ANALYSIS OF CONSTRUCTION DEFECT GENERATION MECHANISM USING MATHEMATICAL APPROACH

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Abstract - *Construction defects can exert significant impacts on project performance. These defects are typically traced back to their initiating root causes, formulated as infectious decisions, practices, or circumstances. The root causes often act as pathogens that propagate to spread numerous other risky conditions, thereby making projects prone to defects. There have been numerous research efforts to minimize construction defects and a variety of suggestions have been provided. However, while all of these suggestions are valuable and have the potential to prevent defects, a construction company may have difficulty adopting them due to financial and practical constraints. Thus, this calls for the identification and characterization of the most influential causes of defects, in order to prioritize defect prevention strategies. To address this necessity, this paper aims to identify the most important causes of defects in terms of frequency, magnitude. For this goal, Nine direct causes and 30 root causes were collected through an extensive literature review. A* questionnaire survey of 52 industry professionals was conducted to examine 30 causes of defects. High frequency and high magnitude causes were identified and traced back to their initiating causes.This paper is valuable to researchers in terms of developing a theoretical foundation to analyze and visualize the complex mechanisms of defect generation in construction. Further, this paper is of value to practitioners in terms of providing an effective tool to set defect prevention strategies and prioritize investment areas for quality improvements.

Keywords: Defect; Error; Risk; Social network analysis

1.INTRODUCTION

A defect is the physical manifestation of an error or omission and are amongst the most common problems in construction industry that can significantly degrade projects performance. In construction, a defect refers to "a failing or shortcoming in the function, performance, statutory or user requirements of a building, and might manifest itself within the structure, fabric, services or other facilities of the affected building It does not only refer to shortcomings that extend to failure (e.g., crack) but also includes undesired non-conformance with principles or requirements, which may or may not result in rework. Rework is defined as the unnecessary effort required to redo a process or activity that was incorrectly implemented the first time .The cost of defects and their resultant rework in a construction project can account for approximately 10% of the total project cost. In addition, rework can result in reduced profit, loss of market share and reputation, increased turnover of management and workforce, lower productivity, higher costs, and costly litigation between participants over the responsibility for overruns and delays. In order to improve the performance of projects, it is necessary to identify the causes and costs of construction rework so that they can subsequently be removed.

The presence of defects means the absence of quality. In fact, the term defect is sometimes used interchangeably with the term quality failure. Although the concept of quality is hard to articulate and bears different standards and meanings to different people and stakeholders one of its obvious measures is the nonexistence of defects. Whether construction firms aim to embrace an efficient quality management framework, or merely aim to minimize the negative impacts associated with defects, they will in either case need to know what yields an effective defect prevention strategy. Defect prevention, is the aspiration of this study, entails improving aspects of the system that protect the most against defects' recurrence. Defect prevention necessitates two major stages: a qualitative and a quantitative stage. The qualitative stage involves systemically identifying and classifying the various causes of defects .On the other hand, the quantitative stage involves observing the most important causes so as to improve aspects of the system that are most capable of restraining defects' recurrence .

1.1 Objectives

This research aims to identify root causes (latent conditions, Pathogens) through literature reviews and To quantify the risk of defect root causes based on frequencies and magnitudes and To demonstrate the applicability of the developed methods.

1.2 Scope

This study develops analytical understanding of defect generation and mathematical formulations. The data used to apply these theories (i.e. the fourth and fifth objectives) are derived from questionnaires from participants with diverse construction backgrounds.

1.3 Mechanics Of Defect Generation

To prevent construction defects, one must first identify and recognize where these originates. A root cause is the most basic reason for an undesirable condition or problem. If the root cause of the problem is not identified, then one is merely addressing the symptoms and the problem will continue to exist. For this reason, identifying and eliminating root causes of problems is of utmost importance. Inorder to identify the root causes of construction defect, the Swiss Cheese Model was utilized. Based on the Swiss Cheese model, defect causes can be traced back to any of the four descending layers of a system (Fig. 1). The first three layers (*Organizational Influences*, *Defective Supervision*, *and Preconditions for Defective Acts*) represent the root causes and the fourth layer (*Defective acts)* represents the direct causes. The root causes are also called *latent conditions* created by higher echelons of the organization owing the emplacement of risky decisions, practices and circumstances. Since the Defective Acts have already being identified in the authors' recent study [4], this study will complementarily focus on identifying the latent conditions.

