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# 15.6. The Six Sigma DMAIC Steps

Experience with applying the five DMAIC steps shows that the team's DMAIC journey needs to be preceded by management selecting the project. The DMAIC journey with its five steps and some of the critical activities in each step are shown in **Fig. 15.2**. Here is a brief explanation of each step.

## 15.6.1. Select the Opportunity

In the select phase, potential projects are identified. Nominations can come from various sources, including customers, reports, and employees. To avoid suboptimization, management has to evaluate and select the projects. While evaluation criteria for project selection are many, the most frequent basis should be the COPQ at the organization or division level. Other criteria include impact on customer loyalty, employee effectiveness, and conformance with regulatory or other requirements. The project problem and goal statements are prepared and included in a team charter, which is confirmed by management. Management selects the most appropriate personnel for the project, assures that they are properly trained, and assigns the necessary priority. Project progress is monitored to ensure success.

# 15.6.2. Select: Deliverables

- List of potential projects
- ROI and contribution to strategic business objective(s) for each potential project
- List of potential projects
- Evaluation of projects
- Selected projects
- Project problem, goal statements, and a team charter for each project
- Formal project team(s) headed by Black Belt

## 15.6.2.1. Select: Questions to Be Answered

1. What customer-related issues confront us?
2. What mysterious, costly quality problems do we have that should be solved?
3. What are the likely benefits to be reaped by solving each of these problems?
4. Which of problems deserves to be tackled first, second, etc.?
5. What formal problem statement and goal statement should we assign to each project team?
6. Who should be the project team members and leader (Black Belt) for each project?

# 15.6.3. Define Phase

The define phase completes the project definition begun with the charter developed during selection. The team confirms the problem, goal, and scope of the project. The completed definition includes the following:

- Identify key customers related to the project
- Determine customer needs with respect to the project in the voice of the customer (VOC)
- Translate the VOC into CTQ requirement statements
- Define a high-level process flow to define the project limits

# 15.6.4. Define: Deliverables

- Confirmed project charter
- Voice of the customer
- CTQ statements
- A high-level flow, usually in the form of a supplier-input-process-output-customer (SIPOC) diagram

## 15.6.4.1. Define: Questions to Be Answered

1. Exactly what is the problem, in measurable terms?
2. What is the team's measurable goal?
3. What are the limits of the project? What is in and what is out of scope?
4. What resources are available—team members, time, finances—to accomplish the project?
5. Who are the customers related to this project?
6. What are their needs and how do we measure them in practical terms?

# 15.6.5. Measure Phase

The project team begins process characterization by measuring baseline performance (and problems) and documenting the process as follows:

- Understand and map the process in detail
- Measure baseline performance
- Map and measure the process creating the problem
- Plan for data collection
- Measure key product characteristics (outputs; Ys) and process parameters (inputs; Xs)
- Measure key customer requirements (CTQs)
- Measure potential failure modes
- Measure the capability of the measurement system
- Measure the short-term capability of the process

# 15.6.6. Map the Process

Focusing on the vital one (or few) outputs (Ys) identified by the Pareto analysis, graphically depict the process that creates it (them) by mapping the process with a flow diagram in order to understand the process anatomy.

## 15.6.7. Determine Baseline Performance

Measure the actual performance (outputs; Ys), such as costs of poor quality, number of defects, and cycle times of the process(es), which creates the problem to discover—by Pareto analysis—which vital outputs (Ys) make the greatest contribution to the problem.

## 15.6.8. Measure Potential Failure Modes

Referring to the analyzed process flow diagram for each process step, perform a failure mode and effect analysis (FMEA) by listing potential process defects (Ys) that could occur, their effects and their potential causes (Xs). (An additional source of ideas of possible Xs is the cause-effect diagram, which displays brainstormed possible causes for a given effect.) In addition, rate the severity of each effect, the likelihood of its occurrence, and the likelihood of its being detected should it occur. Upon completing the analysis, you will be able to identify those potential process failures that have the most risk associated with them. These results are used to further focus the project on those variables most in need of improvement.

