Application of Design for Six Sigma Process Improvement Method for Integrated Engineering Execution in Design-Build Projects

Wen-Bin Chiu

Abstract**—**A Process Improvement Task (PIT) is a performance improvement program aimed at reduction of project cost, quality and cycle time by applying Six Sigma methodology. The goal of this research is to effectively implement Integrated Engineering Design (IED) execution concepts in critical-path portions of design-build projects through a PIT effort. As this PIT progressed through Define, Measure, Analysis, Design and Verify (DMADV) phases, this paper illustrates the Design for Six Sigma (DFSS) techniques and tools to move the engineering design information curve to the left resulted in savings of project total installation cost from a projected reduction in project total cycle time. The purpose of this paper is to share some findings resulted from the application of DFSS methodology for Integrated Engineering Design in design-build projects through a PIT. The key recommendation and achieving this PIT objective will be discussed.

Keywords**—**Process Improvement Task, Design-Build Project, Design for Six Sigma, Integrated Engineering Design.

I. Introduction

SIX Sigma is a data-driven approach to improve the project efficiency and quality. The methodology was developed and utilized for manufacturing companies such as General Electric and Motorola in the early 1980s. The dramatic results and the publicity about their quality programs, created the current wave of Six Sigma deployments worldwide. This statistic-based method uses hard data to know how the processes perform, to understand causes if something goes wrong, and to help develop solutions that result in better performance and capability. By using a rigorous set of statistical and analytic tools, Six Sigma produces process improvements not only in manufacturing production lines, but also help to deliver quality to the customers. This systematic methodology makes it an applicable tool in engineering and construction industry [1].

Applying Six Sigma methodology, a performance improvement program is deployed by a Process Improvement Task (PIT). A PIT is a team-based effort supporting a problem area that builds a case for a course of action and outlines the cost, benefit and risk with the proposed course of action. Two approaches in problem solving technique when applying Six Sigma in a PIT. First, the Six Sigma method referred to as Define, Measure, Analysis, Improve and Control (DMAIC) phases of systematic, scientific, fact-based process for work process improvement. DMAIC is a closed-loop structured problem solving process used by Six Sigma programs to incrementally improve processes. Second, Design for Six Sigma (DFSS) is a five step methodology includes Define, Measure, Analysis, Design and Verify (DMADV) for systematically designing a new work process to meet customer expectations or redesigning an existing process that can no longer be improved to meet customer expectations.

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II. DFSS Process Improvement Method for IED Execution in Design-Build Projects

Integrated Engineering Design (IED) is defined as a systematic approach to the integrated and concurrent design of offerings and their related processes, including manufacturing and support. An IED team is an empowered, multi-disciplinary team working on a system in one total development activity focused on satisfying customer requirements for the purpose of moving the information curve to the left with the final goal of reducing project execution cycle time. The IED execution, implementation of projects, will improve the timeliness and quality of design information and further progress design flexibility required to improve overall project performance.

A comprehensive survey of Architecture, Engineering and Construction (AEC) industry in Taiwan demonstrates that engineering design processes do not accurately reflect standard published standard procedures particularly in the areas of information flow and information interfaces. The survey data indicate that engineers or designer at all design and construction levels are creating new and unique ways of completing deliverables in order to meet aggressive deadlines. Result-driven customized work processes and informal information sharing currently facilitate the majority of cross discipline communications on projects. Instead of suppressing these informal channels of communication and unofficial work processes, this research recognizes this phenomenon as an emerging execution strategy and, as such, will nurture and further develop it with a bold design paradigm shift as shown in Figure 1.

