# Application of Six Sigma Process Improvement Method on Construction Turnkey Projects

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***Abstract*—**A Process Improvement Project (PIP) is a performance improvement program aimed at reduction of quality defect, waste time and cost in a construction project. This PIP identifies the system completion turning over to client process required to be performed to gain the final acceptance. As the PIP progressed through Define, Measure Analysis, Improve and Control (DMAIC) Phases, this paper illustrates Six Sigma techniques and tools to determine possible causes of exceed man-hours spent on the preparing the turnover packages. By applying statistical methods, the final probable causes are determined. The purpose of this paper is to share some findings resulted from the application of Six Sigma methodology to construction turnkey projects through PIP. The key recommendation for eliminating or reducing the probable causes and achieving this PIP objective will be discussed.

***Keywords*—**Process Improvement Project, Six Sigma, Turnover Package.

## I. Introduction

Six Sigma is a data-driven approach to improve project efficiency and quality. The methodology was developed and utilized for manufacturing companies such as General Electric, AlliedSignal 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 statistics-based method uses hard data to know how the processes perform, to understand causes if something goes wrong, and to help to develop solutions that result in better performance and capability. By using a rigorous set of statistical and analytic tools, Six Sigma produces dramatic 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]. In recent years, international engineering constructor company has chosen it as a business improvement method.

From customer's point of view, it helps organizations focus on the cost of poor quality and customer requirements. The Six Sigma methodology of detection, analysis, and correction of defects directly impacts customer satisfaction to deliver quality, timeliness and cost effectiveness. It provides significant benefits to customers, including reduced risk and increased efficiencies. Six Sigma processes help to identify critical components that directly impact project deliverables and help to deliver project budget and schedule certainty, to mitigate project risks and an objective method to understand and manage project risks. On the other hand, business leaders like the effects of Six Sigma. It directly enhances the bottom line by reducing the cost of poor quality.

## II. Process Improvement Project (PIP) for Construction Turnkey Operation

The business case of this PIP was developed by linking the strategy gap of construction turnkey project operation of an engineering constructor in Taiwan and applying the six sigma methodology to achieve the improvement of the final turnover process. After mechanical completion and commissioning phase, the system completion and turnover to client requires to be performed in order to define the project final acceptance by the client. This study was based on the PIP for the Hi-Tech and semiconductor construction turnkey projects in Taiwan.

Data from two completed turnkey projects had indicated a significant amount of reworks in the turnover to client package and these reworks lead to excessive engineering, procurement, construction and startup costs. The average time to prepare per system turnover package was 300 man-hours which contained with waste man-hours and process quality defects. In PIP, the work process and procedure need to be improved to enhance more cost saving and performance benefit, also to standardize system completion and turnover requirements and increase the efficiency of turnover package generation process during client acceptance phase.

## III. Define Phase

Data from two executed turnkey projects, as shown in Figure 1, the average time to prepare per system turnover package was 300 man-hours and the gap of 200 man-hours from the target performance and the process standardization was required to improve the productivity and reduce total installation cost.

PIP objective was to reduce the average time per system turnover package from 300 man-hours to 100 man-hours indicated in standard man-hours estimation and standardize system completion and turnover requirements. By closing the gap of 200 man-hours, this PIP will be implemented and potential cost savings can be identified.

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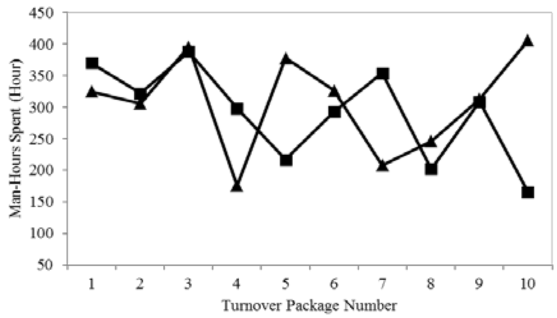


Fig.1 Turnover Package Man-hours for Two Executed Projects

The primary metric was using the average time per system turnover package. As mention in PIP objective, the current baseline was 300 man-hours and the target was 100 man-hours. In order to keep primary honesty tracked, two secondary metric were chosen for this PIP. The first secondary metric was the number of punch list Items per turnover package as quality. The second secondary metric was to measure the deviation of package issue time versus planned schedule.

To confirm the problem to be solved, the Voice of the Customer (VOC) was used to define the expectations and the mission of the PIP. The result is shown in Table I. The key customers include project engineering, procurement, project management and construction.

