7

Value Improvement Methods

David K.H. Chua
National University of Singapore

7.1 Introduction

This chapter deals with several concepts that will help improve value in the design and construction phases of a project. These are value engineering, constructability, and quality management. The essence of each of these concepts is as follows:

- **Value engineering** — To deliver the required functions of a component or product at lowest cost while meeting quality, performance, and reliability specifications
- **Constructability** — To integrate construction knowledge and experience in project planning, design, and execution to better achieve project outcomes
- **Quality management** — To deliver quality with the view of customer satisfaction in all operations

Each of these concepts involves systematic approaches and will require some changes in management perspectives to fully realize the benefits from their implementation. The key principles for each of these concepts will be elaborated in turn. Their methodologies will also be presented.

7.2 Value Engineering

Basic Concepts

The concept of value engineering (VE) was born out of necessity almost immediately after World War II when, as a result of wartime shortages, substitute materials were used in innovative designs that offered better performance at lower costs. Much of this happened in the General Electric Company under the attention of Harry Erlicher, the Vice President of Manufacturing. Eventually, in 1947, Lawrence Miles, a staff engineer with the company, was assigned to formalize the approach. The program saved millions of dollars for the company. To replicate the success, value engineering became a mandatory requirement in the Armed Services Procurement Regulations (ASPR) in 1962. Subsequently, it was introduced to two of the largest contracting companies in the U.S., namely, the U.S. Army Corps of Engineers and the U.S. Navy Bureau of Yards. Eventually, its use spread to other companies and contracting agencies posing similar successes.

Essentially, VE is a systematic approach to eliminate any unnecessary cost of an item that does not add to its required function. It does not simply reduce cost by using cheaper substitutes or lesser quantities. Instead, its methodology centers on the following questions: What must it do? What alternative material or method can perform the same function equally well? This is function analysis: the principal component in VE. Thus, in a construction project, VE involves analyzing the functional requirements of components, subsystems, and even construction methods.

The other aspects of VE are cost and worth. Total cost is the objective to be minimized in any value engineering exercise, while worth represents the minimum costs to achieve the required functions. Worth forms the means for generating alternatives and serves as the baseline against which various alternatives can be compared. Any reduction in unnecessary cost represents the savings achieved.

Methodology

The formal approach for value engineering is often referred to as the job plan. The VE job plan comprises several phases. Generally, although there are possible variations, the following five form the essence of the job plan (see Fig. 7.1):

1. **Information phase** — Getting the facts
2. **Speculation phase** — Brainstorming for alternatives
3. **Analysis phase** — Evaluating the alternatives
4. **Development phase** — Developing the program
5. **Recommendation phase** — Selling the recommendations

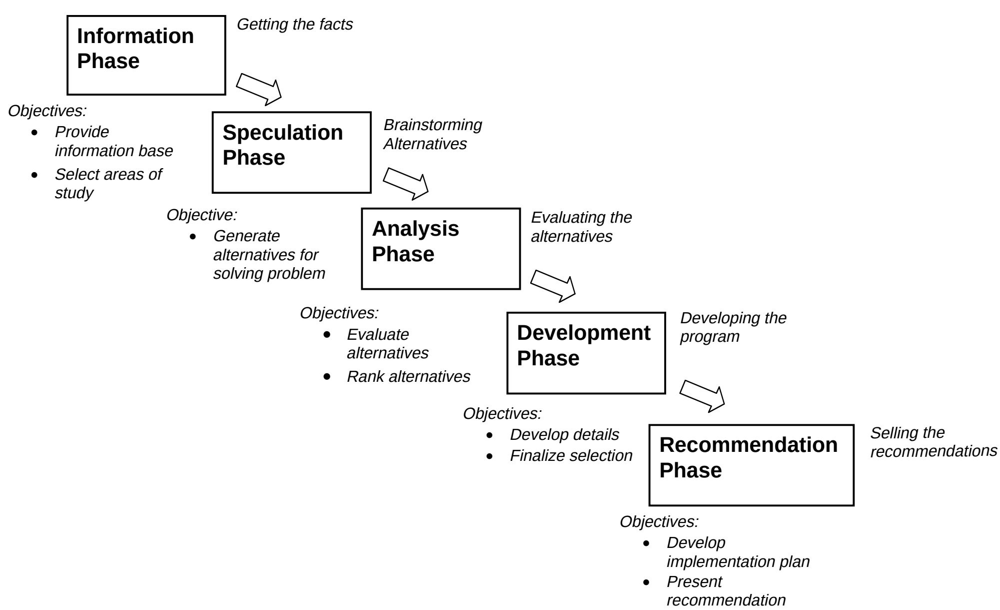

FIGURE 7.1 Phases in the value engineering job plan.

Information Phase

One objective of this phase is to determine and evaluate the function(s) of the items that have the greatest potential for eliminating unnecessary cost. This answers the question "what *must it do?*." The function analysis approach is one method to achieve this (Dell'Isola, 1982). It employs a verb-noun description of the function, for example, the function of a non-load-bearing wall may be defined to be "*enclose space*," where *enclose* is the verb and *space* the noun. In function analysis, the focus is on why an item is necessary (i.e., its function performance) rather than on the item per se. This paves the way for substituting with cheaper alternative ways to achieve the same function(s) in the latter phases.

All the functions identified are classified as either basic or secondary. The basic function of an item is the primary purpose the item must achieve to fulfill the owner's requirement. A secondary function, on the other hand, is not an essential feature to the owner and usually arises from a particular design configuration that makes the item look better. Sometimes, however, a secondary function may be required by regulatory or building codes. In this case, it is still a critical function essential to the performance of the item. The categorization of the functions enables costs incurred for the nonessential secondary functions to be isolated from those required to provide the basic functional performance. In this way, the number of secondary functions with its associated costs can be reduced (or eliminated) without compromising required owner's functions. Moreover, focus can be placed on alternatives to reduce the cost of providing the basic functions.

The next objective is to determine the cost and worth of the various functions identified. The worth of an item is the lowest cost to perform the basic and required secondary functions, while nonessential secondary functions are not assigned any worth. The cost/worth ratio is an indication of the functional efficiency of the item. A high cost/worth is also indicative of the potential for reaping improvements in value.

The Function Analysis Systems Technique (FAST) originally developed by Charles Bytherway in 1965, has been widely used to determine the relationship between functions of an entire system, process, or complicated assembly. A FAST diagram gives graphical representation of the interrelation of functions and their costs and is an excellent technique to use for this phase.

Other information required at this stage may include the following:

- Constraints that still apply at this stage
- Constraints that are unique to the system
- Frequency of use of item
- Alternative designs considered in the earlier concept

Speculation Phase

The sole objective in this phase is to generate various alternative methods of achieving the same functions, answering the question "*what else will satisfy the same needed functions?*" Creative thinking techniques are used to produce as many ideas as possible. The idea in this stage is not to leave out any possible solution. Alternatives will only be evaluated in the next phase.

There are several techniques that can be adopted in this process. Brainstorming is the most popular of these. It is based on the principle that ideas are generated in large numbers if the group is diversified. With a large number of ideas, there is an increased probability of getting good ideas. Some of these may arise spontaneously, whereas others may be derived from building upon those already proposed. At all times, no criticism or evaluation can be offered. All ideas are documented and categorized for later evaluation.

Other group techniques (Jagannathan, 1992) that can be used include:

- **Checklist** — The checklist comprises a set of questions or points. They provide idea clues to the VE team. For example, can the material of the item be changed?
- **Morphological analysis technique** — There are two steps in the technique. The first is to identify all the parameters or characteristics of the item. The next step is to seek alternatives in each

characteristic. These characteristics can then be blended in a variety of ways to improve the basic performance of the item.

- **Delphi method** — This technique uses written questionnaires. It is advantageous in cases where participants find it difficult to attend any VE workshop session.

Analysis Phase

The objective here is to evaluate the alternatives generated in the preceding phase and select the best cost-saving alternative. This process can be difficult if there are too many alternatives in the first place. The number of alternatives can be reduced to a manageable size using filtering (Jagannathan, 1992), where the initial ideas can be rapidly evaluated against the criteria in such filters. For example, one important filter is "safety." Thus, if an alternative is perceived to affect safety levels adversely, it can be filtered out for later consideration. "Technology" can be another filter to defer alternatives that require technology not available in the organization and may require considerable R&D efforts.