## 15.6.9. Plan Data Collection for Short-Term Capability Study

- In preparation for determining the capability of the measurement system (which measures the Xs and Ys upon which the project team has focused) and the short-term capability of the process, create a sampling and data collection plan.
- In preparation for determining the short-term capability of the process, determine the capability of the measurement system to provide consistently accurate and precise data upon which the project team can depend to "tell the truth" about the process.
- If the measurement system is found to be not capable, take corrective action to make it so.
- If the measurement system is found to be capable, proceed with the next step—determining if the process is in statistical control with respect to given variables (Ys).

## 15.6.10. Measure the Short-Term Capability of the Process

- In preparation for measuring short-term capability of the process to meet given specifications (Ys), ascertain whether the process is in statistical control with respect to the given output (Y) of interest. A good way to measure process stability is to use a control chart to plot the process data and discover any indications of instability.
- If the process is not in statistical control—that is, if control charts detect special causes of variation in the process—take action to remove the special causes of variation before proceeding with the process baseline performance measurement.
- If the process is in statistical control—that is, the control charts do not detect special causes of variation in the process—perform a short-term capability study to provide baseline data of the ability of the process to consistently produce a given output (Y).

# 15.6.11. Confirm or Modify the Goal

In light of discoveries made during measurement of the current process performance, determine if the problem and goal statements are still appropriate for this project.

- Evaluate the project's problem statement and goal statement.
  - Does the problem statement and the goal statement meet the criteria of an effective problem and goal statement with clearly defined boundaries?
  - Are the same variables and units of measure found in the problem statement also found in the goal statement?
  - Can the project be handled by a single team?
  - Does it avoid unnecessary constraints but still specify clearly any necessary global constraints, such as organizational strategy?
  - Are there any points that need clarification or modification?
  - Are the team members representative of departments, divisions, or work units affected by the project? The detailed process flow diagram, particularly if it is constructed in "swim lane" fashion, can help with this.
- Verify that the problem truly exists. If the problem has not been accurately measured, the team must do so at this point.
- Validate project goal(s). Verify that the basis for the project goal(s) is (are) one or more of the following:
  - Technology
  - Market
  - Benchmarking
  - History
- Modify the problem statement and goal statement if either does not meet the criteria above.
- Obtain confirmation from the leadership team, Champion, Black Belt, or quality council on any necessary changes to the project goal or to team membership.
- Create a glossary (list of operational definitions) for your project that will serve as a "dictionary" for important terms relating to your project. Select a team member to act as glossary chief with the responsibility of maintaining the project glossary.

# 15.6.12. List Theories of Root Cause Based on the Process Flows and Measures

The team needs to develop a comprehensive and creative list of theories of root cause. A root cause is a factor that affects the outcome, would eliminate or reduce the problem if it were removed or mitigated. Tools typically used include Cause-Effect (fish bone or Ishikawa) diagrams, FMEA, and fault tree analysis.

# 15.6.13. Measure: Deliverables

- Baseline performance metrics describing outputs (Ys)
- Process flow diagram; key process input variables; key process output variables; cause-effect diagram; potential failure mode and effect analysis (FMEA) (to get clues to possible causes [Xs] of the defective outputs [Ys])
- Data collection plan, including sampling plan
- Gage reproducibility and repeatability or attribute measurement system analysis (to measure the capability of the measurement system itself)
- Capability measurement in terms of defect rates, capability indexes, and/or Sigma levels
- Confirmed or modified project goal
- Prioritized list of theories of cause based on cause-effect analysis, FMEA, or similar tools

## 15.6.13.1. Measure: Questions to Be Answered

1. How well is the current process performing with respect to the specific Ys (outputs) identified to Pareto analyses?
2. What data do we need to obtain in order to assess the capability of (a) the measurement system(s) and (b) the production process(es)?
3. What is the capability of the measurement system(s)?
4. Is the process in statistical control?
5. What is the capability of the process(es)?
6. Does the project goal need to be modified?
7. What are all the possible root causes for the problem?

# 15.6.14. Analyze Phase

In the analyze phase, the project team analyzes past and current performance data. Key information questions are answered through this analysis. Hypotheses on possible cause-effect relationships are developed and tested. Appropriate statistical tools and techniques are used: histograms, box plots, other exploratory graphical analysis, correlation and regression, hypothesis testing, contingency tables, analysis of variance (ANOVA), and other graphical and statistical tests may be used. In this way, the team confirms the determinants of process performance (i.e., the key or "vital few" inputs that affect response variable[s] of interest are identified). It is possible that the team may not have to carry out designed experiments (DOEs) in the next (Improve) phase if the exact cause-effect relationships can be established by analyzing past and current performance data.

