# Enhancing Six Sigma with Systems Dynamic

Hari A Yuniarto and Taha MS Elhag

*Abstract*—**The purpose of this paper is to present of how the novelty of future trend in Six Sigma methodology is going to be integrated with Systems Dynamic to establish a new quality framework that is robust in dealing with dynamic circumstances.**

**The new Six-Sigma framework has been proposed, namely DM(AI)$^{+}$C, to accommodate all potential factors involved in the delivering critical quality of customized outputs. Either 'soft factors' or 'hard factors' in real system were modeled using Systems Dynamic in order to understand the interrelationships and causal mechanism among those related factors for the determination of true root causes.**

**At last, the "Analyze-Improve *plus*" of DM(AI)$^{+}$C aims to analyze the dynamic characteristics of failure in a quality system as well as to establish optimum solutions to avoid recurring similar problems.**

***Index Terms*—Root Cause Analysis, Six-Sigma, Strategic Decision Making, Systems Dynamic**

## I. Introduction

In developing a strategic quality management, it is essential that a business be aware of the upcoming trend in market demand to challenge established positions in the global economy. Globalization is widely seen to be an expression for a variety of processes encompassing world wide integration of diverse factors, such as trade liberalization, deregulation, and pressures towards cultural, economic, and social homogeneity (1).

The need to understand a dynamic behavior of business process that is affecting the quality of its product is obliged to do so. Nonconformity of a product or service to its specifications affected by dynamic system behavior drives efforts to identify the root cause of defects comprehensively. It is believed that Six-Sigma, with its well-known *Define-Measure-Analyse-Improve-Control* (DMAIC), would address this issue promptly (2, 3) only if appropriate additional requirements against its DMAIC phase are well fortified.

In this paper, further development on "Analyse" and "Improve" steps within DMAIC is described, leading to a DM**(AI)**$^{+}$C new framework model for improved y = f(x) Six-Sigma transfer function. The proposed model will show the dynamic significance to the detail of root cause failure analysis in maintenance management, such as how these independent variables are connected, how they influence one another, how past behavior and future outcomes arise from certain decision making policies and their interconnections. Therefore, the novelty of beyond Six-Sigma will be conferred into a dynamic business environment.

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## II. Six-Sigma: Why Is It Significant?

The basic concept of Six-Sigma was initially developed by Mikel Harry in 1987 who worked at Motorola originated with the emerging of Statistical Process Control (SPC) during the 60's and 70's (4). It was then developed further by "Six-Sigma Academy" established by Harry within Motorola and propagated to IBM, Lockheed Martin, Nokia, and other companies in the US, Europe, and Asia, either in discrete manufacturing processes or in the process industries (5).

Because the philosophy for Six-Sigma is that every improvement efforts should be based on the facts as the culture of enterprise, therefore it is often defined as a business strategy towards business profitability by improving all processes of effectiveness and efficiency to satisfy customer demands on the basis of data-driven approach (5, 6). Other Six-Sigma's definition from a statistics perspective is defined as a disciplined method of robust statistical analysis of data gathering and pinpointing sources of errors for reducing defect occurrence from *three sigma* level to a *six sigma* level of 3.4 DPMO (7, 8), while this *Defect Per Million Opportunity* measure is defined as the average number of defects per unit observed during an average production run divided by the number of opportunities to make a defect on the product under study during that run normalized to one million. In general, Six-Sigma can be approached from two perspectives: *statistical viewpoint*, i.e. tools and techniques, such as root cause analysis, and *business viewpoint*, i.e. business strategy (9). Figure 1 depicts recent Six-Sigma development when it is integrated with the *Lean* concept, namely as The Lean Sigma (10-13). While, the DMAIC phase of Six-Sigma is illustrated in Table 1.

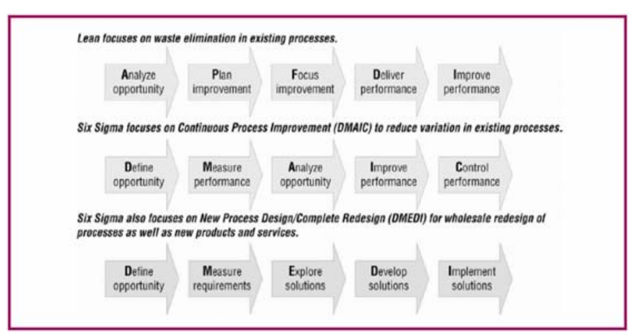


Figure 1. The Lean Six Sigma framework (10)

