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17.4. Design for Six Sigma—DMADV Steps

Table 17.1 summarizes the main activities within each of the DMADV steps. These are discussed in more detail in this section. Experience with applying the five DMADV steps has led us to believe that it is useful to define a step to select the project before the team actually begins its DMADV journey.

Table 17.1 *Major Activities in Phases of DFSS*

Define	Measure	Analyze	Design	Verify
Agree to opportunity	Identify customers	Develop alternative designs	Develop detailed designs	Execute manufacturing/ operations verification
Agree to goals	Discover customer needs	Complete functional analysis	Integrate designs	Execute pilot and ramp-up
Agree to scope	Translate needs into CTQs	Select best-fit design	Model predictions of performance	Execute control plan
Establish project plan	Establish design scorecard	Specify functional requirements	Optimize design parameters	Finalize design scorecard
Assign resources		Specify subsystem functional requirements Complete high-level design review Validate with customer Update design scorecard	Develop statistical tolerances Specify process features and detailed operations Design complete control plan Complete design verification test Validate with customer Complete design review Update design scorecard	Transition to operational owners and validate

17.4.1. Select the Opportunity

The select phase in DFSS is more strategic than for quality improvement or DMAIC projects (see **Chap. 15**, Six Sigma: Breakthrough to in-Process Effectiveness). A target for a new product or capability is identified as part of the strategic and annual business planning processes. When a major opportunity is identified, leadership will determine that it is best served with a new design or redesign of something that exists. Typically this means that a new or emerging market has been targeted; it may also mean that customer needs in an existing market are shifting, or that competition has shifted, and a new approach is required.

This type of project selection is different from a DMAIC project in which specific deficiencies or wastes are targeted for an existing product or process. Rarely is an existing product or process so broken that the initial analysis in DMAIC leads to the conclusion that a total redesign is required. A major health insurer reached that conclusion with respect to payment of claims. Instead of multiple improvement projects, it redesigned the entire claims payment service so as to raise customer satisfaction from 75 to 93 percent, improve timeliness by a factor of 10, and reduce costs by more than one-half.

The project opportunity and goal statements are prepared and included in a team charter, which is confirmed by management. Unlike the rather simple and direct goal statements for a DMAIC project, the DMADV goal statement may, in fact, be multiple statements about the market to be served by the new product and the economic returns to be achieved, such as market penetration, growth, and profitability. Management selects the most appropriate team of personnel for the project, ensures that they are properly trained, and assigns the necessary priority. Project progress is monitored to ensure success.

17.4.2. Select: Deliverables

- Make a list of potential projects.
- Calculate the return on investment and contribution to strategic business objective(s) for each potential project.
- Identify potential projects.
- Evaluate projects and select a project.
- Prepare project opportunity statement and a team charter.
- Select and launch team.
- Formal project team leader should be a qualified practitioner or Black Belt.

17.4.3. Select: Questions to Be Answered

1. What new market opportunities do we have?
2. What new emerging customers or customer needs can we go after?
3. What are the likely benefits to be reaped by gaining or increasing that business?
4. Which of our list of opportunities deserves to be tackled first, second, etc.?
5. What formal opportunity 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?

17.4.4. Define Phase

A project begins with the define phase when it is officially launched by the management team. It may be necessary for the management team or Champion to work closely with the project design team to refine the design opportunity. This refinement will lead to an accurate scope of the project and will ensure a common understanding of the objectives and deliverables. Experience has shown that projects that fail to deliver the expected results frequently get off track at the start, when the project is being defined.

A key task in the define phase is to create the initial business case that validates the selection rationale and establishes the business justification through reduced product cost, increased sales, or entirely new market opportunities. The initial business casework is conducted under the auspices of the management team, and then it is validated and updated continuously by the design team through the subsequent phases of the design project. The management team selects a black belt to lead the design project. The Champion, who is the management sponsor with vested interest in the success of the design, in conjunction with the Black Belt, is responsible for selecting a cross-functional team that will conduct all the activities to complete the design and carry it into production.

17.4.5. Define: Deliverables

- Initial business case is developed.
- Design strategy and project are established; leaders and team are selected.
- Project charter is drafted, including project opportunity statement and design objectives.
- Team is launched and a list of customers defined: market customers, nonmarket customers—users, regulators, stakeholders etc.—and internal customers.