The remaining alternatives are then ranked in order of their effectiveness. Their effectiveness is evaluated based on some weighted criteria measure. The decision matrix in Table 7.1 shows a comparison of various alternatives brainstormed for sealing the joints between pipe sections belonging to a 2400 ft, 8-ft diameter storm sewer line. The problem arose when it was observed that the ground surface along the corridor of the pipeline had large differential settlements. The City Engineers had attributed these settlements to sand being washed down the pipe through joint openings between pipe sections. Due to tidal movement, the ground beneath the pipeline settled, resulting in differential settlement of the 30-ft long pipe sections, breaking the cement mortar that was initially placed between the joints. The list of

TABLE 7.1 Decision Matrix for Sealing Joints

	Cost	Ease of Installation and Time	Durability	Safe Installation	Safe Material	Overall Score	Rank
Methods Weights:	2	1	4	2	2		
Mechanical fastened							
Metal	3	3	3	2	4	33	12
Sieve	3	3	3	2	4	33	12
Rubber/neoprene	3	3	4	2	4	37	3
Field-applied adhesive							
Metal	2	3	3	4	4	35	8
Rubber/neoprene	2	3	4	4	4	39	1
Adhesive backing							
Metal	3	3	3	4	4	37	3
Rubber/neoprene	3	3	3	4	4	37	3
Spring action							
Gasket with metal rods	2	4	3	4	4	36	7
Gasket with lock strip	2	3	3	4	4	35	8
Sealants							
General materials	4	3	3	3	4	37	3
Bentonite	4	2	1	3	4	28	17
Gaskets	4	3	3	4	4	39	1
Inflatable tube							
Placed within joint	2	3	3	4	4	35	8
Placed over joint	2	4	2	4	4	32	14
Metal spring clip insert	2	3	3	4	4	35	8
Grout							
Joint grouting	2	2	3	3	4	32	14
Exterior grouting	1	2	3	4	4	32	14

Note: Overall score obtained using weights; Scoring based on scale: 1 (poor), 2 (fair), 3 (good), 4 (excellent).

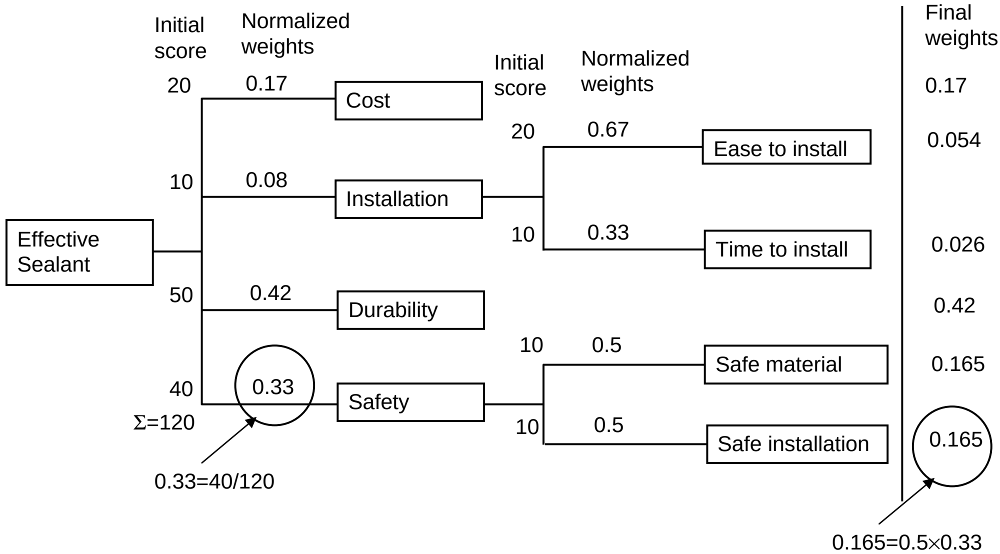

FIGURE 7.2 Value hierarchy.

criteria used to evaluate the performance of the various methods proposed includes cost, safety in installation, time and ease of installation, durability against further differential settlement of pipeline, and safe materials. Scoring of the alternatives is based on a simple scale ranging from 1 (poor) to 4 (excellent) for each criterion. The best alternative is the method with the highest overall score.

For more complex value criteria, a value hierarchy (Green, 1992) can be employed to structure the criteria. The top of the hierarchy comprises the primary objective of the problem. This is progressively broken down to subcriteria by way of a "means-ends" analysis, where the lower-order criterion is a means to the immediate higher criterion. Using the above example, a value hierarchy is developed following similar criteria attributes given in Table 7.1, and depicted as shown in Fig. 7.2. The weighting of each criterion is first obtained by normalizing the initial score of degree of importance (based on a 10 for the least important in the group). The final weighting for the lowest-level criterion is computed as the product of the criterion in the path of the tree to the top. The criteria in the lowest level of each branch with their final weights are used in the evaluation of the alternatives. The analytical hierarchical procedure (AHP) can also be adopted to derive the final weightings of the criteria (Saaty, 1980). The AHP approach has been employed to rank success factors (Chua et al., 1999) and criteria for the selection of design/build proposals (Paek, Lee, and Napier, 1992).

Development Phase

This is the phase when a limited number of the ranked alternatives are taken forward for development. The alternatives are designed in greater detail so that a better appraisal of their cost, performance, and implementation can be made. The cost should be computed based on life-cycle costing. At this stage, it may be necessary to conduct a trial or prepare a model or prototype to test the concept before recommending them to the decision makers.

Recommendation Phase

In this phase, a sound proposal is made to management. The effort in this phase can be crucial because all the good work done thus far could be aborted at this final stage if the proposal is not effectively presented. The presentation must also include the implementation plan so that management can be fully convinced that the change can be made effectively and successfully without detriment to the overall project.

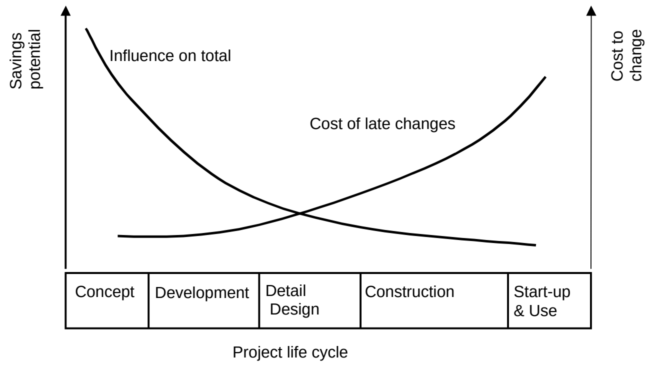

FIGURE 7.3 Cost savings potential over project duration.

Implementation

Value engineering can be applied at any stage of a project. It must, however, be borne in mind that greater benefits can be reaped when it is implemented in the earlier stages of the project. Figure 7.3 shows the drastic decline in cost savings potential over time. In the earlier stages of the project, there are less hard constraints, so there can be greater flexibility for adopting innovative alternatives. As the project proceeds, more constraints are added. Then, there is less flexibility for change, and greater costs will have to be incurred to make the necessary design changes.

Another consideration applies to the level of effort in the program. It is possible to apply VE extensively to every item in a project, but the amount of effort may not be recompensed in the same measure. Alternatively, the 20 to 80% rule should direct the VE efforts. The rule is generally also applicable to the costs of a system or facility, meaning that 20% of the items of a facility contribute to about 80% of its total costs. By the same token, a large proportion of unnecessary costs is contributed by only a few items. Thus, the efforts of VE should be directed at these few items to yield significant cost savings.

It is traditional practice that designers adopt without challenge the owner's requirements and architect's specifications as given constraints from which they will begin to optimize their designs. These constraints, however, can lead to poor cost and value ratios, and if left unchallenged, can lead only to suboptimal solutions. Similarly, in a process-type facility, the owner's and process engineer's specifications typically form the constraints.

In a project for the construction of a wafer fabrication multistory building, for example, the process engineer laid out their process plans for the various floors. The sub-fab facilities were arranged so precariously on one of the floors that the main fabrication area above this level could not be laid out symmetrically with respect to the building. As customary, this was presented as a constraint to the structural engineers and vibration consultants (of which the author was a member). The objective of the design was a waffle floor system that would ensure that the vibration level in the main fabrication area under ambient conditions would not exceed some extremely low threshold criteria (with velocity limits not exceeding 6.25 μm/s over the frequency range 8 to 100 Hz in the 1/3 octave frequency band). With the original layout, the design would demand some elaborate system of beam girders to take advantage of the shear walls at the perimeter (because no shear walls are allowed in any area within the perimeter) and still would suffer from unnecessary torsional rotation due to the eccentricity of the floor system. It was only after several deliberations that the process engineers finally agreed to modify their layout so that a symmetric design could be accommodated. This resulted in significant savings in terms of construction costs and improved vibration performance. It is common that the initial specifications conflict with basic function of the design, which in this case, is a vibration consideration, leading to poor and expensive solutions, if left unchallenged.

