Sewing the Digital Transformation Thread: A Deeper Look into Model-Based Six Sigma (MBSS) and the Model-Based Systems Architecture Processes (MBSAP)

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ABSTRACT
Interfaces within a System-of-Systems are complex in nature and the necessary steps to define those interfaces are often difficult to capture and communicate across responsible parties. Implementation of a robust communication structure is necessary to support System-of-Systems development, production, and sustainment. Communication is one of the key tenets of Systems Engineering and organizational process improvement attempts are futile without it. The structured improvement focus of Model-Based Six Sigma, combined with the knowledge sharing goals of Model-Based Systems Engineering (MBSE) applications, will be analyzed as a collaborative approach to improving communication effectiveness within System-of-Systems relationships digitally.

Key words: Digital Transformation, Lean Six Sigma, MBSE

INTRODUCTION
The elimination of waste associated with over-documentation, inappropriate tool usage, and task duplication, combined with innovative techniques for Model-Based Six Sigma (MBSS) development, can be used to establish a robust framework for process improvement on both the enterprise and program levels. This framework will assist in the translation of customer needs and organizational capabilities into delivered solutions with enhanced efficiency throughout the corporation. The implementation of continuous improvement principles, tools, and methodologies in a model-based environment help provide reference architecture for digitally traceable threads that can be used to alleviate bottlenecks, defects, and errors that threaten program success (Sliva and Ferreira, 2017).

Model-Based Systems Engineering (MBSE) is utilized to capture defining characteristics of a construct within a model, creating a single authoritative source-of-truth. Six Sigma is best known as a set of waste elimination tools and methodologies applied within Manufacturing but has recently emerged as a viable approach to fostering continuous improvement efforts across varying people, products, and process driven systems. This research explores various pathways of enabling effective communication using Six Sigma and MBSE methodologies to capture, assess, and improve System-of-System (SoS) relationships.

Assessing an organization's need for Lean Six Sigma (LSS) and MBSE implementation will be an important step in the development of a reference architecture that can be used as a guide for MBSS usage. Lean Six Sigma principles follow a defined sequence of steps with quantified goals and financial targets (cost reduction and/or profit increase) and rely on statistical tools to deal with uncertainty (Desai and Shrivastava, 2008). To successfully implement Lean Six Sigma techniques in support of process improvement goals, the establishment of an infrastructure with specific roles and responsibilities that help mobilize the DMAIC (*Define*, *Measure*, *Analyze*, *Improve*, and *Control*) methodology will be required.

Applying the DMAIC methodology to various issues that arise throughout the product lifecycle is a widely-used approach within Lean Six Sigma for adjudicating process bottlenecks, system errors, and quality defects. Growing concerns regarding the impact of unresolved system failures have resulted in an increase in process owners seeking methodologies for improvement and optimization of program procedures. This research focuses on creating a more robust and efficient flow of information across interfaces via a MBSS toolset.

Proper identification of organizational roles and responsibilities, alongside the creation of digital threads across systems, aids in the effort to improve communication across integrated product teams, suppliers, and external customers. To meet the customer's digital transformation expectation, this research will not only equip organizations with an MBSS toolset, but it will also provide the framework for Lean Six Sigma and MBSE tool integration. The digital transformation framework proposed by this research will play a significant role in system optimization efforts, leading to an overall reduction of lifecycle waste related to cost, schedule and performance. The results of this research can easily be integrated into engineering and technology operations on a global scale to create a more effective solution for system management and process enhancement.

Background

An approach to implementing the LSS methodology in the context of a MBSE framework in support of Digital Transformation (Dx) initiatives has been developed to optimize SoS operations. LSS is a business improvement methodology that aims to maximize shareholder value by improving quality, speed, customer satisfaction, and costs by merging tools and principles from both Lean and Six Sigma [8]. Determining the readiness and capacity of an organization to effectively implement steps within the nonconformance management process is vital to the success of counterfeit avoidance initiatives, and it aligns well with the goals of LSS principles, which include the following: ensuring products conform to what the customer needs, removing non-value-adding steps (waste) in critical business processes which leads to cycle time savings, and reducing the cost of poor quality that include the use of defective and counterfeit parts. LSS methodology will be used to ensure efficiency, effectiveness, and process improvement throughout the capabilities assessments required for Digital Transformation implementation.