Table 1. The DMAIC phase (14)

| | |
|---|---|
| Define | |
| Measure | 1. Select CTQ characteristic |
| | 2. Define performance standards |
| | 3. Validate measurement system |
| Analyse | 4. Establish product capability |
| | 5. Define performance objectives |
| | 6. Identify variation sources |
| Improve | 7. Screen potential causes |
| | 8. Discover variable relationships |
| | 9. Establish operating tolerances |
| Control | 10. Validate measurement system |
| | 11. Determine process capability |
| | 12. Implement process controls |

Considering its distinct features, such as a closed-loop DMAIC phase, CTQ measures (Critical To Quality), and 6σ specification limit with ± 1.5σ drifts from process mean, makes the Six-Sigma methodology more prominent compared to other quality improvement methodologies (3, 12, 15). Antony (12) accentuated Six-Sigma as a methodology utilizes tools and techniques in a very systematic and sequential manner. Its measurement-based strategy that focuses on process improvement and variation reduction remarks the significance of Six-Sigma (3). Other remarkable aspects in Six-Sigma that are not highlighted in previous quality improvement initiatives are:

- Six-Sigma puts strong emphasize on challenging specific numerical goals for process improvement objective (16, 17).
- It can be pondered as recent quality methodology for achieving competitive advantage that has gained acceptance in many industries across the world (2, 18).
- Six-Sigma provides guideline that unites various basic quality tools with high-level of management encouragement (11, 13, 19, 20)
- It also drives an organization to take improvement level of sigma capability through the rigorous application of statistical knowledge and factual data gathering (9, 21)

Unfortunately, Six-Sigma lacks from investigating dynamicity of a system observed (2, 3, 6, 15, 22) within its transfer function, y = f(x). By using DoE, for example, it just tends to form an analysis framework only into a structured pattern. Actually, a more systemic root cause failure analysis is needed to show the dynamic significance of the detail, such as how these independent variables are connected, how they influence one another, how past behavior and future outcomes arise from certain decision making policies and their interconnections in order to identify the root cause of defects comprehensively.

## III. Future Trend in Quality Demand

The big issue with a contemporary business strategy is always how to deal with the globalization era which exhibits substantial volatility (23-25). This new leaning demand will then emerge high variety of different product requirements related to a diverse range of customers world-wide. Thus, vastly customized products and services in demand can not be eluded.

Customization with increased variety and attractiveness has become a key success factor for emerging, as well as to sustain global market. What this means is that increasingly multiple CTQs need to be recognized, addressed, and balanced. This feature of quality will create *a dynamic system* to the business process (2, 21, 26-30).

According to Sila and Ebrahimpour (31), the highest key success factors for answering those future trends of quality demand are related to: (a) *customer focus and satisfaction*, (b) *learning organization, leadership and top management commitment*, (c) *teamwork*, (d) *employee involvement*, (e) *continuous improvement and innovation*, and (f) *quality information and performance measurement*. These success factors address the dynamicity of a quality system, since mainly those key points are more socio-technical related factors (2).

Recent publications show evidence of supporting this new phenomenon. Goh and Xie (2) proposed ***S****ystem Perspectives* and ***S****trategic Analysis* as the new concept for Six-Sigma. These two additional "**S**s" into Six-Sigma provide systemic guideline for CTQs determination and dynamic market demand management by establishing a base of system thinking. While Antony (3) argued that linkage between six sigma and *organizational learning* may be addressed for future research due to this dynamic market demand, because all works occurred in a system are of an interconnected process.

As the scope of quality demand has expanded beyond the original one, so have a robust quality system needs (32). A robust methodology that is able to deal with those dynamic systems widely applied on various implementation fields. should *not* be selected.

## IV. How Can Six-Sigma Address This Quality Demand?

Six-Sigma is a business strategy that seeks to identify and eliminate causes of defects, or failures, in business processes by focusing on outputs that are critical to customers (33). There is a number of quality tools adopted into Six-Sigma by its DMAIC phase, as classified by Tague (34) with American Society for Quality (ASQ). These categories of tools include (34):

*(1) cause analysis tools*
(2) data collection and analysis tools
(3) evaluation and decision-making tools
(4) idea creation tools
(5) process analysis tools
(6) project planning and implementation tools
(7) seven basic quality tools
(8) seven new management and planning tools

Because the fundamental philosophy in Six-Sigma is to gain understanding of the causal mechanisms underlying a problem for process improvement (35), it is then believed that a *root cause analysis* (RCA) tool will be a pertinent quality tool for Six-Sigma when addressed to find the transfer function of influence factors' effect onto the CTQ (4, 36-38). RCA is originally implemented only in phase "A", *Analyse*, of the DMAIC to identify the root cause of failures by modeling relationships among the independent variables related to the CTQ's behavior.