Another consideration stems from the need to generate alternatives — the selection of the value engineering team. Just as the extent of solutions can be curtailed if some poorly defined constraints are left unchallenged, the scope of alternatives can also be severely limited if the value engineering team comprise only the same designers of the system. These designers become so intimate with their designs that they fail to detect areas of unnecessary costs. The approach is to form a multidiscipline team that cuts across the technical areas of the study, comprising one or two members in the major discipline with the others in related fields. In this way, the alternatives tend to be wider ranging and not limited by the experience of a single group. Greater consideration can also be given to the impact of these alternatives on the system as a whole.

As with any program, the VE program has to be well managed with the support of top management in all practical ways. Visible support will entail their presence in many of the review meetings of VE projects, their support with the necessary budget and staff training and participation, and their time to discuss problems associated with the program and implementation of the alternatives. In the construction industry, it is usual to place the VE group with the purchase or design function of the organization.

The success of the VE program also largely depends on the leader of the VE group. Depending on the size of the program and the organization, he could be the Director VE, Value Manager, or simply the Value Engineer. Nevertheless, he must be able to follow organizational culture to gain acceptance of management and colleagues, yet has to have the necessary qualities to bring about changes for the better. His ability to control the dynamics of the group is important if he is to initiate and direct the program successfully.

There are three other important considerations to initiate a successful VE program:

- Bring about an awareness of VE concepts and methodology within the organization.
- Select simple sure winner projects as starters.
- Audit and publish the project after successful implementation with respect to both technical advantages and monetary savings.

7.3 Constructability

Basic Concepts

There are various definitions of the concept of constructability. The definition offered by the Construction Industry Institute has been adopted because of its broad perspective and its emphasis on the importance of construction input to all phases of a project (Jortberg, 1984): "*…the optimum integration of construction knowledge and experience in planning, engineering, procurement, and field operations to achieve overall project objectives*."

Constructability is not merely a construction review of completed drawings to ensure that they do not contain ambiguities or conflicts in specifications and details that will present construction difficulties later during the execution phase. It is also not merely making construction methods more efficient after the project has been mobilized.

Instead, the concept of constructability arises from the recognition that construction is not merely a production function that is separated from engineering design, but their integration can result in significant savings and better project performance. Construction input in design can resolve many design-related difficulties during construction, such as those arising from access restrictions and incompatible design and construction schedules. Construction input includes knowledge of local factors and site conditions that can influence the choice of construction method and, in turn, the design. The benefits of early construction involvement are at least 10 to 20 times the costs (BRT, 1982), and more recently, a study has shown that savings of 30 to 40% in the total installed cost for facilities are readily achievable from constructability implementation (Jergeas and Van der Put, 2001). The effects of an engineering bias to the neglect of construction input are discussed by Kerridge (1993).

The integration of construction knowledge and experience should come on to the project as early as possible when the cost influence of decisions in the early phases is very high (whose trend follows the curve of influencing total value depicted in Fig. 7.3). The highest ability to influence cost comes at the conceptual phase, where the decisions at that time could greatly affect the project plan, site layout and accessibility, and the choice of construction methods. Full integration will require that the contractor or construction representative be brought into the project team at the same time as the designer. Thus, the choice of the contractual approach can be critical in determining early construction involvement in a project.

Another important consideration for meaningful construction input to design is the commitment to preconstruction planning. Preconstruction planning determines three important elements affecting design and plan sequence:

- Selecting construction method and sequence so that designers can incorporate them in their design
- Ensuring that the design is constructible with at least one feasible way to execute the work
- Assuring that all necessary resources will be available when required, including accessibility, construction space, and information

Some of the pertinent concepts applicable to each phase of the project cycle are briefly presented in the following.

Conceptual Planning

The key issues in this phase relate to evaluating construction implications to project objectives, developing a project work plan, site layout, and selecting major construction methods (Tantum, 1987).

Construction-related issues at this stage can have major impacts on budget and schedule. The project objectives must be clearly established so that alternatives in various decisions can be effectively evaluated. The implications from the construction perspective may not be readily apparent to the planning team, unless there is a member experienced in field construction.

An effective work plan requires that work be adequately packaged and programmed so that design information and essential resources and materials required for each package can arrive in a timely fashion. Without construction input, the packaging and availability of design may not allow desirable work packaging or construction sequence. Moreover, the problems or opportunities from local factors and site conditions may be missed. Construction knowledge is also necessary for developing a feasible schedule.

It is usual for the building and site layouts to be determined solely on plant, process, and business objectives. Too often, construction implications are not considered with resulting severe limitations on construction efficiency due to inadequate space for laydown areas, limited access, and restrictions on choice of construction methods.

Construction knowledge is essential in the selection of major construction methods that will influence the design concepts. The possibility of modularization and the degree of prefabrication, for example, are construction issues that must be considered in this early stage.

Engineering and Procurement

The following are some key ideas that are generally applicable for guiding the constructability initiatives during the engineering and procurement phase of the project. With respect to design per se, the general principle is to provide design configurations and concepts that reduce the tasks on site, increase task repeatability, and incorporate accessibility.

- **Construction-driven design and procurement schedules —** Design and procurement activities are scheduled so that detailed designs, shop drawings, and supplies are available when needed according to construction schedule. This will reduce unnecessary delays in the field caused by resource and information unavailability.
- **Simplified designs —** Simplified design configurations generally contribute to efficient construction. Such designs can be achieved using minimal parts or components, simplifying tasks for

execution, and minimizing construction task dependencies. Boyce (1994) presented some interesting principles in this aspect of designing for constructability.

- **Standardization —** The objective in standardization is to reduce the number of variations in the design elements. This will lead to fewer errors in the field, improved productivity through repetitive work, and advantages in managing the supply chain of fewer differing components.
- **Modularization and Preassembly —** These will simplify field operations because the large number of parts have been modularized or preassembled, and are usually under conditions that can provide better control. Focus instead is given to delivery, lifting, and assembly in the field.
- **Accessibility —** Detailed design should consider the accessibility of workmen, material, and equipment. An accessibility checklist may be useful for this. Computerized simulation CAD models are also used in this regard.

A more detailed list including specifications and designing for adverse weather conditions is obtainable from O'Connor, Rusch, and Schulz (1987).

Field Operations

There are constructability issues remaining during field operations. These pertain to task sequencing and improving construction efficiency and effectiveness. Contractors can still reap the benefits of constructability, which can be quite substantial if the decisions are taken collectively. Innovation has been singled as the key concept for enhancing constructability in this phase and is applicable to field tasks sequence, temporary construction systems, use of hand tools, and construction equipment (O'Connor and Davis, 1988).

Many innovations have been made in the use of temporary construction systems, use of hand tools, and construction equipment. The advantages have been obvious: reduced erection and setup times, improved quality in products delivered, and increased construction productivity in related tasks. Many construction problems on site can be resolved quite easily with proper task sequences. Tasks can be better sequenced to minimize work site congestion with its consequent disruptions of work. Unnecessary delays can be avoided if tasks are properly sequenced to ensure that all prerequisites for a task are available before commencement. Effective sequencing can also take advantage of repetitive tasks that follow each other for learning-curve benefits. Sharing of equipment and systems is also an important consideration in tasks sequencing.

Implementation

As in all value methods, to be effective, constructability has to be implemented as a program in the organization and not on an ad-hoc basis. In this program, the construction discipline, represented by constructability members, becomes an integral part of the project team and fully participates in all design planning decisions.

A special publication prepared by the Construction Industry Institute Constructability Implementation Task Force (CII, 1993) presented a clear step-by-step roadmap to provide guidance for implementing the constructability program at the corporate and project levels. There are altogether six milestones envisaged, namely:

- Commitment to implementing the constructability program
- Establishing a corporate constructability program
- Obtaining constructability capabilities
- Planning constructability implementation
- Implementing constructability
- Updating the corporate program

Alternatively, Anderson et al. (2000) employed a process approach based on IDEF0 function modeling to provide the framework for constructability input.

