The CTQ flowdown as a conceptual model of project objectives

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The CTQ Flowdown as a Conceptual Model of Project Objectives

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The purpose of this article is to describe and clarify a tool that is at the core of the definition phase of most quality improvement projects. This tool is called the critical to quality (CTQ) flowdown. It relates high-level strategic focal points to project objectives. In their turn project objectives are linked to and decomposed into CTQs, which are made operational in the form of measurements. In this article the nature of the connections between strategic focal point, project objectives, CTQs, and measurements is elaborated.

The CTQ flowdown serves several purposes. It provides clear project definitions, clarifies the business rationale of an improvement project, makes explicit business assumptions behind project definitions, helps to focus on the vital few real business drivers, and facilitates optimally solving trade-off problems. This article provides a theoretical grounding of the CTQ flowdown, and also provides practitioners with a prescriptive template.

Key words: balanced scorecard, key performance indicators, measurement, project definition, Six Sigma, tree diagram

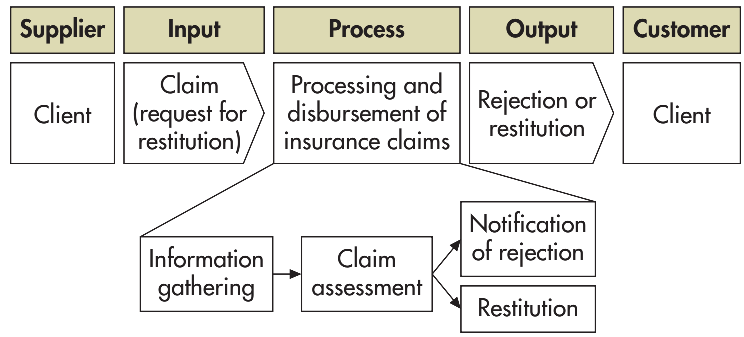
INTRODUCTION

The context of this article is the definition phase of quality improvement projects. Quality improvement projects are understood in the sense of J. M. Juran (1989) and Frank Gryna (2001), and include Six Sigma projects, Taguchi's off-line quality control, and improvement projects in the spirit of total quality management. Potential quality improvement projects are usually identified and defined by program management, project leaders, and project owners.

The project selection process results in a definition of the project's objectives. These project definitions come in different levels of precision and completeness. The dimensions on which the project should aim for improvement are sometimes defined in highly tangible and specific form, for example, in terms of metrics or performance indicators. In other cases they are framed in more abstract terms, lack an operational form, or are defined from a customer perspective rather than from a process control perspective. Sometimes the project definition is so vague as to only define the process that should be improved, without indicating on which dimensions improvement will be measured. Besides lack of clarity about the project's objectives, the rationale and assumptions on which the project definition is based often lack explication as well.

Many standard approaches for quality improvement projects prescribe that the first step of a project is to explicate the objectives of the project in the form of measurable indicators (compare, for instance, the first steps of the Six Sigma approach, Taguchi's method, and the Shainin System (De Mast 2004)). In the Six Sigma approach the translation of a more or less specific project definition into one or a few measurable indicators is done in the define and measure phase (De Koning and De Mast 2006). In this article, the authors adopt Six Sigma's terminology and refer to such measurable indicators that define the objectives of a quality improvement project as critical to quality (CTQ).

Figure 1 SIPOC chart of processing insurance claims.



A commonly used tool to go from a project definition to these specific and measurable CTQs is the CTQ flowdown. It aims to make explicit and structure the rationale underlying the project. It shows how CTQs relate to higher-level concepts such as performance indicators and strategic focal points. Downward it shows how CTQs relate to measurements.

As an example of a CTQ flowdown, the authors study a process of an insurance company that processes insurance claims. The process is concisely described by the SIPOC chart in Figure 1, which specifies the process's inputs and suppliers, as well as its outputs and customers. In addition, the main steps of the process are outlined. Figure 2 shows the CTQ flowdown of a project executed at this company. The company's strategic focal points are customer satisfaction and operational cost. The project objective related to operational cost is reduction of workforce, which amounts to a reduction of the processing time per claim. This one-dimensional CTQ can be decomposed into the constituting cycle times per process step and additional processing time due to complications. Customer satisfaction is translated into the project objective of improving the service quality of the process. Service quality is determined by the total throughput time per claim and the accuracy at which the claim is processed. Throughput time is broken down into total waiting time and total processing time; accuracy is decomposed into complications due to a variety of reasons. The CTQ flowdown is used to describe the sketched relations between strategic focal points, project objectives, and one-dimensional CTQs and their constituents.