Procedure to analyze response variables (outputs, Ys) and input variables (Xs):

- Perform graphical analysis using tools such as histograms, box plots, and Pareto analysis.
- Visually narrow the list of important categorically discrete input variables (Xs).

- Learn the effects of categorically discrete inputs (Xs) on variable outputs (Ys) and display the effects graphically.
- Perform correlation and regression to
  - Narrow the list of important continuous input variables (Xs) specifically to learn the "strength of association" between a specific variable input (Xs) and a specific variable output (Ys).
- Calculate confidence intervals to
  - Learn the range of values that, with a given probability, include the true value of our estimated population's parameter, which has been calculated from a sample (e.g., the population's center and/or spread).
  - Analyze relationships between specific Ys and Xs, to prove cause-effect relationships.
  - Confirm the vital few determinants (Xs) of process performance (Ys).
- Perform hypothesis testing using continuous variables data to
  - Answer the question, Is our population actual standard deviation the same as or different from its target standard deviation? Perform 1 variance test.
  - Answer the question, Is our population actual mean the same as or different from its target mean? Perform 1-sample *t*-tests.
  - Answer the questions, Is our population mean the same or different after a given treatment as it was before the treatment? or Is the average response at level 1 of the X factor the same or different as it is at level 2 of that factor? Perform 2 sample *t*-tests, or if there is a natural pairing of the response variable, paired *t*-tests.
  - Answer the question, Are several (>2) means the same or different? Perform analysis of variance.

Note: The above tests are referred to as parametric tests because they assume normally distributed response data and, in the case of ANOVA, equality of variances across all levels of the factor. For a discussion of nonparametric (also referred to as "distribution free") tests to use when assumptions of normality and or equality of variances are violated.

Perform hypothesis testing using attribute data to

- Answer the question, Is the proportion of some factor (e.g., defectives) in our sample the same or different from the target proportion? Perform a Minitab test and calculation of confidence interval for one proportion.
- Answer the question, Is proportion 1 the same or different from proportion 2? Perform the binomial proportions test and calculation of confidence interval for two proportions.
- Answer the question, Is a given output (Y) independent of or dependent on a particular input (X)? (This involves testing the theory that a given X is an important causal factor that should be included in our list of vital few Xs.) Perform a chi-squared test of independence (also called a contingency table).

# 15.6.15. Analyze: Deliverables

- Histograms, box plots, scatter diagrams, Pareto analysis, correlation and regression analyses (to analyze relationships between response variables [Ys] and potential causes [Xs])
- Results of hypothesis testing (to establish relationships between response variables [Ys] and input variables [Xs])
- List of vital few process inputs (Xs) that are proven root causes of the observed problem

## 15.6.15.1. Analyze: Questions to Be Answered

1. What patterns, if any, are demonstrated by current process outputs (Ys) of interest to the project team?
   - Analyze response variables (outputs; Ys).
   - Analyze input variables (Xs).
   - Analyze relationships between specific Ys and Xs, identifying cause-effect relationships.
2. What are the key determinants of process performance (vital few Xs)?
3. What process inputs (Xs) seem to determine each of the outputs (Ys)?
4. What are the vital few Xs on which the project team should focus?

# 15.6.16. Improve Phase

In the improve phase, the project team seeks to quantify the cause-effect relationship (mathematical relationship between input variables and the response variable of interest) so that process performance can be predicted, improved, and optimized. The team may utilize DOEs if applicable to the particular project. Screening experiments (fractional factorial designs) are used to identify the critical or "vital few" causes or determinants. A mathematical model of process performance is then established using 2k factorial experiments. If necessary, full factorial experiments are carried out. The operational range of input or process parameter settings is then determined. The team can further fine-tune or optimize process performance by using such techniques as response surface methods (RSM) and evolutionary operation (EVOP). Procedures to define, design, and implement improvements include

1. Plan designed experiments
2. Conduct screening experiments to identify the critical, vital few process determinants (Xs)
3. Conduct designed experiments to establish a mathematic model of process performance
4. Optimize process performance
5. Evaluate alternative improvements
6. Design the improvement

## 15.6.17. Plan Designed Experiments

- Learn about DOEs in preparation for planning and carrying out experiments to improve the "problem" process.
- Design in detail the experiments required by the project.

