_t = percentage of errors per unit of time at time t

P = desired percentage of errors per unit of time

a = initial efficiency of the process

μ = process rate of adaptation = $f(y_1, y_2, y_3, \dots, y_n)$

t = time t

Figure 4-1 presents a general graphical representation of Equation 4-2.

By considering systems archetypes as building blocks for a system dynamic model of Equation 4-2, a balancing loop is the logical choice to start since it provides a goal seeking exponential growth (positive or negative). However there are some other factors to consider such as unintended consequences (used as damping factors) and the effects they may have on management to change the original goal (B).

Figure 4-1 Graphical Representation of Levy's Adaptation Function as Behavior of Q_t Over Time

Therefore, a fixed structure and a drifting goal structure should also be considered. Figure 4-2 shows the resulting model represented in a causal loop diagram:

Figure 4-2 Transition-Phase Management Model Causal Loop Diagram

Therefore, a new mathematical model can be proposed under system dynamics perspective.

$$Q_t = \int_{t_0}^{t_f} (F - a - \mu) dt$$

Equation 4-3. Initial Transition-Phase Management Model

$$\text{Until } |Q_t - P| \approx 0$$

where

Q_t = percentage of errors per day

a = initial efficiency of the process = $f(\text{organizational culture, training, time})$

μ = process rate of adaptation = $f(\text{experience, learning ability, feedback, time})$

F = Damping Factor = $f(a, \mu, \text{forgetting})$

and

$$P = \int_{t_0}^{t_f} B dt + P_0; \text{ where}$$

P_0 = initial desired percentage of errors

$$B = \text{Pressure to Adjust } P = f(|P - Q_t|, \text{time}) \begin{cases} 0 & \text{if } |\dot{P} - \dot{Q}_t| \rightarrow 0, \text{ regardless of } t \\ \geq 0 & \text{if } |\dot{P} - \dot{Q}_t| > 0 \text{ and } (t_f - t) \rightarrow 0 \end{cases}$$

Notice that in F (damping factor) forgetting is included as an independent variable. It follows Morrison's (2008) statement that forgetting is an intrinsic part of learning, but that enough time spent with a new skill will offset the effects of forgetting.

Exploratory Study

The first task is to transform the causal loop diagram in Exhibit 3 into a stock and flow diagram. Vensim Professional was selected to conduct the study. For this exploratory study, the substructures a , μ and F are not developed and their behavior over time is approximated through goal programming techniques. Figure 4-3 presents the resulting stock and flow diagram.

Figure 4-3 Stock and Flow Diagram for of the Transition-Phase Management

Notice that table functions (lookups) are used to approximate the behaviors of a , μ and F , as well as the B substructure (pressure to adjust the goal P). The model was expected to produce an exponential decay behavior with dampened oscillation caused by delays in

managerial decisions and information systems. Figure 4-4 presents the behavior over time results for Q_t and $P-Q_t$.

Figure 4-4 Behavior of Q_t & $P-Q_t$ Over Time

In addition, a sensitivity analysis was conducted to determine the responsiveness of the model to changes in variable values and delay times. Figures 4-5 and 4-6 show the behaviors of Q_t and $P-Q_t$ respectively.

The model behaves within the expected bounds within expected extremes in variations of variables levels and delay times. The results of the exploratory provide confidence to continue developing the model as a mean to produce a generalized model to manage transition-phases in healthcare environments.

Figure 4-5 Sensitivity Results for Q_t

Figure 4-6 Sensitivity Results for $P-Q_t$

Conclusions

The proposed conceptual system dynamics model for managing transition-phases in healthcare environments has the potential to aid healthcare managers to better determine new process implementation strategies and enhance project implementation performance evaluations. Management is prediction (Deming, 1998), therefore the prospect to increase the ability to reduce uncertainty is worthy of effort. As future work, the model proposed in this paper, will be further refined to better reflect the practice of healthcare managers by developing second level of resolution for the a , μ and F structures. The model can be further refined to be effective in Lean and Six Sigma settings or for other applications of the engineering management profession.

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CHAPTER V

A GENERALIZED SYSTEM DYNAMICS MODEL FOR MANAGING TRANSITION-PHASES IN HEALTHCARE ENVIRONMENTS

Abstract

Learning curve theory, and in particular the adaptation function have proven useful to identify organizational learning patterns. Yet they are limited in the information they provide in that they provide a general understanding on how long it will take to reach a desired outcome level. If the adaptation function is to be employed to plan a transition-phase, it should be capable of helping managers to balance quality, time and resource cost, along with determining periods of instability and of dynamic equilibrium. The adaptation function theory can be strengthened by combining it with systems thinking principles and a simulation model based on system dynamics be developed as a result. The purpose of the work presented in this paper is to develop a transition phase management model based on a complementarist approach. Healthcare managers can benefit from the model in two ways: 1) the model is developed into a simulation model that possesses a user friendly interface; 2) Managers are able to forecast implementation quality, time and resource costs, identify variables that can be modified to obtain a better outcome by reducing periods of instability or accelerating the learning process.

Introduction

The literature points at the use of statistical process control (SPC), total quality management (TQM), six sigma, lean thinking, and simulation as the main industrial engineering and engineering management tools and philosophies employed in healthcare. Many levels of success are reported, but in general, the literature suggests there have been more partial successes and failures in implementing these methods and philosophies than successes in healthcare and reflects on the possible causes. For instance, Benneyan

(1996) offers an overview of the possible benefits that SPC could bring to healthcare. He warns about mistakes –such as using the wrong charts and using shortcut formulas –that can be committed if SPC tools and their application are not understood correctly.

Benneyan (1998a, 1998b, 2001) talks about control charts and their potential uses in medical environment providing useful theoretical guidelines on how to implement them, and analyzes their accuracy.

Callender and Grasman (Callender & Grasman, 2010) identify the following barriers to implementation of supply chain management: Executive Support, Conflicting Goals, Skills and Knowledge, Constantly Evolving Technology, Physician Preference, Lack of Standardized Codes, and Limited Information Sharing. It is possible to extrapolate their reasoning to lean thinking implementation, as they are new or foreign "industrial engineering tools" for the medical community considering that acceptance of new ways is always a challenge. The best practices offered can be lessened by good Lean practices and especially with the electronic health records implementation.

Towill and Christopher (2005) advocate for the analog use of industrial logistics and supply chain management in the National Health Service (NHS) in the United Kingdom. They argue that material flow and pipeline concepts should be applied to the healthcare delivery context to better match demand and the need for a more cost-effective practice.

Young (2005) proposes simulation as a tool to re-structure healthcare delivery on a macro-level by researching patient flow, as the big hospitals go against Lean thinking principles by promoting big queues. Young also suggests that system dynamics and theory of constraints could work together since system dynamics is well suited to identify bottlenecks in a process (p. 192).

Several attempts to combine methodologies, such as managerial philosophies like total quality management, six sigma, theory of constraints, reengineering, and discrete event

simulation(de Souza, 2009, p. 125) to overcome their inherent limitations have been tried, all arising from the authors' observations that single methodologies are rarely a one-size-fits-all solution. Yasin et al (Yasin, Zimmerer, Miller, & Zimmerer, 2002) conducted an investigation to evaluate the effectiveness of some managerial philosophies applied into a healthcare environment. The authors report that "it is equally clear from the data that some tools and techniques were more difficult to implement than others" (Yasin et al., 2002, p. 274), implying that many of the failures were due to inadequate implementations or lack of understanding of the scope. From a systems thinking perspective, these two types of failures in implementing a methodology are explained by the methodology's inability to deal with very specific problem situations. This supports the point that a complementarist industrial engineering and engineering management - systems thinking approach can be explored by taking an atypical approach by tackling ""small"" problems, instead of large and complex problems. This approach should convince management of the effectiveness of a complementarist managerial philosophy using systems thinking.

Systems Thinking

Formalized systems science theory, and applied methodologies date back to the middle of the 1900's with the strong contributions by Ludwig von Bertalanffy's general system theory, Jay Forrester's system dynamics, Russell Ackoff's , Churchman's and Maturana and Varela's autopoiesis.

The Engineering Management practice is teleologically oriented. That means that the focus on the development of theories and their application is goal-seeking or purposeful. Systems thinking is also teleologically oriented. Engineering management and systems thinking are oriented to provide solutions for systems that can display choice of means and/or ends.

[The systems age] is interested in purely mechanical systems only insofar as they can be used as instruments of purposeful systems. Furthermore, the Systems Age is most concerned with purposeful systems, some of whose parts are purposeful; these are called social groups. The most important class of social groups is the

one containing systems whose parts perform different functions, that have a division of functional labor; these are called organizations. Systems-Age man is most interested in groups and organizations that are themselves parts of larger purposeful systems. All the groups and organizations, including institutions, that are part of society can be conceptualized as such three-level purposeful systems. There are three ways in which such systems can be studied. We can try to increase the effectiveness with which they serve their own purposes, the self-control problem; the effectiveness with which they serve the purposes of their parts, the humanization problem; and the effectiveness with which they serve the purposes of the systems of which they are a part, the environmentalization problem. These are the three strongly interdependent organizing problems of the Systems Age (Ackoff, 1973, p. 666).

When healthcare managers embark on the implementation of a EHR, or a new billing procedure –large purposeful systems, change management is a key element of such purposeful system.

Critical Systems Thinking

Critical systems thinking embraces five major commitments by seeking to demonstrate critical awareness, showing social awareness, dedication to achieve human emancipation, commitment to the development of complementary and informed development of systems thinking methodologies at the theoretical level, and commitment to the complementary and informed use and application of methodologies (Flood, 2010, p. 279; Jackson, 1991, pp. 184-187).

System dynamics

System dynamics creates diagrammatic and mathematical models of feedback processes of a system of interest. Models represent levels of resources that vary according to rates at which resources are converted between these variables. Delays in conversion and resulting side-effects are included in models so that they capture in full the complexity of dynamic behaviour. Model simulation then facilitates learning about dynamic behaviour and predicts results of various tactics and strategies when applied to the system of interest (Flood, 2010, p. 273).

System dynamics was developed by Jay W. Forrester to model feedback loops in systems where non-linear time dependent interactions are present. System dynamics presents a powerful approach to modeling complex systems in accordance to what their internal

structure and interactions actually are, and not in accordance to what statistics and/or mathematical models suggest alone. Feedback is present in non-linear systems where its components sustain complex interactions and that emergent properties arise from such interactions. With the use of level and rate variables, it is possible to model the interactions and feedback loops between system components. Dynamic modeling can help identify lack of understanding of a process or system, and to identify what are the most important variables in a process or system (Hannon & Ruth, 2001, p. 10).

Senge (2006) advocated for the use of systems thinking as the quintessential tool to enhance the efficacy of managerial endeavors. As Forrester's disciple, Senge's approach is focused on the use of system dynamics, and causal loop models.

The foundation blocks, or the common structures that describe all systems are the level and rate equations (J.W. Forrester, 1961, 1968; 1971). Level equations result from integrations of flows proceeding from rate inflow equations minus the integration of rate outflows equations over time (see Equation 5-2).

In its simplest form, a rate equation depends on the state of the level variable. A rate equation regulates, depending on the state of the level variable the flow rate (see Equations 5-1 and 5-2).

$$Level_t = \int_{t=0}^n Inflow Rate - \int_{t=0}^n Outflow Rate \quad \text{Equation 5-2}$$

$$Rate_t = \frac{dLevel}{dt} = Inflow Rate_t - Outflow Rate_t \quad \text{Equation 5-2}$$

There are two graphical tools to represent the relationships expressed in Equations 5-1 and 5-2: Causal Loop Diagrams, and Level and Rate diagrams. A causal loop diagram is a graphical representation of the interactions between the level and rate variables in the system. In Figure 5-1 we can see the graphical representation of Equations 5-1 and 5-2.

The state of the level is determined by the inflow and outflow rates. The arrows connecting the variables indicate the nature of the relationship (feedback) between them. A positive feedback means that the rate change will be in the same direction as the change observed in the level. A negative feedback means that the rate change will be in the opposite direction of the change observed in the level. For instance, if the state of the level increases, the inflow rate will decrease.

Figure 5-1 Causal Loop Diagram

Figure 5-2 shows a Level and Rate diagram where the rate of flow and stock of goods, materials, money, information, etc. is represented by valves and stock components. The valves (Inflow and Outflow Rates) are controlled by the feedback received from the stock variable (Level).

Figure 5-2 Rate and Level Diagram

A system dynamics model is constructed using, according to Forrester (1971; 1961, 1968) from the use of mental, written, and numerical databases (see Figure 2-8). Different components of the model are extracted from these databases allowing the model to replicate the real system characteristics accurately.

Figure 5-3 Mental Data Base and Decreasing Content of Written and Numerical Data Bases

Barlas (1996) presents a guideline on generalized steps employed to develop a system dynamics model:

1. Problem identification
2. Model conceptualization (construction of a conceptual model)
3. Model formulation (construction of a formal model)
4. Model analysis and validation
5. Policy analysis and design
6. Implementation

The construction of a conceptual model is generally aided by the use of causal loop diagrams.

Causal loop diagrams as mental models

Systems thinking authors such as Peter Checkland (1979a, 1979b, 1981, 1985, 1988, 1999, 2000; Checkland, Forbes, & Martin, 1990; Checkland & Scholes, 1990) and Forrester (1961, 1971a, 1971b, 1980, 1987a, 1987b, 1991, 1992, 1994, 1995, 1999; J. Forrester, Low, & Mass, 1974; J. Forrester & Senge, 1980) advocate for the use of mental models to better understand, or learn about the system at hand. “The real value of modeling is not to anticipate and react to problems in the environment, but to eliminate the problems by changing the underlying structure of the system” (Sterman, 2000, pp. 655-656). Causal loop diagrams help the practitioner to uncover the underlying structure of the system.

Efficiency, efficacy, and effectiveness of a model

When creating any model, the purpose, objectives, and benefits expected—or ends—and the resources available – or means—must be clearly stated. Proper allocation of means and ends can be balanced through their efficient, efficacious, and effective use within a model. Efficiency refers to the ratio between resources used and their product (or what the outcome is). A system is efficient if the value of the outcome or the benefit is perceived to be higher than the value of the resources employed to produce/generate it.