The CTQ flowdown is mainly described in training material, for example, as part of Six Sigma training curricula. It is commonly used in practice, but like many tools developed through practical usage, it lacks a precise formulation and theoretical grounding. The purpose of this article is to provide a clear formulation of the CTQ flowdown by discerning the elements that it consists of and elaborating on these. Further, the article aims to provide theoretical grounding of the CTQ flowdown by linking the elements that it consists of to relevant literature.

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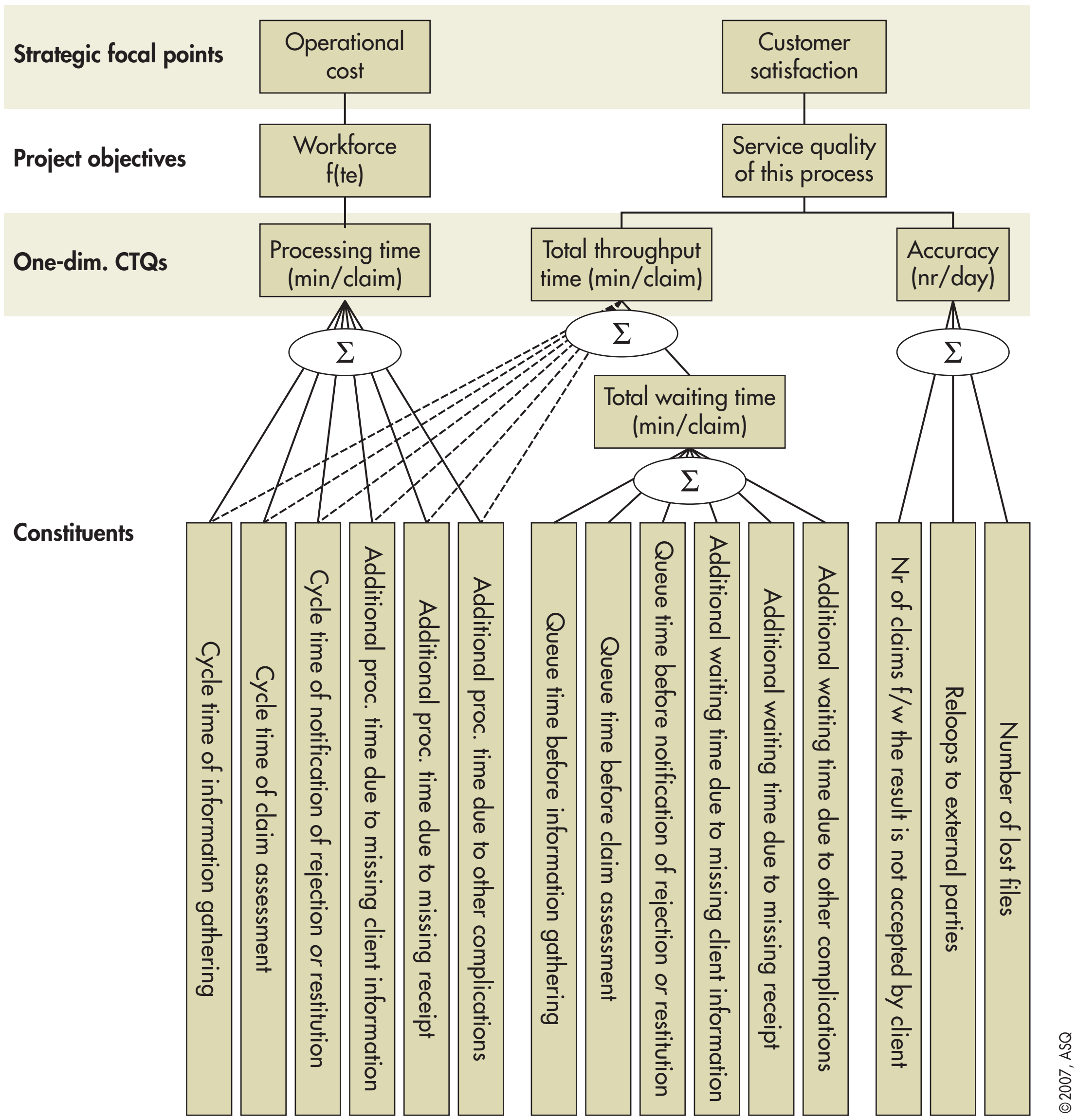
The purpose of diagrams such as in Figures 1 and 2 is that they provide a conceptual model for the context and objectives of a quality improvement project. They structure thinking and communication processes by defining terminology and a frame of reference. A conceptual model is understood to be a network or graph consisting of concepts (nodes) and

Figure 2 Example of a CTQ flowdown for processing insurance claims.