## IV. Measure Phase

Investigations were undertaken between left limit of receive and process turnover requirements and right limit of turnover package completion and final turnover acceptance to determine the potential causes. By using data from projects, an extensive investigation was conducted employing collection techniques. The scope of surveys covered 75 turnover package, 160 scoped system, and 879 test record and reports.

Value Stream Mapping before Improvement was identified to find the source of waste and improvement opportunities in the processes. The Mapping is shown in Figure 2. The process cycle efficiency was 57% and the works need to be balanced.

TABLE I
Voice of the Customer

| Customer Identification | | Customer Requirement |
|---|---|---|
| Project Engineering | Internal | Turnover package is issued accordance with schedule |
| Project Engineering | Internal | Turnover package is accurate |
| Project Management | Internal | Turnover package meets minimum requirement |
| Project Management | Internal | Turnover package is completed within budget |
| Client | External | Turnover package is follow contract requirement |
| Client | External | Turnover package is organized according to proper format |
| Client | External | Turnover package is issued based on final vendor and engineering data |
| Client | External | Turnover package is updated for actual condition after startup |

A fishbone diagram was completed by brainstorming exercise of the PIP team to identify cause and effect. This tool yielded a total of 40 possible inputs (Xs) and all of the Xs identified in the fishbone were summarized and combined where possible and input into the Cause and Effect Matrix. In order to assess the impact of the inputs to the outputs of the process, Cause and Effect Matrix identified the relationship between inputs and outputs. After combining similar Xs, the total list taken into the Cause and Effect Matrix Ranking was 20 as shown in Table II. The result of the Cause and Effect Matrix, total of 16% inputs are caused from engineering, 28% from construction, 32% from planning and 24% form startup.