Throughout industry, the standard LSS data-driven methodology is used to solve complex business problems and can be thought of as a roadmap for continuous improvement. Sigma is a statistical measurement of variability, showing how much variation exists from a statistical average. Sigma measures how far an observed data deviates from the mean value. DMAIC is a systematic methodology that is an acronym for *define*, *measure*, *analyze*, *improve*, and *control*. The DMAIC methodology (Table 1) seeks to quantify and reduce variation, resulting in a statistical shift that can be definitively measured. In the *Define* phase, it is essential to define the project goals as well. In the *Measure* phase, a complete measurement system analysis must occur in order to determine baseline performance parameters. Key Process Input Variables (KPIV) development is the major focus during the *Analyze* phase, where the problem statement assessment also occurs. In order to progress through the Improve phase, solutions based on KPIVs must be identified and implemented into the process. Ensuring that proven gains are sustained with a plan is key to control phase completion.

DMAIC	PROCESS DESCRIPTION
Define	Processes that balance aggregate demand and supply to develop a course of action which best meets sourcing, production and delivery requirements
Measure	Processes that procures goods and services to meet planned or actual demand
Analyze	Processes that analyzes current state to meet planned or actual demand
Improve	Processes that provide finished goods and services to meet planned or actual demand, typically including order management, transportation management, and distribution management
Control	Processes associated with returning or receiving fraudulent products and updating process to prevent future occurrences. These processes extend into post-delivery customer support

Table 1. DMAIC Process Definitions

Digital Transformation

Critical steps to determine the integrity of nonconforming material and the resulting impact of counterfeit parts on the nonconformance management process must be readily accessible to both internal and external customers. Through Digital Transformation, specifically MBSE platforms (i.e. Cameo, 3DX, etc.), multiple teams can engage and act, using relevant procedures involved in the capture, investigation, determination, and disposition of suspect materials.

A digital thread is a linked set of information related to a product that includes all stages of the product lifecycle phases, including concept, requirements, design, manufacturing, sustainment, and retirement. Linking counterfeit avoidance procedures to the model will allow an organization to quickly assess internal and external metrics associated with the material management process. Data is a foundational element of digital transformation, and the organization is responsible for ensuring the data is accurate, complete, and timely to meet the customers' expectations. By stewarding the data through every step of its life cycle, information management is practiced. Internal metrics represent the performance of the company while external metrics are those that are "customer-facing".

Model-Based Systems Engineering

It is well established that a strict translation of paper-based systems to digital media does not usually result in the most efficient information system capability. The initial conversion of the traditional paper drawing system to digital media created representations of paper drawings in CAD systems. This allowed for the more efficient production of the paper drawing artifacts. Moving beyond the creation of electronic drawings to more advanced practices such as parametric design, 3D modeling, digital threads, and digital twins poses an ever-increasing challenge to the translation of paper practices to digital media. The challenge for digital systems is to carry over all the essential concepts that are embedded in the old paper-based system while taking advantage of the new digital media.

Through MBSE, a Record-of-Authority is created, leading to the immediate capture of artifacts directly associated with the product. This includes artifacts created with engineering tools, manufacturing systems, shop floor systems, product planning and procurement, and operational and maintenance systems. Combatting fraudulent parts in the global supply chain begins and ends with inventory management and properly identifying organizational capabilities and readiness. The creation of digital threads across various systems of interest aids in the reduction of counterfeit part usage and distribution by improving communication across integrated product teams, suppliers, and external customers. To meet the customer's digital transformation expectations, this research will not only equip organizations with a readiness assessment toolset for counterfeit parts, but it will also provide the framework for LSS and MBSE tool integration.