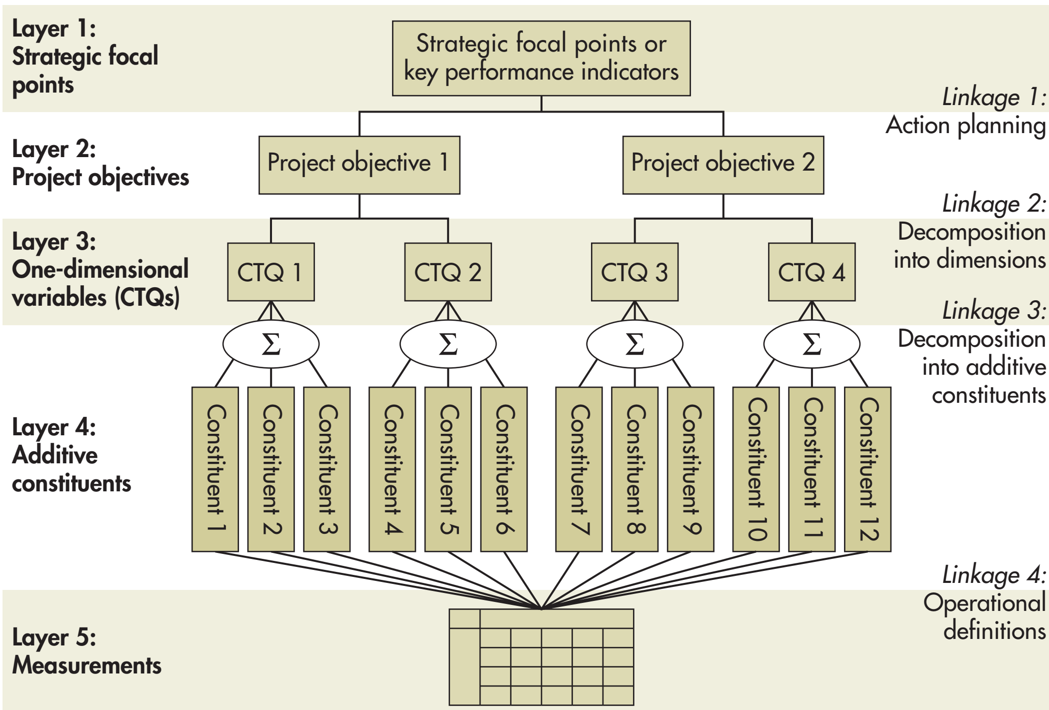


relationships (linking the nodes) (see Thagard 1992). The CTQ flowdown combines several forms of conceptual modeling, which can be found in different contexts in the literature.

This article is built around the notion that CTQ flowdowns generally consist of various canonical layers of nodes and canonical relationships, as specified in Figure 3. In this article the canonical layers are defined and the relationships between them will be clarified. Current practice in the use of the CTQ flowdown is taken as a starting point, but is improved upon with the help of scientific literature. The elaboration of the CTQ flowdown will provide a prescriptive template for practitioners, which will help them to effectively deploy and execute quality improvement projects.

The CTQ flowdown is related to other tools that model relationships among concepts in a diagrammatic form. Kaplan and Norton's (2001) balanced scorecard links a business strategy to measurable

Figure 3 Template of canonical layers of the CTQ flowdown.



performance indicators in the context of performance control. Cause and effect diagrams (Gano 2001; Doggett 2005) relate symptoms to their causes, while Goldratt's current reality tree (Doggett 2005) models more complex cause and effect structures.

The article's structure follows the template of canonical layers shown in Figure 3. This article forms part of a larger research project that aims to study the validity of the Six Sigma method. The design of this research project, based on the rational reconstruction approach, is expounded in De Koning and De Mast (2005).