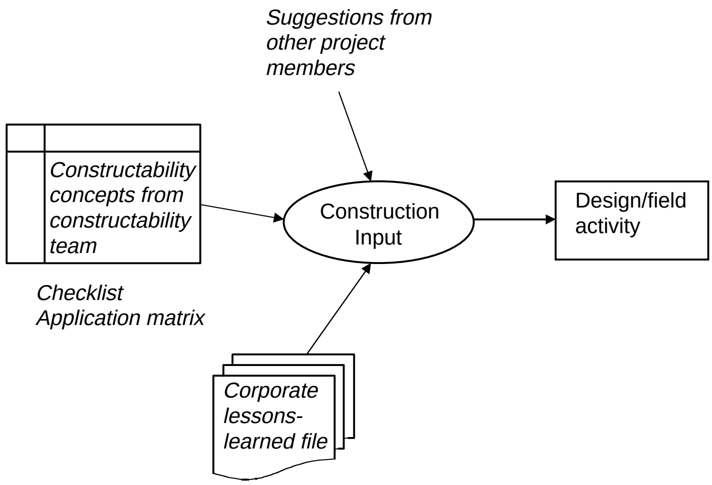

FIGURE 7.4 Constructability integration with activity.

Although there cannot be a single unique constructability program that can suit all companies, invariably, the commitment to a constructability program must come from senior management and be communicated clearly through the organization. Successful and consistent implementation also requires a single point executive sponsor of the program, whose primary role is to promote its awareness and to be accountable for its success.

Another important consideration in the program is to adopt a forward integration planning approach, rather than a backward constructability review of fully or partially completed designs. In the latter approach, the constructability team is excluded from the design planning process, thus preventing early construction input integration. Any changes to be made after the review will usually be taken in an adversarial perspective, in which the designer becomes defensive and takes them to be criticisms. Moreover, the design reworks are unnecessary and make the process inefficient and ineffective. In the forward integration as shown in Fig. 7.4, the constructability concepts are analyzed at each planning phase, and the alternatives from the construction, business, and design perspectives are available up-front and are jointly evaluated before incorporation into the design. The outcome is obvious: improved design quality and reduced design reworks.

As depicted in Fig. 7.4, the constructability activities can be guided from three sources: corporate lessons-learned file, team discussions of constructability concepts, and constructability suggestions. The first contains the feedback on the constructability program documenting specific lessons learned along the way. When the project terminates, each functional design should be evaluated and added to the lessons-learned file. The discussions of constructability concepts can be guided by a checklist of the constructability concepts at each phase or by using a Constructability Applications Matrix (see Fig. 7.5) (Tools 16–19, CII, 1993). More ideas for constructability can also be obtained from suggestions by other personnel involved in the project.

The project constructability team leads the constructability effort at the project level. The constructability team comprises the usual project team members and additional construction experts. If the contractor has not been appointed, an appropriate expertise with field experience has to be provided. The specialists, for example, rigging, HVAC, electrical, and instrumentation, are only referred to on an ad-hoc basis, when their area of expertise is needed for input. A constructability coordinator is also needed, whose role is to coordinate with the corporate constructability structure and program.

Before concluding this section on constructability, it is important to realize that constructability is a complex process, and the constructability process itself is unstructured. Especially, in these days of high-speed computing, technology has provided assistance in conducting this process, and its development

Key Activities in ________ Phase Constructability Concepts		Activity 1	Activity 2	Activity 3	Activity 4	Activity 5	Activity 6	Activity 7	Activity 8	Activity 9	Activity 10
Id. No.	Description										
1	Concept 1									■	
2	Concept 2			■	■					■	
3	Concept 3		■				■	■			
4	Concept 4		■				■	■			■
5	Concept 5				■	■					■
6	Concept 6	■			■	■					■
7	Concept 7	■			■	■			■		■
8	Concept 8	■							■		

Shaded cells in matrix indicate inapplicable concepts

FIGURE 7.5 Constructability applications matrix.

should be closely followed so that it can be incorporated to enhance its effectiveness. Four-dimensional models (McKinny and Fischer, 1997), that is, three-dimensional CAD models with animation, are providing the visualization capabilities to enhance communication between the designers and the constructors. Other models have also been developed for various aspects of constructability, for example, a constructability review of merged schedules checking for construction space, information, and resource availability (Chua and Song, 2001), and a logical scheduler from the workspace perspective (Thabet and Beliveau, 1994).

7.4 Quality Management

Basic Concepts

It cannot be overemphasized that quality is an objective of project management that is equally important to project budget and schedule. Specifications are written into contracts to ensure that the owner gets from the main contractor a product with the type of quality he envisaged. Being able to deliver this is not something that can be left to chance. It will require management. Quality management is the process to use to consistently satisfy the owner's expectations. Quality management has been defined as follows: "*All activities of the overall management function that determine the quality policy, objectives and responsibilities, and implement them by means such as quality planning, quality control, quality assurance, and quality improvement within the quality system*" ISO 8402 (1995).

Quality management has progressed through four stages, beginning with inspection and quality control (QC), and has now arrived at quality assurance (QA) and total quality management (TQM) (Dale et al., 1994). Inspection is the activity that assesses by measurement or testing whether an element has conformed to specifications. Corrective work is then ordered to rectify any nonconformance in the element. QC builds upon the inspection efforts and relies largely on statistical techniques to determine trends and detect problems in the processes. Such techniques are being used routinely in manufacturing. With respect to the construction industry, concrete cube testing is one rare example. Instead of merely detecting the errors for remedial measures, QA and TQM are based on a quality system, with the objective of reducing and ultimately eliminating their occurrences.

Both QA and TQM are focused on meeting customer requirements, and this is at the top of the agenda. Customer in TQM does not necessarily refer only to the owner, as QA tends to imply. The customer perspective in TQM is derived from the process viewpoint. At every stage of a process, there are internal customers. They belong to the group of people who receive some intermediate products from another group. For example, in an on-site precast operation depicted in Fig. 7.6, the crew setting up the mold

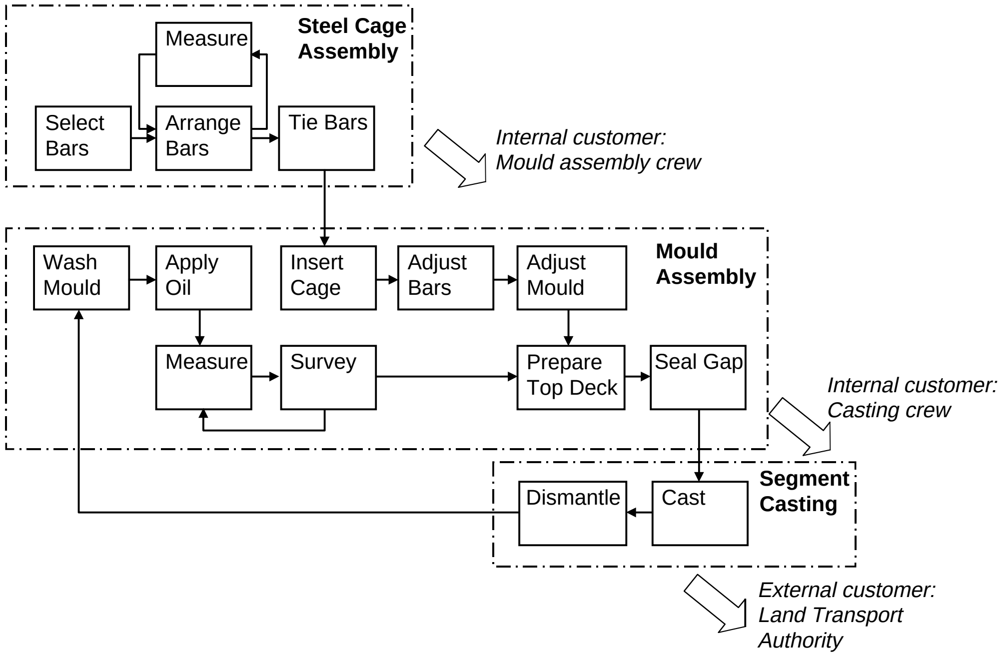

FIGURE 7.6 On-site precast operation.

for casting receives the steel reinforcement assembly from the crew assembling the steel cage. The mold crew is the internal customer of the assembly process. In turn, the casting crew is the internal customer of the mold assembly process, while the Land Transport Authority is the external customer of casting. Each of these crews will require that the intermediate product they receive meets the quality standards to avoid rework. The concept of internal customers ensures that quality permeates through the total operation, and thus by addressing the internal processes in this way, total quality improvement can be achieved.

To ensure that customers get what they want, there is a need to fully understand their requirements and to communicate this throughout the organization. This is at the heart of quality management and is the goal of the quality system. The quality system comprises quality manuals providing the templates to guide the worker in the performance of each particular task. These templates ensure management that proper work has been performed and provide confirmation to the owner that the work has met his requirements. The core of these systems is to present a way of working that either prevents problems arising, or if they do arise, identifies and rectifies them effectively and cheaply. In the next section, an overview of the ISO 9000 quality system will be presented.