Model-Based Systems Architecture Process

MBSE supports a wide range of systems engineering activities, including requirements definition, design, analysis, verification, and validation, beginning with the conceptual design phase continuing throughout development. A well-constructed model allows description and analysis to facilitate understanding of the entity and communication among stakeholders, including suppliers. The Model-Based Systems Architecture Process (MBSAP) provides a framework and methodology for applying MBSE and enjoying its benefits in dealing with a wide range of technology-intensive systems that extend beyond system design. The MBSAP approach can be applied to challenges such as optimizing organizations and their processes and providing objective analyses and data products for improved technical and programmatic decision-making abilities (Borky and Bradley, 2019).

METHODOLOGY

In modeling the DMAIC process, the initial step is to create the Use Case diagram to capture the high-level operational context of the process, as shown below in Figure 1.

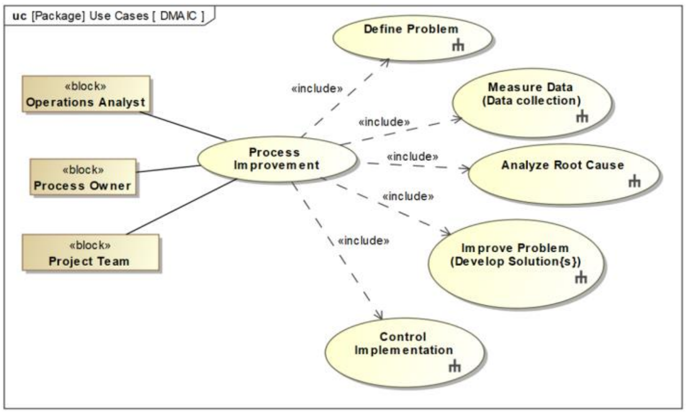

Figure 1. Process Owner/Team Model

Observed in Figure 1 are the actors (*Operations Analyst*, *Process Owner*, *Project Team*) involved in *Process Improvement* and the various other Use Cases that make up the DMAIC process (e.g. *Define Problem, Measure Data, Analyze Root Cause, Improve Problem*, and *Control Implementation*). These elements can be expended in subsequent diagrams; for example, the structure of the *Project Team* can be given further granularity to specify team members in another diagram.

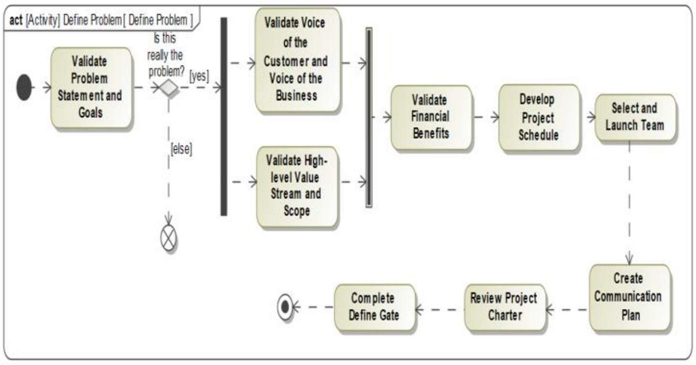

Figure 2. DMAIC Activity Diagram

The Use Cases above represent the operational behavior of the DMAIC process, to be broken down to the step-by-step scenarios in activity diagrams, as shown in Figure 2 above is the step-by-step scenario for Use Case "*Define Problem*". This activity diagram also shows the logical modeling for the problem definition status as per this team's understanding (i.e., a different analyst may consider some steps to be sequential versus being modeled concurrent, or vice versa, this is where the modeler can use their discretion to tailor the model as per their envisioned workflow). Each action in an activity diagram can be given further specification and have a lower tier scenario modeled under it, as seen below in Figure 3.