LAYERS 1 AND 2: STRATEGIC FOCAL POINTS AND PROJECT OBJECTIVES

In this section the authors discuss the first canonical layer, which consists of strategic focal points (or key performance indicators, or other concepts that specify the objectives on the level of a business), and they show how it is linked to the second layer, the one consisting of project objectives. The link is established by a type of relationship called *action planning*.

Strategic focal points guide and focus action at the level of a business and characterize its strategy. For example, a company pursuing a strategy of cost leadership could try to increase the efficiency of its operations. To this company improvement of operating efficiency is one of the strategic focal points. To translate strategy into actions, projects are defined. Project objectives delineate an improvement project and serve as a yardstick of project success. A company that wants to improve operating efficiency as a part of its strategy to attain cost leadership can select project objectives such as "reduce the number of defective products" or "increase machine utilization" depending on the business it operates in. As another example, consider the insurance company introduced in the previous section (see Figures 1 and 2). Two of the company's strategic focal points are customer satisfaction and operational cost. The project objective related to customer satisfaction is the improvement of the service quality of the insurance claims processing. Similarly, the strategic focal point "operational cost" can be translated into the project objective "reduction of the workforce."

The translation of strategic focal points to project objectives is called "action planning" by Mintzberg (1994). According to Mintzberg, the goal of action planning is before-the-act specification of behavior. In particular, strategic focal points are translated into improvement programs, which, in turn, initiate and coordinate improvement projects.

For example, a company pursuing a strategy of cost leadership could try to increase the efficiency of its operations. To this company improvement of operating efficiency is one of the strategic focal points. To translate strategy into actions, projects are defined. Project objectives delineate an improvement project and serve as a yardstick of project success. A company that wants to improve operating efficiency as a part of its strategy to attain cost leadership can select project objectives such as "reduce the number of defective products" or "increase machine utilization" depending on the business it operates in.

Action planning as a first part of a project may seem a bit after-the-fact. After all, the project objectives have already been established in the project selection process. Why then, as a first step of the project, should the project leader reconsider the selection of objectives? The issue here is that although in some cases project selection has been such a disciplined and structured process that clearly defined project objectives are available and their relations to strategic focal points are explicit, in many cases objectives are not delineated so clearly, and their relationship to strategic focal points is not clearly articulated. In the latter case, the project leader has to reconstruct after the fact:

- *The rationale of the project.* How do objectives link to the bigger scope and strategic focal points in particular?
- *A precise definition of the project's objectives.* This gives a clear and articulated account of the "what" and "why" of a project, which helps communicate the motivation for and exact goal of the project.

LAYERS 2 AND 3: PROJECT OBJECTIVES AND ONE-DIMENSIONAL VARIABLES

Project objectives are often stated in terms of aggregate concepts. If that is the case, they should be decomposed into their constituting dimensions. This decomposition of a project objective into one-dimensional variables is represented in the authors' structure in the link between the second and third layer.

An example of an aggregated project objective could be the statement that a project seeks to increase the quality of a service. The concept of service quality aggregates a number of aspects, such as fitness for use, timeliness, professionalism, and courtesy (Parasuraman, Zeithaml, and Berry 1985). Similarly, a project objective to enhance the ease with which semi-manufactures can be processed in further process steps could be decomposed into various geometrical dimensions, and perhaps dimensions such as brittleness and crookedness. Finally, service quality of insurance claims processing can be decomposed into the throughput time of processing a claim and the accuracy at which a claim is processed (see Figure 2).

By decomposing an aggregate project objective into its composing dimensions, the objective is made more precise. Further, this translation into one-dimensional variables is a first step toward making the project objective measurable. The link between the aggregate concept (the project objective) and the individual dimensions it consists of is called a "part of" relationship. An aggregate decomposed into its

Figure 4 Measurement plan.

Unit	Processing time						Waiting time						Accuracy			Attributes			
Case nr	Cycle time of information gathering	Cycle time of claim assessment	Cycle time of notification of rejection *or* restitution	Additional processing time due to missing client information	Additional processing time due missing receipt	Additional processing time due to other complications	Queue time before information gathering	Queue time before claim assessment	Queue time before notification of rejection *or* restitution	Additional waiting time due to missing client information	Additional waiting time due to missing receipt	Additional waiting time due to other complications	Number of lost files	Reloops to external parties	Number claims for which the result is not accepted by the client	Employee-id	Claimed amount	District	Type of claim
Case 1																			
Case 2																			
Case 3																			
Case 4																			
Case 5																			
Case 6																			
Case 7																			

constituting dimensions is called a Cartesian product structure in the theory of semantic networks (Hoare 1972; Smith and Smith 1977; Thagard 1992).