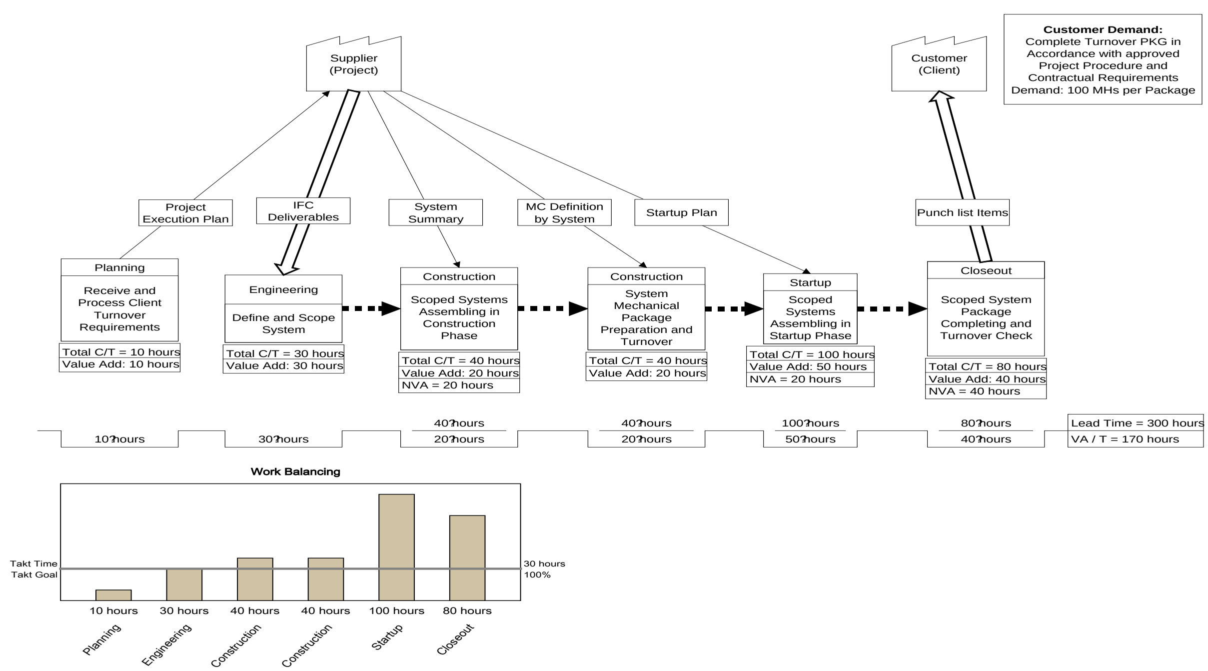


Fig.2 Value Stream Mapping before Improvement

TABLE II
CAUSE AND EFFECT MATRIX RANKING

| Ranking | % | Input Variables (X's) |
|---|---|---|
| 1 | 8.02% | Inadequate Functional Coordination |
| 2 | 8.02% | Inadequate System Turnover Requirement Defined |
| 3 | 8.02% | Improper Construction Turnover Package Developed |
| 4 | 6.95% | Improper System Scope Defined |
| 5 | 6.95% | Incomplete Test Records and Reports |
| 6 | 6.95% | Lake of Standard Format for Operation & Maintenance Manual |
| 7 | 5.35% | Late As Build Drawings Issued |
| 8 | 5.35% | Inadequate Vendor Data Provided |
| 9 | 4.28% | Inadequate Progress Monitoring System |
| 10 | 4.28% | Lake of Knowledge Database System |
| 11 | 4.28% | Open Work Item Not Properly Identified |
| 12 | 4.28% | Improper Startup Work List Developed |
| 13 | 4.28% | Comments from Client Not Properly Incorporated |
| 14 | 4.28% | Improver Startup and Test Schedule Planning |
| 15 | 4.28% | Improper Startup Field Reporting |
| 16 | 3.74% | Late Field Change Request Issued |
| 17 | 2.67% | Late Revision of Electrical One Line Diagram |
| 18 | 2.67% | Late Revision of P&I Diagram |
| 19 | 2.67% | Late Design Change Notice Issued |
| 20 | 2.67% | Improper Design Interface Defined |

The possible Xs from the Cause and Effect Matrix were input into the Process Failure Mode Effects Analysis (FMEA) where used to anticipate what could be go wrong so that steps can be taken to prevent the failure from happening or escaping from the process. Reviewed 4 critical process steps from detailed process map and ranked by Criticality Number, Risk Priority Number. The team developed a prioritized list of possible Xs and a list of these Xs, the results of the FMEA left with following order,

X1: Improper System Scope Defined
X2: Improper Construction Turnover Package Developed
X3: Lack of Standard Format for Operation & Maintenance Manual
X4: Inadequate System Turnover Requirement Defined
X5: Lack of Knowledge Database System
X6: Incomplete Test Records and Reports
X7: Inadequate Vendor Data Provided
X8: Inadequate Functional Coordination

Under the prerequisites of validated measurement system and capability analysis, the PIP had a list of possible Xs through the analyses completed during the Measure Phase. The list of possible Xs contained eight identified inputs that carried to analyzed phase to had further examination.

## V. ANALYSIS PHASE

The Xs were identified as possible causes and further analyzed by applying statistical methods including hypothesis tests and regression analysis in order to identify probable causes [3].

X1: Improper System Scope Defined

To determine the effects of improper system scope defined, the data was collected and analyzed by using the number of system in package without definition from projects. The data from projects was plotted in scatter diagram. The result did not showed any correlation and the results from Minitab output confirmed the suspicion that there was no correlation. Therefore, X1 was not significant.

X2: Improper Construction Turnover Package Developed

To determine the effects of improper construction turnover package developed, the data was collected and analyzed by using the number of mechanical completion definition in turnover package from projects. The data from projects was plotted in scatter plot, where indicated graphically not any correlation and the results from Minitab output confirmed the suspicion that there was no correlation. Therefore, X2 was not significant.

X3: Lack of Standard Format for Operation & Maintenance Manual

To evaluate the effects on lack of standard format for Operation & Maintenance Manuals, the data was collected and analyzed by using the number of Operation & Maintenance Manuals without standard format in turnover package from projects. The result of Fitter Line Plot was a visible trend. A regression analysis from Minitab output concluded that X3 was significant. The team identified three main causes of Operation & Maintenance Manuals without standard format were (1) not use standard format, (2) incomplete Operation & Maintenance Manuals, (3) no Operation & Maintenance Manuals.

X4: Inadequate System Turnover Requirement Defined

To determine the effects of inadequate system turnover requirement defined, the data were collected and analyzed by using the number of systems with incomplete checklist in turnover package from projects. A trend was visible on the graph. The Minitab output for the regression analysis, the regression of X4 was significant and there was correlation. There three main causes were (1) no system checklist, (2) not use standard system checklist, (3) incomplete system checklist.

X5: Lack of Knowledge Database System

To evaluate the effects of lack of knowledge database system, the data were collected and analyzed by using the number of system without database from projects. A trend was not visible on the graph, where the plot graphically did not show any correlation and the results from Minitab output confirmed the suspicion that there was no correlation. Therefore, X5 was not significant.