An efficient model should minimize efforts while maximizing the value of outcomes. Unfortunately when special attention is paid to the means to achieve the ends a paradox arises. This contradiction takes place because as more resources are invested to increase the value of the benefits, those resources become more costly, making it impossible to reach a superior model, leading to a compromise in end quality so that the feasibility of a model is maintained (see Figures 5-2 and 5-4)

$$Efficiency = f(value) = \frac{\sum Benefits}{\sum Resources} \text{ where:} \quad \text{Equation 5-3} \quad \text{Efficiency in model development}$$

Resources = time allocated, personnel, money invested

Benefits = accuracy, completeness, robustness

Efficiency < 1 (ideally should be ≥ 1)

Figure 5-4 Ratio relationship between Resources and Benefits to achieve efficiency

Efficacy refers to the ability a system has to perform as and/or do what it is designed to do. That is, the ends are what matters, regardless of the means employed. It is then, as presented in the previous section, that achieving efficacy in a model results in a paradox, but nonetheless is a highly desired characteristic.

Effectiveness refers to the alignment of what the system actually does and what the system is supposed to do. That is, it questions the adequateness of the outcome produced by the system. A system may be efficient and/or efficacious within its own design but still fail to perform as desired, not effective⁴. Hence, a model is only effective if its performance –regardless of its complexity—is aligned with what it is expected to do.

⁴ It is important to note that defining efficiency and efficacy carefully is important to approach the expected behavior of the model.

Thus, efficiency, efficacy and effectiveness, can be used to validate a model.

Procedure depends on the purpose, so the procedure presented here is valid within that premise.

Model Validity in a System dynamics Model

C.I. Lewis (1924), states that knowledge is probable only if our experiences and/or interpretations of the object (what we are studying, a model for instance) and the a priori (knowledge of the real world) –through our senses are in accordance to each other. Also that empirical truth is possible through conceptual interpretation of the given, hence we can have an empirical object, an imaginary construct of a reality extrapolated from our own past experiences – an a priori. Hence, a model is a valid construct to depict a system, a selected set of parts, interactions, and characteristics of a particular given.

Validity means “adequacy with respect to a purpose” (Barlas, 1996, p. 188). Thus, if a model is efficient, efficacious, and effective, it is valid. However, the process of model validation has to use semi-formal and subjective components (Barlas, 1996, pp. 183, 184). For instance, a white-box model –a system dynamics model, is built to reproduce/predict the real world behavior, and to explain how the behavior germinates. Ideally, the model should also suggest ways of changing the existing behavior (Barlas, 1996, p. 186).

System dynamic models are built to assess the effectiveness of alternative policies or design strategies on improving the behavior of a given system. Therefore, “a valid model [is] one of many possible ways of describing a real situation” (Barlas, 1996, p. 187).

Barlas (1996) presents a summary of activities that can be used to validate a system dynamics model based on a literature review (see Figure 5-5).

Figure 5-5 Overall nature and selected tests of formal model validation

The structure confirmation test, requires comparison of the form of the equations of the model against the real system (J. Forrester & Senge, 1980) as part of the mental database and correspondence with the numerical database (as presented in Figure 5-3). The comparison to the written database is called a theoretical structure test. It is conducted by comparing the model equations with knowledge found in the literature (Barlas, 1996, p. 190).

The information used to validate the structure of the model is qualitative in nature, a process similar to the validation of computer models in that the structures and data flows are compared to the real world. It is important to test individual expressions to extreme conditions and see if they still behave in a manner that could be expected in the real world. Structural tests should be applied to the whole model and to subsections of the model through simulation of normal and extreme conditions. With these tests, the sensitivity of the model is to be uncovered, changes can be made, or at least unreliable operation conditions are uncovered.

Learning Curve Theory

The organizational learning curve was first explored by Wright-Patterson (1936), who observed that unit labor costs in air-frame fabrication declined with cumulative output. From Levy (1965), Newnan, Eschenbach, and Lavelle (2004), and Yelle (1979) the general form of the learning curve model is extracted and presented in Equation 5-4:

$$T_N = T_{Initial} \times N^b \quad \text{Equation 5-4}$$

where
$$b = \frac{\log(\theta)}{\log 2.0}$$

and T_N = time requirement for the Nth unit of production
 $T_{Initial}$ = time requirement for the initial unit of production
 N = number of completed units (cumulative production)
 θ = learning rate expressed as a decimal
 $1 - \theta$ = The progress ratio

Relevant learning curve theory to this research work

Argote and Epple (1990) identified that organizational forgetting, employee turnover, transfer of knowledge across products and organizations, incomplete transfer within organizations, and economies of scale are factors that produce variability in learning curves across organizations.

Wyer and Lundberg (1956; 1953) propose that the learning curve slope is affected by the amount of planning put forward by management. Adler and Clark (1991) propose a model that focuses on single -traditional experience variables and double loop learning - two key managerial variables (engineering change and training). The authors conclude that the learning process can vary significantly between departments and that learning can be intensive in labor and capital intensive operations. Adler and Clark (1991) first proposed and Lapré, Mukherjee, & Van Wassenhove (2000) confirmed that induced learning can facilitate or disrupt the learning, stressing the importance that management involvement has.

Adler and Clark (1991) posit that the “human learning process model begins with the relationship between experience and the generation of data driven by that experience” (p. 270). As more data is generated, it is processed by the organization leading to the creation of new knowledge, which in turn leads to a change in the production process. Part of this new knowledge directly affects single-loop learning based on repetition and on the associated incremental development of expertise. This learning helps workers or direct laborers be more effective at their jobs. The other part of the knowledge generated will affect the double loop learning process. Here, the learning takes place in the management environment, where decision rules, data interpretation and data generation are adapted to be in line with newly acquired knowledge to increment output. The authors caution that even though a double loop-learning model is certainly a facilitator of learning, it can disrupt knowledge either temporarily or permanently depending on

management's understanding of the learning system. It is worth noting that Adler and Clark's model is consistent with Stern's (2000) double loop-learning model presented in Chapter 2.

Formal training and equipment replacement illustrate how managerial decision making is improved due to a better understanding of past behavior (Yelle, 1979, p. 309), as a result of double loop learning. Adler and Clark also express that training time should lead to improvement in worker performance concluding that experience is also affected by training. Learning in management is prompted by the problems encountered throughout the production process. The new policies generated by management should result in improved productivity. Figure 2.3 presents Adler and Clark's learning process model.

Figure 5-6 Learning Process Model

Adaptation Function Learning Model

Levy (1965) believes that the planning process can be improved through a better understanding of how the individual worker, as well as the firm, have historically adapted to past learning situations. Furthermore, Levy posits that the lack of a goal seeking behavior in traditional learning curves is not realistic. For that reason, Levy proposes an alternative to the traditional learning curve model:

$$Q(t) = P[1 - e^{-(a+\mu t)}] \quad \text{Equation 5-5}$$

where

$Q(t)$ = percentage of errors per day at time t

P = desired rate of output expressed in errors per day

a = initial efficiency of the process expressed in percentage of errors

μ = process rate of adaptation expressed in percentage of errors

t = cumulative time

“We suggest that the firm's cumulated experience or stock of knowledge on a particular job at a specified time can be summarized in the stock of the product it has produced up to that time. Thus, as the firm produces more and more of a given product, it increases its stock of knowledge on that product and is able to come closer to the desired rate of output” (Levy, 1965, pp. B-137).

The model assumes that there is a known, or expected, level of performance P =desired rate of output. It also assumes that the process will start at an unwanted or initial rate of output $Q(q)$ with $q=0$. As q starts to increase, $Q(q)$ will approach P at a rate determined by a and μ . Levy suggests that the initial efficiency of the process (a) is an estimation of the amount of training provided to the worker. The process rate of adaptation (μ) is a function of different variables that influence the rate at which an organization can learn. The process rate of adaptation then is influenced by the experience the worker has in similar job functions. That is, the more experienced a worker is, the faster he/she will be

able to identify problems with the process and find solutions. With that, Levy suggests that learning can happen in three different ways: autonomous learning, planned or induced learning, and random or exogenous learning. Induced learning is influenced by pre-planning activities such as mock runs, pre-production models, tooling determination, etc, and by industrial engineering tools such as time and motion studies, and control charts after the process starts. Random or exogenous learning happens when the form gains knowledge of the process from unexpected sources such as new materials characteristics, suppliers, government, etc. Finally, autonomous learning happens as the worker gains more experience with the actual process and identifies ways to improve or make more efficient his/her tasks.

Carrillo and Gaimon (2000) introduce a dynamic model to maximize profit in a process change strategy. The model seeks to identify optimal process rate change (and when the change should start – rate and timing for investment in process change) subject to the ratio of cost to marginal contribution of preparation/training times to effective capacity, cumulative knowledge, and marginal revenues produced by the new process. The authors state that the input parameters can be adjusted to run different scenarios to select the appropriate process change alternative.

Levy's adaptation function (1965) introduces a goal-seeking behavior to the learning curve body of knowledge. Equation 5-1 will generate a diminishing goal seeking behavior until the initial percentage of errors per day reaches the desired percentage of errors per day. Figure 5-1 presents the expected behavior over time as expressed by Equation 5-1.

Figure 5-7 Levy's Adaptation Function seen as behavior over time graph

The initial approach to link the adaptation function behavior to a system archetype is to look at the 'balancing loop' structure and its corresponding behavior over time (see Figure 5-1). When the desire state and the current state interact they create a gap, measured as the difference between the desired and the current state. An action then causes the current state to move towards the desired state thus reducing the gap, and then reducing the magnitude of the action until the gap approaches 0.

Figure 5-8 'Balancing Loop' Causal Loop Diagram and Behavior Over Time Graph

At first glance, the 'balancing loop' appears to be a good fit to the behavior over time described in Figure 5-1. However, in reality a transition-phase will not occur without glitches or inconsistencies – a limitation that the adaptation function possesses. For instance, the balancing loop ignores the effects of factors like forgetting, employee absenteeism, different levels of experience, varying learning abilities, pressure to adjust the goals, and pressure to complete the project on time.

The 'drifting goals' archetype considers negative effects from low levels of experience, and learning abilities which may result in changes on deadlines, or target state. Figure 5-3 presents the 'drifting goals' archetype using causal loops.

Figure 5-9 'Drifting Goals' Causal Loop and Behavior Over Time Graph

Notice how the lack of convergence from the current state concerning the desired state generates pressure to adjust either the target percentage of errors per day or the deadline. On the other hand, the current state may differ from the desired state due to errors in planning that cause unintended consequences. The 'fixes that fail' archetype would be the option. Figure 5-4 presents the 'fixes that fail' archetype in causal loop format.

Figure 5-10 'Fixes that Fail' Causal Loop and Behavior Over Time Graphs
The 'drifting goals' and 'fixes that fail' archetypes provide more complete solutions than the 'balancing loop' archetype and/or the adaptation function alone. However, if used separately they provide an incomplete solution. Figure 5-5 presents the combination of the 'balancing loop' with the 'drifting goals' and 'fixes that fail' archetypes. This new

structure derived from a complementarist approach is called the adaptation function causal loop.

Figure 5-11 Adaptation Function Causal Loop Diagram

The action variable is a result of learning ability or efficiency of the process and process rate of adaptation. The authors propose efficiency of the process and process rate of adaptation as actions and autonomous learning (lack of) as unintended consequences. Levy (1965) suggests that there are three types of adaptation processes. The first one is planned or induced learning that impacts directly the potential efficiency of the process. The second one is random or exogenous learning, resulting from information received about the process that could not be anticipated or planned for and it impacts the process rate of adaptation. The third type is autonomous learning, which results from planning and on-the-job learning mitigating the effects of unintended consequences..

Efficiency of the Process

Levy posits that the less the firm pre-plans, the more opportunity there would be for the firm to improve its operation. He suggests that the amount of planning should be inversely related to the rate of learning (Levy, 1965, p. B139). However based on Figures 5-2 to 5-5 it is possible to conclude that the less the firm plans (efficiency of the process) the bigger the gap will be and the larger the unintended consequences will be.

Therefore factors that can be controlled before the new process implementation and that are endogenous to the organizational structure such as training, business seasonality, organizational culture and technology available are determine the efficiency of the process.

Process rate of adaptation

The process rate of adaptation is composed by variables that are affect the implementation process during the implementation process such as learning ability, employee's experience, and education. That is, the faster the organization adapts to changes, the smoother the implementation will be (it will reduce the oscillation) and the faster it will converge with the desired state.

Unintended consequences (or damping factors)

Autonomous learning is according to Levy (1965) a result of the efficiency of the process and the process rate of adaptation. Autonomous learning will be considered as negative unintended consequences; that is, the less autonomous learning there is, the bigger the effect of the unintended consequences will be.

Research Question

Thus, the concern addressed in this research is: Can a generalized system dynamics transition-phase management model be developed by combining adaptation function theory and system dynamics?

Model Development – System Identification

Development of the substructures requires the development of operational definitions for each factor. Each factor is evaluated, based on their operational definition, in accordance to a general rubric (see Table 5-1)

Table 5-1 General Rubric to Evaluate Factors

Grade	1	2	3	4	5
Meaning	Very Poor or non-existent	Poor	Average	Above average	Superior or excellent

Managers wishing to evaluate their organization's capacity to implement a new process need to grade each one of the factors in accordance to their operational definitions as suggested in the general rubric (Table 5-1). Grades do not have to be integers.

Efficiency of the Process substructure (a)

In this sub-structure the factors that have an effect on the efficiency of the organization to implement new processes are considered. The factors were selected in accordance to mental data bases (see Figure 2-8) after informal interviews with healthcare managers. It is worth noting that in independent interviews, the managers listed the same factors.

The efficiency of the process substructure is designed to calculate the magnitude of its impact to the current percentage of errors per day (Q_t) and to determine delays resulting from the factors values. Figure 5-1 presents the resulting structure:

Figure 5-12 Efficiency of the Process Sub-structure (a)

Adequacy of Technology in Company

This factor identifies how efficient, efficacious and effective is the current technology (computing, software, communications) with regards to the company's operations. For instance, a grade of 1 may indicate that not even the most basic tasks are supported correctly by the current technological standards. A grade of 5 may represent that there is room for improvement, but all basic operations are satisfied with current standards. A grade of 10 may indicate that all technology is state-of-the-art and the company is leader in operations and standards.

Adequacy of Technology for Project

Identifies how efficient, efficacious and effective is the current technology (computing, software, communications) with regards to the proposed new process requirements. For instance, a grade of 1 may indicate that not even the most basic tasks would be supported correctly by the current technological standards. A grade of 5 may represent that there is room for improvement, but all basic operations would be satisfied with current standards. A grade of 10 may indicate that all technology is state-of-the-art and the company is

leader in operations and standards. Note: both technology factors are evaluated on a scale of 1-10.