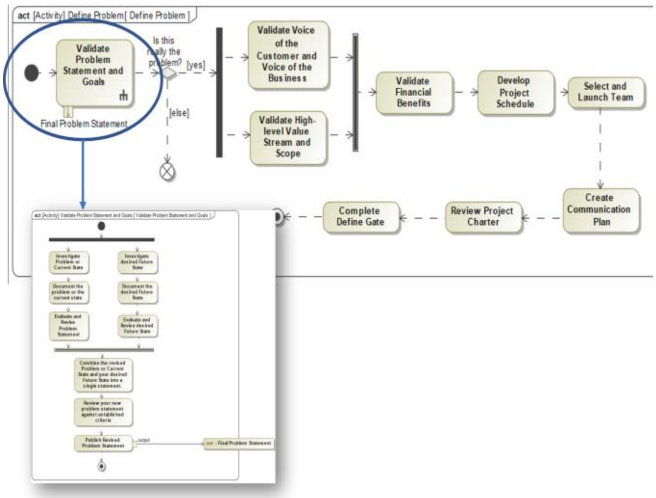

Figure 3. Action Pin Usage

Additionally, the figure above shows an element called an "action pin" which can be observed on the "Validate Problem Statement and Goals" action; this element details the flow of some output/input of data or information from one action to another. This specifies what data is generated at what step in the process, as well as establishing dependencies of steps in a scenario. In Figure 3, this action pin denotes the output of the "Final Problem Statement" from the action. The "throughput" of the action can be observed below in Figure 4.

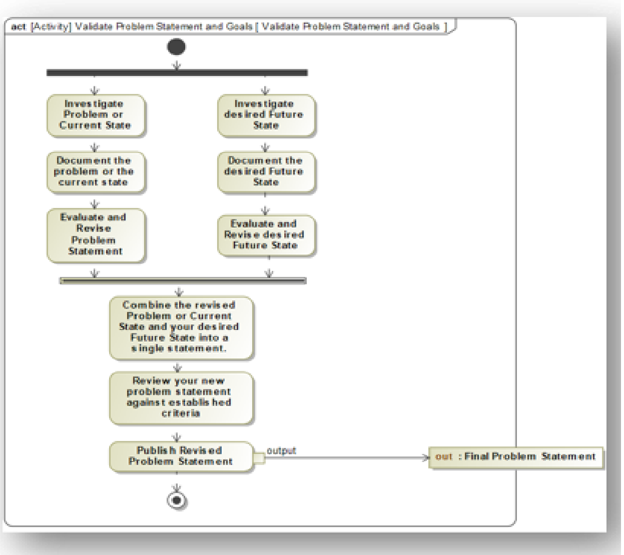

Figure 4. Action Throughput

The steps in Figure 4 modeling the action "Validate Problem Statement and Goals" is pulled directly from documentation that is normally used by Process Analysts, as shown below in Figure 5. This increases the integrity of this modeling effort in validating the pedigree of the modeled material.

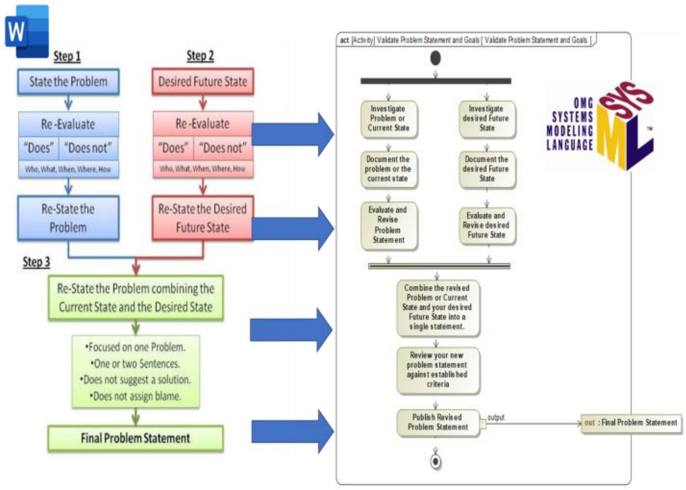

Figure 5. Document Conversion

It is not the intent of this effort to re-engineer the DMAIC process or the reference material used by the actors in the process, but rather place all the information in one digital repository. Guidance and reference information can also be captured in the model, as shown below in Figure 6 and Figure 7, using the encapsulation capability of object-oriented modeling to capture the information in the SysML objects themselves.

