
Application of Six Sigma Methodologies to Improve Requirements Management for Customer Programs

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ISBN 0-7680-1631-2



SAE *International*[™]

2006 SAE World Congress
Detroit, Michigan
April 3-6, 2006

The Engineering Meetings Board has approved this paper for publication. It has successfully completed SAE's peer review process under the supervision of the session organizer. This process requires a minimum of three (3) reviews by industry experts.

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ISSN 0148-7191

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Printed in USA

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ABSTRACT

A clear understanding of Customer and User requirements is essential to successfully develop, design, build, test and produce components and systems for Customer Programs. Failure to thoroughly understand Customer Requirements can result in costly design and tooling changes, schedule delays and ultimately, Customer dissatisfaction. Statistics across all industries indicate that 25-50% of all projects that fail to meet their imperatives are due to poor requirements and lack of user involvement.

A team was formed to develop and apply Six Sigma Green Belt methods and tools to address project requirements management. The hypothesis of this study was that a substantial opportunity exists to increase project efficiency while providing what the Customer wants by following a standardized work practice for managing requirements throughout the life of a project.

The team evaluated four projects for analysis with the objective of assessing and correcting root causes of project problems due to requirements issues. Using the methodology of Six Sigma, the team utilized lessons learned to determine "Impact Issues," relative to requirements management. These issues were then addressed by the addition of improvements to the Product Development Process.

The paper will present how the process can lead to the development of requirements management tools and methodologies that can be used to improve Project performance, cost and timing while delivering quality products to the Customer.

INTRODUCTION – A CASE FOR ACTION

It is critically important to properly manage Customer and product requirements. Requirements management is defined as the systematic approach to identifying, organizing, communicating and managing the initial and changing requirements of a system/software product. Lack of requirements issues and risk management has

been attributed as a major root cause of project inefficiency and waste. In the drive for innovation and continuous improvement, product line Chief Engineers were asked to select key, recently completed projects that could have been improved in retrospect. Four projects, each representing different products, were selected for analysis. Upon initial review with the respective project teams, it was apparent that all had one thing in common – a set of lessons learned which needed to be shared across all project teams.

Multiple examples (via "lessons learned") exist that attribute project imperatives "misses" to requirements issues management. Specifically, unforeseen integration, test, verification, validation and manufacturing problems occur due to poor management of requirement issues, missing requirements or continual requirements changes. As requirements issues management was noted to occur throughout many projects across multiple product lines, a Six Sigma project was initiated to investigate several past and current projects and address how proper requirements management would increase operating efficiency and Customer satisfaction.

A Six Sigma Green Belt team was formed and a contract was created between the team and its stakeholders – Engineering Management. The team's hypothesis was that a substantial opportunity exists to increase design and manufacturing efficiency for complex projects by developing, following and institutionalizing a "best practice" for managing requirements including associated risks throughout a project's life.

The team was also tasked to implement the selected approach through changes or additions to the product development process.

APPROACH – USING SIX SIGMA TOOLS

WHAT IS SIX SIGMA

The Six Sigma Problem Solving Process is a rigorous, data-driven, disciplined methodology that uses a variety

of problem solving tools to improve a company's operational performance by identifying and eliminating "defects" in their product design, manufacturing processes, business transactions and service-related processes. The use of this Six Sigma philosophy will help to take those defects to zero level. It is a methodology based upon understanding Customer requirements and the disciplined use of facts, data and statistical analysis to analyze, improve and control processes.

The Six Sigma process uses the **DMAIC** (Define, Measure, Analyze, Improve and Control) methodology as a roadmap for problem solving, as well as for product, process and business systems improvement. DMAIC is described as follows:

Define the problem in objective terms.

Measure the process output performance.

Analyze the problem to identify causes of variation.

Improve output of processes by shifting performance to the target and reducing variation.

Control the process performance to assure predictable results.

Six Sigma can be used for any activity related to product designs, manufacturing processes, business processes and service providers, that is concerned with cost reduction, waste elimination, scrap, faster, quality of results, etc. The objective is to improve these processes to do things better, faster and at lower cost.