Training Frequency

Training frequency refers to how close from each other are held the training sessions. A grade of 1 represents a daily training schedule. A grade of 2 represents a 3 day a week training schedule. A grade of 3 represents 2 days a week training schedule. A grade of 4 represents 1 day per week training schedule. And a grade of 5 represents less than one day a week training schedule.

Training Duration

Training duration refers to the length of each training session. A grade of 1 represents a session shorter than 1 hour. A grade of 2 represents a session of 1 hour. A grade of 3 represents a session of 1.5 hours. A grade of 4 represents a session of 2 hours. A grade of 5 represents a session longer than 2 hours.

Business Seasonality

Business seasonality refers to the state of the business cycle in a healthcare provider, i.e. if it is flu season, budgeting season, etc. A grade of 1 refers to a very busy business cycle (i.e. flu season, financial reports) and a grade of 5 represents a slow business cycle (meaning priority can be placed to the new process implementation).

Organizational Culture

Organizational culture refers to the flexibility and organizational climate in the organization with respect to new process adoption. A grade of 1 represents a very poor organizational culture. A grade of 5 indicates excellent organizational culture.

Maximum delay expected

Managers should make an assumption on what they expect to be the longest delay that could be caused by the factors within the structure.

Does the Project Demand Changes in Technology?

This factor does not mean the changes will be made, it only considers whether a change is required. This is a binary grade factor where a grade of 0 means the project does not require a change and a grade of 1 means the project does not demand a change in technology. An example would be if the new process requires the use of tablets and wireless communications and the organization does not possess tablets and/or the current technology does not support wireless communications.

Process Rate of Adaptation substructure (μ)

In this sub-structure the factors that have an effect on the process rate of adaptation to implement new processes are considered. The factors were selected in accordance to mental data bases (see Figure 2-8) after informal interviews with healthcare managers. It is worth noting that in independent interviews, the managers listed the same factors.

The process rate of adaptation substructure is designed to calculate the magnitude of its impact to the current percentage of errors per day (Q_t) and to determine delays resulting from the factors values. Figure 5-2 presents the resulting structure:

Figure 5-13 Process Rate of Adaptation Sub-Structure

Feedback Turnover Time

Feedback turnover time refers to how long does it take for the implementation team to address inquiries from end users. This is an estimation that has to be made with the best knowledge available. The value is to be expressed in days. The rubric is not required for this factor.

Implementation Team Effectiveness

Measures how experienced, cohesive and dynamic the implementation team is. It is measured with respect to the expected impact it can have on the transition phase. A grade of 1 represents a very poor or negative impact and a grade of 5 represents an excellent positive impact.

Staff Learning Rate

Staff learning rate refers to the overall learning ability of the staff. A grade of 1 represents a very poor learning rates and a grade of 5 represents excellent learning rates. It is to be expressed as an average of all involved staff in the new process operations.

Communication Skills

Communication skills refer to the organization's personnel ability and willingness to communicate with each other. A grade of 1 represents very poor communication skills and a grade of 5 represents excellent communication skills.

Staff Experience

Staff experience refers to the level of experience that the staff possesses both in professional jobs and in a job related to their current one. A grade of 1 indicates no at all and a grade of 5 indicates a high level of relevant experience.

Staff Educational Level

Staff educational level refers to the minimum and maximum academic levels achieved by the staff. A grade of 1 indicates incomplete K-12 education. A grade of 5 indicates graduate degrees.

Feedback Turnover Time

Refers to the expected normal time to receive, acknowledge and resolve issues. It is expressed in days.

Damping Factors Sub-Structure

The damping factors sub-structure calculates the magnitude of a unexpected consequences based on the existence of standard operating procedures (SOPs) and the effect of forgetting. In the main structure it reacts to the values generated by the efficiency of the process and process rate of adaptation sub-structures.

Figure 5-14 Damping Factors Sub-Structure

Forgetting

It is an estimation of the percentage of training and process details expected to be forgotten by the process users.

Existence of SOPs (Standard Operating Procedures)

A grade of 0 represents no presence of SOPs for the new process. A grade of 1 represents existence of SOPs for the new process.

All factors were determined based on Figure 5-3 approach using as mental database the interviews with the managers and by identifying the five *Ms+E* (Measurements, Materials, Personnel, Environment, Methods and Machines) from Ishikawa's fishbone diagram and adapting them to the particular activities within a healthcare environment. The written database from the literature review validated the observations from the managers and their interpretations of Ishikawa's five *Ms+E*.

Model Validation - Simulation

In this section, a sensitivity analysis is presented varying the ranges of inputs of different sets of variables and to all input variables at once and their effects to the initial state (Q_0), current state (Q_t), gap (Q_0-P_0), all efficiency of the process (a) factors, and all process rate of adaptation (μ) factors. Table 5-2 presents a relation between the parameters being tested and the corresponding Figure according to the function employed.

Table 5-2 Relation of Validation Tests, Parameters and Corresponding
Figure

Test #	Parameters	Figure	
		Uniform	Triangular
1	P_0 and Q_0	5-4	
2	All sub-structures factors	5-5	
3	All sub-structures factors, P_0 and Q_0	5-6	5-9, 5-11, 5-13
4	Pessimistic scenario with all sub-structures factors set at 1	No Distribution	5-7 (a)
5	Moderate scenario with all sub-structures factors set at 3		5-7 (b)
6	Optimistic scenario with all sub-structures factors set at 5		5-7 (c)
			5-8 5-10 5-12

The tests were performed using the built in sensitivity analysis in Vensim Professional software. Each parameter possible value is explored either using a uniform or a triangular distribution. 10,000 replications were conducted for each sensitivity test. A time frame of 90 days was set.

Extremes tests

In this section, Figures 5-15 to 5-18 show the results of sensitivity analysis by testing the model throughout its extreme values. The tests serve to investigate if the model behaves in unexpected ways, and as it can be observed it does not.

Figure 5-15 Sensitivity analysis varying P_0 and Q_0 using uniform distribution. The rest of the parameters are set to a moderate scenario (Value of 3).

Notice that when all parameters are set to a moderate scenario and the initial and desired states are tested the expected behavior described in section 2.3. In addition, it can be observed some pressure to adjust the goal is present, a behavior that arises when oscillation is high helping $Q_t - P$ reach a value of 0.

Figure 5-16 Sensitivity analysis varying all factors in substructures using a random uniform distribution P_0 and Q_0 fixed.

Notice how when all factors are randomly varied, the distribution of possible outcomes becomes wider and the pressure to adjust the goal (P) is incremented substantially. In this test it is possible to observe that all possible behaviors that the model can generate are consistent with section 2.3. The center line indicates the average of all 10,000 runs.

Figure 5-17 Sensitivity analysis varying all factors in substructures and P_0 and Q_0 using a random uniform distribution.

All factors plus P_0 and Q_0 are varied throughout the whole range of values in accordance to section 2.3 depicting all possible values the model can generate showing no undesired behavior.

Figure 5-18 Discrete analysis setting all factors in to a pessimistic (a), moderate (b), and optimistic (c) scenarios with $P_0=10\%$ and $Q_0=50\%$.

As can be seen the behaviors over-time depicted in Figures 5-18 a, b and c are consistent with those from Figure 5-15 to 5-17.

Substructures effect on Q_t

In this section a sensitivity analysis is run just varying separately the factors of each structure.

Figure 5-19 *a* substructure impact on Q_t

Figure 5-20 μ substructure impact on Q_t

Figure 5-21 F substructure impact on Q_t

Figures 5-20, 5-21 and 5-22 demonstrate that a , μ , and F substructures do have an effect on the percentage of errors per day (Q_t). Note that if there is an increase in P , B is having an effect it means the goal $Q_t - P \rightarrow 0$ is not being met therefore inducing pressure to adjust the goal.

Bias analysis

Next sensitivity simulations using triangular distributions to vary the factor values in accordance to a pessimistic, moderate and optimistic scenario (much like Figure 518) are presented.

Figure 5-22 Sensitivity analysis using triangular distribution with peak set to pessimistic scenario varying all factors in substructures (value of 1).

Figure 5-23 Sensitivity analysis using triangular distribution with peak set to pessimistic scenario varying all factors in substructures (value of 1) plus varying P_0 and Q_0 .

Figures 5-23 and 5-24 portray a sensitivity analysis with a bias towards a pessimistic scenario using a triangular distribution.

Figure 5-24 Sensitivity analysis using triangular distribution with peak set to moderate scenario varying all factors in substructures(value of 3).

Figure 5-25 Sensitivity analysis using triangular distribution with peak set to moderate scenario varying all factors in substructures (value of 3) plus P_0 and Q_0 .

Figures 5-25 and 5-26 portray a sensitivity analysis with a bias towards a moderate scenario using a triangular distribution.

Figure 5-26 Sensitivity analysis using triangular distribution with peak set to optimistic scenario (value of 5)

Figure 5-27 Sensitivity analysis using triangular distribution with peak set to optimistic scenario (value of 5) including P_0 and Q_0 .

Figures 5-27 and 5-28 portray a sensitivity analysis with a bias towards an optimistic scenario using a triangular distribution.

Conclusions

Can the model developed serve as a generalized system dynamics transition-phase management model? Figures 5-4 to 5-15 present evidence to answer affirmatively the question.

Dampened Oscillation

In detail, Figure 5-4 tests the effects that varying the initial state of the system or initial percentage of errors per day Q_0 , desired percentage of errors per day P_0 separately and then together have on the percentage of errors per day, pressure to adjust the goal and the gap ($Q_t - P$). The rest of the parameters are set to a moderate scenario (mid values throughout their range). It shows that varying initial percentage of errors per day Q_0 and desired percentage of errors per day P_0 create oscillation and that the bigger the difference between Q_0 and P_0 the larger the oscillation is and the smaller the effect of the dampening is. That combination produces pressure to adjust the goal when the oscillation is larger and the effects of the dampening are small. For managers, it means that in order to reduce instability of the process, it is necessary to reduce the gap between Q_0 and P_0 by either reducing Q_0 or by increasing P_0 .

Path Forecasting

Figure 5-5 presents a simulation varying all factors but Q_0 and P_0 with their gap set to be 40% of errors per day. The rest of the factors are varied using uniform distribution assuming same probabilities for each of their values to occur. The results show the full range of paths that a process can take assuming a moderate gap size (Q_0 and P_0). When factors combine in their highest values the dynamic equilibrium state is reached fast, and when factors combine in their lowest values the process can completely go out of control.

Figure 5-6 presents the full potential range when all factors are varied uniformly. The range of paths is increased as the amplitude of the oscillation. Managers can understand periods of instability (non-dynamic equilibrium) and expected performance (path) of the

implementation process. As an illustration, Figure 5-7 presents specific cases where all factors are set to pessimistic (5-7a), moderate (5-7b) and optimistic scenarios (5-7c).

Effects of the substructures on the percentage of errors per day

Figures 5-8, 5-9 and 5-10 explore the effects that each of the substructures a (efficiency of the process), μ (process rate of adaptation) and F (damping factors) have on Q_t (percentage of errors per day). Figure 8 shows how the efficiency of the process has a bigger effect on the amplitude and dampening of the oscillation, an effect that is consistent with the definition of efficiency of the process provided in the introduction section. It means that managers can invest more in their organizational structure to minimize instability and/or to accelerate the rate at which the new process can reach dynamic equilibrium.

Figure 5-9 shows how the implementation of the new process path can vary; if the parameters are set at a pessimistic scenario the path will move further away from the desired state. Conversely, if the parameters are set to an optimistic scenario then the path will converge faster with the desired state (it will reach dynamic equilibrium faster).

Figure 5-10 shows the effects that the damping factors have on the percentage of errors per day. If the parameters are set to a pessimistic scenario, then the effect of the shortages in a and μ are accentuated creating big deviations and large delays on the response times.

Model behavior in pessimistic, moderate and optimistic scenarios

Figures 5-11 to 5-16 present the results of sensitivity simulations varying all parameters, and all parameters minus Q_0 and P_0 using a triangular distribution setting the peak at pessimistic, moderate and optimistic scenarios. Odd numbered Figures show simulations

with all parameters but Q_0 and P_0 and even numbered Figures show simulations varying all parameters.

Figures 5-11, 5-13 and 5-15 show the distribution density of the paths using all parameters sans Q_0 and P_0 being consistent with the bias incorporated into the simulation by the triangular distribution. Figures 5-12, 5-14 and 5-16 show the show the distribution density of the paths using all parameters being consistent with the bias incorporated into the simulation by the triangular distribution. The latter means that the model is accurate in predicting the paths, periods of instability and when the dynamic equilibrium is expected to be reached.

Future Work

The results from the sensitivity simulations are encouraging. The model behaves according to the theory and is capable of forecasting different behaviors arising from all factors' possible combinations.

The model still requires to be tested in real life projects to better assess its accuracy and reliability. For that, future work requires the application of the model in real world scenarios exploring projects that present different completion lengths and differences between Q_0 and P_0 .

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CHAPTER VI

APPLICATION OF TRANSITION-PHASE MANAGEMENT MODEL IN BILLING HEALTHCARE ENVIRONMENT

Abstract

The implementation of an electronic health records system requires changes in processes, which in turn require management of such transition-phases. Electronic health records systems implementations are composed of various subsystems such as medical, clerical, administrative and billing. The complexity of each an electronic health records implementation in each of these subsystems is affected by project length, and size measured by the number of places it is deployed and the timing of each deployment. An evaluation of the transition-phase management model on a long term multi-phase electronic health records implementation process is presented. Analysis of the adequacy and accuracy of the model is provided and guidelines for interpretation are suggested.

Introduction

The transition-phase management model, developed by Calvo-Amodio, et. al. (201X) present a method to evaluating the capabilities of an organization to implement an electronic health records system according to their current state and resources available. In this paper, the transition-phase management model is evaluated against a multi-phase long term electronic health records system implementation project.

Background

Attempts to better manage healthcare organizations have been made using lean thinking. De Souza (2009) proposes a taxonomy of the application of Lean thinking on healthcare through a literature review. De Souza divides the lean healthcare literature into two categories: case studies and theoretical, concluding that lean healthcare appears to be an

effective way to better healthcare organizations. He argues that lean is a better fit to healthcare as it is more adaptable in healthcare settings than other management philosophies, the potential it has to empower staff along with the concept of continuous improvement. He states that it “is believed that lean healthcare is gaining acceptance not because it is a ‘new movement’ or a ‘management fashion’ but because it does lead to sustainable results” (p. 122). Lean healthcare is a relatively new concept, as can be seen in the history of lean thinking in a Figure De Souza adapted from Laursen et al. (2003, p. 3) (Figure 2-1).