17.4.6. Define: Questions to Be Answered

1. What are the design goals or objectives of the project?
2. What are the specific goals of the project team?
3. What is the business case that justifies the project?
4. What charter will the team members receive from management empowering them to carry out the project?
5. What will be the project plan?
6. How will the project be managed?
7. Who will be the customers of this project?

17.4.7. Measure Phase

The measure phase in the DMADV sequence is mainly concerned with identifying the key customers, determining what their critical needs are, and developing measurable critical quality (CTQ) requirements necessary for a successfully designed product. An initial assessment of our markets and customer segmentation by various factors is required to identify the key customers. This assessment is often completed by the marketing organization and is then reviewed and verified by the design team. However, it is the design team's responsibility to complete the customer needs analysis and compile the results into a prioritized tabulation of customer needs. The design team transforms the critical customer needs into measurable terms from a design perspective. These translated needs become the measurable CTQs that must be satisfied by the design solution. Competitive benchmarking and creative internal development are two additional sources to generate CTQs. These methods probe into design requirements that are not generally addressed or possibly even known by the customer. The result is a set of CTQs stated in specific technical requirements for design in the voice of the organization that become the measurable goals (specifications) for product performance and ultimate success.

The project team may use several means to set the goals for each CTQ. Some tools include competitive benchmarking, competitive analysis, value analysis, criticality analysis, and stretch objectives for current performance. The result is a combination of customers' stated requirements, and requirements that may not be generally addressed or known by the customer. The measure phase ends with the assessment of the current baseline performance against the enumerated CTQs and performance of risk assessments. To establish these baselines, typical process capability methods and tools are utilized. These include the following:

- Establish the ability of the measurement system to collect accurate data using measurement system analysis (MSA)
- Measure the stability of the current or surrogate process(es) using statistical process control techniques
- Calculate the capability and sigma level of the current or surrogate process(es)
- Evaluate risk by using tools such as design failure mode effects analysis (DFMEA) and process failure mode effects analysis (PFMEA)

Another tool employed by some design project teams is the set of quality function deployment (QFD) matrices (see **Fig. 17.2**). Each matrix lists vertically some objectives to be fulfilled (the "what") and then horizontally the means to fulfill the objectives (the "how"). Within the body of the matrix are indicators for how well each objective is met by the respective means. For example, the first matrix displays how well each of the customer needs is addressed by the specific CTQs. As a group, the matrices are tied together, with the means (how) of one matrix becoming the objectives (what) of the next. In this way the customer needs are tied seamlessly to the CTQs, to the functional requirements, to the design requirements, finally to the process requirements, and ultimately to the control requirements. In this way nothing critical is lost and no extraneous matters are introduced.

The QFD matrix (or simpler version) is meant to highlight the strengths and weaknesses that currently exist. In particular, the weaknesses represent gaps that the design team must shrink or overcome. The demand on the team then is to provide innovative solutions that will economically satisfy customer needs. Keeping this matrix up to date provides a running gap analysis for the team.

17.4.8. Discover Customer Needs

- Plan to collect customer needs from internal customers and external customers.
- Collect list of customers' needs in their language.
- Discover and prioritize customer needs in terms of the customer-perceived benefit.

17.4.9. Translate and Prioritize Customer Needs

- Translate needs and benefits from the voice of the customer (VOC) into voice of the producer as CTQ requirements.
- Establish measurement for all prioritized CTQs, including units of measure, sensor, and validation.
- Establish targets and upper and lower specification limits for all CTQs.
- Establish target permissible defect rate (DPMO, Sigma) for each CTQ.

17.4.10. Establish Baseline and Design Scorecard

Once the prioritized list of CTQs is produced, the design team proceeds to determine the baseline performance of relevant existing product and production process. The current baseline performance is determined in terms of multiple components:

- Measurement systems analysis
- Product capability
- Production process capability
- Risk assessment by using tools such as product FMEA
- Competitive performance

Finally, a design scorecard is created that tracks the design evolution toward a Six Sigma product performance. This tool is used in the attempt to predict what the final product performance and defect levels will be after integration of all the design elements. The design scorecard is updated throughout the project to ensure that objectives are met.