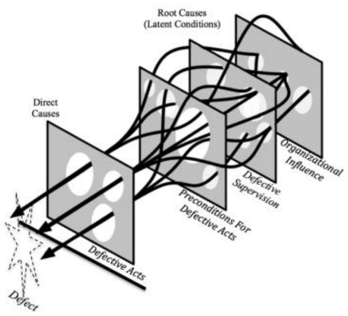

Fig -1: The Mechanics of Defect Causes (The Swiss Cheese Model).

2. METHEDOLOGY

The aim of this study is to fill the gap by developing the analytical understanding of the complex mechanisms of defect generation so as to identify and quantify defects' most influential causal patterns, and accordingly develop effective defect prevention strategies.

2.1 Identification of latent conditions

Table -1: Organizational Influences

Label	Latent Condition
L1	Insufficient liquidity or start-up budget
L2	Organizational Culture
L3	Unstable positions of personnel
L4	Inadequate employee training
L5	Allocating unfit or incapable supervisores/engineers on duty
L6	Getting involved in projects that are beyond the organizations capacity
L7	Low managerial priority for quality
L8	Workplace quality system
L9	Financial constraints upon operational expenses
L10	Time pressure & constraints
L11	Lack of support from the main office to the site
L12	Lack of support from the main office to the site

Table -2: Defective Supervision

Label	Latent Condition
L13	Change orders
L14	Failure to correct a known problem
L15	Inadequate supervision
L16	Supervisor/s not adhering to rules or procedures
L17	Poor document control
L18	Lack of client Involvement
L19	Lack of clear schedule float
L20	Contractor misinterpreted designers' instructions
L21	Designer issued misleading drawings/instructions
L22	Misleading instructions from worker's direct supervisors
L23	Misunderstanding clients requirements
L24	Poor coordination between the project team

Table -3: Preconditions For Defective Acts

Label	Latent Condition
L25	Impaired or poorly maintained tools/machinery
L26	Inappropriate materials supply
L27	Technical/Constructability challenges and constraints
L28	Site Mismanagement
L29	Workers' adverse psychological state (Stress)
L30	Workers' insufficient skill or knowledge level

2.2 Data collection

Data collection is the most critical part of the study since the accuracy of the data will determine the success or failure of the research. Data obtained through these questionnaires will be analyzed accordingly using appropriate analysis techniques. Responses from questionnaires will then be compiled and analyzed. Data collected from different questions will be gathered to answer different objectives. Analysis is done using mathematical methods. The questionnaire survey was conducted from about thirteen companies. Most of the data was collected from construction buildings site and interview was done with project managers, project managers, contractors, clients, site in charge.

2.3 Measuring the importance of defect causes

Determining the most important causes of defects involves facing several difficulties. One main difficulty lies in the fact that the contribution of an individual cause to triggering a defect can vary, not only between one project and another, but also between two identical defect instances, occurring within the same project. That is, each defect instance can result from a different causal recipe, consisting of a unique composition of latent conditions. An example of a causal recipe is the joint influence of a worker's lack of skill and the inadequate supervision of the responsible site engineers that fail to detect the worker's mistakes. Although both a worker's lack of skill and inadequate supervision are part of the exemplified recipe, they do not necessarily have equal effects. Similarly, there are numerous combinations of latent conditions that can result in a defect, each of which has its unique distribution of effects. Thus, in order to generalize about the variety of risks imposed by latent conditions, two criteria need to be taken into account: (1) the number (i.e., frequency) of causal recipes that are taken part in, and (2) the effect (i.e., magnitude) that they have on the formation of these recipes. These two criteria are addressed in the method proposed by . This method utilizes fault trees to aggregate data obtained from numerous defect instances, in order to formulate the various defect recipes in a unified risk model. Once a model is constructed, analysts can quantify a cause's frequency and magnitude, by observing how the overall risk model (set at a reference point of R =1) changes, which results from including or excluding the examined latent condition. This entails observing two extreme values: (1) the overall risk index (RLi−)when a latent condition (Li) is included (i.e., probability set to 1 in the fault tree), and (2) the overall risk index when a latent condition(Li) is excluded (i.e., probability set to 0). Subsequently,