Figure 6-1. The appearance of lean healthcare.

As can be observed in Figure 6-1 (de Souza, 2009, p. 123), lean healthcare is relatively a new practice and research area. As would be expected, there is still much work to be done. Berwick, Kabacoff, & Nolan (2005) mention that lean healthcare, although is on the right path, still has a long way to go to be comparable with mainstream applications of lean thinking.

De Souza concludes that the majority of the literature is theoretical, with 30% being speculative and less than 20% being methodological in nature, and expects the field to grow in the near future.

Action Research

Action research “results from an involvement with members of an organization over a matter which is of genuine concern to them” (Eden & Huxham, 1996, p. 75). Action research was developed for research in management sciences. However, it should also provide a great tool for industrial engineering and engineering management research where a significant part of the focus on research is on problem solving applications. Action research is adequate for situations when the application of some knowledge (new or existing) into a particular problem context can have wider research consequences that are worth investigating. A practitioner can apply an industrial engineering and engineering management tool to a particular system. However, without a systemic thinking mode, the solution may end up causing some undesired effects within the same system and/or on a seemingly unrelated system. This can bring a methodological debate between practitioners and researcher as to how to address such vicissitudes.

Rosmulder et al (2011) explore the use of simulation models while conducting action research. They conclude that “the design of the simulation model would play a crucial role in the AR experiment” (p. 400). They stress that in order to have all the stakeholders willing to take action during the action research process; they should accept the model and have confidence in the structure and outcomes it generates.

Problem Context

In order to complete the validation of the model, it has to be compared against real world data. In this experiment focus is placed on a multiple-phase long-term project. Data about errors per day committed by end users of a new electronic health records process was provided by a local healthcare center.

Oral in-person sessions were conducted resulting in agreement of the healthcare center to provide qualitative and quantitative data regarding the implementation process. All identifiers from personnel related data were removed by the data providers, eliminating the possibility for the researcher to relate data to any staff member. The procedure for data collection and a handout containing the major steps are presented below.

Data Collection Procedure

Data was obtained through interviews with the process change manager. Table 6-1 presents a summary of the data required:

Table 6-1 Summary of Data

Variable		Output Value	Delivery Format
Adequacy of Technology in Company		1-10	Fill-in format to be provided to managers.
Refers to how well does the current technology (computing, software, communications) contributes to their operations. A grade of 1 represents very poorly and a grade of 5 excellent.			
Adequacy of Technology for Project		1-10	
Refers to how well does the current technology (computing, software, communications) is aligned with the process requirements of the new process to be implemented. A grade of 1 represents very poorly and a grade of 5 excellent.			
Training Frequency		1-5	
Training frequency refers to how close from each other are held the training sessions. A grade of 1 represents a daily training schedule. A grade of 2 represents a 3 day a week training schedule. A grade of 3 represents 2 days a week training schedule. A grade of 4 represents 1			

day per week training schedule. And a grade of 5 represents less than one day a week training schedule.	
Training Duration	1-5
Training duration refers to the length of each training session. A grade of 1 represents a session shorter than 1 hour. A grade of 2 represents a session of 1 hour. A grade of 3 represents a session of 1.5 hours. A grade of 4 represents a session of 2 hours. A grade of 5 represents a session longer than 2 hours.	
Business Seasonality	1-5
Business seasonality refers to the state of the business cycle in a healthcare provider, i.e. if it is flu season, budgeting season, etc. A grade of 1 refers to a very busy business cycle (i.e. flu season) and a grade of 5 represents a slow business cycle.	
Organizational Culture	1-5
Organizational culture refers to the flexibility and organizational climate in the organization with respect to new process adoption. A grade of 1 represents a very poor organizational culture. A grade of 5 indicates excellent organizational culture.	
Feedback Turnover Time	0-Project Duration
Feedback turnover time refers to how long does it take for the implementation team to address inquiries from end users.	
Implementation Team Effectiveness	1-5
Measures how experienced, cohesive and dynamic the implementation team is. It is measured with respect to the expected impact it can have on the transition phase. A grade of 1 represents a very poor impact and a grade of 5 represents a very good impact.	
Staff Learning Rate	1-5

Staff learning rate refers to the overall learning ability of the staff. A grade of 1 represents a very poor learning rates and a grade of 5 represents excellent learning rates.		
Communication Skills	1-5	
Communication skills refers to the organization’s personnel ability and willingness to communicate with each other. A grade of 1 represents very poor communication skills and a grade of 5 represents excellent communication skills.		
Staff Experience	1-5	
Staff experience refers to the level of experience that the staff possesses both in professional jobs and in a job related to their current one. A grade of 1 indicates no experience and a grade of 5 indicates a lot of relevant experience.		
Staff Educational Level	1-5	
Staff educational level refers to the minimum and maximum academic levels achieved by the staff. A grade of 1 indicates incomplete K-12 education. A grade of 5 indicates graduate degrees.		
Existence of SOPs	0 or 1	
A grade of 0 represents no presence of SOPs. A grade of 1 represents existence of SOPs.		
Desired Percentage of errors per day	0 to 100% calculated from number of errors committed per day divided by total number of transactions.	
Based on historical performance expectations before implementation		

Percentage of errors per day throughout the project duration	0 to 100% calculated from number of errors committed per day divided by total number of transactions.	Excel spreadsheet generated by managers from their databases.
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The data was filled using the control panel view of the model (Figure 6-1). The control panel is built to ease the input of factors' values and to allow the use of the SyntheSim mode in Vensim. The SyntheSim mode allows managers to vary factor values, test different policies and identify how they can best use their resources to reach the desired goal I accordance to Figure 2-19.

Table 6-2 presents the values for all sub-structure factors for the clinic. All these factors were provided by the clinic's process change manager based on his knowledge of the system. This data is of qualitative nature.

Figure 6-2 Control Panel View

Table 6-2 Short-term lived project parameters

Variable	Output Value
Adequacy of Technology in Company	6
Adequacy of Technology for Project	8.5
Does Project Demand Changes in Technology?	1
Training Frequency	1
Training Duration	5
Business Seasonality	5
Organizational Culture	4
Feedback Turnover Time	3
Implementation Team Effectiveness	3.75
Staff Learning Rate	3
Communication Skills	3
Staff Experience	2
Staff Educational Level	3
Existence of SOPs	1
Expected % of Forgetting	40%
Desired Percentage of errors per day	20%

Long-term multi-phase project

The project is of a clerical section of an electronic health records implementation over a healthcare center's different clinics with different rollout times. The electronic health records implementation focused on the clerical work related to billing processes. The project was scheduled to last 440 days. Management expected the process to start with 80% errors per day; however data shows that 29.11% was the initial percentage of errors per day. The initial "low" percentage of errors per day can be attributed to being rolled out into only one clinic. However the percentage of errors per day increased as more clinics were rolled out as shown in Table 6-3 and Figures 6-3 to 6-5. Q_i represents the initial percentage of errors per day per new phase and T_i the time counted in days after the initial rollout.

Table 6-3 Multiple-Phase Factor Values

$Q_1 = 57\%$	$Q_2 = 51\%$	$Q_3 = 52\%$	$Q_4 = 51\%$	$Q_5 = 50\%$	$Q_6 = 69\%$
$T_1 = 159$	$T_2 = 224$	$T_3 = 237$	$T_4 = 265$	$T_5 = 387$	$T_6 = 435$

Figure 6-3 Historical Data Plot as Percentage of Errors per Day

Figure 6-4 Model Generated Data Plot as Percentage of Errors per Day

Figure 6-5 Model Generated Data vs. Historical Data Plot as Percentage of Errors per Day

Figure 6-6 Historical and Model Generated Data Variances Plot

Figure 6-7 Histogram of Differences Between Historical and Model Generated Data Plot

Conclusions

In Figure 6-5 it can be observed that the model does a good job at predicting the general path of the historical data. The oscillation shown is also in accordance to the manager's accounts of the implementation process, meaning that there was much instability in the implementation process. Figure 6-6 is presented to explain the differences observed in Figure 6-5. As expected the model generated data presents more variation, due to the intrinsic dampened oscillation, that indicates instability in the process. Figure 6-7 is a histogram calculated over the differences between the model generated data and the historical data; it shows that the model in a general sense does a decent job at tracking the real world data, but there is an inevitable bias due to the dampened oscillation.

Therefore, a good measurement to assess whether the model identified periods of instability and predicted the path would be to construct a histogram plot like Figure 6-7 and if the plot shows a similar shape, then it can be assumed that the model was accurate. The R^2 for the paired comparison of both data sets is 0.1149, indicating a low model

forecasting description capacity which confirms the observations presented in Figures 6-4, 6-5 and 6-6. This means that under long term projects the model is not to be used to forecast exact data patterns. It should be used to identify periods of instability (where oscillation exists), however the model is still capable to identify general trend of the transition-phase.

From the results it can be inferred that the model is adequate to predict periods of instability in the implementation process and the general path the real implementation will follow. Further experimentation is required to validate this observation and is discussed in chapter 8.

Future Work

Forecasting capabilities

Even though the results are encouraging, further experimentation to validate capabilities of the model to predict within short, mid and long term projects is necessary to better understand the capabilities of the model.

Further investigation on the meaning of the histogram and R^2

Even though Figure 6-7 and the R^2 values agree in the sense that the model does not do a good job at forecasting individual data points, further research is necessary to establish the exact relationship between these two tests and how to use them to have better understanding of the model.

Detailed measurement methods

Develop quantitative methods to estimate initial percentage of errors per day. This includes decrease in efficiency as a result of subsequent rollouts of new subsystems into the transition-phase.

Forecasting ability

Explore if higher resolution level and probably a dynamic behavior for the factors in each of the substructures can enhance the forecasting ability of the model.

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CHAPTER VII

APPLICATION OF TRANSITION-PHASE MANAGEMENT MODEL FOR AN ELECTRONIC HEALTH RECORD SYSTEM IMPLEMENTATION

Abstract

The implementation of an electronic health records system requires changes in processes, which in turn require management of such transition-phases. Electronic health records systems implementations are composed of various subsystems such as medical, clerical, administrative and billing. The complexity of each an electronic health records implementation in each of these subsystems is affected by project length, and size measured by the number of places it is deployed and the timing of each deployment. An evaluation of the transition-phase management model on a short and a mid-term electronic health records implementation process is presented. Analysis of the adequacy and accuracy of the model is provided and guidelines for interpretation are suggested.

Introduction

The transition-phase management model, developed by Calvo-Amodio, et. al. (201X) present a method to evaluating the capabilities of an organization to implement an electronic health records system according to their current state and resources available. In this paper, the transition-phase management model is evaluated against one short-term and one mid-term electronic health records system implementation project.

Background

Complementary use of methodologies with lean thinking

Several attempts to combine methodologies, such as managerial philosophies like total quality management, six sigma, theory of constraints, reengineering, and discrete event simulation(de Souza, 2009, p. 125) to overcome their inherent limitations have been

attempted, all arising from the authors' observations that single methodologies are rarely a one-size-fits-all solution. Yasin et al (Yasin, Zimmerer, Miller, & Zimmerer, 2002) conducted an investigation to evaluate the effectiveness of some managerial philosophies applied into a healthcare environment. The authors report that "it is equally clear from the data that some tools and techniques were more difficult to implement than others" (Yasin et al., 2002, p. 274), implying that many of the failures were due to inadequate implementations or lack of understanding of the scope. From a systems thinking perspective, these two types of failures in implementing a methodology are explained by the methodology's inability to deal with very specific problem situations. This supports the point that a complementarist industrial engineering and engineering management - systems thinking approach can be explored by taking an atypical approach by tackling ""small"" problems, instead of large and complex problems. This approach should convince management of the effectiveness of a complementarist managerial philosophy using systems thinking.

Lean Six Sigma

Consider the case of the Lean Six Sigma (LSS) philosophy as an example of a methodology that was built to enhance its constituent methodologies strengths and further their scope. On one end we have a six sigma focus on the "lowest hanging apples" (Arnheiter & Maleyeff, 2005, p. 12), which may not be the best place to start. On the other end, lean thinking focuses on waste reduction from the consumer perspective, without consideration of quality or stability of processes. The complementarist Lean Six Sigma approach suggests that Lean organizations can gain "a good balance between an increase in value of the product (as viewed by the customer) and cost reduction in the process [as] an outcome of combining Lean and SS" (Arnheiter & Maleyeff, 2005, p. 16). The authors suggest that an organization that follows the Lean Six Sigma philosophy would possess key characteristics belonging to both philosophies, as stated in Table 2-1 (Arnheiter & Maleyeff, 2005)

Table 7-1 Organizational Lean Six Sigma Characteristics

Lean	Six Sigma
(1) It would incorporate an overriding philosophy that seeks to maximize the value-added content of all operations.	(1) It would stress data-driven methodologies in all decision making, so that changes are based on scientific rather than ad hoc studies.
(2) It would constantly evaluate all incentive systems in place to ensure that they result in global optimization instead of local optimization.	(2) It would promote methodologies that strive to minimize variation of quality characteristics.
(3) It would incorporate a management decision-making process that bases every decision on its relative impact on the customer.	(3) It would design and implement a company-wide and highly structured education and training regimen.

The authors also posit how a LSS approach would balance value and costs as perceived by the customer and producer respectively (see Figure 2-2 (Arnheiter & Maleyeff, 2005, p. 16).

Figure 7-1 Nature of competitive advantage.

Socio-technical systems - lean thinking

Joosten, Bongers and Janssen (2009, p. 344) take a socio-technical systems approach to lean thinking. They suggest that value in lean thinking “is not seen as an individual level concept, but as a system property. According to lean, a system has an inherent, maximal value that is bounded by its design, rather than by the will, experience or attitude of individual members”. They state that socio-technical systems can provide a framework to improve healthcare delivery by complementing the intrinsic operational approach of lean thinking with the social aspect of implementations.

Knowledge Production as a Control Variable

Dorroh, Gulledge, and Womer (1994) state that at the beginning of a new process implementation, education and training are the primary tasks performed by the worker, and as the project advances then production becomes dominant (p. 947). Their model is different from a learning-by-doing model because “knowledge is produced independent of production experience” (p. 952). Dorroh, Gulledge, and Womer (1994) state that higher levels of knowledge allow for easier knowledge production, resulting in more resources allocated for learning, and a faster rate of knowledge production –or a sharper learning curve. They conclude that knowledge creation is a managerial decision, and that the rate of knowledge production is a control variable (p.957). As the process implementation advances, the need to generate more knowledge (knowledge value) decreases, reducing the resources devoted to knowledge generation (Dorroh et al., 1994, p. 955; Epple, Argote, & Devadas, 1991, p. 65).