17.4.11. Measure: Deliverables

In summary, the key deliverables that are required to complete the measure phase are

- A prioritized list of customer needs
- A prioritized list of CTQs
- A current baseline performance
- A design scorecard

17.4.12. Measure: Questions to Be Answered

1. What customer needs must the new product meet?
2. What are the critical product and process requirements that will enable the customer needs to be met?
3. How capable is our current product and production process of meeting these requirements?
4. How capable must any new product and production process be to meet these requirements?

17.4.13. Analyze Phase

The main purpose of the analyze phase is to select a high-level design and develop the design requirements that will be the targets for performance of the detailed design. This is sometimes referred to as system-level design versus the subsystem or component design levels.

The design team develops several high-level alternatives that represent different functional solutions to the collective CTQ requirements. A set of evaluation criteria is then developed, against which the design alternatives will be analyzed. The final configuration selected may be a combination of two or more alternatives. As more design information is developed during the course of the project, the design may be revisited and refined.

In developing the high-level design, the team establishes the system's functional architecture. The flow of signals, flow of information, and mechanical linkages indicate the relationship among the subsystems for each design alternative. Hierarchical function diagrams, functional block diagrams, function trees, and signal flow diagrams are commonly used to illustrate these interrelationships. Where possible, models are developed and simulations run to evaluate the overall system functionality.

The requirements for each subsystem are expressed in terms of their functionality and interfaces. The functionality may be expressed as the system transfer function, which would represent the desired behavior of the system or subsystem. Interfaces are described in terms of the input and output requirements and the controls (feedback, feed-forward, automatic controls). These specifications will be provided to the detail design teams in the design phase.

In the analyze phase, DMADV analysis tools enable the design team to assess the performance of each design alternative and to test the differences in performance of the competing design alternatives. The results of these tests lead to the selection of the best-fit design, which is then the basis to move into the next phase, detailed design. These analyses are accomplished using graphical and statistical tools including

- Competitive analysis
- Value analysis
- Criticality analysis
- Fault-tree analysis
- Risk analysis
- Capability analysis
- High-level design matrices from QFD
- TRIZ (teoriya resheniya izobretatelskikh zadach; Russian, literally "theory of the resolution of invention-related tasks")
- Updated design scorecard

One of the significant advances affecting this process is the availability of several statistical analysis tools. These software applications, running on desktops or laptop computers, speed up the number crunching required to perform the preceding analysis. This availability has also made it necessary for individuals who would not normally use these tools to be trained in the use and interpretation of the results.

17.4.14. Analyze: Deliverables

Develop a high-level product or service and process design and detail design requirements.

- Design alternatives
- Functional analysis
- Best alternative selected
- Best-fit analysis
- High-level quantitative design elements
- High-level resource requirements and operating ranges
- High-level design capability analysis and prediction
- Detail design requirements for subsystems/modules
- Key sourcing decisions
- Initial product introduction resources and plans
- Updated design scorecard
- QFD design matrices

17.4.15. Analyze: Questions to Be Answered

1. What design alternatives could be employed in the new product or process service?
2. Which is the "best" alternative?
3. What are the requirements for the detailed design?
4. Has customer feedback been obtained?
5. Does the high-level design pass a business and technical design review?
6. Has the design been validated with customers?

17.4.16. Design Phase

The design phase builds upon the high-level design requirements to deliver a detailed optimized functional design that meets operational manufacturing and service requirements. Detail designs are carried out on the subsystems and eventually integrated into the complete functional system (product). DMADV tools focus on optimizing the detail-level design parameters.

In particular, designed experiments and/or simulations serve several purposes. One purpose is to determine the best set of features (optimum configuration) to employ. Another purpose can be to obtain a mathematical prediction equation that can be used in subsequent modeling and simulations. Experiments are typically designed at differing levels of complexity, from minimal-run screening experiments to multilevel replicated design. Screening experiments typically try to establish which factors influence the system, providing somewhat limited results for modeling. More detailed experiments, including response surface and mixture designs, are conducted to determine system performance more accurately and produce a mathematical equation suitable for prediction and modeling applications. More complex products will often require nonlinear response surface models as well as mixture and multiple-response models.