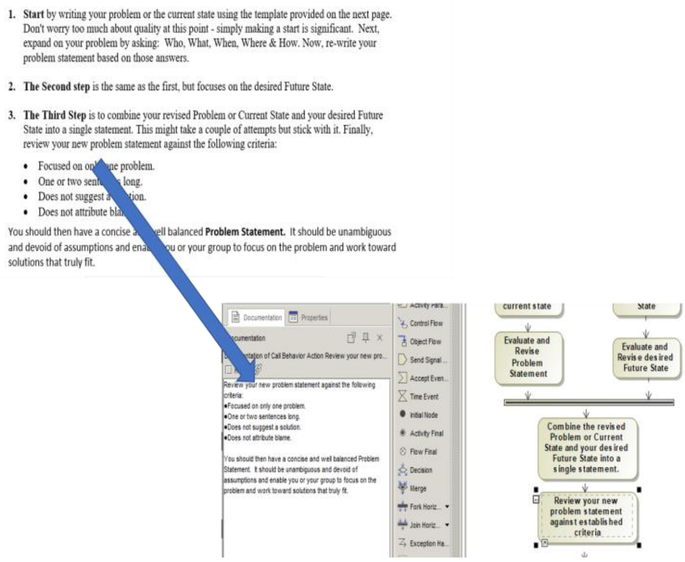

Figure 6. Process Guidance

Having this guidance in one model-based repository creates the opportunity to access and manage the material from one source of truth, as well as document the implementation of the process improvement activities within a model.

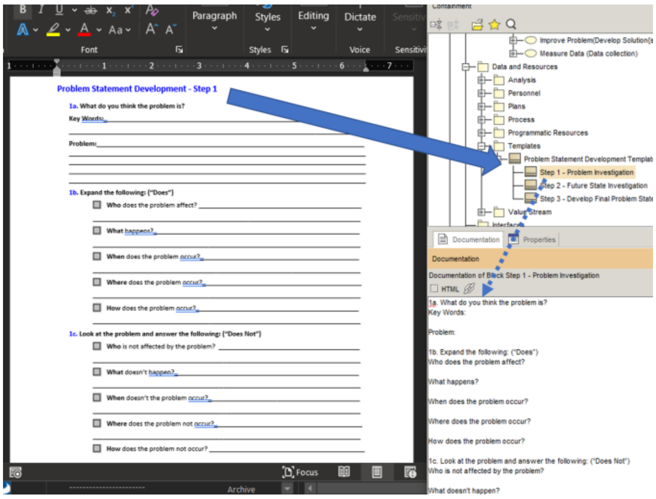

Figure 7. Model-Based Repository

Once the actions are modeled, they can then be allocated to the various actors in the process via the model element "swimlanes", as shown in Figure 8 below.