According to Epple, Argote, & Devadas (1991), learning from the experience of others can benefit an organization. It is worth noting that knowledge acquired through learning will depreciate at a relatively fast rate. Epple, Argote, & Devadas (1991) also state that when learning caused by the use/implementation of new technologies, then learning will transfer –at least partially from one department to another, from one shift to another as long as that technology is used within.

For further reference, read Yelle (1979) and Levy (1965) for reviews of the learning curve literature.

Learning Loop Model

Sterman (Senge, 2006; 1994, 2000) introduced an idealized learning loop model (Figure 7-2).

Figure 7-2 Idealized learning loops.

The validity of the model Sterman introduces is that it provides a good justification for the use of simulation models as learning tools. By simplifying reality and putting it into a virtual world, it is possible to perform experiments within it. Policies and approaches can be challenged by managers without having to wait for feedback from reality, which can be expensive.

Problem Context

In order to complete the model control validation (Figure 3-5) one more experiment is required. In this experiment focus is placed on a short-lived and a mid-lived project. Data about errors per day committed by end users of a new electronic health records process was provided by a local healthcare clinic.

Oral in-person sessions were conducted resulting in agreement of the clinic to provide qualitative and quantitative data regarding the implementation process. All identifiers from personnel related data was removed by the data providers, eliminating the possibility for the researchers to relate data to any staff member. The procedure for data collection and a handout containing the major steps are presented below.

Data Collection Procedure

Data was obtained through interviews with the process change manager. Table 7-1 presents a summary of the data required:

Table 7-2 Summary of Data

Variable	Output Value	Delivery Format
Adequacy of Technology in Company	1-10	Fill-in format to be provided to managers.
Refers to how well does the current technology (computing, software, communications) contributes to their operations. A grade of 1 represents very poorly and a grade of 5 excellent.		

Adequacy of Technology for Project	1-10
Refers to how well does the current technology (computing, software, communications) is aligned with the process requirements of the new process to be implemented. A grade of 1 represents very poorly and a grade of 5 excellent.	
Training Frequency	1-5
Training frequency refers to how close from each other are held the training sessions. A grade of 1 represents a daily training schedule. A grade of 2 represents a 3 day a week training schedule. A grade of 3 represents 2 days a week training schedule. A grade of 4 represents 1 day per week training schedule. And a grade of 5 represents less than one day a week training schedule.	
Training Duration	1-5
Training duration refers to the length of each training session. A grade of 1 represents a session shorter than 1 hour. A grade of 2 represents a session of 1 hour. A grade of 3 represents a session of 1.5 hours. A grade of 4 represents a session of 2 hours. A grade of 5 represents a session longer than 2 hours.	
Business Seasonality	1-5
Business seasonality refers to the state of the business cycle in a healthcare provider, i.e. if it is flu season, budgeting season, etc. A grade of 1 refers to a very busy business cycle (i.e. flu season) and a grade of 5 represents a slow business cycle.	
Organizational Culture	1-5
Organizational culture refers to the flexibility and organizational climate in the organization with respect to new process adoption. A grade of 1 represents a very poor organizational culture. A grade of 5 indicates	

excellent organizational culture.		
Feedback Turnover Time	0-Project Duration	
Feedback turnover time refers to how long does it take for the implementation team to address inquiries from end users.		
Implementation Team Effectiveness	1-5	
Measures how experienced, cohesive and dynamic the implementation team is. It is measured with respect to the expected impact it can have on the transition phase. A grade of 1 represents a very poor impact and a grade of 5 represents a very good impact.		
Staff Learning Rate	1-5	
Staff learning rate refers to the overall learning ability of the staff. A grade of 1 represents a very poor learning rates and a grade of 5 represents excellent learning rates.		
Communication Skills	1-5	
Communication skills refers to the organization’s personnel ability and willingness to communicate with each other. A grade of 1 represents very poor communication skills and a grade of 5 represents excellent communication skills.		
Staff Experience	1-5	
Staff experience refers to the level of experience that the staff possesses both in professional jobs and in a job related to their current one. A grade of 1 indicates no experience and a grade of 5 indicates a lot of relevant experience.		
Staff Educational Level	1-5	
Staff educational level refers to the minimum and maximum academic levels achieved by the staff. A grade of 1 indicates incomplete K-12 education. A grade of 5 indicates graduate degrees.		
Existence of SOPs	0 or 1	

A grade of 0 represents no presence of SOPs. A grade of 1 represents existence of SOPs.		
Desired Percentage of errors per day	0 to 100% calculated from number of errors committed per day divided by total number of transactions.	
Based on historical performance expectations before implementation		
Percentage of errors per day throughout the project duration	0 to 100% calculated from number of errors committed per day divided by total number of transactions.	Excel spreadsheet generated by managers from their databases.

The data is to be filled using the control panel view of the model (Figure 7-1). The control panel is built to ease the input of factors' values and to allow the use of the SyntheSim mode in Vensim. The SyntheSim mode allows managers to vary factor values, test different policies and identify how they can best use their resources to reach the desired goal in accordance to Figure 2-19.

Table 7-2 presents the values for all sub-structure factors for the clinic. All these factors were provided by the clinic's process change manager based on his knowledge of the system. This data is of qualitative data.

Figure 7-3 Control Panel View

Short-term project

The short-term project is of a clerical section of an electronic health records implementation. The electronic health records implementation focused on patient registration, billing information generation and check-out processes. The project was scheduled to last 27 days. It was expected to and started with 20% errors per day as a result of good training programs and the simplicity of the new process to be implemented. Table 7-3 presents all the detailed factors values.

Table 7-3 Short-term lived project parameters

Variable	Output Value
Adequacy of Technology in Company	6
Adequacy of Technology for Project	9
Does Project Demand Changes in Technology?	1
Training Frequency	2
Training Duration	5
Business Seasonality	3
Organizational Culture	3.5
Feedback Turnover Time	3
Implementation Team Effectiveness	3.75
Staff Learning Rate	3.5
Communication Skills	3.75
Staff Experience	4
Staff Educational Level	3.25
Existence of SOPs	1
Expected % Forgetting	20%
Desired Percentage of errors per day	5%

Figures 7-4 to 7-8 present results and analyses on the model. After the Figures a detailed analysis on their meaning is presented.

Figure 7-4 Historical Data Plot as Percentage of Errors per Day

Figure 7-5 Model Generated Data Plot as Percentage of Errors per Day

Figure 7-6 Model Generated Data vs. Historical Data Plot as Percentage of Errors per Day

Figure 7-7 Historical and Model Generated Data Variances Plot

Figure 7-8 Histogram of Differences Between Historical and Model Generated Data Plot

Mid-Term Project

The mid-term project is of a clerical section of the medical processes from the same healthcare clinic as in section 7.1. The electronic health records implementation focused on patient hand in from check in to providers, flow throughout the different providers, and hand in to check-out. The project was scheduled to last 97 days. It started with 56% errors per day as a result of being rolled while the short-term project was being concluded, situation that required training during another project rollout, and the complexity of the new process to be implemented. Table 7-4 presents all the detailed factors values and Figure 7-9 presents the control panel with the factor values.

Table 7-4 Short-term lived project parameters

Variable	Output Value
Adequacy of Technology in Company	6
Adequacy of Technology for Project	9
Does Project Demand Changes in Technology?	1
Training Frequency	2
Training Duration	5
Business Seasonality	3
Organizational Culture	3.5
Feedback Turnover Time	3
Implementation Team Effectiveness	3.75
Staff Learning Rate	3.5
Communication Skills	3.75
Staff Experience	4
Staff Educational Level	3.25
Existence of SOPs	1
Expected % Forgetting	20%
Desired Percentage of errors per day	5%

Figure 7-9 Control Panel View

Figures 7-10 to 7-14 present results and analyses on the model.

Figure 7-10 Historical Data Plot as Percentage of Errors per Day

Figure 7-11 Model Generated Data Plot as Percentage of Errors per Day

Figure 7-12 Model Generated Data vs. Historical Data Plot as Percentage of Errors per Day

Figure 7-13 Historical and Model Generated Data Variances Plot

Figure 7-14 Histogram of Differences Between Historical and Model Generated Data Plot

Conclusions

Short-term project

Figure 7-5 shows a very good fit for the model generated data against the historical data in path, it looks like a fitted function. Figure 7-7 helps illustrate the last point in that the histogram for the differences shows normality with little kurtosis and skewedness.

Figure 7-6 is used to explain the differences between the variances, and as expected the real world data shows more variation than the model generated data; a characteristic that helps explain the quasi fitted line behavior of the model generated data. The R^2 for the paired comparison of both data sets is 0.86, indicating a very good model forecasting description capacity which confirms the observations presented in Figures 7-5, 7-6 and 7-7.

From the results it can be inferred that when the difference between the initial percentage of errors per day and the desired percentage of errors per day, the length of the project is short, and the values of all factors are set around a moderate scenario, the model is capable to indicate the path that the implementation percentage of errors per day will follow. Further experimentation is required to validate this observation and is discussed in the final section of this paper.

Mid-term project

Figure 7-12 shows a good fit for the model generated data against the historical data in path, and portrays dampened oscillation in a phase of the implementation that the manager identified as an adjustment phase. Figure 7-13 is used to explain the differences between the variances, and as expected the real world data shows more variation than the model generated data. Figure 7-14 helps illustrate the goodness of fit of the model generated data versus the historical data. The histogram for the differences shows normality with some kurtosis and skewedness. The long left tail can be explained by the warm-up period (dampened oscillation phase) in the model. The R^2 for the paired comparison of both data sets is 0.08384, indicating a poor model forecasting description capacity which confirms the observations presented in Figures 7-12, 7-13 and 7-14. What the histogram and R^2 value mean is that even though the model is capable of providing a good representation of the path, the actual fit when a point-to-point pairwise comparison is performed is poor, meaning that the model is not good to forecasting data.

From the results it can be inferred that at mid length projects with medium difference between the initial and desired percentage of errors per day the model is capable of indicating the path that the real world implementation will follow in addition to identifying periods of instability. Further experimentation is required to validate this observation and is discussed in chapter 8.

Future research

Dynamic equilibrium determination

It is important to be able to determine when periods of instability and stability (dynamic equilibrium) will occur within a new process implementation to better anticipate them. For that end, a proposed methodology was identified during the development of this dissertation, however it still need more development.

Further investigation on the meaning of the histogram and R^2

Even though Figures 7-7 and 7-14 and the R^2 values agree in the sense how the model forecasts individual data points, further research is necessary to establish the exact relationship between these two tests and how to use them to have better understanding of the model.

Dynamic equilibrium

The suggested tool for managers to evaluate when they can expect that the period of instability will be over can be done as follows and shown in Figure 7-14. A manager may determine that a 5% variation would be acceptable, and then by measuring the Euclidean distance from the top of consecutive hills of the model generated data the manager can determine where the model becomes stable.

Therefore, determination of what can be constituted as an acceptable variation, and a mathematical generalizable procedure to determine points of inflection between instability and stability (dynamic equilibrium) need to be developed.

Figure 7-15 Instability Period End Concept for Proposed Test

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CHAPTER VIII

CONCLUSION

Features of this Research

The model is developed to help healthcare managers manage transition-phases in their organizations. Managers can determine their objective function in accordance to Figure 8-1

Figure 8-1 Objective Function for Transition Phase Management Model
(Figure 2-19)

Figure 8-1 can be used as follows:

1. If managers choose to maximize the quality of the new process implementation (minimize the difference between the current state and the desired state), the model will help them to find the best balance between resources costs and completion time.

The mathematical expression is:

$$\text{Min } |Q_t - P| \text{ and } P_0 + B$$

Equation 8-1

Subject to:

$$Q_t = Q_0 + F - a - \mu$$

$$t_f - t_0$$

2. If managers choose to minimize resource cost in the implementation process, the model will help them find the best balance between the implementation quality and the completion time.

The mathematical expression is:

$$\text{Min } Q_0 + F - a - \mu$$

Equation 8-2

Subject to:

$$|Q_t - P|$$

$$P_0 + B$$

$$t_f - t_0$$

3. If managers choose to minimize the completion time, the model will help them to find the best balance between the implementation quality and the use of resources.

The mathematical expression is:

$$\text{Min } t_f - t_0$$

Equation 8-3

Subject to:

$$|Q_t - P|$$

$$P_0 + B$$

$$Q_0 + F - a - \mu$$

By using repeatedly the model, managers will learn about their organization (see section 8.3 for details). Under repeated use, a double loop learning process as portrayed in Figure 2-4 is generated.

As it has been presented in chapters VI and VII, the model requires little (chapter VI) to no modification (Chapter VII) and presents the managers a user friendly interface (Figures 6-1, 7-1 and 7-7) to input all parameters. The model can be used with any version of Vensim simulation software under its SyntheSim function thus minimizing the need to invest in expensive versions of the software.

Findings from this Research

Complementarist Approach:

It is possible to develop an accurate simulation model based on a complementarist approach using Levy's (1965) adaptation function, systemic concepts (system archetypes) and System Dynamics theory.

Validity of the model:

As presented in section 2.3 and chapters IV and V the model is capable of reproducing the behaviors of the balancing loop, drifting goals and unintended consequences system archetypes through an exponential decay (or growth depending on the parameters) and with dampened oscillation as the process gains stability.

Dynamic Hypotheses

Chapters VI and VI presented that the model is capable to reproduce the behavior over-time presented in Dynamic Hypothesis (Figures 6-2, 7-2 and 7-8). The model will indicate the path of the dynamic hypothesis, and indicate periods of instability.

Research applicability

Healthcare managers will benefit from the use of the model in the following ways:

1. First time use: the model will provide managers an assessment of their organization's capabilities to implement new processes. They can identify their areas of opportunity and evaluate which area can have the biggest impact to achieve the desired outcome.
2. Repeated use: will provide organizational learning (double-loop learning approach) by allowing the managers to further calibrate the model and their organizations to function to the best of its possibilities.

Future Research Needs

Based on the papers presented in chapters V, VI and VII the transition-phase management model can be enriched if the following areas are further explored:

Detailed measurement methods

- Develop quantitative measurement methods to determine the sub-structure factors values following a Bayesian approach.
- Double loop learning process should be implemented to increase knowledge of each variable within a same organization.