OBJECTIVES AND BENEFITS OF SIX SIGMA

Six Sigma's main objective is focus on the Customer by increasing profit/services through improved quality. Companies that utilize Six Sigma identify and eliminate costs that provide no value to customers. They analyze their processes to find out where and how defects occur, measure them, eliminate the problems and put controls into place to assure continued conformance.

TOOLS AND METHODOLOGIES

While there are many different Six Sigma problem-solving tools, the main tools (defined in Definitions, Acronyms and Abbreviations section at the end of this paper) used in this project consisted of the following:

- SIPOC (Supplier, Inputs, Process, Outputs, Customer)
- Thought Process Map (TMAP)
- Process Map (PMAP)

- Failure Effects Mode Analysis (FMEA)
- MSE (Measurement Systems Evaluation)
- Control Plan

USING THE SIX SIGMA PROCESS

The team was selected to provide the following expertise – Senior Engineering Management (to lead the team and provide the management support), Systems Engineering (a primary resource within Delphi product engineering responsible for developing requirements), and Program Management (who brought experience with product development process). From their combined experiences, the team understood that Customer and User Requirements are essential to successfully develop, design, build, test, and produce components and systems for Customer Programs.

DEFINING THE PROBLEM

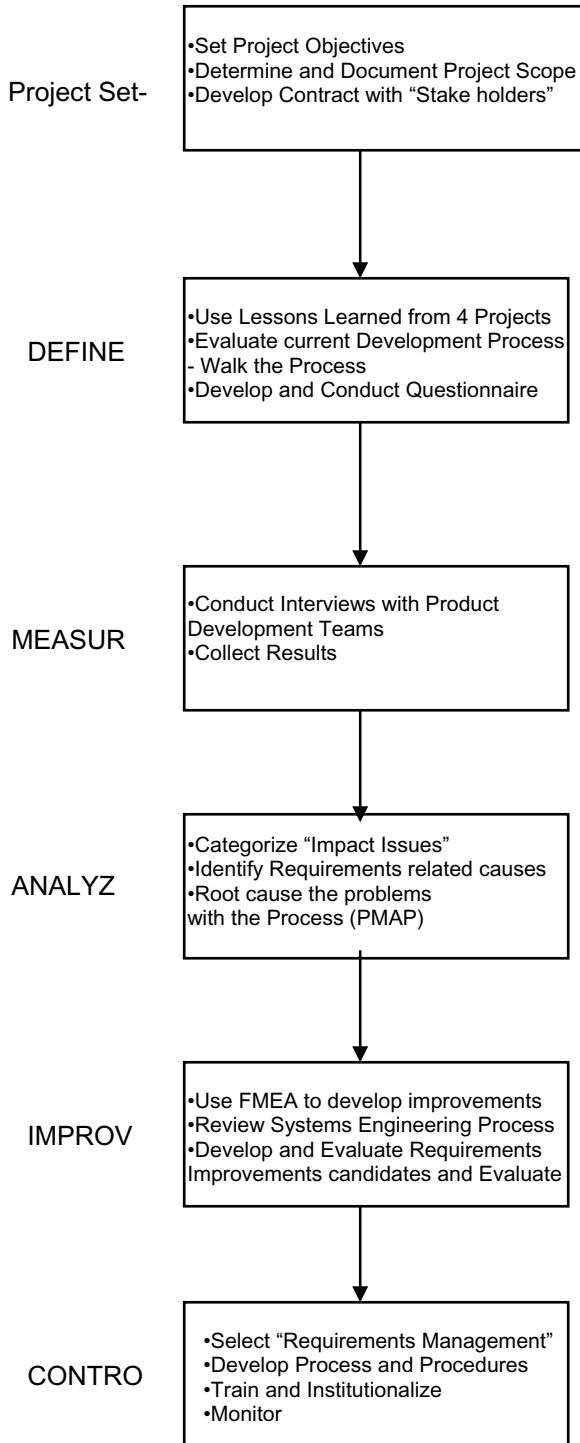
Throughout industry, it has been widely reported by various internal and professional Project Management organizations that up to half of the projects that fail to meet project requirements of performance/quality, cost or schedule commitments do so through the lack of requirements and user involvement. This typically results in a product that does not meet Customer expectations, which in turn results in costly and potentially iterative re-design, re-test and re-validation. Finding a missing requirement during integration and testing can result in cost and schedule losses that may be 10 to 100 times the cost to do it correctly during requirements collection, analysis, and allocation.