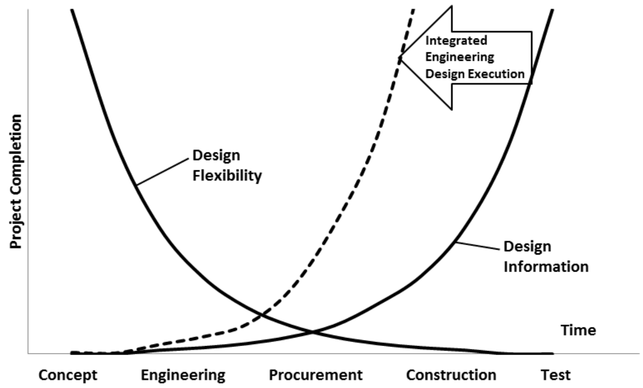

Fig.1 Design Paradox

This study is applying DFSS methodology to design and implement integrated engineering principles across the contractors of AEC industry in Taiwan, this research unlocks and enhance team dynamics that are instrumental to a project's success. A thorough Voice of the Customer (VOC) investigation was conducted to identify customer requirements and constraints to begin the integrated engineering team design, Analytical Hierarchy Process (AHP) Matrix to prioritize the VOC, Quality Function Deployment (QFD) to identify design requirements, Concept Selection Matrix (CSM) to generate concepts to be used to establish the core principles that are the basis for establishing final integrated and concurrent execution attributes.

DFSS is the act of designing a product, process or service resulting in a Six Sigma output that satisfies both external customers and internal business Critical-to-Quality (CTQ) requirement. This PIT was using the DMADV methodology as shown in Figure 2.

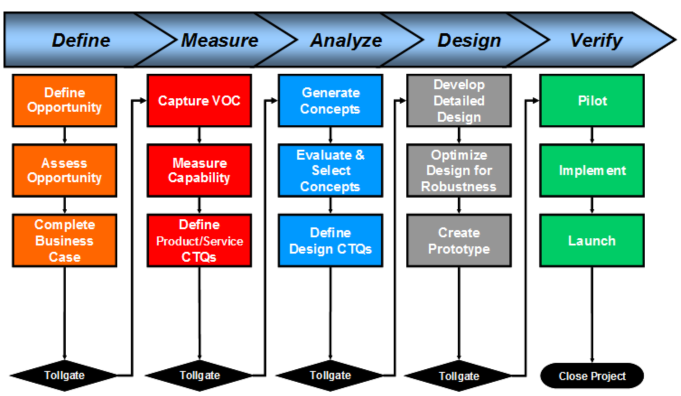

Fig.2 DMADV Six Sigma Methodology

In the Define phase, the emphasis is on understanding the customers and the customers' needs and wants. The VOC is critically important in this phase. In the Measure phase, the emphasis on establishing metrics for the project and developing the inputs that are important. In the Analyze phase, initial design alternatives are developed. In the design phase, an approach is selected from among high level design alternatives identified during the Analyze phase and initial implementation plan is developed. In the Verify phase, the team verifies that the design will meet the requirements.

A. Define Phase

In order to back up the hypothesis, a comprehensive survey of on Semiconductor and High-Tech projects in Taiwan further demonstrates that current work processes do not accurately reflect published procedures particularly in the areas of information flow and information interfaces. To assess historical variation between major milestones, a baseline variation analysis and a probability curve was generated to represent the overall current performance baseline. Figure 3 displays the baseline historical High-Tech projects cycle time probability curve between the start of detail design and mechanical completion milestones.