LAYERS 3 AND 4: ONE-DIMENSIONAL VARIABLES AND THEIR ADDITIVE CONSTITUENTS

Often, the one-dimensional variables that the project objective is decomposed into can be viewed as a sum of lower-level constituents. In the authors' structure, the decomposition of one-dimensional variables into their constituents takes place in the transition from the third to the fourth layer.

The insurance company example introduced earlier illustrates this idea. The throughput time of processing a claim is decomposed into the sum of processing time and waiting time. Processing time and waiting time, in turn, may be decomposed into the cycle times and queue times of the individual process steps and the additional processing and waiting time due to a variety of complications. Likewise, the accuracy can be decomposed into the number of lost files, the number of reloops to external parties, and the number of claims for which the result is not accepted by the client (see Figure 2). Notice that the Σ symbol is used in the CTQ flowdown to indicate that lower-level constituent's terms sum to the one-dimensional CTQ one level higher. Moreover, note that the link between total throughput time and the processing times is indicated by dashed lines. Processing time will typically be only a minor constituent of throughput time, and, therefore, as a first approximation, throughput time links only to waiting times.

By breaking down total sums into their constituents the dominant contributants can be discerned from the trivial many (Pareto principle). This helps to focus the project and reduces the scope.

LEVEL 5: MEASUREMENTS

In this section the authors discuss how CTQs, broken down into their constituents, are linked to the fifth canonical layer, consisting of measurements. The gap between CTQs and the realm of measurements is bridged by operational definitions. Operational definitions make CTQs measurable by specifying a measurement procedure. Choosing a measurement procedure means, among other things, that one has to choose per what one will measure, that is, *per what* entity a datum will be collected. If, for instance, yield is the CTQ, one should indicate whether it is measured per day, shift or hour (that is, is one datum a daily yield, a yield per shift, or hourly yield?). The methodological name for the entity per which measurements are collected is (experimental) unit. The collection of all units for which the authors aim to make conclusions is called the population.

By giving an operational definition for one or a few CTQs, the project leader defines a template for data collection (a measurement plan). A measurement plan has the structure of a datamatrix. The rows of the datamatrix correspond to units (for each unit there is a CTQ value and thus a row in the datamatrix or dataset) and the columns correspond to CTQs.

As an example the authors turn to the operational definition of the CTQs "waiting time," and "processing time," defined for the processing of insurance claims (Figures 1 and 2). The unit for these CTQs is a single claim (case number). All claims together form the population on which the measurements are defined. To measure the waiting time and processing time each claim gets a time stamp when it enters and leaves each process step for the first time. The difference between the start and end time of a process step is the cycle time of a claim; the difference between the end time of one process step and start time of the next is the queue time between these steps. The resulting measurement plan is shown in Figure 4. The dataset does not contain the raw data, but data already transformed into CTQ measurements. For instance, for the cycle times this means that the end and start data are simply subtracted, but often this involves more complicated manipulations.

The translation of strategic focal points to project objectives is called "action planning" by Mintzberg (1994). According to Mintzberg, the goal of action planning is before-the-act specification of behavior. In particular, strategic focal points are translated into improvement programs, which, in turn, initiate and coordinate improvement projects.

Note that, although CTQ measurements typically are numerical, they can also be categorical. If, for example, one measures whether a product conforms to customer requirements, the measurements can adopt two possible values: conforming or nonconforming. Because numerical measurements contain more information these are preferable over categorical measurements.

Operational definitions were a hallmark of a philosophy called operationism (Bridgman 1927). Making the meaning of concepts more specific by giving an operational definition ensures that the statements in which they occur are testable and that they lend themselves to use in explanations and predictions. The extreme stance of operationism, that a concept is synonymous with the corresponding set of operations, is generally regarded untenable (it implies that two different measurement procedures to measure cycle time would define two different concepts), but the importance of operational definitions as the link between concepts and empirical data is generally acknowledged.