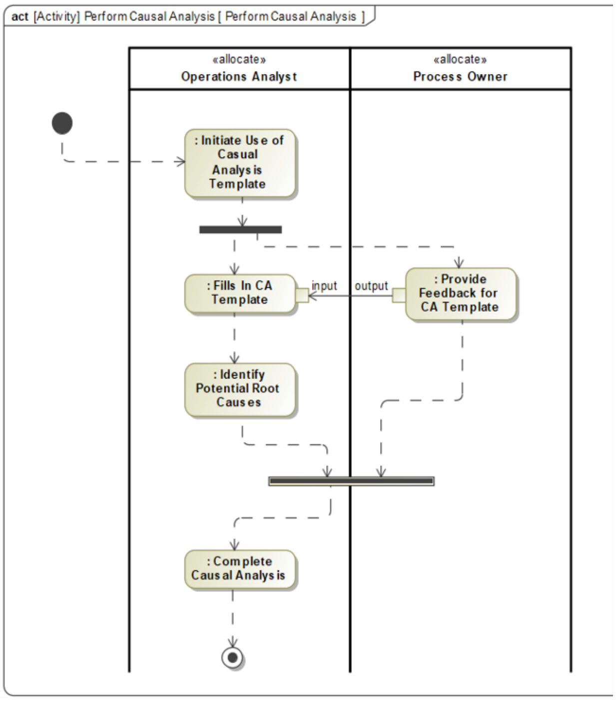

Figure 8. Model Element Swimlanes

The above figure is useful in that it shows the exact allocation of activities and expectations of the modeled actors. If more granularities can be achieved, these swimlanes can be tailored to named team members, rather than just roles. This allocation can then be queried in tables or within the elements themselves to see who is supposed to be performing what action and what data/information is supposed to be supplied. As the DMAIC process is modeled more in-depth, this entire model can be accessed as a more mature starting point for any process improvement initiative. Rather than just being delivered as part of a Contract Data Requirements List (CDRL) to a customer, this model can used as a keystone to tie together an entire effort between various stakeholders.

Lean Six Sigma methodology, with a specific emphasis on the DMAIC approach, was implemented for this research because of the particular focus on required quality improvement and management of defects not easily identifiable via traditional inspection methods. The main focus or the outcome from Six Sigma usage is the reduction in the number of defects per million opportunities (DPMO). Capability Matrix development in support of counterfeit avoidance efforts begins with a clear and concise understanding of an organization's current capacity to accurately identify and eliminate fraudulent components.

DMAIC was implemented to understand the process and the defects in the components studied as part of this research. In the process of the DMAIC methodology, as shown in Figure 1, the *define* phase comprises the initial observation of the process under study. The process is examined, and a potential opportunity for defect reduction is identified. The tools used in this phase are a Pareto chart, process flow diagram, supplier input processing output customer (SIPOC) diagram, and a project charter. In the *measure* phase, the data regarding the quality characteristics and variables under interest are collected (Drab, et. al, 2015). Measurement tools assist with gauging required roles and responsibilities, analyzing process capability, and gathering performance data, using graphical aids such as stem and leaf diagrams, scatter plots, histograms, etc.

In the *analysis* phase, the analysis of the data collected in the measured phase is completed. Various causes for the variations are identified which are involved in the defect generation. The tools used in this phase are failure mode and effects analysis (FMEA), control charts, etc. In the *improve* phase, the causes for the variations are analyzed using tools like cause-and-effect diagrams, brainstorming, and design of experiments (DOEs). The improvements obtained in the improve phase are implemented, and the state of the process is measured in the *control* phase using relevant quality control tools like control charts as shown in figure 9 below.

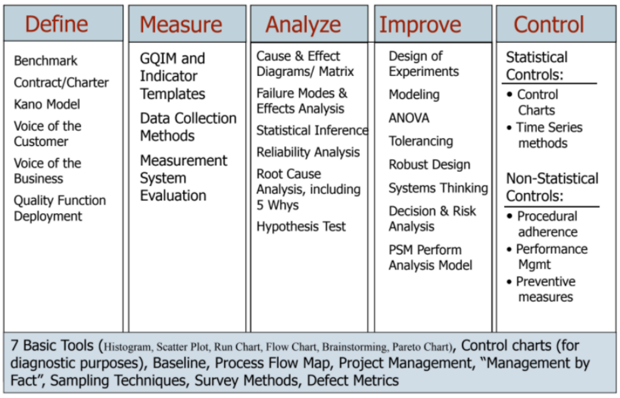

Figure 9. Lean Six Sigma Toolkit

Understanding which metrics are important to your internal and external customers provides key parameters and guidance for metric collection. Linking specific artifacts that aid in the metric collection process to existing system models allows for seamless, digital communication of program progress.

We start with understanding the existing processes, known as the "as-is" state. Then, together with industry benchmarks and best practices relating to management and software, the "future" state is envisioned. Once the two states have been worked through, a gap analysis relative to these processes and metrics are performed to determine the delta between what exists currently and what is desired. Newly discovered gaps provide roadmaps for additional analysis as well as MBSAP implementation opportunities for interface linkages.