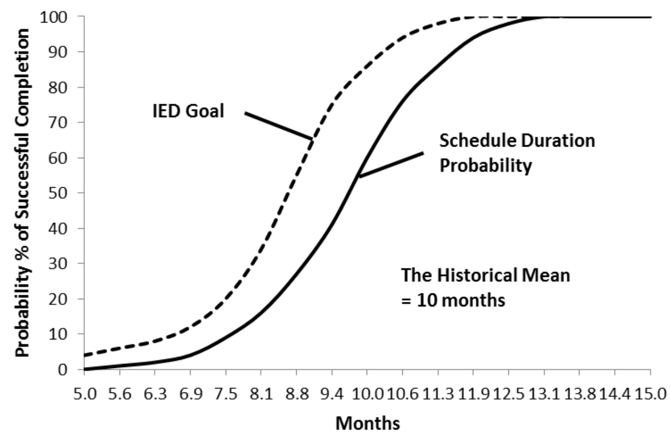

Fig.3 Schedule Duration Probability Curve

As IED teams are planning to deploy on projects, the PIT primary metric is the overall project cycle time between the start of detailed design and mechanical completion milestones for historical projects. The secondary metrics that are available through various existing tracking systems include quantity growth, job hours, labor costs, productivity, and quality. The nature of this PIT does not permit a comprehensive data collection exercise to measure all existing secondary metrics. This PIT was based on functional process management systems and ongoing benchmarking PITs as a reliable source of these metrics. Secondary metrics were closely monitored during the implementation of this PIT.

The formation of IED teams should occur as soon as project scope is defined and schedule, quantities and cost goals are firm and clear. IED team formation milestone should ideally start during the basic engineering design or, at the latest, during the early detailed design phase. The right boundary of this PIT or equivalent dissolution of the IED team should occur with the issuance of all related scope work packages. The goal of the PIT is to effectively implement integrated and concurrent engineering design concepts in critical-path portions of design-build projects in order to improve overall project cycle time. Moving the information curve to the left will result in savings of approximately 3% of total installation cost of a projected 2% reduction in total cycle time.

B. Measure Phase

Data collected from design engineers in the AEC industry in Taiwan indicates that, on average, engineers believe that they start a task with preliminary information 57% of the time and 39% of the time, engineers complete a task with preliminary information. On average, 45% of the time, employees rely on informal communications to complete a task and 50% of their rework is caused by changes in upstream information. The design engineers estimate that they spend 26% of the time doing rework [3].

A voice of the customer study was performed in order to determine the design requirements or design constraints necessary to begin the IED team design. The PIT team engaged the customers as shown in Table I.

TABLE I
INTERNAL AND EXTERNAL CUSTOMER

Internal Customer		External Customer	
Direct	Indirect	Direct	Indirect
Project Management Team	Engineering Lead	Client	Corporate Services
	Procurement Lead		Operations
	Construction Lead		Suppliers
Project Engineering Team	Schedule Lead	Client Project Team	Subcontractors
	Cost Lead		JV Partners
	Quality Lead		Licensing Partners

An important question was posed to the above customers in order to obtain critical requirements when operating in an integrated and concurrent engineering mode:

"What are your requirements when projects deploy multi-discipline high-performing project teams working integrated and concurrently with less red tape and empowered to make tough decisions in order to reduce overall cycle time without sacrificing cost and quality"

The VOC requirements were captured and prioritized in an Analytical Hierarchy Process (AHP) matrix. The result is shown in Table II.

TABLE II
ANALYTICAL HIERARCHY PROCESS RANKING

Ranking	Analysis Hierarchy Process (AHP) Requirements
1	Maintain Safety Record
2	Maintain Technical Quality
3	Ensure Healthy Project Bottom Line
4	Improve Mechanical Completion Date
5	Reduce Total Installation Cost

The top five requirements in the AHP matrix were subsequently analyzed in a Quality Function Deployment (QFD) matrix. The QFD was completed based on the top five customer requirements as follows, 1. Achieve zero lost-time accidents, 2. Meet project technical requirements, 3. Ensure or improve as sold performance, 4. Improve mechanical completion date, 5. Hold or even reduce the total installation cost, all listed as shown in Table III.