X6: Incomplete Test Records and Reports

To determine the effects of incomplete test records and reports, the data were collected and analyzed by using the number of incomplete test records and reports from projects. A trend was visible on the graph. A regression analysis from Minitab output indicated the results cannot conclude that X3 was significant, since it existed marginal and the team decided to have further analysis. The team surveyed the reasons for the incomplete test records, there three main causes were (1) incomplete test records, (2) not use standard test record form, (3) no test record.

X7: Inadequate Vendor Data Provided

To determine the effects of inadequate vendor data provided, the data were collected and analyzed by using the total number of system without Vendor data in turnover package from projects. A trend was not visible on the graph. The plot graphically did not show any correlation and the results from Minitab output confirmed the suspicion that there was no correlation. Therefore, X7 was not significant.

X8: Inadequate Functional Coordination

To evaluate the effects of inadequate functional coordination the data was collected and analyzed by using the number of incomplete review and checklist in different functions from projects. The result of Fitter Line Plot had not a visible trend. The plot graphically did not show any correlation and the results from Minitab output confirmed the suspicion that there was no correlation. Therefore, X8 was not significant.

Eight possible Xs through the analyses completed during the analyze phase concluded as Table III.

TABLE III
PROBABLE INPUTS AND THE ANALYSIS RESULTS

| Probable Inputs | | Analyzed Results |
|---|---|---|
| X1 | Improper System Scope Defined | Not Graphically Significant |
| X2 | Improper Construction Turnover Package Developed | Significant but Dropped in Multiple Regression Analysis |
| X3 | Lack of Standard Format for O&M Manual | Significant |
| X4 | Inadequate System Turnover Requirement Defined | Significant |
| X5 | Lack of Knowledge Database System | Not Graphically Significant |
| X6 | Incomplete Test Records and Reports | Significant |
| X7 | Inadequate Vendor Data Provided | Not Graphically Significant |
| X8 | Inadequate Functional Coordination | Not Statistical Significant |

As shown in Table III, these eight possible Xs through the analyses completed, X3, X4 and X6 were identified as significant and hence be carried forward as probable Xs to the output on to the Improve Phase.

## VI. IMPROVE PHASE

Design of Experiment (DOE) was performed on historical data of the three inputs identified as probable as in Analyze Phase. By using a specific methodology to analysis of the results, three inputs were identified as probable by using analyze tools to find a potential relationship between the Xs and output and were hence examined and validated relationship by using designed experiments in the Improve Phase [2]. Analyzing the number of incomplete test records in standard form versus engineer experience and following procedure. The historical DOE results suggested that the higher level in following the test procedure, lower the incomplete test records and lower level in following the test procedure, higher the incomplete test records for both junior and senior engineers. As the outcomes from main effect plot in DOE, higher level in following the procedure, lower the incomplete test record, lower level in following the test procedure, higher the incomplete test records for both junior and senior engineers.

Improved future state value stream mapping was performed to evaluate the process cycle efficiency after improvement opportunities being taken. The mapping is shown in Figure 3, the process cycle efficiency is 70% and the works can be balanced. The information from the DOE were be used to focus our attention in the control stage of the PIP. Therefore, the three probable causes determined in Analyze Phase were carried through into Control Phase.

## VII. CONTROL PHASE

In order to assist in prioritizing potential improvements, improvement selection matrix was used to rate all the critical Xs in terms of their relative importance to the process improvement. The improvement selection matrix was identified by impact, cost and risk for each improvement [5], and the result is shown in Table IV. There were seven improvements with an overall rating significant greater than the others, hence the seven improvements were carried forward into the implementation plan.

TABLE IV
IMPROVEMENT SELECTION RANKING RESULTS

| Ranking | Improvement |
|---|---|
| 1 | Establish Requirements for System Turnover from Startup to Client |
| 2 | Develop Standard Format for Operation & Maintenance Manuals |
| 3 | Develop Standard Format for Test Records and Reports |
| 4 | Establish Requirements for Turnover from Construction to Startup |
| 5 | Develop Standard Turnover Package Contents and Documentation |
| 6 | Develop Checklist for System Mechanical Completion |
| 7 | Incorporate Client Turnover Plan in Project Execution Plan |
| 8 | Schedule Regular Coordination Meeting for Turnover Status |
| 9 | Issue Standard Work Process Procedure Deviations |
| 10 | Setup Auto Scoped System Reporting and Tracking Software |

Based on the Improvement Selection Matrix, the implementation plan was developed to explain PIP actions to management to ensure and organize and successful implementation of activities needed to accomplish the PIP objective. According to seven improvements actions selected and carried from Improvement Selection Matrix, implementation actions with responsible individual, issues and barriers, risk level and mitigation, and target and actual completion were identified by the team.