Significant interviewing of all Six Sigma stakeholders was conducted using the SIPOC, a Six Sigma tool that identifies the stakeholders, resources required by the process, description of the top level process, the process deliverables, input and output requirements and what is delivered to the Customer. The projects for analysis were selected by the divisional Chief Engineers to encompass all divisional product lines. Each project had significant system complexity, differing Customers and technical, schedule and financial challenges.

MEASURING THE CURRENT STATUS

A Six Sigma tool known as the TMAP – Thought Process Map – was used to plan and schedule the project. The TMAP (shown following) consists of the five Six Sigma phases - DMAIC (Define, Measure, Analyze, Improve and Control) process. The definition phase determined the project objective (set by the contract) and the scope of the project (set by the SIPOC). The definition phase was followed by a root cause analysis where causes were hypothesized through walking the current process so that a future solution might be found.

Figure A. Requirements Management TMAP



The measurement phase follows where metrics are desired to determine a solution. A questionnaire was developed and utilized to question the four project teams and to determine the issues. The Product Development Teams (PDT) from each of the four selected projects

were interviewed using this questionnaire. Each PDT consisted of cross functional areas of sales, product engineering, project management, purchasing, manufacturing and other functional organizations that had participated throughout the lifetime of the project. The key question “What were the issues that impacted the program” was used to collect the root causes. Sixty-nine (69) “Impact Issues” were reported by the teams and were separated in terms of common categories.

ANALYZING THE PROBLEM AND WALKING THE PROCESS –

Seventeen “Impact Issues” associated with requirements management (almost 25% of the total) were identified from the four projects. It is crucial to note that in each of the four projects, there was a common “Impact Issues “ with regard to Requirements – **Requirements not clearly defined by the Customer or understood by the Supplier.** The next step in the Six Sigma process is to identify and document the requirements process. This is termed the Process MAP (PMAP).

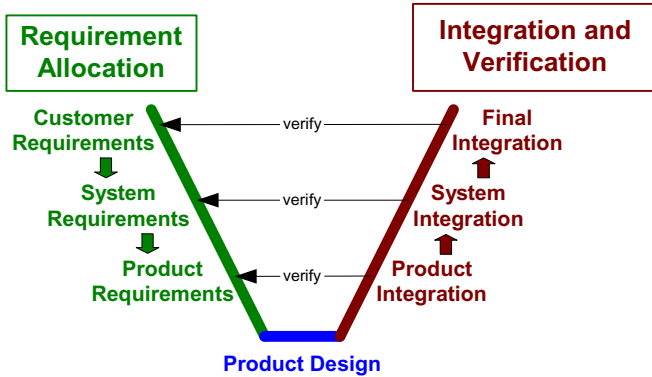
The current requirements process (including design reviews, integration and verification) within the Product Development Process was found to have eighteen steps. Once the PMAP was established and verified, a Failure Effects Mode Analysis tool was employed to analyze where the above problem(s) occurred and offer potential solutions.

Prior to proceeding to the isolation of root cause to the process, one must understand how requirements are handled within the Delphi Product Development Process (PDP). The Product Development Process is divided into 5 phases – Project Launch, Concept Direction, Concept Approval, Final Approval and Production Approval.

The Systems Engineering process, illustrated by the following figure known as the “Systems Engineering V diagram”, is used to collect, analyze, and allocate these requirements within the PDP process. The left hand side of the “V” develops the Customer requirements and the allocation and further development of these requirements that allows the synthesis of system alternatives. This is known as “Top Down” requirements allocation. Upon the tradeoff selection of the product solution, further allocation of performance, operational and interface requirements occurs at the subsystems, components and piece parts levels. Simultaneously at each requirements development level, verification cross reference index (VCRI) or compliance matrix and complementary integration and test plans are developed. (A requirement is fully developed only if can be verified e.g. test, demonstration, inspection or

simulation.) These verification activities and planning connect the left and right hand sides of the “V”.

Figure B. The Systems Engineering “V” Diagram



The right hand side of the “V” is the “Bottoms Up” integration and test conduct leading to the final validation of the product to the original Customer functional and performance requirements within the vehicle. “Bottoms up” refers to starting at the component level and successively integrating other components and then subsystems tests which leads to system testing.