- Frequency is computed using the Fussell and Vesely importance measure

$$FV_{Li} = \frac{R_{Li} - R_{Li} -}{R_{Li} -}$$

- Magnitude is computed using Birnbaum's (1969) importance measure

$$BI_{Li} = (R_{Li}+) - (R_{Li}-)$$

In terms of defect management, removing high frequency (i.e., most common) causes allows for the decrease in the number of pathways by which a defect can be formulated. On the other hand, removing high magnitude (i.e., most likely to cause a defect) causes allows for the strengthening of the "defense-in-depth" of a system .The frequency and magnitude measures, proposed by, are limited to characterizing a cause's immediate capacity to yield a defect, but do not accommodate the fact that some causes indirectly account for the existence of others. Consider a project that suffers from financial constraints. This is an example of a non immediate latent condition that usually lies in the organizational influences layer (Fig. 1). When a project suffers from financial constraints, numerous other risky conditions may result such as a worker's lack of skill, inadequate supervision, poor materials supply, and so forth. In this case, financial constraint is not only an immediate cause of defects, but also a pathogen that triggers the spread of the above-mentioned problematic conditions. Thus, latent conditions should be evaluated not only in terms of frequency and magnitude.

3. RESULTS ANALYSIS

Table -4: The quantification of the root causes' influences

Label	Frequency[F]	Magnitude(BI)
L1	0.32	0.7
L2	0.66	1.4
L3	0.33	0.7
L4	0.72	1.5
L5	0.68	0.16
L6	0.32	0.7
L7	0.67	1.4
L8	0.75	1.6
L9	0.5	1.2
L10	0.66	1.5
L11	0.7	1.1
L12	0.56	1.3
L13	0.31	0.8
L14	0.64	1.4
L15	0.79	1.7
L16	0.68	1.6
L17	0.4	1.3
L18	0.37	1.1
L19	0.28	1
L20	0.43	1.3
L21	0.69	1.8
L22	0.72	1.7
L23	0.5	1.4
L24	0.72	1.6
L25	0.34	1.1
L26	0.4	1.3
L27	0.76	2.1
L28	0.74	1.7
L29	0.31	0.8
L30	0.81	1.8

4. CONCLUSIONS

- Mathematical data analysis reveals that the three most frequent latent conditions are workers' insufficient skill or knowledge level (FV_{L30}=81%), inadequate supervision (FV_{L15}=79%), and constructability/technical challenges and constraints (FV_{L27}=76%).

- The removal of these three causes is expected to significantly reduce the pathways in which defects occur

- The removal of high frequency root causes has a high capacity to instantly prevent defects but not necessarily improve the system's susceptibility to it,

- Constructability/technical challenges and constraints (BI_{L27}=2.1), workers' insufficient skill or knowledge level (BI_{L30} =1.8),inadequate supervision (BI_{L15}=1.7), and designer issues or misleading drawings/instructions (BI_{L21}=1.8) the highest magnitude latent conditions.

- The removal of these four causes is expected to significantly improve the immunity of projects to defect

- High magnitude root causes are those that jeopardize the system

- The removal of high magnitude root causes yields the most immediate system improvements

- Three of the aforementioned latent conditions (i.e., L15, L27, and L30) attained both high frequency and magnitude values.

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