Analogous to the future trend in quality demand, the behavior of a *dynamic system failure* is also related to the influence factors that causally affect it. The original Six-Sigma transfer function, $[y_1, y_2, \ldots, y_m] = f(x_1, x_2 \ldots, x_n)$, quantifies the behavior of quality variable of a system failure affected from its root cause influential factors (5).

Consider the formula; $y_i$, f, and $x_i$ are quality variables (dependent variables), process, and process variables (independent variables) respectively. From these relationships, a systematic effort to identify the truly involved independent variables and to reduce their variances for improved operating point could be gained gradually, and when the desired level has been reached these independent variables are set at the optimum values. Thus, improvement actions also, as framed in phase "I" of DMAIC, will be closely based on the understanding of relationships among factors and on the discovery of causal mechanisms (35).

As the scope of quality demand has expanded beyond the original one, so have a robust quality system needs (32). A root cause analysis tool, which would be applicable for those dynamic systems if certain requirements adapted, will become an important quality system tool for Six-Sigma. Unfortunately in fact, the transfer function within the original Six-Sigma lacks from investigating the dynamicity of a system observed (2, 3, 6, 15, 22). It does not challenge *soft-factors* and *hard-factors* implied as comprised within a real dynamic system.

In terms of maintenance management, for instance, a hard-factor is used to refer to *technical factors* of root cause, such as, seal leakage, unbalanced bearing, cavitations, corrosions, and so forth. Whereas, soft-factor is defined as a representation of *social factors* of root causes caused by, for example, a vague corporate objective, lack of skills, improper strategy used, and so on.

According to Antony (3), as well as Goh and Xie (2), the integration of system thinking (39-41) and organizational learning (29) into DMAIC tools (7) could greatly facilitate the handling of complex and changing dynamic situations, as well as optimize multiple decisions under operational or resource constraints. Kwak et.al (6) also supports this idea as he suggested that future of Six-Sigma is likely to be integrated with other innovative management practices due to focusing on improving overall management performance systemically. Goh and Xie (2) have actually proposed this integration; but unfortunately, it is merely conceptual rather than practical.

## V. A New DM<u>(AI)</u>$^+$C Model For RCA

While, Six-Sigma has originally provided applicable framework to satisfy requirement for critical to quality, its original DMAIC concept and practice needs to be innovated further to meet the new requirements towards those future trends. Ignoring consideration of soft-factors and hard-factors integration within the phase of "Analyse" and "Improve" can not clarify actual root-cause of failure so as to optimize Six-Sigma transfer function, especially for dynamic business environment.

In this study, a DM**<u>(AI)</u>**$^+$C is then proposed as a new Six-Sigma framework to fill in this gap. This "Analyse-Improve plus" will get the System Dynamics methodology into Six-Sigma (2, 3) to establish *system thinking-based Root Cause Analysis* (Systemic-RCA). Figure 2 sets out the new model of DM**<u>(AI)</u>**$^+$C advocated. While, Figure 3 shows the **<u>(AI)</u>**$^+$ element of DM**<u>(AI)</u>**$^+$C model in details.