A Failure Effects Mode Analysis (FMEA) was conducted for the seventeen “Impact Issues” items for each process map element to analyze where within the process that the problem could be improved and/or solved. The analysis indicated that approximately 80% of these problems could be eliminated as early as in the first six Systems Engineering process steps.

These first six process steps are –

1. Develop the Initial Systems Engineering Management Plan (SEMP) for the Quote Phase
2. Compile, analyze and assess the initial Customer Requirements
3. Develop the Product Requirements through the allocation of Requirements to subsystems and components
4. After Award of Business, the SEMP is updated to include tasks for the remainder of the Product Development Process
5. Internal Requirements Design Review
6. Requirements Review with the Customer.

IMPROVING THE PROCESS

These six process steps were then analyzed for those having the greatest promise or the largest leverage. While planning of the requirements activities is essential (process steps 1 and 4), it was judged that the actual analysis of the Customer related requirements had the largest likelihood of being associated with “Issues Impact” process steps 2, 5 And 6. Each of these steps was evaluated for candidate solutions and their likely success.

2. Compile, analyze and assess the initial Customer Requirements

Customer’s statement of requirements can come in many formats and levels of detail. Obviously a thorough evaluation and analysis is initially and continuously required to ensure Customer and user understanding. In order to facilitate this analysis, a comprehensive list of requirements characteristics were compiled such that these could be used to evaluate both Customer and internally generated requirements. These characteristics include: necessary, unambiguous, implementation independent, complete, verifiable, concise, consistent, maintainable, traceable and feasible. The ones that were found to most useful were the following.

Complete - The stated requirement is complete and does not need further amplification. Completeness is dependent upon the author’s intent.

- Complete implies that all factors that are needed for the definition of the requirement are defined.

Consistent - The stated requirement does not contradict other requirements. It is not a duplicate of another requirement. The same term is used for the same item in all requirements.

- The requirements within all the Customer specifications must be in accord and compatible.

Implementation Independent – The requirement states what is required, not how the requirement should be met.

- Ask the question “Why is the requirement needed?” helps identify questions to ask the Customer for clarifications of requirements.

Unambiguous - Each requirement must have one and only one interpretation.

- The requirement can have only a single definite and clear meaning.

Verifiable - The stated requirement is verifiable if there exists some cost-effective process with which a person or machine can check that the product meets the requirements.

- A requirement is verifiable if it can be shown to meet the required

criteria/threshold with a test, a demonstration, an analysis/ simulation, an inspection or by data from a previous program or product.

5. Company Internal Requirements Design Review

Technical design reviews are a "Best" Systems Engineering and product development process. Requirements design reviews are typically early in the project when the greatest cost, product performance and quality, and schedule benefits can be gained through a thorough understanding of requirements. They typically ask the question – Do we fully understand the requirements? Objectives of such requirements reviews are to:

- Assess completeness and stability of requirements
- Identify undefined, risky, or difficult requirements.

While requirements completeness and stability can be dealt with, the subject of requirements issues and RISK must be considered.

Risk is formally defined as a measure of the uncertainty of attaining a goal, objective or requirement pertaining to technical performance, cost or schedule. Many companies use the following basic risk identification of RED for High Risk, YELLOW for Low Risk and GREEN as little or no risk:

- A "**High Risk**" design is one in which issues exist that are beyond team's control, there is no plan for resolution or has a low probability of successful resolution.
- A "**Low Risk**" design is one in which issues exist that are within the team's control, has a plan for resolution and has a high probability of successful resolution.
- A "**No Risk**" design is considered to have either no risk or even though there is an issue, experience indicates that it can be solved within the normal course of design.

A candidate requirements management technique that was evaluated was to review each Customer requirement for issues and the degree of risk when measured against these criteria. In order to ensure these criteria would be useable throughout all projects with differing products, the definition and assessment of risk must be consistently understood and applied as explained below.

A Six Sigma tool, Measurement System Evaluation - Attribute Measurements was used to evaluate to determine if the risk definitions were understood and consistently applied across the engineering cadre.

Consultation with a company resident Six Sigma Master Black Belt, led to the recommendation of the use of the IntraClass Correlation (ICC) attribute measurement evaluation technique. The ICC is applicable for data evaluation with three or more classifications.