CONCEPTUAL MODELING OF THE CAUSAL STRUCTURE OF PROBLEMS

A hallmark of quality improvement programs is the principle that improving a process requires an understanding of how it works. To understand a process means that one is able to relate the behavior of the CTQs to so-called influence factors. This is symbolized by the equation $CTQ = f(X_1, X_2, \ldots, X_n)$. Without understanding the mechanics of a process, solutions to the problem will be cosmetic, that is, one is just fighting symptoms. In most quality improvement programs (such as the Shainin System, Taguchi's method, and the Six Sigma approach) the project leader typically starts searching for influence factors after the definition phase. The relations between these influence factors and CTQs are shown graphically in diagrams, whose form is similar to the CTQ flowdown. Instances of such diagrams are the cause-and-effect diagram and the current reality tree (Gano 2001; Doggett 2005).

By decomposing an aggregate project objective into its composing dimensions, the objective is made more precise. Further, this translation into one-dimensional variables is a first step toward making the project objective measurable.

To illustrate the idea, one can examine the measurement plan of Figure 4. Apart from units and CTQs, attributes, such as employee-id and type of claim, also are included. Although these attributes are not shown in the CTQ flowdown (they are not part of the project definition proper) they are taken along to get as much detail out of the measurements as possible. These attributes are potential influence factors, so taking them along helps diagnosis and find the solution later in the project. For instance, if some employees work more efficiently than others, this will show up in the data: One will see differences in cycle times between employees. The solution could possibly be to reduce these differences by adopting the work practices of the best employee.

CONCLUSIONS

The definition phase of quality improvement projects results in project definitions that come in different levels of precision and completeness: sometimes clarity about the project's objectives lacks, or sometimes the rationale and assumptions on which the project definition is based are not clear. It is argued that the CTQ flowdown helps to structure the project definition and make explicit the rationale underlying the project. Strategic focal points, project objectives, one dimensional CTQs, and constituent parts of CTQs are placed in a diagram linking them to together. Moreover, these concepts are related to measurements in this diagram. The elaborate study of the CTQ flowdown allows one to draw a number of conclusions about this tool. Linking concepts has the following purposes:

1. The CTQ flowdown makes explicit the business economic rationale for the project. Project objectives are linked to strategic focal points, which enables program management and the project owner to check the rationale of the project before it is started.
2. The project is placed in its larger scope. This makes explicit the choices as to which aspects will be excluded from the project. These aspects might be suitable topics for later projects, but are excluded from the current project for feasibility reasons. In the example of processing insurance claims (see Figures 1 and 2) one could, for instance, focus the

project on reducing *throughput time* and leave the improvement of *accuracy* to another project. Placing the project in its larger scope is also crucial for a second reason: focusing. Modeling the larger business economic scope enables one to identify the real drivers of performance, and thus allows the verification that the project is tackling one of the vital few issues (as opposed to one of the trivial many).

3. The CTQ flowdown makes explicit the assumptions on which the project is based. For example, the decomposition of service quality into throughput time and accuracy is based on the assumption that accuracy and throughput time drive service quality (see Figure 2). Making this assumption explicit enables a debate or consideration of its legitimacy.
4. The CTQ flowdown serves as a communication tool by providing a common frame of reference and a common language.

The gap between CTQs and the realm of measurements is bridged by operational definitions. Operational definitions make CTQs measurable by specifying a measurement procedure. Choosing a measurement procedure means, among other things, that one has to choose per what *one will measure, that is, per what entity a datum will be collected.*

Making concepts measurable, the second function of the CTQ flowdown, has the following purposes:

1. Effective problem-solving activities and improvements are based on well-defined, crystal-clear problem definitions. The first four canonical layers, the ones consisting of strategic focal points, project objectives one dimensional CTQs, and their constituent parts, are all formulated in abstract terminology and too abstract and intangible to base improvement on. Operational definitions make them well defined and crystal clear.
2. Measurements focus the project on the most important (sub) problems by quantifying the relative magnitude of various aspects of the problem to be solved. This helps to focus on the vital few dominant problems (Pareto principle). For example, only after one has measured the processing times of the several process steps (see Figure 2) will it become clear what process step has the largest contribution to the total processing time and, consequently, on which process step one must focus improvement efforts.
3. Many problems (quality versus cost, speed versus defects) are trade-off problems. The matter, then, is not "either/or," but "how much of one and how much of the other?" Quantification sheds light on the trade-off nature of problems and makes it possible to solve problems optimally.

This article provides a theoretical grounding of the CTQ flowdown. Although it mainly developed through practical usage, the previous sections relate elements of the CTQ flowdown to theories about business strategy/action planning, semantic networks/Cartesian product structures, and scientific method/operational definitions.

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BIOGRAPHIES

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