TABLE III
QUALITY FUNCTION DEPLOYMENT RESULT

Ranking	Quality Function Deployment (QFD) Requirements
1	Achieve Zero Loss Time Accidents
2	Meet Project Technical Requirements
3	Ensure and Improve As Sold Performance
4	Improve Mechanical Completion Date
5	Hold or Reduce Total Installation Cost

C. Analysis Phase

A thorough voice of the customer investigation was conducted to determine customer requirements necessary to begin the concurrent team design. QFD design requirements include achieve zero loss time accidents, meet project technical requirements, ensure or improve as sold performance, improve mechanical completion date, hold or even reduce total installation cost. A Concept Selection Matrix (CSM) was used to establish the core concepts required to design the final concurrent execution attributes. The team relied on the top five customer requirements to generate concepts which will be used as the basis for formulating a robust integrated concurrent team design [4]. The CSM is shown in Figure 4.

Concept Selection Matrix	Current Operational Structure	**Concept: Location**			**Concept: Leadership**			
		Team Centrally Locate	Virtual Team	Team Physically Co-located	Tradition Discipline Lead	Traditional APE	Team Reports to Leader Regardless of Discipline	Team Manager Required to Ensure Business Constraints are Respected
Achieve Zero Loss Time Accidents	Datum	s	-	+	s	s	s	+
Meet Project Technical Requirements		+	s	+	+	s	+	+
Ensure and Improve As Sold Performance		s	s	+	-	+	+	s
Improve Mechanical Completion Date		-	-	+	-	s	+	s
Hold or Reduce Total Installation Cost		+	s	+	s	+	+	+
Total +s		2	2	6	2	2	5	4
Total -s		1	2	0	2	2	0	0

Fig.4 Concept Selection Matrix

Several of the core concepts by which this PIT team to design an IED team are as follows, 1. Team physically co-located to promote an effective communication environment. 2. A team led and under the direct supervision of visionary, energetic, experienced motivator. 3. In addition to team leader, team manager keeps team "grounded".

D. Design Phase

Integral members of a multi-functional, integrated concurrent execution team include but are not limited to engineering, vendor representatives, procurement, project controls and construction personnel. This team is designed to be led and under the direct supervision of a visionary, energetic, experience motivator. In summary, a integrated concurrent engineering team is an empowered and relatively autonomous, multi-discipline team working on a system in one total development activity in order to move the information curve forward.

D.1 Integrated Engineering Team Preliminary Design

In order to design the correct attributes in a project multi-functional IED team around the concepts described in Concept Selection Matrix in analyze phase, the PIT team structured a series of brainstorming sessions using Mind Manager Software package. The results of these IED attributes are listed in Table IV.

TABLE IV
INTEGRATED ENGINEERING DESIGN ATTRIBUTES

Item	Attributes
Team	Team Empowerment
	Understand information risk
	Paint timeline to set procedure strategy
	Quantify and quality of information
	Engage construction early
	Early and clear procurement strategy
Process	Simple, everyone understands them
	Flexible, workaround when necessary
	In tune with Clients
	Understood and supported by suppliers
	Owned by our people, no one hides behind the process
	Supported by management
	Focused on quality
	Execution strategies and plan are fully developed
People	Responsible and professional Engineering Team
	Personal ownership
	Commitment to each other
	Can do attitude
	Adopt a concept-to-commissioning attitude
	Trust and integrity
Scope	All drawings must be stamped for construction
	Efficient design
	Identification of risks that affects the design scope
	Clear understanding of design requirements
	Checklist for area design
	Information exchange strategy or timing

D.2 Integrated Engineering Team Detailed Design

The PIT team created a detailed engineering procedure which expanded the concepts and attributes presented in the sections above. This detailed procedure describes in full detail how the concepts and attributes designed in the design phase are translated into practical project instructions for the formation, management and coordination of concurrent engineering teams.

In summary, an integrated engineering team is composed of but not limited to engineering, procurement, vendors or suppliers, construction, and project controls. The primary metric of overall project cycle times is shortened by the early team involvement of downstream members, team empowerment to make decisions and work from incomplete or informal information, the entire team is accountable for final deliverables and a well-designed work environment which supports close communications.