Another culture of quality management is the dedication to continual improvement. Such a commitment requires accurate measurement and analysis of the performance of the processes from the viewpoint of the customer. This can take the form of a trend chart showing the trend of the problem. Control charts are also useful to highlight out-of-control conditions. A flowchart or process flow diagram will put the problem in the perspective of the whole operation. Histograms, scatter diagrams, and pareto analysis are other tools that may be used to identify and present the problem. Mears (1995) gave a good account of these and other techniques that have been used for quality improvement. The problem has to be analyzed to identify the root cause. A common and useful technique is the fishbone diagram, also called the cause-and-effect diagram. This and some other improvement techniques will be presented later. The action plan and monitoring of the implementation are the other two steps to complete the improvement process as shown in Fig. 7.7. The action plan describes the action to be taken, assigning responsibility and time lines. Monitoring would confirm that the conditions have improved.

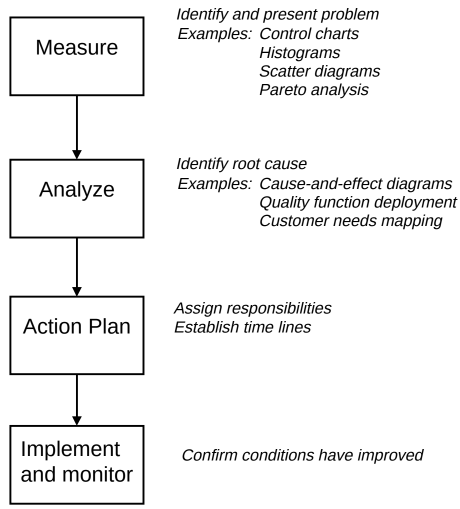

FIGURE 7.7 Quality improvement process.

Quality System

Underlying the concept of quality management is a quality system. It is becoming increasingly common for the ISO 9000 Standards certification to be necessary for tendering in big projects. The Standards provide the framework for developing the quality system. They comprise four main parts:

- **ISO 9001** — Specifications for design/development, production, installation, and servicing
- **ISO 9002** — Specifications for production and installation
- **ISO 9003 —** Specifications for final inspection and test
- **ISO 9004 Parts 1–4** — Quality management and quality systems elements

A company will decide on a suitable form appropriate for its operations and develop its quality system accordingly. ISO 9002 excludes design and is the most appropriate choice for controlling the operations of a contractor. This is also adequate to cover design and build projects, provided that the design is bought-in. ISO 9001 carries an additional clause 4.4 to control design activities and is necessary for a company that carries out design work.

The standards only provide the key elements in a quality system. Evidently, there can be no standardized quality system because the specific choice of quality measures depends on factors such as the main fields of activity, the operational procedures, and the size and structure of the company. Nevertheless, there is a hierarchy of documents making up the quality system (see Fig. 7.8). The quality manual according to Part 1 of ISO 9004 defines an outline structure of the quality system and serves as a permanent reference in the implementation and maintenance of the system. This is supported by the procedures and instructions common to the whole organization at the company level. There are also quality documentation comprising forms and checklists, procedures, and work instructions that are more project specific, in order to operate effectively in the unique circumstances of the project.

There are 20 main clauses in the ISO 9000 Standards (see Table 7.2). A brief synopsis of some of the pertinent clauses follows.

Clause 4.1 Management Responsibility

The implementation of a quality system requires a strong commitment of senior management and clear communication to every member in the organization. This clause relates to quality policy, organization structure defining responsibilities, authority and action to be carried out, management review, and

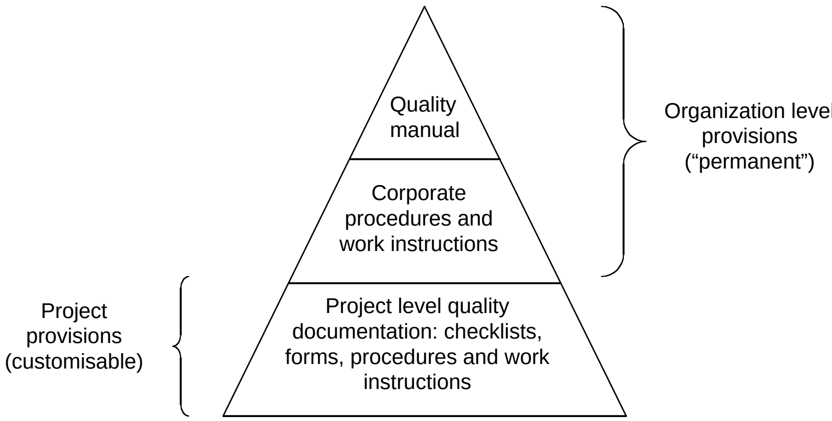

FIGURE 7.8 Hierarchy of documents in quality system.

TABLE 7.2 Main Clauses in ISO 9000 Standards

Clause	Requirement
4.1	Management responsibility
4.2	Quality system
4.3	Contract review
4.4	Design control
4.5	Document and data control
4.6	Purchasing
4.7	Control of customer-supplied product
4.8	Product identification and traceability
4.9	Process control
4.10	Inspection and testing
4.11	Control of inspection, measuring, and test equipment
4.12	Inspection and test status
4.13	Control of nonconforming product
4.14	Corrective and preventive action
4.15	Handling, storage, packaging, preservation, and delivery
4.16	Control of quality records
4.17	Internal quality audits
4.18	Training
4.19	Servicing
4.20	Statistical techniques

management representatives. Review is necessary to ensure the integrity of the system and continual improvement.

Clause 4.2 Quality System

This clause refers to the setup and maintenance of the quality system. It describes the implementation of a quality manual and the documentation necessary to operate the system. Quality planning is also a requirement in the clause, demonstrating how the system will be implemented and consistently applied. It also comprises the quality plans that set out the required good quality practices according to the specific requirements of the contract.

Clause 4.3 Contract Review

Contract review is the process to review the client's requirements. It ensures that they are adequately defined and understood, and any ambiguities or contradictions are resolved. It also looks at the resources available to ensure that the organization can fulfill the requirements. This clause also includes a documentation of the results of the process.

Clause 4.4 Design Control

This clause has the most elements and deals with the design activity. Design and development planning, and organization and technical interfaces relate to the resources and organizational aspects of the design process. The input and output elements deal with compliance with customer and statutory requirements and mode of output. The remaining elements relate to the management of the design, comprising design review, verification, and validation, to ensure that the design actually meets requirements and original intention, and design changes, ensuring that revisions are adequately communicated and versions are adequately recorded.

Clause 4.5 Document and Data Control

This clause relates to the control of all documents, including external documentation such as codes of practices, health and safety legislation, building regulations and manufacturers' guidelines, and data contained in computer systems. The procedures ensure that the proper documents would be used, that there would be uniform documentation, and that revisions and obsolete documents would be properly handled.

Clause 4.6 Purchasing

The objective is to ensure that all bought-in resources comply with customer's requirements and that those providing them, i.e., subcontractors and suppliers, are competent. The clause covers the evaluation of subcontractors and suppliers, standardization and specification of purchasing data, and verification of the purchased product. Related procedures must also be in place to ensure that customer (client) supplied services or products, including information, also comply with quality standards (Clause 4.7). There are related procedures controlling product identification by marking or by accompanying documentation (Clause 4.8).

The remaining clauses deal with process control, inspection and testing matters, handling and storage issues, quality records, audits, training, servicing, and statistical techniques. The servicing clause deals with after-sales service and may not be appropriate in every construction company.

Quality Improvement Techniques

Mistakes and problems that arise provide opportunities for learning and continual improvement. There are numerous tools that have been used in this context. These range from simple checklists, flowcharts, scatter diagrams, and pareto analysis, to fishbone diagrams and more sophisticated tools such as benchmarking, customer needs mapping, and quality functional deployment (QFD). Essentially, they collect data so that the problem can be identified and aid in finding the cause and developing solutions to improve the situation. In this section, only the fishbone diagram, customer needs mapping, and QFD will be briefly presented. The reader may refer to Mears (1995) and McCabe (1988) for other techniques available.

Fishbone Diagram

The fishbone diagram was first developed by Karou Ishikawa. Essentially, it is a cause and effect analysis used to identify the root causes of a particular problem. The final diagram resembles the skeleton of a fish as shown in Fig. 7.9, where the head is the effect or problem, and the minor spines lead to the main areas or processes that could contribute to the effect. The ribs on the minor spines are the causes within the main areas and can make up a chain of causes. The last rib in the chain is the fundamental root cause that is specific enough to take action on.