Model Based Six Sigma

The Model-Based Six Sigma framework developed as part of this research serves as a starting point for the various organizational processes identified as candidates for improvement. MBSS allows organizations to maintain and demonstrate traceable accountability throughout the process improvement activity, resulting in customizable template for program management to implement. To facilitate SoS management, federated models within the MBSS framework, containing problem/focus area identification and program data, will be used to measure statistical shifts and determine whether or not improvements have been made from a quality assurance perspective. Data from the model will produce the traceability and relationships required to analyze relevant processes and expose opportunities for waste reduction within those processes. System capability improvements alongside optimal waste reduction activities will be identified and documented for future front-end assessment.

For process improvement scenarios that include multiple "touchpoints", the activities of process owners and team members at various stages of the identified timeline, can be incorporated into the model to document capabilities for all entities involved. This approach supports the proposed digital thread initiative by removing silos separating the Six Sigma facilitator, process owner, and team members. Establishing a traceable thread throughout the structured improvement activity is a key part of this research that encapsulates the importance of a non-document centric approach. Because of this effort, organizations will be equipped with the tools necessary to fully identify, document, and mitigate relative waste scenarios that each traditional process can unknowingly generate. As waste scenarios are documented, continuous gathering of metrics can be used to assess improvements as well as empirically verify that waste has been reduced.

DISCUSSION

Communication enhancements resulting from the development and implementation of Model-Based Six Sigma for process improvement purposes help drive the efficiency and effectiveness required for digital transformation activities. The transition of Structured Improvement Activities (SIAs) from a heavily document-centric focus to a digital, model-based approach has the potential to revolutionize how program issues are identified and adjudicated. The value of the MBSS approach will be assessed (through process, metrics, and benchmark review), in addition to the return on process efficiency, quality, and cost associated with implementing the proposed changes. MBSS allows users of the DMAIC process to quickly and easily locate information pertaining to the problem they are trying to solve and key points of contact responsible for data collection and delivery.

Data collected at each phase in the DMAIC process will be evaluated withing the model-based environment, using the appropriate linear or nonlinear program to determine which key process input or output variables (KPIVs) require additional exploration, with all financial, timing, and scope constraints considered. Implementations will be based on perceived statistical shifts in performance goals and with some degree of consideration for the impact these improvements will have on company processes, metrics, and adherence to industry best practices.

Results

As a result of this initial research and MBSS development, communication between key stakeholders throughout the DMAIC process improved, by demonstrating a continuous flow of information to cross seamlessly via a digital, model-based environment.

Implementation will be based on perceived statistical shifts in performance and less on the overall impact on company processes, metrics, and adherence to industry best practices. Now that the entire DMAIC methodology has been modeled existing processes, known as the "as-is" state, can be fully defined, with all stakeholders identified, in a digital space. Together with industry benchmarks and best practices relating to management and software the "to-be" state will be envisioned as part of future state development. The next steps will require the organization to perform a gap analysis relative to these processes and metrics resulting from this study.

Opportunities for MBSAP implementation occur when gaps in process efficiency are discovered. Upon investigating the linkages within the system model, continual analysis regarding which metrics will be needed to sustain the improved state with respect to cost/benefit milestones that are measured (Laureani and Anthony, 2012). Frequent data collection paves the way for continual process improvement, revealing new opportunities for increased efficiency and effectiveness. Best practices for Model-Based Six Sigma environments includes organizational insight into the people, processes and products that contribute to mission success and are imperative to the continuous improvement process on the component, subsystem, and system level.

Digital approaches to process improvement efforts proposed by this research will transform how quality defects, program bottlenecks, and system errors are adjudicated within System Engineering organizations, leading to an overall increase in communication across interfaces. The results of this research can easily be integrated into various industry and commercialized System of Systems environments on a global scale. Projected future improvements include the creation of a more robust model that includes process improvement activities outside of Engineering and Technology organizations to include Human Resources and Information Technology, just to name a few.

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