E. Verify Phase

Cycle time gains projected by this PIT were established through early involvement of downstream members, the entire team empowered to make decisions, the team empowered to work from informal deliverables, and a redesigned work environment that supports close communications, yielding a result-oriented team accountable for the final deliverables. An Engineering Instruction was created by the PIT team in order to formalize a detailed description that can aid projects to form and manage self-sufficient multi-discipline teams in order to expedite the completion of the technically complex scope [5].

III. PROTOTYPE DESIGN AND IMPLEMENTATION

The attributes listed in the detailed engineering work instruction provide projects the option to form, manage, control and dissolve a concurrent execution team within projects in order to expedite schedule-critical scope. This PIT shall be considered fully implemented contingent on the issue of the aforementioned Engineering Instruction.

A. Control Plan

In order to accurately validate this PIT, a simple log designed to capture detailed information flow data was complemented existing data collection systems. The IED operational data include Task or deliverable description, task start date, the information required for completing tasks, source of information, quality of information, discipline or person that contributed to the task, actual task duration, duration estimate if using perfect information, maximum duration estimate, amount of task rework, discipline or person that receives deliverable and final and unusual observations. The PIT team used this data to recreate an integrated concurrent team performance and assess gains in a pilot project during the validation phase.

B. Pilot Details

Based on the IED Instruction, the PIT team assisted a specified High-Tech project in the design of a pilot program that uses IED approaches to design, procure and install the project's utility system work scope. The utility systems include water, air, electrical, where are designed and constructed to support the basic operation and production requirements in a High-Tech plant. The goal of the pilot is to expedite the utility system schedule in the project without over-running quantity and job-hour budgets and also to meet the satisfaction of the customer [6].

The project team was co-located on the project location with an office layout design that encourages frequent and effective communication. A PIT was created in the project to monitor and analyze utility system design performance based on metrics generated during the execution of this IED team.

IV. EVALUATION

The PIT designed a pilot program in conjunction with the utility system scope in a selected High-Tech project that was closely monitored to assess team execution performance and provide the basis for future adjustments as necessary. Moving the information curve to the left was resulting in savings of approximately 3% of total installation cost of a projected 2% reduction in total cycle time. This is equivalent to a 2-week reduction in overall cycle times for typical High-Tech projects and the savings to be calculated on an individual project basis. The initial results of the PIT had been positive and a number of contributions to the planning and management of the IED execution process. The immediate savings have been realized on going High-Tech projects as a result of the improvements. Over the duration of ongoing projects, the IED performance has improved substantially and the cost saving was recognized. This has mainly resulted from the improvement and implementation actions [7].

IED execution cycle time gains projected by this PIT was established through early involvement of downstream members, the team empowered to make decisions as well as to work from informal deliverables and a redesigned work environment that supports close communications. The result-oriented team shall be fully accountable for the final deliverables.

V. Conclusion

The DFSS methodology in this paper provides an applicable tool for the process in IED installation cost of a construction project. This approach is intended to cause management to consider all elements of the product life-cycle from conception through disposal, including quality, cost, schedule, and client requirements. IED execution implementation on projects, can improve the timeliness and quality of design information and further progress design flexibility required to improve overall project performance.

This PIT was based on the established IED theory that has proven effective in other industries, linked the IED operation strategy and applied the six sigma methodology to achieve the goal. The PIT team designed an IED team structure to improve project performance that complements AEC industry culture. The processes and procedures are analyzed, designed and verified by the VOC, AHP, QFD and CSM to establish the basic principles, and a prototype pilot program had been designed to validate expected gains in the schedule without negatively affecting quantities, labor cost or quality. This paper shares some findings from the application of DFSS methodology of design-build project through a PIT. Future research should focus on improvement findings and their application on other projects, thereby adjusted and validated. By implementing this approach on future projects focused on schedule critical scope, the Six Sigma application can be deployed in the entire design-build operation process.

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