## 15.6.18. Conduct Fractional Factorial Screening Experiments

- Perform fractional factorial screening experiments to reduce even further the list of input variables to the vital few that strongly contribute to the outputs of interest. (A relatively large number of factors [Xs] are examined at only two levels in a relatively small number of runs.)

## 15.6.19. Conduct Further Experiments, If Necessary, to Develop Mathematical Model and Optimize Performance

- Perform 2k factorial experiments. Multiple factors (Xs, identified by screening experiments) are examined at only two levels to obtain information economically with relatively few experimental runs. Constructing equations that predict the effect on output Y of a given causal factor X discovers precise mathematical relationships between Xs and Ys. In addition, not only are the critical factors (X) identified, but also the level at which each factor performs the best and any significant interactions among the factors.
- If necessary, perform full factorial experiments. More information than is provided by 2k factorial experiments may be required. A full factorial experiment produces the same type of information as a 2k factorial does, but does so by examining multiple factors (Xs) at multiple levels.
- If necessary, and in addition, utilize RSM and/or EVOPs techniques to further assist in determining optimal process parameters.
- Using results of experiments derive mathematical models of the process and establish optimal settings for process parameters (Xs) to achieve desired (Ys).

## 15.6.20. Evaluate Alternatives and Choose Optimal Improvements

- Identify a broad range of possible improvements.
- Agree on criteria against which to evaluate the improvements and on the relative weight each criterion will have. The following criteria are commonly used:
  - Total cost
  - Impact on the problem
  - Benefit-cost relationship
  - Cultural impact or resistance to change
  - Implementation time
  - Risk
  - Health, safety, and the environment
- Evaluate the improvements using agreed-upon criteria
- Agree on the most suitable improvements

## 15.6.21. Design the Improvements

- Evaluate the improvements against the project goal.
- Verify that it will meet project goals.
- Identify the following customers:
  - Those who will create part of the improvements
  - Those who will operate the revised process
  - Those served by the improvements
- Determine customer needs with respect to the improvements.
- Determine the following required resources: people, money, time, and materials.
- Specify the procedures and other changes required.
- Assess human resource requirements, especially training.
- Verify that the design of the improvement meets customer needs.
- Plan to deal with any cultural resistance to change.

# 15.6.22. Improve: Deliverables

- Plan for designed experiments
- Reduced list of vital few inputs (Xs)
- Mathematical prediction model(s)
- Established process parameter settings
- Designed improvements
- Implementation plan
- Plans to deal with cultural resistance

## 15.6.22.1. Improve: Questions to Be Answered

1. What specific experiments should be conducted to arrive ultimately at the discovery of what the optional process parameter settings should be?
2. What are the vital few inputs (Xs, narrowed down still further by experimentation) that have the greatest impact on the outputs (Ys) of interest?
3. What is the mathematical model that describes and predicts relationships between specific Xs and Ys?
4. What are the ideal (optimal) process parameter settings for the process to produce output(s) at Six Sigma levels?
5. Have improvements been considered and selected that will address each of the vital few Xs proven during the analyze phase?
6. Has expected cultural resistance to change been evaluated and plans made to overcome it?
7. Has a pilot plan been developed and executed and the solutions appropriately adjusted based on the results?
8. Have all solutions been fully implemented along with required training, procedural changes, and revisions to tools and processes?

# 15.6.23. Control Phase

The project team designs and documents the necessary controls to ensure that gains from the improvement effort can be sustained once the changes are implemented. Sound quality principles and techniques are used, including the concepts of self-control and dominance, the feedback loop, mistake proofing, and statistical process control. Process documentations are updated (e.g., the failure mode and effects analysis), and process control plans are developed. Standard operating procedures (SOP) and work instructions are revised accordingly. The measurement system is validated, and the improved process capability is established. Implementation is monitored, and process performance is audited over a period to ensure that the gains are held. The project team reports the goal accomplished to management, and upon approval, turns the process totally over to the operating forces and disbands.