These points will enable the validation of the substructure values and variables used along with the resolution level employed in the model.

Further investigation on the meaning of the histogram and R^2

Both tools can be integrated to develop a statistical test for the managers to use in order to assess the efficiency of their estimations of the parameters and to better calibrate their assessments of their organizations versus the real world.

Forecasting capabilities

Even though the results are encouraging, further experimentation to validate capabilities of the model to predict within short, mid and long term projects is necessary to better understand the capabilities of the model.

Training duration and frequency

Develop a quantitative measurement technique to determine the impact of the interaction between training frequency and training duration. Throughout the model development it was hypothesized that an optimum range for the interaction should exist. Figure 8-2 presents the conceptualized range.

Figure 8-2 Hypothesized Optimal Range Graph

Parameter optimization

Internal control parameters and weights were determined based on goal programming, however there is still potential to optimize these parameters.

- Therefore, the development of a state-space mathematical model can aid to proof

the concept and to determine accurate parameters.

- In addition, the parameter optimization function in Vensim Professional should be used to cross reference the findings from the state-space optimization.

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APPENDIX A

INTERNAL REVIEW BOARD PROPOSAL

EXEMPT PROPOSAL FORMAT FOR RESEARCH USING HUMAN SUBJECTS

**Title: A Generalized System Dynamics Model for Managing Transition Phases in
Healthcare Environment**

PI: Patrick E. Patterson, Ph.D., P.E., CPE

Co-PI: Milton L. Smith, Ph.D., P.E.

Co-PI: Javier Calvo Amodio

I. Rationale:

Combining industrial engineering and engineering management tools to improve a particular problem situation in the healthcare industry has proven successful. The use of industrial engineering and engineering management tools (scientific management approach) to improve operation conditions and maximize revenue has been gaining popularity in the health care environment. Examples range from the implementation of the TQM model, to the incorporation of Lean thinking and Six Sigma methodologies.

The use of statistical process control (SPC), total quality management (TQM), six sigma, lean thinking, and simulation as the main industrial engineering and engineering management tools and philosophies in healthcare has been reported. The literature presents success cases, reflects on failures, and suggests improvements in implementations of these methods and philosophies in healthcare. For instance, Benneyan (1996) offers an overview of the possible benefits that SPC could bring to healthcare. Warns about mistakes –such as using the wrong charts and using shortcut formulas –that can be committed if SPC tools and their application are

not understood correctly. Benneyan (1998a, 1998b, 2001) talks about control charts and their potential uses in medical environment; also provides useful theoretical guidelines on how to implement them, and analyzes their accuracy.

Callender and Grasman (2010) identify the following barriers to implementation of supply chain management: Executive Support, Conflicting Goals, Skills and Knowledge, Constantly Evolving Technology, Physician Preference, Lack of Standardized Codes, and Limited Information Sharing. It is possible to extrapolate their reasoning to lean thinking implementation, as they are new or foreign "IE tools" for the medical community considering that acceptance of new ways is always a challenge.

Towill and Christopher (2005) advocate for the analog use of industrial logistics and supply chain management in the National Health Service (NHS) in the United Kingdom. They argue that material flow and pipeline concepts should be applied to the healthcare delivery context to better match demand and the need for a more cost-effective practice.

Young (2005) proposes simulation as a tool to re-structure healthcare delivery on a macro-level by researching patient flow, as the big hospitals go against Lean thinking principles by promoting big queues. Young also suggests that system dynamics and theory of constraints could work together since system dynamics is well suited to identify bottlenecks in a process (p. 192).

However, research of transition phases in a healthcare environment, using a holistic scientific management approach, has received little attention. The estimation of time and resources required to conduct a transition phase, usually employs "rule of thumb" approaches based on simple calculations— rather than a holistic scientific management method. The management of these transition phases has yet to be explored under a holistic scientific management perspective. A transition phase management methodology will allow managers to make better use of their resources, and to identify potential problems before they become too costly.

The study of the proposed methodology based on real world data is a requisite for validation. Health Sciences Center and Community Health Center of Lubbock have accepted to provide the necessary data of past projects to measure percentage of errors per day.

Relevant Definitions:

Problem Context

A situation where operational change is expected, requiring the implementation of a new process or processes that entail staff training and learning by doing. When their efficiency is measured as percentage of errors per day, healthcare managers are decision makers, and the healthcare institution is subject to locally available resources such as staff, money, and training.

Generalized Model

A Generalized Model is a model that is commensurate with projects that align with the problem context as defined for which requiring minimal or no adjustments necessary.

Transition-Phase Management

Transition-phase management is an operational change that is focused on minimizing the percentage of errors per day, seen as learning by doing process. It is the result of the implementation of projects that require changes in processes, and at times, of organizational cultures

II. Subjects: Data about errors per day committed by end users or a new process are the subjects; however there is no need to have any contact with these subjects. The subjects involved directly are the managers in charge of implementing new processes at the Community Health Center of Lubbock and the Health Sciences Center. Hereinafter the managers from Health Sciences Center and Community Health Center of Lubbock are known as the data providers.

The initial contact has already been established to determine the feasibility of the research. Oral in-person recruitment sessions have been conducted resulting in agreement of both parties to provide qualitative and quantitative data regarding the implementation process and staff performance. All identifiers from personnel related data will be removed by the data providers, eliminating the possibility for the researchers to relate data to any staff member. The procedure

for data collection (see section III and appendices A and B for details) has been explained, and a handout containing the major steps has been provided (see appendices A and B for details).

III. Procedures:

Academic Procedure

The variable of interest is percentage of errors per day (Q_t) committed by staff throughout the transition-phase management process. Model validation is conducted via the comparison of the output from the model and the output of the real process. The output of the real process will be expressed as behavior over time of the percentage of errors per day. For that, quantitative and qualitative data regarding the variables presented in the following model are required:

$$\text{Min: } |\bar{Q}_t - \bar{P}|$$

Equation 1 Transition-Phase Management

Subject to

$$\dot{Q}_t = -\dot{a} - \dot{\mu} + \dot{F}$$

$$\dot{P} = \dot{P}_0 + \dot{B}$$

where

Q_t = percentage of errors per day

a = initial efficiency of the process = $f(\text{organizational culture, training, time})$

μ = process rate of adaptation = $f(\text{experience, learning ability, feedback, time})$

F = Damping Factor = $f(a, \mu, \text{forgetting})$

P_0 = initial desired percentage of errors

$$B = \text{Pressure to Adjust } P = f(|P - Q(t)|, \text{time}) \begin{cases} 0 & \text{if } |\dot{P} - \dot{Q}(t)| \rightarrow 0, \text{ regardless of } t \\ \geq 0 & \text{if } |\dot{P} - \dot{Q}(t)| > 0 \text{ and } (t_f - t) \rightarrow 0 \end{cases}$$

This includes obtaining historical information about employee performance such as errors committed per day during new process implementation projects, frequency and duration of training sessions, learning abilities (estimated by past performance of individuals), experience measured in years in current position and in work force, and institutional feedback structures.

The type of data to be collected can be quantitative and qualitative, depending on the data availability and managerial practices of each data provider, and is related but not limited to years of experience, number of training hours for a particular task, and learning ability (all descriptors of errors committed). All data will be obtained only through the data providers, no interviews or direct contact with employees is required.

To better illustrate the rationale of the procedure refer to Figure 1 that depicts the process followed to build a system dynamics model. Note that quantitative and qualitative data are important.

Figure 1. Mental Data Base and Decreasing Content of Written and Numerical Data Bases (J. W. Forrester, 1980, p. 556)

The data gathering process in a system dynamics model is iterative in nature. It starts with the formulation of a dynamic hypothesis –or a theoretical model (see Figure 2). In it, the most basic structure and data required are identified to generate the variable of interest: percentage errors

per day or $Q(t)$. Only after the actual model is build and simulation starts is when more detail in structure and data is slowly incorporated into the model until a reasonable degree of confidence is reached (J. W. Forrester, 1971a, 1980, 1992; J. W. Forrester & Senge, 1978; J. Forrester & Senge, 1980; Sterman, 2000, 2002). Figure 3 shows this process:

Equation 1 translates into the causal loop diagram shown in Figure 2.

Figure 2 Initial Transition-Phase Management Model

Figure 3. Model Validation Process

A model building procedure requires three steps: identifying the system, simulating the system, and controlling the system. Each step requires the use of three tools: creativity, choice, and implementation. Creativity allows joining the researcher and manager's mental data bases to create dynamic structures by combining the written databases contained in the relevant literature. Then a suitable structure is selected, and numerical databases are implemented into the system. Table 1 indicates the goal for each one of the steps.

Table 1 Model Validation Matrix

<div> <div>Characteristic</div> <div>Verification</div> </div>	First run order	Input	Model	Output
	1	Known	Unknown	Known
System Identification	2	Known	Known	Unknown
Simulation	3	Unknown	Known	Known
Control				

Data and information obtained from the data providers will be used to validate the model in accordance to Table 1.

Required Information:

Table 2 presents a list of the information that will be asked to Health Sciences Center and Community Health Center of Lubbock managers.

Table 2

Variable	Output Value	Delivery Format
Adequacy of Technology in Company	1-5	Fill in format to be provided to Health Sciences Center and Community Health Center of Lubbock managers.
Managers will be asked to make an assessment of how well does the current technology (computing, software, communications) contributes to their operations. A grade of 1 represents very poorly and a grade of 5 excellent.		
Adequacy of Technology for Project	1-5	
Managers will be asked to make an assessment of how well does the current technology (computing, software, communications) is aligned with the process requirements of the new process to be implemented. A grade of 1 represents very poorly and a grade of 5 excellent.		
Training Frequency	1-5	
Training frequency refers to how close from each other are held the training sessions. A grade of 1 represents a daily training schedule. A grade of 2 represents a 3 day a week training schedule. A grade of 3 represents 2 days a week training schedule. A grade of 4 represents 1 day per week training schedule. And a grade of 5 represents less than one day a week training schedule.		
Training Duration	1-5	
Training duration refers to the length of each training session. A grade of 1 represents a session shorter than 1 hour. A grade of 2 represents a session of 1 hour. A grade of 3 represents a session of 1.5 hours. A grade of 4 represents a session of 2 hours. A grade of 5 represents a session longer than 2 hours.		
Business Seasonality	1-5	

Business seasonality refers to the state of the business cycle in a healthcare provider, i.e. if it is flu season, budgeting season, etc. A grade of 1 refers to a very busy business cycle (i.e. flu season) and a grade of 5 represents a slow business cycle.		
Organizational Culture	1-5	
Organizational culture refers to the flexibility and organizational climate in the organization with respect to new process adoption. A grade of 1 represents a very poor organizational culture. A grade of 5 indicates excellent organizational culture.		
Feedback Turnover Time	0-Project Duration	
Feedback turnover time refers to how long does it take for the implementation team to address inquiries from end users.		
Implementation Team Effectiveness	1-5	
Measures how experienced, cohesive and dynamic the implementation team is. It is measured with respect to the expected impact it can have on the transition phase. A grade of 1 represents a very poor impact and a grade of 5 represents a very good impact.		
Staff Learning Rate	1-5	
Staff learning rate refers to the overall learning ability of the staff. A grade of 1 represents a very poor learning rates and a grade of 5 represents excellent learning rates.		

Table 2 (Continued)

Variable	Output Value	Delivery Format
Communication Skills	1-5	
Communication skills refers to the organization’s personnel ability and willingness to communicate with each other. A grade of 1 represents very poor communication skills and a grade of 5 represents excellent communication skills.		
Staff Experience	1-5	
Staff experience refers to the level of experience that the staff possesses both in professional jobs and in a job related to their current one. A grade of 1 indicates no experience and a grade of 5 indicates a lot of relevant experience.		
Staff Educational Level	1-5	
Staff educational level refers to the minimum and maximum academic levels achieved by the staff. A grade of 1 indicates incomplete K-12 education. A grade of 5 indicates graduate degrees.		
Existence of SOPs	0 or 1	
A grade of 0 represents no presence of SOPs. A grade of 1 represents existence of SOPs.		
Desired Percentage of errors per day	0 to 100% calculated from number of errors committed per day divided by total number of transactions.	
Based on historical performance expectations before implementation		
Percentage of errors per day throughout the project duration	0 to 100% calculated from number of errors committed per day divided by total number of	Excel spreadsheet

	transactions.	generated by Health Sciences Center and Community Health Center of Lubbock managers from their databases.
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It is important to note that the 1 – 5 scale in the model is translated into behavior over time in the model. Therefore, a grade of 1 generates a behavior that is detrimental to the organization/transition phase. A grade of 3 generates an average behavior that does not affect and does not add to the normal progression of the transition phase. And that a grade of 5 represents a behavior that positively affect the transition phase.

Data Collection Procedure

Information will be obtained from one interview with one manager from Health Sciences Center and one manager from Community Health Center of Lubbock. The contact method is through work phones and email addresses for both managers. An initial contact to determine if the managers possess data for this research project, their availability, and willingness to participate has already been conducted. In the initial contact, both managers (Community Health Center of Lubbock and Health Sciences Center) were informed of the scope of the project (as described previously in this document), and asked for their voluntary participation. Both managers were informed that their participation is voluntary and that they can end it at any time.

For the interviews, both managers will be contacted via email to schedule an appointment. The email will be followed by a phone call three days after. In the email (see appendix A) details of their involvement will be provided and will be asked to set up the interview time and place at their convenience. A table will be attached (see appendix B) to the email containing a guide to the information that is expected to be provided by them.

IV. Adverse Events and Liability: No adverse events are expected and no liability plan is offered.

V. Consent Form: N.A.

VI. References

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Attachment 1 for Email

To: *Manager*
Organization

Good morning/afternoon,

This email is a follow up to our previous conversation were you graciously accepted to contribute to the development of a transition-phase management model. To accomplish this, I kindly request a meeting (60 minutes) with you to conduct an interview to collect relevant data related to a new process implementation project. Please let me know what time and place is convenient for you. I will be calling you in three days to follow up.

In a previous conversation, a past project was identified that was suitable to the structure and data requirements to the research project.

The procedure for your participation is as follows:

1. Research Project Purpose:

To develop a Transition Phase Management model capable of forecasting results before and during implementation phases. The outcome will be a simulation model where the decision maker can generate different scenarios and observe the outcomes for each scenario. The simulation model will help the user to manage transition phases. The simulation model will be based on system dynamics.