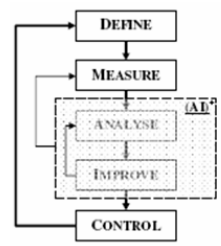


Figure 2. The DM<u>(AI)</u>$^+$C

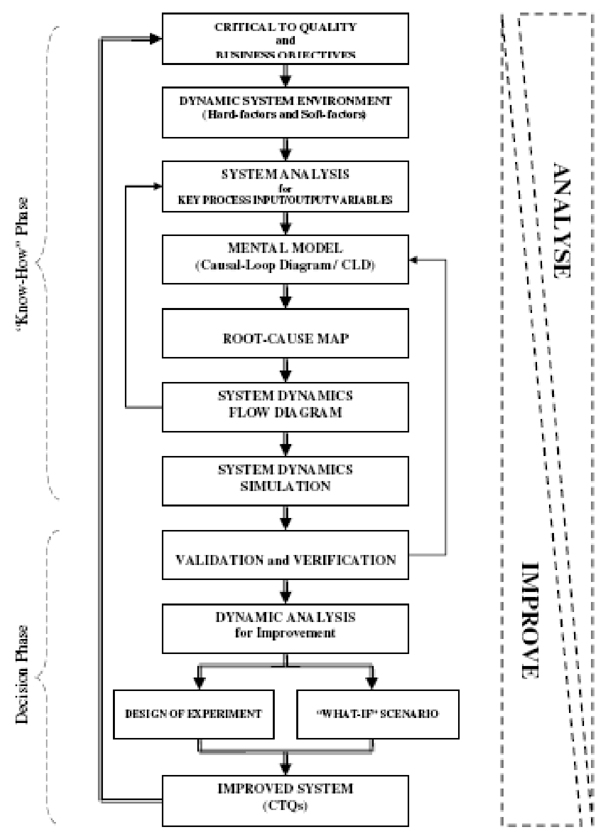


Figure 3. The **<u>(AI)</u>**$^+$ element of DM**<u>(AI)</u>**$^+$C

Despite implementing *Analyse* and *Improve* phases subsequently, DM**<u>(AI)</u>**$^+$C contends this with concurrent implementation of those two phases as illustrated in Figure 2. In *Analyse*, not only just identifying key process variables that cause failures, but also understanding root cause's behavior of why failures occur. Parallel to that, *Improve* phase initiates identification of redesign and any improvement actions by discovering influence factors relationships based on causes of failure that determine the CTQs' behavior. It should be realized that this new framework model is of an iterative nature involving habitual closed-loop feedback.

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Figure 3 sets out the foremost attributes of DM**(AI)**$^{+}$C whose aim is to establish a systemic approach to analyzing the dynamic characteristics of system failure so as to highlight the root cause of problems and hence to develop suitable solutions (42). Since understanding and analyzing behavior on process variations are keys to success (2, 3), as it represents the main cause of quality problems, thus this framework will consist of two distinct phases. Initially, it is *Analyse* phase that employs "know-how" abstraction, and then followed by *Improve* phase that adopts "decision" concept. Because the main cause of quality problems is variations, these phases are therefore overlapping in some extent while modeling practice will get variations identified, measured, reduced, and corrected consecutively from top to bottom.

The Analyse-phase:

This phase deals with acquiring sufficient intuitive and conceptual knowledge to understand behavior of the system failures such that some root causes may be revealed. The initial stage of system analysis assists in defining boundaries and interfaces that exists. Referring to business objectives and its CTQ, *Key Process Input* and *Key Process Output* variables are analyzed by considering any hard-factors and soft-factors involved within a dynamic system environment.

The knowledge and information data gained from the system analysis aids in the development of appropriate conceptual mental-model with the use of Causal-Loop Diagram (CLD). This diagram will represent the causal-feedback relationships between hard and soft factors driving system failures. Figure 4 exhibits an example of CLD. Simultaneously, the next stage is to undertake root cause mapping driven by data from CLD. As illustrated in Figure 5, the map aims to identify major contributors to the failures, called *causal factors*, rather than the root cause itself. Those factors are contributors in which, if eliminated, will prevent the occurrence of failure or mitigate its severity.

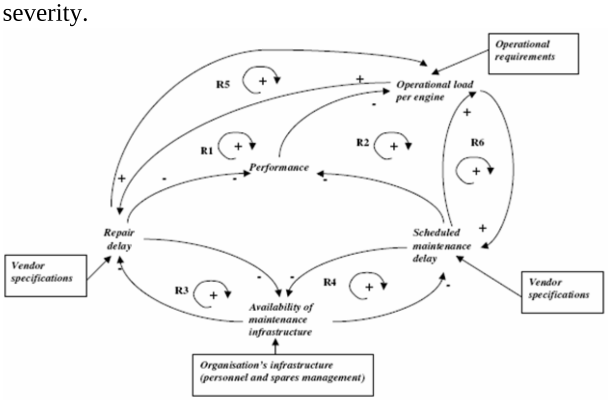


Figure 4. Causal-Loop Diagram (43)

Since the true nature of dynamic behavior of system failure become known, the CLD with highlighted causal factors will then be converted into a system dynamics Flow Diagram (FD). FD offers better depiction of exact relationships between various interacting hard and/or soft factors in the mental-model by including mathematical notation. This diagram is always related to a certain system dynamics software package used, such as Powersim, iThink, Vensim, STELLA, and so forth.

The final stage in an Analyse-phase is to simulate the FD, by using appropriate system dynamics software package. It is at this stage that considerable true root cause of failure will finally be attained such that rigorous simulation exercise may be undertaken to reveal the underlying causal mechanisms. Simulation models are directly developed from FD with different equations set-up for causal relationships. Figure 6 represents a particular Flow Diagram implemented in maintenance management.