Cause and effect analysis is usually used in a brainstorming setting, in which all members of the group should be familiar with the nature of the problem. The analysis begins with a clear definition of the problem, defining its symptom or effect. The effect forms the "fish head" of the diagram. The possible causes are identified, and the main areas for the minor spines are derived by classifying them into natural

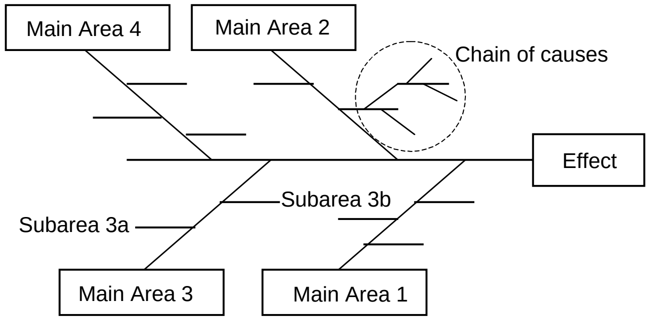

FIGURE 7.9 Fishbone diagram layout.

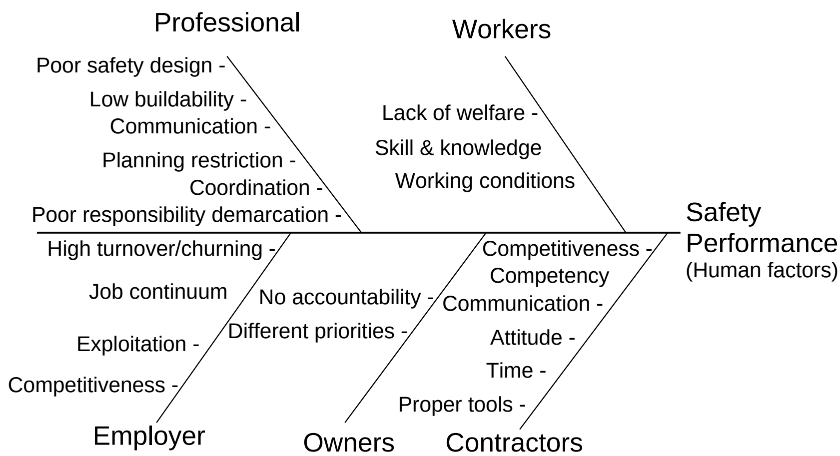

FIGURE 7.10 Fishbone of safety performance (human factors).

groupings or major processes. Figure 7.10 shows the resulting fishbone diagram for improving the human factor element of safety performance in the construction industry obtained in a safety workshop conducted with the participation of leading companies, professional societies, and associations. The major areas have been grouped according to the major project players. In the case of process-related problems, the major groupings can usually be categorized according to resource and methods, such as tools, components, production methods, people, and environment. In larger operations, the groupings could include the major processes making up the whole operation.

The major categories are then refined to determine the root causes. This can be assisted by asking the following questions:

- What causes this?
- Why does this condition exist?

The "why" question may be asked several times, until the causes are specific enough for action to be taken. A plan of action is then formulated based on the root causes that have been uncovered according to a priority ranking system.

Customer Needs Mapping

Customer needs mapping is a technique that analyzes the effectiveness of the internal processes to meet customer requirements (or needs). It is based on a matrix approach, as shown in Fig. 7.11. The customer in the analysis could be an internal customer, especially in the case of support activities such as inventory control and the IT department. After the customers have been identified, their needs may be determined

Customer needs		Importance Rating	Process 1	Process 2	Process 3	Process 4
Main group 1	Need 1.1	5	M	L	L	H
	Need 1.2	3	M	M	L	M
	Need 1.3	2	L	H	L	M
	Need 1.4	4	M	L	L	H
Main group 2	Need 2.1	4	L	L	L	L
	Need 2.2	1	H	L	L	M
	Need 2.3	5	L	M	L	H

FIGURE 7.11 Customer needs mapping.

through a combination of customer interviews and brainstorming. The left-hand column of the matrix makes up the customer needs. An importance rating on a scale of 1 (least important) to 5 (most important) is assigned to each item.

The top row of the matrix identifies the internal processes required to meet these needs. Only the major processes are necessary so as not to be bogged down by the details of a complex operation. To complete the matrix, the effectiveness of each process in meeting customer needs is evaluated. The evaluation is obtained through customer interviews and is based on the following scale: high (H), medium (M), and low (L).

With this mapping, the quality improvement team can now identify internal processes that need to be enhanced to improve quality delivery. A customer need with high importance is one point of focus. An internal process that is not effective in meeting any customer needs should also draw attention, for example, internal process 3 of Fig. 7.11. Another benefit of the mapping is the identification of customer requirements that have been neglected, such as customer need 2.1 of Fig. 7.11. A detailed flowchart of the whole operation usually accompanies the mapping so that improvement plans can be developed as a result of the analysis.

Quality Function Deployment

Quality function deployment (QFD) is a structured approach to translating customer requirements into appropriate technical requirements so that customers' needs can be better satisfied. It was first introduced at the Kobe shipyards of Mitsubishi Heavy Industries Ltd. in 1972. Since then, it has gone through several stages of development and has been used in various applications, not only in manufacturing, but also in the AEC industry.

QFD uses a matrix structure in the form of the house of quality (see Fig. 7.12), so called because of its resemblance to a house. The customers' needs are the inputs to the matrix, and the outputs help to set competitive targets and determine the priority action issues for improving customer satisfaction based on their requirements (Day, 1993). The house of quality comprises six main sections, as shown in Table 7.3.

The product characteristics or processes are the technical counterparts that must be deployed to meet customer requirements. These technical counterparts are often related, and their interactions are shown using symbols as shown in Fig. 7.12. The relationship matrix is the main matrix of the house. It shows the relationship between the customer requirements and the technical counterparts. Symbols as shown in the figure are also used to indicate the strength of their relationships. The customer requirements are

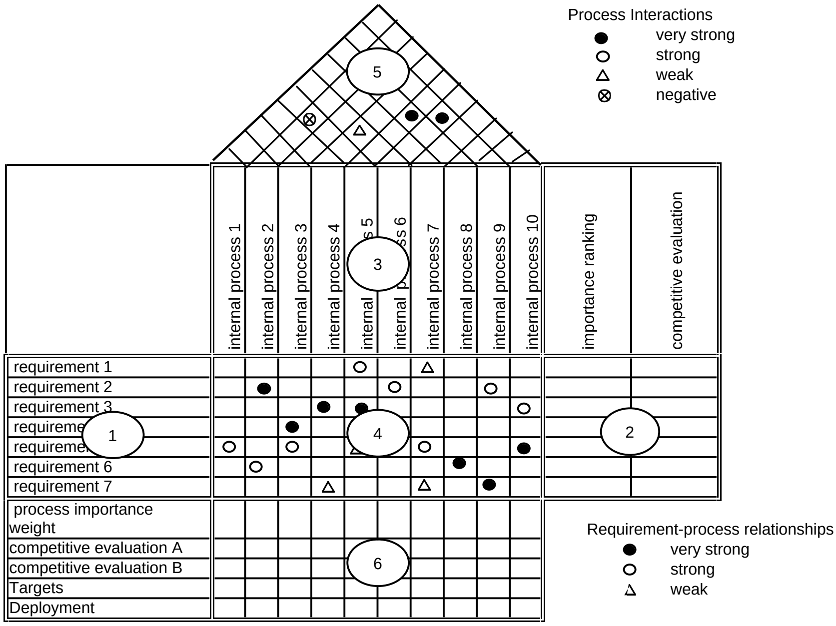

FIGURE 7.12 House of quality.

TABLE 7.3 Main Sections of House of Quality

Section	Description
1	Customer requirements for the product
2	Ranking and rating of customer requirements
3	Product characteristics or processes (technical counterparts)
4	Relationship matrix between customer and technical counterparts
5	Correlation matrix showing technical interactions — this forms the roof of the house
6	Technical rankings and ratings

ranked to give their importance values. It is usual to denote their importance on a 5-point scale (where 5 represents the highest importance). Alternatively, the analytical hierarchical approach (AHP) referred to in the earlier section on value engineering can be used to rank their importance (Akao, 1990). This section of the house of quality also comprises the competitive evaluation of competitors to highlight their strengths and weaknesses to meet their customer needs.

If a numerical score is given to the relationship matrix, the technical rankings (or process importance weights) can be derived as shown in Fig. 7.13 for the case of improving the quality of mold assembly operation in an on-site precast yard. The rankings show the importance of the internal processes in achieving the quality of the finished mold for the casting crew, an internal customer of the whole precast operation. The house of quality can be modified by incorporating an improvement ratio as shown in Fig. 7.14 for the same example, which is the ratio of the planned level and current rating of the customer requirement. The technical rankings obtained in this way would have taken into consideration the current deficiencies in the technical counterparts in meeting the customer requirement.