To complete this part of the research project, during the interview you will be asked to evaluate a set of variables in accordance to their definitions. The attached word file to this email presents the list of variables for your consideration and preparation in anticipation of the meeting. During the interview you will provide to me the values to each of the variables. Your evaluation does not have to be quantitative in nature, rough estimations based on their definitions is acceptable.

2. Data Gathering and Confidentiality:

The information pertaining to project implementation performance is presented in Table 1. The information can be quantitative or qualitative in nature depending on availability of data.

I appreciate your participation and enthusiasm.

Thank you for your time and consideration in helping us develop the Transition Phase Management model.

If you have any questions, please do not hesitate to call Dr Patrick Patterson, Dr. Milton Smith or Javier Calvo at 806-742-3543.

Sincerely,

Patrick E. Patterson, Ph.D., P.E., CPE,
Professor and Chair
Department of Industrial Engineering
Texas Tech University

Attachment 2 for email**Table 1**

Variable	Output Value	Delivery Format
Adequacy of Technology in Company	1-5	Fill in format to be provided to Health Sciences Center and Community Health Center of Lubbock managers.
Refers to how well does the current technology (computing, software, communications) contributes to their operations. A grade of 1 represents very poorly and a grade of 5 excellent.		
Adequacy of Technology for Project	1-5	
Refers to how well does the current technology (computing, software, communications) is aligned with the process requirements of the new process to be implemented. A grade of 1 represents very poorly and a grade of 5 excellent.		
Training Frequency	1-5	
Training frequency refers to how close from each other are held the training sessions. A grade of 1 represents a daily training schedule. A grade of 2 represents a 3 day a week training schedule. A grade of 3 represents 2 days a week training schedule. A grade of 4 represents 1 day per week training schedule. And a grade of 5 represents less than one day a week training schedule.		
Training Duration	1-5	
Training duration refers to the length of each training session. A grade of 1 represents a session shorter than 1 hour. A grade of 2 represents a session of 1 hour. A grade of 3 represents a session of 1.5 hours. A grade of 4 represents a session of 2 hours. A grade of 5 represents a session longer than 2 hours.		
Business Seasonality	1-5	

Business seasonality refers to the state of the business cycle in a healthcare provider, i.e. if it is flu season, budgeting season, etc. A grade of 1 refers to a very busy business cycle (i.e. flu season) and a grade of 5 represents a slow business cycle.	
Organizational Culture	1-5
Organizational culture refers to the flexibility and organizational climate in the organization with respect to new process adoption. A grade of 1 represents a very poor organizational culture. A grade of 5 indicates excellent organizational culture.	
Feedback Turnover Time	0-Project Duration
Feedback turnover time refers to how long does it take for the implementation team to address inquiries from end users.	
Implementation Team Effectiveness	1-5
Measures how experienced, cohesive and dynamic the implementation team is. It is measured with respect to the expected impact it can have on the transition phase. A grade of 1 represents a very poor impact and a grade of 5 represents a very good impact.	
Staff Learning Rate	1-5
Staff learning rate refers to the overall learning ability of the staff. A grade of 1 represents a very poor learning rates and a grade of 5 represents excellent learning rates.	

Table 1 (Continued)

Variable	Output Value	Delivery Format
Communication Skills	1-5	
Communication skills refers to the organization’s personnel ability and willingness to communicate with each other. A grade of 1 represents very poor communication skills and a grade of 5 represents excellent communication skills.		
Staff Experience	1-5	
Staff experience refers to the level of experience that the staff possesses both in professional jobs and in a job related to their current one. A grade of 1 indicates no experience and a grade of 5 indicates a lot of relevant experience.		
Staff Educational Level	1-5	
Staff educational level refers to the minimum and maximum academic levels achieved by the staff. A grade of 1 indicates incomplete K-12 education. A grade of 5 indicates graduate degrees.		
Existence of SOPs	0 or 1	
A grade of 0 represents no presence of SOPs. A grade of 1 represents existence of SOPs.		
Desired Percentage of errors per day	0 to 100% calculated from number of errors committed per day divided by total number of transactions.	
Based on historical performance expectations before implementation		
Percentage of errors per day throughout the project duration	0 to 100% calculated from number of errors committed per day divided by total number of	

	transactions.	Health Sciences Center and Community Health Center of Lubbock managers from their databases.
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APPENDIX B

- MODEL DETAILS

Long-Term Multi-Phase Project

Model for Experiment 1:

Main Structure:

Efficiency of the Process (*a*) substructure:

Process Rate of Adaptation (μ) substructure

Damping Factors (F) substructure

Equations for Long-term multi-phase project:

Simulation Control Parameters

Simulation Control Parameters

(01) FINAL TIME = 447

Units: Day

The final time for the simulation.

(02) INITIAL TIME = 0

Units: Day

The initial time for the simulation.

(03) SAVEPER = TIME STEP

Units: Day [0,?]

The frequency with which output is stored.

(04) TIME STEP = 1

Units: Day [0,?]

The time step for the simulation.

(05) a = DELAY INFORMATION (IF THEN ELSE (Qt > Po :AND: "Qt-P" > 0, "Qt-P"* a substructure / 340, 0) , Delay for Substructure a ,IF THEN ELSE (Qt > Po :AND: "Qt-P" > 0, "Qt-P" * a substructure / 340, 0))

Units: percentage of errors per day

(06) a substructure = Adequacy of Technology + Business Seasonality + Organizational Culture Weighted+ IF THEN ELSE (Training Duration >= 2 :AND: Training Duration <= 4, 8, 1) + IF THEN ELSE (Training Frequency 2 :AND: Training Frequency <= 3, 8, 2)

Units: errors per day

(07) Adequacy of Technology = (IF THEN ELSE ("Does Project Demand Changes in Technology?" = 1, Adequacy of Technology in Company * Lookup for ATP (Adequacy of Technology for Project) , Adequacy of Technology in Company)) * 0.04

Units: Impact in a [0,4]

(08) Adequacy of Technology for Project = 6

Units: **undefined** [0,10,0.01]

(09) Adequacy of Technology in Company = 8.5

Units: **undefined** [0,10,0.01]

(10) B = IF THEN ELSE (P < 1 :AND: "Qt-P" < 1, IF THEN ELSE (Time Remaining < Panic Time :AND: "Qt-P" > 0.1, "Qt-P" * 0.01, 0) , 0)

Units: percentage of errors per day

(11) Business Seasonality = 5

Units: Impact in a [1,5,1]

(12) Communication Skills = 3

Units: percentage of errors per day [1,5,0.01]

(13) Communication Skills Weighted = (Communication Skills * Implementation Team's Effectiveness Weighted/ 40) * 7

Units: percentage of errors per day

(14) Delay for Substructure a = Maximum Delay Expected for a Substructure * (1 - (a substructure / 34))

Units: Day

(15) Delay for Substructure F = IF THEN ELSE (Feedback Turnover Time >= 2, Feedback Turnover Time + Forgetting , Forgetting) + 3 * (1 - a substructure/ 34) + 3 * (1 - μ substructure / 31)

Units: Day

(16) Delay for Substructure μ = Feedback Turnover Time + RANDOM UNIFORM (0, Implementation Team's Effectiveness Weighted , 0) + (31/ Staff Learning Ability)

Units: Day

(17) "Does Project Demand Changes in Technology?" = 1

Units: **undefined** [0,1,1]

(18) Existence of SOPs = 1

Units: Impact on F [0,1]

1 indicates existence of SOPs; 0 Indicates no SOPs exist

(19) "Expected % Forgetting" = 0.4

Units: **undefined** [0,1,0.05]

(20) $F = \text{DELAY INFORMATION} \left((a + \mu) * 0.25 * (F \text{ substructure} * \text{Lookup for } F \right.$
 $\left. (a \text{ substructure} / 34) * \text{Lookup for } F (\mu \text{ substructure} / 31) \right), \text{Delay for Substructure } F, (a$
 $+ \mu) * F \text{ substructure} / 800)$

Units: percentage of errors per day

(21) $F \text{ substructure} = \text{IF THEN ELSE} (\text{Training Duration} \leq 2 : \text{AND: Training}$
 $\text{Duration} \geq 4, 8, 1) + \text{IF THEN ELSE} (\text{Training Frequency} \leq 2 : \text{AND: Training}$
 $\text{Frequency} \geq 3, 8, 1) + \text{IF THEN ELSE} (\text{Existence of SOPs} = 1, 1, 5) + \text{IF THEN ELSE}$
 $(\text{Feedback Turnover Time} > 2, 5, 0) + \text{Forgetting}$

Units: percentage of errors per day

(22) $\text{Feedback Turnover Time} = 3$

Units: Day [0,50,0.1]

(23) $\text{Forgetting} = a \text{ substructure} * \text{"Expected \% Forgetting"}$

Units: **undefined**

(24) $\text{Implementation Team's Effectiveness} = 3.75$

Units: percentage of errors per day [1,5,0.01]

(25) $\text{Implementation Team's Effectiveness Weighted} = \text{Implementation Team's}$
 $\text{Effectiveness} * (8 / 5)$

Units: percentage of errors per day

(26) $\text{Lookup for ATP} ([(0,0)-(10,1)], (0,1), (1,0.9), (2,0.8), (3,0.7), (4,0.6),$
 $(5,0.5), (6,0.4), (7,0.3), (8,0.2), (9,0.1), (10,0))$

Units: Impact in a

(27) Lookup for F ([(0,0)-
(1,1),(0.00705882,1),(0.103529,0.960854),(0.237647,0.928826),(0.244706,0.935943),(0.407059,0.879004),(0.538824,0.818505),(0.647059,0.768683),(0.738824,0.676157),(0.851765,0.508897),(0.936471,0.270463),(0.971765,0.103203),(1,0.0213523)],(0.00705882,1),
(0.101176,0.701068),(0.244706,0.565836),(0.369412,0.533808),(0.489412,0.505338),(0.588235,0.462633),(0.689412,0.377224),(0.757647,0.348754),(0.830588,0.281139),(0.905882,0.238434),(0.971765,0.103203),(1,0.0213523))

Units: percentage of errors per day

(28) Maximum Delay Expected for a Substructure = 13

Units: ****undefined**** [0,50,0.1]

(29) Organizational Culture = 4

Units: percentage of errors per day [1,5,0.01]

(30) Organizational Culture Weighted = Organizational Culture * (9 / 5)

Units: percentage of errors per day

(31) $P = \text{INTEG}(B, P_o)$

Units: percentage of errors per day [0,1,0.001]

(32) Panic Time = 200

Units: Day [1,500,1]

(33) $P_o = 0.2$

Units: percentage of errors per day [0,1,0.01]

(34) Project Duration = 447

Units: Day [0,150,1]

$$(35) \quad Q1 = 0.568182$$

Units: percentage of errors per day

$$(36) \quad Q2 = 0.505942$$

Units: percentage of errors per day

$$(37) \quad Q3 = 0.518966$$

Units: percentage of errors per day

$$(38) \quad Q4 = 0.509358$$

Units: percentage of errors per day

$$(39) \quad Q5 = 0.501623$$

Units: percentage of errors per day

$$(40) \quad Q6 = 0.692913$$

Units: percentage of errors per day

$$(41) \quad Qo = 0.8$$

Units: percentage of errors per day [0,1,0.01]

$$(42) \quad Q_t = \text{INTEG}(F - a - \mu + \text{Pulse}(T1, 1) * (Q1 - Q_t) + \text{Pulse}(T2, 1) * (Q2 - Q_t) \\ + \text{Pulse}(T3, 1) * (Q3 - Q_t) + \text{Pulse}(T4, 1) * (Q4 - Q_t) + \text{Pulse}(T5, 1) * (Q5 - Q_t) \\ + \text{Pulse}(T6, 1) * (Q6 - Q_t), Q_o)$$

Units: percentage of errors per day [0,1,0.001]

$$(43) \quad "Q_t-P" = Q_t - P$$

Units: percentage of errors per day

- (44) Staff Educational Level = 3
Units: Impact in μ [1,5,0.01]
- (45) Staff Experience = 2
Units: Impact in μ [1,5,1]
is staff experience detrimental? yes
- (46) Staff Learning Ability = Communication Skills Weighted + Implementation Team's Effectiveness Weighted+ Staff Educational Level + Staff Experience + Staff Learning Rate Weighted
Units: percentage of errors per day [0,31,0.1]
- (47) Staff Learning Rate = 3
Units: percentage of errors per day [0,5,0.01]
- (48) Staff Learning Rate Weighted = (Implementation Team's Effectiveness Weighted* Staff Learning Rate / 40) * 6
Units: percentage of errors per day
- (49) T1 = 159
Units: Day [0,500,1]
- (50) T2 = 224
Units: Day [0,500,1]
- (51) T3 = 237
Units: Day [1,500,1]

- (52) $T4 = 265$
Units: Day [1,500,1]
- (53) $T5 = 387$
Units: Day [1,500,1]
- (54) $T6 = 435$
Units: Day [1,500,1]
- (55) Time Remaining = Project Duration - Time
Units: Day
- (56) Training Duration = 5
Units: Impact in a [1,5,1]
24 hours per week training
- (57) Training Frequency = 1
Units: Impact in a [1,5,1]
3 times per week
- (58) $\mu = \text{DELAY INFORMATION (IF THEN ELSE (} Qt > Po \text{ :AND: "Qt-P" } > 0, \text{"Qt-P"} * \mu \text{ substructure / 310, 0) , Delay for Substructure } \mu \text{ ,IF THEN ELSE (Qt } > Po \text{ :AND: "Qt-P" } > 0, "Qt-P" * \mu \text{ substructure / 310, 0))}$
Units: percentage of errors per day
- (59) $\mu \text{ substructure} = \text{Staff Learning Ability}$
Units: percentage of errors per day

Short-Term Project

Model for Experiment 2:

Main Structure:

Efficiency of the Process (*a*) substructure

Process Rate of Adaptation (*μ*) substructure

Damping Factors (F) substructure

List of Equations for short-term project:

a= DELAY INFORMATION (

IF THEN ELSE($Q_t > P_o$:AND: " $Q_t - P$ " > 0, " $Q_t - P$ " * a substructure / 340 , 0), Delay for Substructure a, IF THEN ELSE($Q_t > P_o$:AND: " $Q_t - P$ " > 0, " $Q_t - P$ " * a substructure / 340 , 0))