The activities required to complete the control step include

1. Design controls and document the improved process
2. Design for culture
3. Validate the measurement system
4. Establish the process capability
5. Implement and monitor

# 15.6.24. Design Controls and Document Improved Process

- Update FMEA to ensure that no necessary controls have been overlooked.
- Mistake-proof the improvement(s), if possible.
  - Identify the kind(s) of tactic(s) that can be incorporated into the improvements to make it mistake proof. Some options include
    - Designing systems to reduce the likelihood of error
    - Using technology rather than human sensing
    - Using active rather than passive checking
    - Keeping feedback loops as short as possible
    - Designing and incorporating the specific steps to mistake-proof as part of the improvements
- Design process quality controls to ensure that your improved levels of inputs (Xs) and outputs (Ys) are achieved continuously. Place all persons who will have roles in your improved process into a state of self-control to ensure that they have all the means necessary to be continuously successful.
- Provide the means to measure the results of the new process
  - Control subjects
  - Output measures (Ys)
  - Input measures and process variables (Xs)
  - Establish the control standard for each control subject
  - Base each control standard on the actual performance of the new process
- Determine how actual performance will be compared to the standard.
  - Statistical process control
- Design actions to regulate performance if it does not meet the standard. Use a control spreadsheet to develop an action plan for each control subject.
- Establish self-control for individuals so
  - They know exactly what is expected (product standards and process standards).
  - They know their actual performance (timely feedback).
  - They are able to regulate the process because they have
    - A capable process.
    - The necessary materials, tools, skills, and knowledge.
    - The authority to adjust the process.

# 15.6.25. Design for Culture to Minimize or Overcome Resistance

- Identify the likely sources of resistance (barriers) and supports (aids). Resistance typically arises because of
  - Fear of the unknown
  - Unwillingness to change customary routines
  - The need to acquire new skills
  - Unwillingness to adopt a remedy "not invented here"
  - Failure to recognize that a problem exists
  - Failure of previous solutions
  - Expense
- Rate the barriers and aids according to their perceived strengths
- Identify the countermeasures needed to overcome the barriers. Consider
  - Providing participation
  - Providing enough time
  - Keeping proposals free of excess baggage
  - Treating employees with dignity
  - Reversing positions to better understand the impact on the culture
  - Dealing with resistance seriously and directly
- Install statistical process control (SPC) where necessary to ensure that your process remains stable and predictable, and runs in the most economic manner.
- Consider introducing 6s standards to make the workplace function smoothly with maximum value-added activity and minimum non-value-added activity.

# 15.6.26. Validate Measurement System

Utilize commercially available software such as Minitab to evaluate measurement system capability (as in the measure phase) to ensure that the measurements utilized to evaluate control subjects can be depended on to tell the truth.

# 15.6.27. Establish Process Capability

- Prove the effectiveness of the new, improved process to ensure that the new controls work and to discover if your original problem has improved, and ensure that no new problems have inadvertently been created by your improvement(s).
- Decide how the improvements will be tested
  - Agree on the type of test(s)
  - Decide when, how long, and who will conduct the test(s)
  - Prepare a test plan for each improvement
  - Identify limitations of the test(s)
    - Develop an approach to deal with limitations.
    - Conduct the test.
    - Measure results.
    - Adjust the improvements if results are not satisfactory.
    - Retest, measure, and adjust until satisfied that the improved process will work under operating conditions.
- Utilizing control charts, ensure that the new process is in statistical control with respect to each individual control subject. If not, improve the process further until it is.
- When, and only when, the process is in statistical control, utilize Capability Analysis—as in the measure phase—to determine process capability for each individual control subject.