Implementation

Developing a Quality System

The quality system is an essential aspect of the concept of quality management. The development process is not merely a compilation of forms and documents of procedures and organization, and the amount

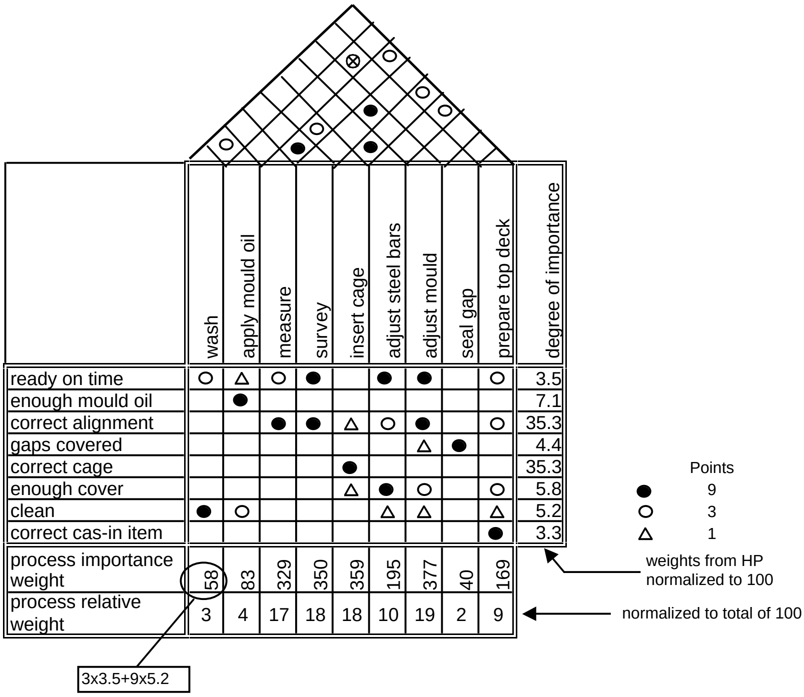

FIGURE 7.13 House of quality for mold assembly.

	degree of importance	current rating	planned level	improvement ratio	attribute importance weight	attribute relative weight
ready on time	3.5	4	3	0.75	2.6	3.2
enough mould oil	7.1	4	4	1	7.1	8.5
correct alignment	35.3	5	4	0.8	28.2	33.9
gaps covered	4.4	3	3	1	4.4	5.3
correct cage	35.3	5	4	0.8	28.2	33.9
enough cover	5.8	4	4	1	5.8	7.0
clean	5.2	5	4	0.8	4.2	5.0
correct cas-in item	3.3	5	4	0.8	2.6	3.2
					83.2	

sum of importance weights (83.2)

normalized to total 100 and used to obtain technical rankings (attribute relative weight)

FIGURE 7.14 Modified ratings with improvement ratio.

of effort required cannot be underestimated. It is not the work of an individual appointed from within the organization, in addition to their other duties, as is frequently done. The process can become too long drawn, with the accompanying consequence of loss of impetus or of even having the whole process stalled. Otherwise, there may be a compromise on the depth of coverage, resulting in an ineffective system.

It is insufficient to develop the system. Full implementation, as shown in Fig. 7.15, begins with the analysis phase, which is essentially a critical review of the company in terms of its existing organization

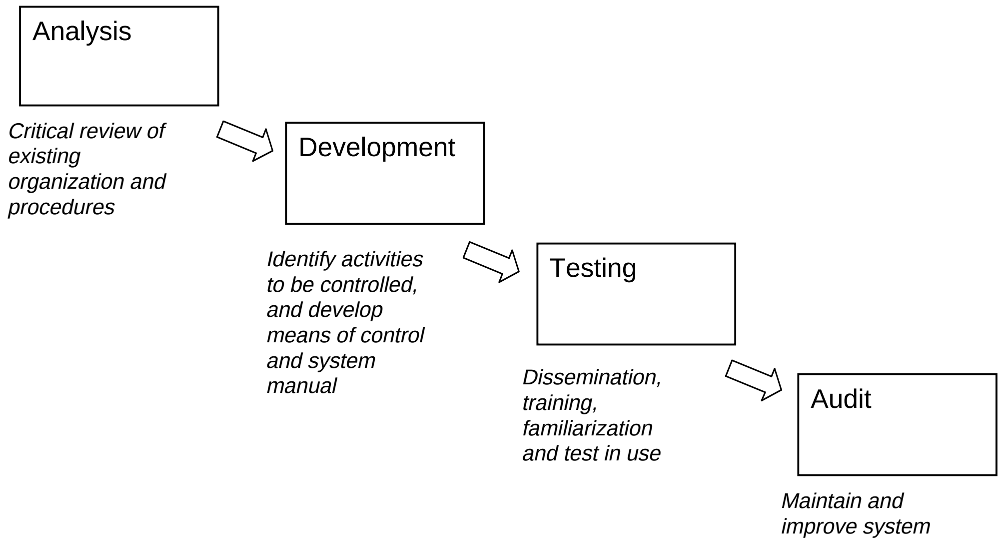

FIGURE 7.15 Implementation cycle of quality system.

and procedures. After development, the system has to be tested before it can be implemented, and auditing is required to maintain the system. Of these phases, the analysis is perhaps most crucial in determining the success of the quality system. Typically, the analysis will reveal deficiencies in the present organization that need to be redressed, such as procedures being ignored or modified for a variety of reasons and contradictory and outdated procedures. Information is gathered through a combination of interviews, questionnaires, review of existing forms and documents, and observation. Effective control can be formulated only if there is sufficient depth in the analysis.

Successful implementation also entails a balance of the need for knowledge of quality management and an understanding of the organization and processes. The use of QA consultants fulfills the first requirement but falls short of the need for company knowledge. A QA manager appointed from within the company's management should lead the implementation, and a combination of self-analysis by departments and by external QA consultants should provide the advantages of expertise and company knowledge to ensure success.

Developing a Quality Culture

The other aspect of successful implementation is developing a quality culture in which everyone is encouraged to be concerned with delivering quality in his or her own work. Instead of merely adopting the quality system as the way things should be done, the quality system will have to become the way things are actually done. Because it requires things to be done differently, a clear and strong commitment from senior management is not an option. Though it starts from the top, this quality culture must be communicated to the worker level.

One way of developing this, is to set up a quality council, which is essentially an executive or steering committee dedicated to maintaining the organization's focus on quality management. It also provides the mechanism for selecting quality improvement projects for developing, forming, and assisting the quality teams, and following up on their implementation. Without such a structure, good improvement ideas suggested by workers, which goes beyond a single department, are usually not followed through because of the lack of authority. Typically, the council is headed by a senior VP of the organization.

Another necessary change is realizing employee participation because such quality initiatives may require the workers to change the way things are done. They must believe that the improvement is good and must also be motivated to put in their best (and thus quality) in their tasks, with the attitude of doing things right the first time. Along with this is the concept of employee empowerment. Empowerment has been defined as the method by which employees are encouraged to "take personal responsibility for improving the way they do their jobs and contribute to the organisation goals" (Clutterbuck, 1994). Clutterbuck also suggested some techniques for empowerment. They relate to expanding employees' knowledge-base and scope of discretion, involving them in policy making, and providing opportunities to change systems that can affect procedures across functional lines and departments. Employee empowerment is an important key to continuous improvement because they are most involved in line operations and would be most familiar with problems. Quality circles (Lillrank and Kano, 1989) center on the line workers whose day-to-day observation of the process is crucial to continuous improvement.

7.5 Conclusions

Three concepts for value improvement have been presented together with their methodologies and implementation. There are overlaps in their objectives, but their approaches are distinct. Nevertheless, to achieve any significant success, the implementation of any of these concepts must be strongly supported by senior management of the organization and communicated through the organization. Moreover, they cannot be practiced on an ad-hoc basis. A corporate program with clear policies has to be developed, wherein employee activities are integrated into the other activities of the organization. It has been demonstrated that the application of these concepts will lead to great benefits to the organization, such as reduced costs, increased value, better designs, improved performance, and enhanced quality.

Before concluding this chapter, there should be a brief mention of lean construction, which is an emerging concept also focused on value improvement. The concepts of lean construction are applicable to design and field operations and are based on the new production philosophy in manufacturing that has been called by various terms, such as lean production, just-in-time (JIT), and world class manufacturing. It is believed that just as the new production philosophy has made significant impact on production effectiveness and has led to dramatic changes in production management in manufacturing, lean construction can have similar effects in the construction industry.