The significant implementation recommendations are,

Improvement Actions for X3: Lack of Standard Format for Operation & Maintenance Manuals are (1) develop standard format for Operation & Maintenance Manuals, (2) incorporate client turnover requirements in project execution plan. Improvement Actions for X4: Inadequate System Turnover Requirement Defined are (1) develop checklist for system mechanical completion, (2) develop checklist for turnover requirement for construction to startup and startup to client.

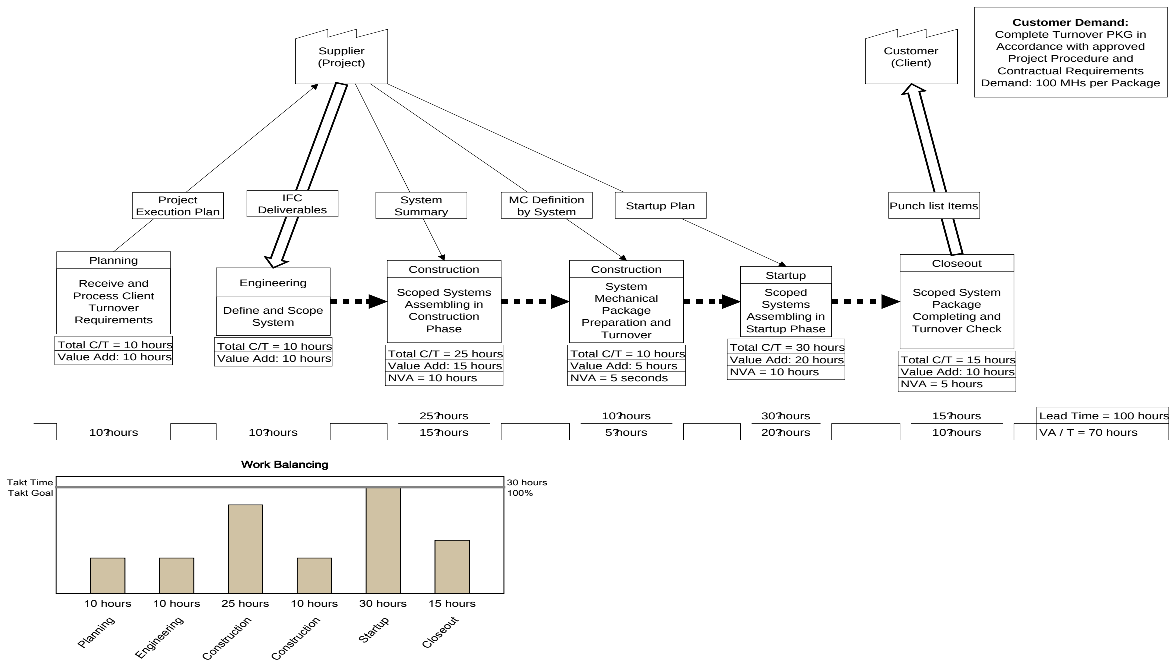


Fig.3 Value Stream Mapping after Improvement

Improvement Actions for X6: Incomplete Test Records and Reports are (1) establish standard templates for test records and reports (2) standardize turnover package contents and documentation.

In order to describe the ongoing monitoring and process controls needed to ensure the process owners sustain the gain of the process improvement, the control plan was developed to track PIP actions to ensure and organize and successful control of activities needed. According to implementation plan, control actions with responsible individual and Control Charts and Metrics were identified by the team. Control actions were planned according primary and secondary metrics and linked by implementation actions. A Reaction Plan was also developed and identified to mitigate the possible problems. Validation actions were planned according primary and secondary metrics and linked to control actions [6].

## VIII. Evaluations

The initial results of the PIP had been positive and number of contributions to the planning and management of the turnover process. The immediate savings have been realized on going turnkey projects as a result of the improvements. Over the duration of the project, the turnover process performance has improved substantially and the cost saving was recognized. This has mainly resulted from the improvement and implementation actions.