# 15.6.28. Implement the Controls and Monitor

- Transfer to the operating forces all the updated control plans, etc., and train the people involved in the process in the new procedure.
- Develop a plan for transferring the control plan to the operating forces. The plan for transferring should indicate:
  - How, when, and where the improvements will be implemented?
  - Why the changes are necessary and what they will achieve?
  - The detailed steps to be followed in the implementation.
- Involve those affected by the change in the planning and implementation.
- Coordinate changes with the leadership team, Black Belt, Champion, executive council, and the affected managers.
- Ensure preparations are completed before implementation, including
  - Written procedures

  - Training
  - Equipment, materials, and supplies
  - Staffing changes
  - Changes in assignments and responsibilities
  - Monitoring the results
- Periodically audit the process, and also the new controls, to ensure that the gains are being held
- Integrate controls with a balanced scorecard
- Develop systems for reporting results
- When developing systems for reporting results, determine
- What measures will be reported?
- How frequently?
- To whom (should be a level of management prepared to monitor progress and respond if gains are not held)?
- Document the controls

When documenting the controls, indicate

- The control standard
- Measurements of the process
- Feedback loop responsibilities (who does what if controls are defective)
- After a suitable period, transfer the audit function to the operating forces and disband the team (with appropriate celebrations and recognition)

# 15.6.29. Control: Deliverables

- Updated FMEA, process control plans, and standard operating procedures
- Validated capable measurement system(s)
- Production process in statistical control and able to get as close to Six Sigma levels as is optimally achievable, at a minimum accomplishing the project goal
- Updated project documentation, final project reports, and periodic audits to monitor success and hold the gains

## 15.6.29.1. Control: Questions to Be Answered

- What should be the plan to ensure the process remains in statistical control and produces defects only at or near Six Sigma levels?
- Is our measurement system capable of providing accurate and precise data with which to manage the process?
- Is our new process capable of meeting the established process performance goal?
- How do we ensure that all people who have a role in the process are in a state of self-control (have all the means to be successful on the job)?
- What standard procedures should be in place, and followed, to hold the gains?

# 15.6.30. Training and Certification of Belts

The introduction of Six Sigma in the past decade led to a surge in the certification of Belts. This was largely due to a lesson learned from the Total Quality Management (TQM) era. During TQM, many so-called experts were trained in the "methods of TQM." Unfortunately, few were trained in the tools to collect and analyze data. As a result, numerous organizations did not benefit from the TQM program.

Motorola introduced a core curriculum that all Six Sigma practitioners needed to learn. That evolved into a certification program that went beyond the borders of Motorola. As a result, there are many "certifiers" that will provide a certification as a Master Black Belt, Black Belt, Green Belt, and so on. Most certifications state that the person certified is an "expert" in the skills of Six Sigma or Lean or both. Certification did lead to improved performance, but also to some weak experts due to no oversight of the certifiers, many of which were consulting companies or universities not well versed in the methods or tools of Six Sigma and Lean.

The American Society for Quality (ASQ) for many years offered certification for quality technicians, quality auditors, quality engineers, and quality managers. As the Six Sigma movement grew, the ASQ and its affiliates around the world prepare a minimum body of knowledge for various belt levels. The ASQ provides a widely-accepted standard that any practitioner should at a minimum master. Certification must be based on legitimacy to be effective.

ASQ's Certified Quality Engineer (CQE) program is for people who want to understand the principles of product and service quality evaluation and control (ASQ, 2009). For a detailed list of the CQE body of knowledge, the reader is referred to the certification requirements for Certified Quality Engineer at **www.asq.org**.

ASQ also offers a certification for quality officers at the quality management level, called Certified Manager of Quality/Organizational Excellence. ASQ views the Certified Manager of Quality/Organizational Excellence as "a professional who leads and champions process-improvement initiatives—everywhere from small businesses to multinational corporations—that can have regional or global focus in a variety of service and industrial settings. A Certified Manager of Quality/Organizational Excellence facilitates and leads team efforts to establish and monitor customer/supplier relations, supports strategic planning and deployment initiatives, and helps develop measurement systems to determine organizational improvement. The Certified Manager of Quality/Organizational Excellence should be able to motivate and evaluate staff, manage projects and human resources, analyze financial situations, determine and evaluate risk, and employ knowledge management tools and techniques in resolving organizational challenges" (ASQ, 2009).

Note: No matter what organization you use to certify your experts, here are some lessons learned about certification:

- One project is not enough to make someone an expert
- Passing a written test that is not proctored is no guarantee the person who is supposed to be taking the test is actually taking it
- If you get someone in your organization to sign off on the success of the Belt project, you need independent evidence that the person is knowledgeable about the methods of Six Sigma
- Select a reputable certifying body