A questionnaire using ICC evaluation was designed for scenarios of varying risk for typical product development experiences. This questionnaire, if it could be proved to be consistent, would be used to train the organization such that the risk evaluation could be used as a common control process for requirements as will be described below. An independent risk assessment of requirements available from industry available literature was utilized to design nine scenarios with either no, low or high risks. The evaluators were asked to classify the risk to the above risk criteria by assigning numbers to the risk factor 8-10 for high, 4-6 for low and 0-2 for no risk with the highest number having the highest risk.

The questionnaire was given to two sets of evaluators – one (eight evaluators) which had just received a Systems Engineering training course in Risk Management and a group of Product Engineering managers (six) representing all product lines within the division. The results from both groups showed almost an identical correlation of 0.8; coefficients of 0.7 – 0.9 show adequate correlation for usage. Thus the results of this study indicated that the division wide understanding of the risk definitions was adequate. Also the close results from two independent groups indicated that the questionnaire would be useful for training the project risk evaluators for all projects within the division.

6. Requirements Review with the Customer.

The successful completion and integration of process steps 2 and 5 are essential to the preparation and presentation of requirements issues with the Customer. The resulting recommended requirements management tools and methodologies were –

- A complete and comprehensive analysis of the Customer supplied requirements and an independent assessment of the each requirement against selected requirements criteria listed above.
- The development of requirements issues and the determination of risk such that they could be discussed internally and then directly with the Customer at the Customer requirements review.

Controlling the Improved Process across all Projects

The findings of the team were presented to Senior Engineering Management and the Chief Engineers who

were sponsors of the projects. The results of the project were hardily endorsed and the team was asked to incorporate "improvements" within the division Project Management process and to train all project Product Development Team's. It was determined that the requirements risk assessment could be requested from all projects and be included in a monthly project management report. In this manner, problems with requirements, previously unreported, now could be brought to management's immediate attention. This will greatly reduce project imperative problems and result in significantly higher Customer Satisfaction. Requirements issues with High Risk can then be rapidly identified and entered into risk mitigation at the proper technical and/or management level.

CONCLUSION

Requirements Management issues impact project imperatives in direct proportion to project and product complexity. This in no way can account for the loss in Customer satisfaction and good will. A team of a Senior Engineering Manager, a Systems Engineer and a Project Management expert using Six Sigma tools and problem solving process developed a requirements analysis and risk assessment tool. Introduction of this tool into the Product Development Process will consistently detect issues with requirements management and immediately alert technical and management teams through periodic risk assessment project reports. It is anticipated that this approach will improve project performance for projects with high technical content by identifying issues and risks that allow the simultaneous meeting or exceeding of Customer expectations.

Acknowledgments

The Six Sigma Green Belt Team, made up of Tom Austin, Jim Eaton, and Steve Rohr, used the Six Sigma Problem Solving Tools and Methodologies save time and money by developing a standardized work practice for managing requirements throughout the life of a program. Tony Wojcik, a Delphi Six Sigma Master Black Belt who helped the team with the MSE portion while Todd Griggs, then of ATI, was the Six Sigma instructor who taught the team the fundamentals and acted as coach throughout this project. My management of Ms. Barbara Sanders, also executive champion for Systems Engineering within this division, and Matt Tecklenburg provided guidance and strong support for this paper.

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DEFINITIONS, ACRONYMS, ABBREVIATIONS

SIPOC (Supplier, Inputs, Process, Outputs, Customer) -

A tool that is used to initiate the project by developing the scope through the identification of process and boundaries, the outputs, Customers of each output, requirements at each output, inputs, the supplier and requirements for each input.

Thought Process Map (TMAP) –

The plan for project problem solving that uses the DMAIC process. (See Figure A).

Process Map (PMAP) –

A tool is a visual representation that identifies the steps, activities, inputs and outputs required to complete an activity.

FMEA (Failure Mode & Effects Analysis) –

Analysis used to identify and prioritize potential failures through the evaluation of critical characteristics as measured against established criteria.

MSE (Measurement Systems Evaluation) –

The MSE is the identification and quantification of potential error sources and their measurement variability.

Control Plan –

The plan that ensures that the process stays in control after problem solutions have been implemented.