## IX. Conclusion

The Six Sigma method provides an applicable tool to improve process in construction execution and operation. This PIP linked the turnkey operation strategy and applied the six sigma methodology to achieve the improvement of the final acceptance turnover process. By applying the Six Sigma techniques including the fishbone diagram, cause and effect matrix through DMAIC phases, and statistical methods and design of experiments, the final probable causes were determined and the key recommendation for eliminating or reducing the probable causes and achieving this PIP objective. As a result, the strategy gap can be closed and the target performance and standardization help to improve productivity and reduce project total installation cost. The process and procedure are improved to enhance more cost saving and performance benefits, also to standardize system completion and turnover requirements and increase the efficiency of turnover package generation process during client acceptance phase. This paper shares some findings from the application of Six Sigma methodology to construction turnkey project through PIP. Future research should focus on the quantification of benefits on the process improvement, and the Six Sigma application of entire construction operation process.

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# The Empirical Study of Flood Risk Maps to Cultural Heritages in Taiwan

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***Abstract*—**Due to extreme climate change, catastrophe normality has turned into a global trend. The idea of "preventive conservation" is now the epic of cultural preservation worldwide; many countries begin to plan adaptive strategies and steps towards impacts to cultural heritage under climate change. Application of risk map has become the tool to predict cultural heritage vulnerabilities. However, cultural heritage preservation in Taiwan remains emphases on insect-resist, antisepsis and structural reinforcement, fire prevention of architectural heritage. Unfortunately, these limited approaches can barely confront with disasters by extreme weather. This study aims first to analyze and explore current global approaches then try to build a domestic risk map targeted on cultural heritage combining disaster-prone area analysis in Taiwan. Analysis is made with research methods, i.e., thematic analysis, field study, in-depth interview, and focus group discussions. Finally, based on cultural heritage vulnerability, examining present cultural heritage preservation strategy, rediscovering the three aspects of "sustainable management, disaster management, climate change and adaptation" in response to cultural heritage management respectively.

***Keywords*—**cultural heritage, risk map, sustainable management, preventive conservation.

## I. Introduction

DUE to global climate change, "the normalization of catastrophe" has become an unavoidable trend. Catastrophe causes serious damages more than ever. In 2009, Typhoon Morakot brought heavy rainfall and caused flooding and mudflow in Taiwan, resulting in massive damages and losses. According to the post-catastrophe cultural heritage inspection, the loss of cultural heritage reached about NTD 0.5 billion. However, as for the cultural essence it destroyed, damages of at least 6 national historic sites, 11 county-designated historic sites, and 14 historic buildings were immeasurable. Even the Executive Yuan approved a NTD 280 million recovery project to repair these damages, the value of the genuine cultural heritage could never be duplicated. Typhoon Morakot was not a single incident in Taiwan and various climate features will become more and more severe and frequent. Besides the huge threat of life and property, we are now confronting the crisis on our spiritual level, historic memories, and the irreplaceable human civilization, which are disappearing fast.

Disasters are the crucial challenges for the conservation of cultural heritages. More tools should be developed and presented for facing the rising uncertainty. Besides, we should keep following the future trends. From the perspective of emergency management chain, the connection of risk management, disaster management, and consequence management is very important and it is the current developing direction of present emergency management. Risk map is presently an important rational tool and the basic foundation for drawing up various strategies for disaster adjustment and relief. The risk map should not only reflect the present situation but actively grasp and respond to the development of future dynamic trends for lowering the uncertainty. Thus, it is our emergent task to set up our national risk map of cultural heritages.

## II. Scope and Method of This Study

According to Article 3 of *Cultural Heritage Conservation Law*, cultural heritage means the seven designated or registered types of heritages that hashistoric, cultural, artist, and scientific value. This study tries to find out advantageous,correct and disaster-reducing response measures when cultural heritages are facing floods. The other issue is how to reduce the risk when designing environmental plans. Therefore, the objective of this study is the immovable tangible cultural heritages that are hard to recover after they are damaged and their relationship with the surrounding environments. There are five categories, including historic sites, historic buildings, villages, relics, and cultural landscapes. This study takes New Taipei City as the operation example. There are a total of 29 administrative districts in New Taipei City, with a total area of 2053 square kilometers. Based on the information provided by the Cultural Affairs Department, there are 6 national historic sites, 57 municipality-designated historic sites, 30 historic buildings, 3 relics, 4 cultural landscapes in New Taipei City, adding up to 100.

Physical impacts on tangible cultural heritages caused by natural phenomena of climate changes (such as change of atmospheric moisture and temperature), while indirect impact means social and economic changes caused by climate changes (i.e., the climate change changes the utilization of land, economic structure, and population structure). These changes

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