Units: Percentage of Errors per Day

a substructure = Adequacy of Technology + Business Seasonality + Organizational Culture Weighted + IF THEN ELSE(Training Duration >= 2 :AND: Training Duration <= 4, 8 , 1) + IF THEN ELSE(Training Frequency >= 2 :AND: Training Frequency <= 3, 8 , 2)

Units: Percentage of Errors per Day

Adequacy of Technology = (IF THEN ELSE("Does Project Demand Changes in Technology?" = 1, Adequacy of Technology in Company * Lookup for ATP (Adequacy of Technology for Project), Adequacy of Technology in Company)) * 0.04

Units: Impact in a [0,4]

Adequacy of Technology for Project = 9

Units: Impact in a [0,10,0.01]

hardware, good

Adequacy of Technology in Company = 6

Units: Impact in a [0,10,1]

software 3, hardware speed storage processing 8, software usability, report capacity

B = IF THEN ELSE($P < 1$:AND: " $Q_t - P$ " < 1, IF THEN ELSE(Time Remaining < Panic Time :AND: " $Q_t - P$ " > 0.05, " $Q_t - P$ " * 0.01 , 0), 0)

Units: Percentage of Errors per Day

Business Seasonality=3

Units: Percentage of Errors per Day [1,5,1]

Communication Skills=3.75

Units: Impact in μ [1,5,0.01]

Communication Skills Weighted=(Communication Skills*Implementation Team's Effectiveness Weighted/40)*7

Units: Impact in μ

Delay for Substructure a=Maximum Delay Expected for a Substructure*(1-(a substructure/34))

Units: Day

Delay for Substructure F=IF THEN ELSE(Feedback Turnover Time $\geq$ 2, Feedback Turnover Time + Forgetting, Forgetting)+3*(1-a substructure/34)+3*(1- μ substructure/31)

Units: Day

Delay for Substructure μ =Feedback Turnover Time+RANDOM UNIFORM(0, Implementation Team's Effectiveness Weighted , 0)+(31/Staff Learning Ability)

Units: Day

"Does Project Demand Changes in Technology?"=1

Units: Impact in a [0,1,1]

Existence of SOPs=1

Units: Impact on F [0,1]

1 indicates existence of SOPs; 0 Indicates no SOPs exist

"Expected % Forgetting"=0.2

Units: Impact on F [0,1,0.05]

$F = \text{DELAY INFORMATION } ((a+\mu)*0.25* \text{ IF THEN ELSE (Project Duration}>50, (F \text{ substructure} * \text{Lookup for F(a substructure}/34) * \text{Lookup for F}(\mu \text{ substructure}/31)), (F \text{ substructure} * \text{Lookup for F(a substructure}/34) * \text{Lookup for F}(\mu \text{ substructure}/31)/3)) ,$
 Delay for Substructure F $(a+\mu)*F \text{ substructure}/800)$

Units: Percentage of Errors per Day

$F \text{ substructure} = \text{IF THEN ELSE}(\text{Training Duration} \leq 2 : \text{AND} : \text{Training Duration} \geq 4, 8, 1) + \text{IF THEN ELSE } (\text{Training Frequency} \leq 2 : \text{AND} : \text{Training Frequency} \geq 3, 8, 1) + \text{IF THEN ELSE}(\text{Existence of SOPs} = 1, 1, 5) + \text{IF THEN ELSE}(\text{Feedback Turnover Time} > 2, 5, 0) + \text{Forgetting}$

Units: Impact on F

Feedback Turnover Time=3

Units: Day [0,50,0.1]

FINAL TIME = 27

Units: Day

The final time for the simulation.

$\text{Forgetting} = a \text{ substructure} * \text{"Expected \% Forgetting"}$

Units: Impact on F

Implementation Team's Effectiveness=3.75

Units: Impact in μ [1,5,0.01]

Implementation Team's Effectiveness Weighted=Implementation Team's
Effectiveness*(8/5)

Units: Impact in μ

INITIAL TIME = 0

Units: Day

The initial time for the simulation.

Lookup for ATP([(0,0)-(10,1)],(0,1),(1,0.9),(2,0.8),(3,0.7),(4,0.6),(5,0.5),(6,0.4),(7,0.3
,(8,0.2),(9,0.1),(10,0))

Units: Impact on a

Lookup for F

([(0,0)-(1,1),(0.00705882,1),(0.103529,0.960854),(0.237647,0.928826),(0.244706
,0.935943),(0.407059,0.879004),(0.538824,0.818505),(0.647059,0.768683),(0.738824
,0.676157),(0.851765,0.508897),(0.936471,0.270463),(0.971765,0.103203),(1,0.0213523
)],(0.00705882,1),(0.101176,0.701068),(0.244706,0.565836),(0.369412,0.533808
,(0.489412,0.505338),(0.588235,0.462633),(0.689412,0.377224),(0.757647,0.348754
,(0.830588,0.281139),(0.905882,0.238434),(0.971765,0.103203),(1,0.0213523)
)

Units: Percentage of Errors per Day

Maximum Delay Expected for a Substructure=13

Units: Day [0,50,0.1]

Organizational Culture=3.5

Units: Impact in a [1,5,0.01]

Organizational Culture Weighted=Organizational Culture*(9/5)

Units: Impact in a

P= INTEG (B, Po)

Units: Percentage of Errors per Day [0,1,0.001]

Panic Time=10

Units: Day [1,100,1]

Po=0.05

Units: Percentage of Errors per Day [0,1,0.01]

Project Duration=30

Units: Day [0,150,1]

Qo=0.2

Units: Percentage of Errors per Day [0,1,0.01]

Qt= INTEG (F-a-μ,Qo)

Units: Percentage of Errors per Day [0,1,0.001]

"Qt-P"=Qt-P

Units: Percentage of Errors per Day

SAVEPER = TIME STEP

Units: Day

The frequency with which output is stored.

Staff Educational Level=3.25

Units: Impact in μ [1,5,0.01]

Staff Experience=4

Units: Impact in μ [1,5,1]

Staff Learning Ability=Communication Skills Weighted+Implementation Team's Effectiveness Weighted+Staff Educational Level+Staff Experience+Staff Learning Rate Weighted

Units: Impact in μ [0,31,0.1]

Staff Learning Rate=3.5

Units: Impact in μ [0,5,0.01]

Staff Learning Rate Weighted=(Implementation Team's Effectiveness Weighted*Staff Learning Rate/40)*6

Units: Impact in μ

Time Remaining=Project Duration-Time

Units: Day

TIME STEP = 1

Units: Day

The time step for the simulation.

Training Duration=5

Units: Impact in a [1,5,1]

24 hours per week training

Training Frequency= 2

Units: Impact in a [1,5,1]

3 times per week

μ = DELAY INFORMATION (IF THEN ELSE($Q_t > P_o$:AND: " $Q_t - P$ " > 0, " $Q_t - P$ " * μ substructure/310 , 0), Delay for Substructure μ , IF THEN ELSE($Q_t > P_o$:AND: " $Q_t - P$ " > 0, " $Q_t - P$ " * μ substructure/310 , 0))

Units: Percentage of Errors per Day

μ substructure = Staff Learning Ability

Units: Percentage of Errors per Day

Mid-Term Project

Model for Experiment 2 part II:

Main Structure:

Efficiency of the Process (a) substructure

Process Rate of Adaptation (μ) substructure

Damping Factors (F) substructure

Equations for Mid-Term project:

(01) $a = \text{DELAY INFORMATION (IF THEN ELSE (} Q_t > P_o \text{ :AND: "Qt-P" } > 0, \text{"Qt-P"} * a \text{ substructure} / 340, 0) , \text{Delay for Substructure a ,IF THEN ELSE } Q_t > P_o \text{ :AND: "Qt-P" } > 0, \text{"Qt-P"} * a \text{ substructure} / 340, 0)$

Units: Percentage of Errors per Day

(02) $a \text{ substructure} = \text{Adequacy of Technology} + \text{Business Seasonality} + \text{Organizational Culture} + \text{IF THEN ELSE (Training Duration } \geq 2 \text{ :AND: Training Duration } \leq 4, 8, 1) + \text{IF THEN ELSE (Training Frequency } \geq 2 \text{ :AND: Training Frequency } \leq 3, 8, 2)$

Units: Percentage of Errors per Day

(03) Adequacy of Technology = (IF THEN ELSE ("Does Project Demand Changes in Technology?" = 1, Adequacy of Technology in Company * Lookup for ATP (Adequacy of Technology for Project , Adequacy of Technology in Company)) * 0.04

Units: Impact in a [0,4]

(04) Adequacy of Technology for Project = 9

Units: ****undefined**** [0,10,0.01]

hardware, good

(05) Adequacy of Technology in Company = 6

Units: ****undefined**** [0,10,1]

software 3, hardware speed storage processing 8, software usability, report capacity

(06) B = IF THEN ELSE (P < 1 :AND: "Qt-P" < 1, IF THEN ELSE (Time Remaining < Panic Time :AND: "Qt-P" > 0.1, "Qt-P" * 0.01, 0) , 0)

Units: Percentage of Errors per Day

(07) Business Seasonality = 3

Units: Impact in a [1,5,1]

(08) Communication Skills = (3.75 * Implementation Team's Effectiveness / 40) * 7

Units: Impact in μ [1,7,0.01]

(09) Delay for Substructure a = Maximum Delay Expected for a Substructure * (1 - (a substructure / 34))

Units: Day

(10) Delay for Substructure F = IF THEN ELSE (Feedback Turnover Time ≥ 2 ,
Feedback Turnover Time + Forgetting , Forgetting) + 3 * (1 - a substructure/ 34) + 3 * (1 - μ substructure / 31)

Units: Day

(11) Delay for Substructure μ = Feedback Turnover Time + RANDOM UNIFORM (0, Implementation Team's Effectiveness , 0) + (31 / Staff Learning Ability)

Units: Day

(12) "Does Project Demand Changes in Technology?" = 1

Units: **undefined** [0,1,1]

(13) Existence of SOPs = 1

Units: Impact on F [0,1]

1 indicates existence of SOPs; 0 Indicates no SOPs exist

(14) "Expected % Forgetting" = 0.2

Units: **undefined** [0,1,0.05]

(15) F = DELAY INFORMATION ((a + μ) * 0.25 * (F substructure * Lookup for F (a substructure / 34) * Lookup for F (μ substructure/ 31) / 1.3) , Delay for Substructure F ,(a + μ) * F substructure / 800)

Units: Percentage of Errors per Day

(16) F substructure = IF THEN ELSE (Training Duration ≤ 2 :AND: Training Duration ≥ 4 , 8, 1) + IF THEN ELSE (Training Frequency ≤ 2 :AND: Training Frequency ≥ 3 , 8, 1) + IF THEN ELSE (Existence of SOPs= 1, 1, 5) + IF THEN ELSE (Feedback Turnover Time > 2 , 5, 0) + Forgetting

Units: Percentage of Errors per Day

(17) Feedback Turnover Time = 3

Units: Day [0,50,0.1]

(18) Forgetting = a substructure * "Expected % Forgetting"

Units: **undefined**

(19) Implementation Team's Effectiveness = $3.75 * (8 / 5)$

Units: Impact in μ [1,8,0.01]

(20) Lookup for ATP ([(0,0)-(10,1)],(0,1),(1,0.9),(2,0.8),(3,0.7),(4,0.6),
(5,0.5),(6,0.4),(7,0.3),(8,0.2),(9,0.1),(10,0))

Units: Impact in a

(21) Lookup for F ([(0,0)-

(1,1),(0.00705882,1),(0.103529,0.960854),(0.237647,0.928826),(0.244706,0.935943),(0.407059,0.879004),(0.538824,0.818505),(0.647059,0.768683),(0.738824,0.676157),(0.851765,0.508897),(0.936471,0.270463),(0.971765,0.103203),(1,0.0213523)],(0.00705882,1),
(0.101176,0.701068),(0.244706,0.565836),(0.369412,0.533808),(0.489412,0.505338),(0.588235,0.462633),(0.689412,0.377224),(0.757647,0.348754),(0.830588,0.281139),(0.905882,0.238434),(0.971765,0.103203),(1,0.0213523))

Units: Percentage of Errors per Day

(22) Maximum Delay Expected for a Substructure = 13

Units: **undefined** [0,50,0.1]

(23) Organizational Culture = $3.5 * (9 / 5)$

Units: Impact in a [1,9,0.01]

- (24) $P = \text{INTEG}(B, P_o)$
Units: Percentage of Errors per Day [0,1,0.001]
- (25) Panic Time = 30
Units: Day
- (26) $P_o = 0.2$
Units: Percentage of Errors per Day [0,1,0.01]
- (27) Project Duration = 60
Units: Day [0,150,1]
- (28) $Q_o = 0.56$
Units: Percentage of Errors per Day [0,1,0.01]
- (29) $Q_t = \text{INTEG}(F - a - \mu, Q_o)$
Units: Percentage of Errors per Day [0,1,0.001]
- (30) " $Q_t - P$ " = $Q_t - P$
Units: Percentage of Errors per Day
- (31) Staff Educational Level = 3.25
Units: Impact in μ [1,5,0.01]
- (32) Staff Experience = 4
Units: Impact in μ [1,5,1]

(33) Staff Learning Ability = Communication Skills + Implementation Team's Effectiveness+ Staff Educational Level + Staff Experience + Staff Learning Rate

Units: Impact in μ [0,31,0.1]

(34) Staff Learning Rate = (3.5 * Implementation Team's Effectiveness / 40) * 6

Units: Impact in μ [0,6,0.01]

(35) Time Remaining = Project Duration - Time

Units: Day

(36) Training Duration = 5

Units: Impact in a [1,5,1]

24 hours per week training

(37) Training Frequency = 2

Units: Impact in a [1,5,1]

3 times per week

(38) μ = DELAY INFORMATION (IF THEN ELSE ($Q_t > P_o$:AND: " Q_t-P " > 0, " Q_t-P "* μ substructure / 310, 0) , Delay for Substructure μ ,IF THEN ELSE ($Q_t > P_o$:AND: " Q_t-P " > 0, " Q_t-P " * μ substructure / 310, 0))

Units: Percentage of Errors per Day

(39) μ substructure = Staff Learning Ability

Units: Percentage of Errors per Day

.Control

Simulation Control Parameters

- (40) FINAL TIME = 97
Units: Day
The final time for the simulation.
- (41) INITIAL TIME = 0
Units: Day
The initial time for the simulation.
- (42) SAVEPER = TIME STEP
Units: Day [0,?]
The frequency with which output is stored.
- (43) TIME STEP = 1
Units: Day [0,?]
The time step for the simulation.