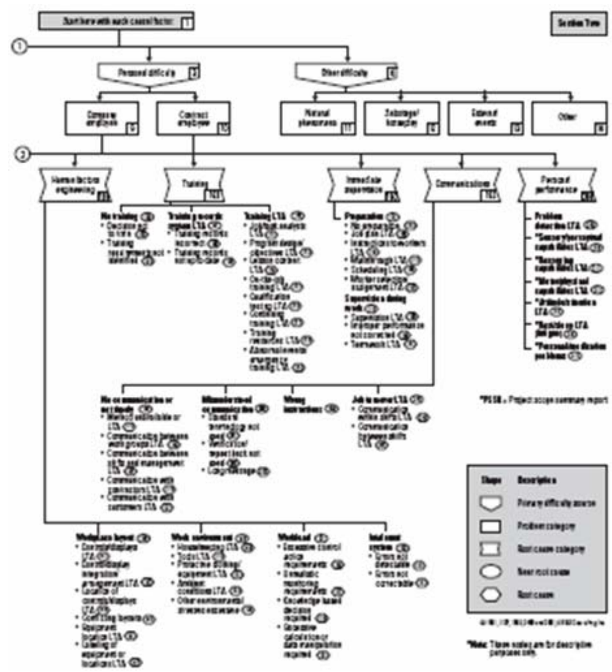

Figure 5. Root-Cause Map (44)

The Improve-phase:

Verification of the simulation model comprises feedback to ensure the correctness of the model, from both persons who supplied data for the mental-model and other interested parties. A validation could be taken by inputting actual data collected from a real dynamic system into the model. The output validation is then compared with outputs from the actual system observed.

Within this Improve-phase, the validated model will be dealt with extensive dynamic analysis towards *strategic decision-making* on failures prevention strategy. The objective of this phase is to analyze the dynamic characteristics of system failure so as to highlight the causal mechanism and hence to develop suitable solutions, by subjecting the model to "what-if scenario". Sensitivity analysis is undertaken to reveal how vigorous the system is to changes in root cause variably with regard to possible corrective, as well as preventive, actions. Concurrently, the Design of Experiment (DoE) could also be used to strategic decision-making for more sound numerically means.

Once the root causes of failure are identified and the appropriate actions are suggested, it is now a case of distinguishing a pivoted action for problem solution. Using the *Analytical Hierarchy Process* (AHP) as one of well-known techniques in Multiple Criteria Decision Making (MCDM), a model is then built to represent

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hierarchy of levels with respect to objectives, criteria, failure categories, failure details, and failed component (45, 46). Eventually, this phase initiates identification of redesign or any improvement actions based on causal mechanism of failure. It should also be notified that this new framework model is of an iterative nature to continuous improvement.

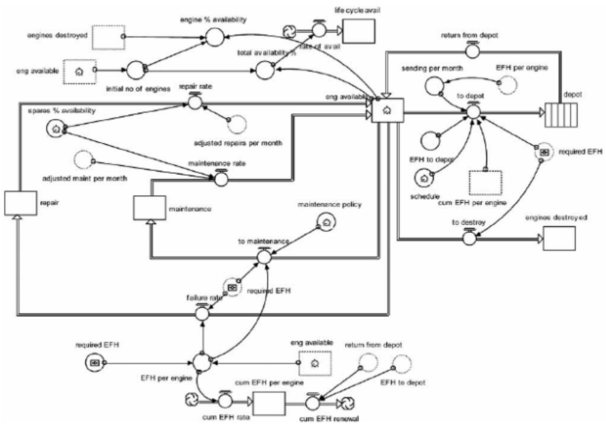

Figure 6. Flow Diagram (43)

## VI. Conclusions

Six-sigma needs to be developed in order to meet requirements of recent trend in dynamic business environment. To get through this intense product customization, the way how to identify a truly root cause of the product failure should be established with high efficiency and effectiveness.

The DM**(AI)**$^{+}$C has been established and illustrated to address this issue. The new framework incorporates soft factors of system failure which when utilized with its hard factors allows for structured approach to root cause failure analysis. Because of its concept integration between system thinking, optimization and total quality control, it will facilitate understanding the dynamic behavior of system failure: not only discern the causal mechanism, but also optimize decision making in the strategic failure management.

This model will also benefit from the “what-if” scenario due to its capability for decision maker to interact with the model for strategic decision making. By setting-up a certain range of “what-if” queries into the model, it is possible to elaborate which possible solution is the best compared to others.

Eventually, the new framework of Six-Sigma has been developed and is still in the process of being refined. Following this is to implement the framework model in practice. Future work will focus on investigating barriers to practical implementation into maintenance management and to evaluate the validity of the framework.

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