During the design phase, the design team is also concerned about the processes that must be developed to provide the service or build the product. During the measure phase, the team examines the current capability of the business to deliver the product or service at the expected quality levels (approaching Six Sigma). During the design phase, the team continually updates the design scorecard with the results of designed experiments, benchmarking results, process capability studies, and other studies to track the design performance against the established goals, continuing the gap analysis that runs throughout the project. The product design is also reevaluated against the manufacturing or operational capability. Product designs may be revised as needed to ensure reliable, capable manufacturing and operations.

Part of the design for operations includes the validation of tolerances for each parameter. Designed experiments can contribute to developing these tolerances, and statistical tolerancing can also validate them.

To conclude the design phase requires the goals of the design for performance to be verified through testing of prototype, preproduction models, or initial pilot samples or pilot runs. The design team documents the set of tests, experiments, simulations, and pilot builds required to verify the product/service performance in a design verification test (DVT) plan. Upon completion of the several iterations that occur during the DVT and pilot runs, the design is solidified and the results of testing are summarized. A design review meeting marks the conclusion of the design phase, when the results of the DVT are reviewed. The design scorecard is updated, and each area of the development plan (quality plan, procurement plan, manufacturing plan, etc.) is adjusted as necessary.

17.4.17. Design: Deliverables

- Optimized design parameters (elements)—nominal values that are most robust
- Prediction models
- Optimal tolerances and design settings
- Detailed functional design
- Detailed designs and design drawings
- Detailed design for operations/manufacturing
- Standard operating procedures, standard work, and work instructions
- Reliability/lifetime analysis results
- Design verification test results
- Updated design scorecard

17.4.18. Design: Questions to Be Answered

1. What detailed product design parameters minimize variation in product performance?
2. What tolerances both are practical and ensure performance?
3. How do we ensure optimum product reliability?
4. How do we ensure simplicity and ease of manufacture or operations?
5. What detailed process parameters consistently and predictably minimize production process variation around target values?

17.4.19. Verify Phase

The purpose of the verify phase in the DMADV sequence is to ensure that the new design can be manufactured or service delivered and field supported within the required quality, reliability, and cost parameters. Following DVT, a ramp-up to full-scale production is accomplished via the manufacturing verification test (MVT) or operations verification test (OVT). The objective of this series of tests is to uncover any potential production or support issues or problems. The operations process is typically exercised through one or more pilot runs. During these runs, appropriate process evaluations occur, such as capability analyses and measurement systems analyses. Process controls are verified and adjustments are made to the appropriate standard operating procedures, inspection procedures, process sheets, and other process documentation. These formal documents are handed off to downstream process owners (e.g., manufacturing, logistics, and service). They should outline the required controls and tolerance limits that should be adhered to and maintained by manufacturing and service. These documents come under the stewardship of the company's internal quality systems. One of the considerations of the design team is to ensure that the project documentation will conform to the internal requirements of the quality system.

The design team should ensure that appropriate testing in a service and field support environment is accomplished to uncover potential lifetime or serviceability issues. These tests will vary greatly, depending on the product and industry. These tests may be lengthy and possibly not conclude before production launch. The risks associated with not having completed all tests depend on the effectiveness of earlier testing and the progress of final MVT/OVT tests that are underway. A final design scorecard should be completed, and all key findings should be recorded and archived for future reference. The team should complete a final report that includes a look back at the execution of the project. Identifying and discussing the positive and not-so-positive events and issues will help the team learn from any mistakes made and provide the basis for continuing improvement of the DFSS sequence.

17.4.20. Verify: Deliverables

- Verify product/process performance against project targets
- Pilot build is complete
- Pilot tests are completed and results are analyzed
- All operational and control documentation, procedures, controls, and training are complete
- Scale-up decision(s) are made
- Full-scale processes are built and implemented
- Business results are determined/analyzed
- Processes are transitioned to owners
- DFSS project is closed

17.4.21. Verify: Questions to Be Answered

1. Is the product or process meeting the specifications and requirements?
2. Is the production process "owned" by the business?