The new production philosophy originated from plant floor developments initiated by Ohno and Shingo at the Toyota car factories in Japan in the 1950s, but only analyzed and explained in detail in the 1980s. It was only in 1992 that the possibility of applying this new production philosophy in construction was mooted and put into a report (Koskela, 1992). Since then, the application of this philosophy in construction has been termed lean construction. Many of the concepts are still in their germination stages, but they are generally based on adopting a flow production view of construction instead of the traditional activities perspective. By focusing on the flow of production, the nonvalue activities can be identified and minimized, while the value adding activities can be enhanced (Koskela, 1992). One key concept is improving work plan reliability, or conversely reduced variability, through production shielding using the Last Planner system (Ballard and Howell, 1998). The Integrated Production Scheduler (IPS) (Chua and Shen, 2002) is an Internet-enabled system for collaborative scheduling that implements the Last Planner concept and identifies key constraints in the work plan. Some other related principles for flow process design and improvement include reduce cycle times, increase process transparency, and task simplification. The implementation of lean construction will also require a re-look at the relationships to be cultivated between the main contractor and their suppliers and subcontractors.

References

Akao, Y. (1990). Quality Function Deployment: Integrating Customer Requirements into Products Design. Production Press, Portland, OR.

Anderson S.D., D.J. Fisher, and S.P. Rahman. (2000). Integrating Constructability into Project Development: a Process Approach, Jnl of Constr Engrg and Mgment, ASCE, 126(2): 81–88.

Ballard, G. and G. Howell. (1998). Shielding Production: Essential Step in Production Control, Jnl of Constr Engrg and Mgment, ASCE 124(1): 11–17.
Boyce, W.J. (1994). Design for Constructability, Hydrocarbon Processing, Dec: 81–85.
Chua, D.K.H., Y.C. Kog, and P.K. Loh. (1999). Critical Success Factors for Different Project Objectives, Jnl of Constr Engrg and Mgment, ASCE, 125(3): 142–150.
Chua, D.K.H. and Y. Song. (2001). Component State Model and its Application in Constructability Analysis of Construction Schedule, Proceedings 8th International Conference on Civil and Structural Engineering Computing, 19–21 September, Eisenstadt, Vienna, Austria
Chua, D.K.H. and L.J. Shen. (2002). Constraint-Based Planning with Integrated Production Scheduler over the Internet, Jnl of Constr Engrg and Mgment, ASCE (in print).
CII. (1993). Constructability Implementation Guide, Special Publication 34–1, prepared by Construction Industry Institute Constructability Implementation Task Force, May.
Clutterbuck, D. (1994). The Power of Empowerment: Release the Hidden Talents of Your Employees. BCA and Kogan Page, London.
Dale, B.G., R.J. Boaden, and D.M. Lascelles. (1994). Total Quality Management: An Overview, in B.G. Dale (ed.), Managing Quality. Prentice Hall, Hemel Hempstead.
Day, R.G. (1993). Quality Function Deployment: Linking a Company with its Customers. ASQC Quality Press, Milwaukee, WI.
Dell'Isola, A.J. (1982). Value Engineering in the Construction Industry, 3rd ed., Van Nostrand Reinhold Co. Ltd.
Green, S.D. (1992). A SMART Methodology for Value Management, Occasional Paper No. 53, Chartered Institute of Building.
Jagannathan, G. (1992), Getting More at Less Cost — the Value Engineering Way, Tata McGraw-Hill Publishing Co. Ltd.
Jortberg, R.F. (1984). CII Constructability Committee's Status, presented at the Construction Productivity Conference, the University of Texas at Austin, Austin, TX.
Kerridge, A.E. (1993). Plan for Constructability, Hydrocarbon Processing, Jan: 135–145.
Koskela, L. (1992). Application of the New Production Philosophy to Construction, Technical report 72, Centre for Integrated Facility Engineering, Stanford University, Sep.
Lillrank, P., and N. Kano. (1989). Continuous Improvement: Quality Control Circles in Japanese Industry, Michigan papers in Japanese studies: no. 19. Centre for Japanese studies, The University of Michigan, Ann Arbor, MI.
McCabe, S. (1998). Quality Improvement Techniques in Construction. Longman Ltd., Edinburgh Gate, England.
McKinny, K. and M. Fischer (1997). 4D Analysis of Temporary Support, Proceeding of the Fourth Congress in Computing in Civil Engineering, ASCE, Philadelphia, PA, 1997: 470–476.
Mears, P. (1995). Quality Improvement — Tools and Techniques, McGraw-Hill, Inc.
O'Connor, J.T. and Davis V.S. (1988). Constructability Improvements During Field Operations, A report to the Construction Industry Institute, The University of Texas at Austin, Austin, TX, May.
O'Connor, J.T., S.E. Rusch, and M.J. Schulz. (1987). Constructability Concepts for Engineering and Procurement, Jnl of Constr Engrg and Mgment, ASCE, 113(2): 235–247.
Paek, J.H., Y.W. Lee, and T.R. Napier. (1992). Selection of Design/Build Proposal Using Fuzzy-Logic System. Journal of Construction Engineering and Management, ASCE, 118(2), 303–317.
Saaty, T.L. (1980). The Analytic Hierarchy Process: Planning, Priority Setting, Resources Allocation. McGraw-Hill International Book Co., London, England.
Tantum, C.B. (1987). Improving Constructability During Conceptual Planning, Jnl of Constr Engrg and Mgment, ASCE, 113(2): 191–207.
Thabet, W.Y., and Y.J. Beliveau. (1994). HVLS: Horizontal and Vertical Logic Scheduler for Multistory Projects, Jnl of Constr Engrg and Mgment, ASCE, 120(4): 875–892.

Further Information

Value Engineering

Brown, J. (1992). Value Engineering: A Blueprint, Industrial Press Inc., New York.

Connaughton, J.J. and S.D. Green. (1996). Value Management in Construction: A Client's Guide, Construction Industry Research and Information Association, Special publication 129.

Kelly, J. and S. Male. (1993). Value Management in Design and Construction — The Economic Management of Projects, E & FN Spon.

O'Brien, J.J. (1976). Value Analysis in Design and Construction, McGraw-Hill Book Company.

The Institute of Civil Engineers. (1996). ICE Design and Practice Guide: Creating Value in Engineering, Thomas Telford Publishing.

Constructability

CII Australia. (1992). Constructability Principles, Construction Industry Institute, Australia, Nov.

Construction Management Committee of the ASCE Construction Division. (1991). Constructability and Constructability Programs: White Paper, Jnl of Constr Engrg and Mgment, ASCE, 117(1): 67–89.

Gugel, J.G. and J.S. Russell. (1994). Model for Constructability Approach Selection, Jnl of Constr Engrg and Mgment, ASCE, 120(3): 509–521.

O'Connor, J.T. and S.J. Miller. (1993). Constructability: Program Assessment and Barriers to Implementation, A Report to the Construction Industry Institute, The University of Texas at Austin, Austin, TX, Jan.

Russel, J.S., M.W. Radtke, and J.G. Gugel. (1992). Project-Level Model and Approaches to Implement Constructability, A Report to the Construction Industry Institute, The University of Texas at Austin, Austin, TX, Oct.

Tantum, C.B., J.A. Vanegas and J.M. Williams. (1987). Constructability Improvement Using Prefabrication, Preassembly and Modularisation, A Report to the Construction Industry Institutue, The University of Texas at Austin, Austin, TX, Feb.

Quality Management

CIRIA. (1996). The Control of Quality on Construction Sites, Special Publication 140, Construction Industry Research and Information Association, London.

Construction Industry Training Board. (1990). Guide to Managing Quality in Construction, CITB, Kings Lynn.

Hughes, T. and T. Williams. (1995). Quality Assurance: A Framework to Build On, 2nd ed., Blackwell Science Ltd, Oxford, UK.

Jackson, P. and D. Ashton. (1995). Achieving BS EN ISO 9000, Kogan Page, London.

Kennedy, C. (1994). Managing with the Gurus: Top Level Advice on 20 Management Techniques, Century, London.

Kolarik, W.J. (1995). Creating Quality: Concepts, Systems, Strategies, and Tools, McGraw-Hill, New York.

McGoldrick, G. (1994). The Complete Quality Manual: A Blueprint for Producing Your Own Quality System, Pitman, London.

Thomas, B. (1995). The Human Dimension of Quality, McGraw-Hill, Maidenhead.