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Synergistic Effect or Something Else

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ABSTRACT
The unforeseeable effect of project changes can lead to a cumulative impact, which in turn can result in a loss of productivity (LOP). The cumulative impact of changes refers to the synergistic effect of changes not adequately captured in change orders, which are often forward priced. Though a certain correlation between project productivity and the combined volume of changes was observed in published statistical studies, it was also observed that a portion of the productivity impact was not driven by the volume of changes. This paper offers a discussion on this issue.

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I. INTRODUCTION

In addition to the direct impact, the compounding effect of multiple changes can be unforeseeable, and greater than the sum of the effects of the individual changes. This phenomenon of the synergistic effect of project changes is typically called the “cumulative impact.” In the United States, several courts and boards of contract appeal have acknowledged a general right of recovery in published decisions for a cumulative impact resulting from owner-responsible changes.[1] Despite this general acknowledgement, proving a cumulative impact claim remains a very challenging task.

A correlation between the project changes and loss of productivity was observed in previous research, including Leonard (1988) [2], Ibbs and Allen (1995) [3], Ibbs (1997, 2005, 2012, 2021) [4][5][6][7], Hanna et al. (1999a, b) [8][9] and Hanna and Iskandar (2017) [10], and Zhao (2021) [11]. It has been suggested that factors other than the volume or amount of cumulative project changes affect labor productivity.[2][11] This paper presents the latest findings and recommendations regarding the relationship between loss of productivity and project changes.

II. LITERATURE REVIEW

There have been many studies published over the years on the topic of the cumulative impact of changes on the labor productivity of unchanged work. One of the earliest studies was Leonard (1988), in which the relationship between % Change, determined by comparing the actual labor hours for changed work to those for the base scope, and % Loss of Productivity (% LOP), determined by dividing the lost labor hours by the total actual labor hours for the base scope work, was investigated. Leonard based his statistical analysis on data from 90 cases in dispute from 57 construction projects, mainly in Canada. Leonard also considered the potential impact from major causes, such as acceleration, out-of-sequence work, over stacking of trades, and lack of materials.

Hanna et al. (1999a, b) [8][9] and Hanna and Iskandar (2017) [10] investigated the link between productivity and various influencing factors, including changes, on the electrical and mechanical work from a collection of projects. Hanna et al. (1999a, b) [8][9] and Hanna and Iskandar (2017) [10] suggested that the factors affecting labor productivity for electrical work were not consistent with that for mechanical work, but no explanation was offered for this inconsistency. Ibbs and Allen (1995) [3] and Ibbs (1997, 2005, 2012, 2021) [4][5][6][7] studied the relationship between the project index (PI), calculated as the ratio of earned hours and actual hours for the base scope, and % Change-Hours, calculated using the ratio between the actual hours for the changed work and total actual labor hours. These studies confirmed the correlation between project changes and labor productivity.

Zhao (2021) [11] identified the shortcomings of the regressed trend functions in past research, such as Ibbs and Allen (1995) [3] and Ibbs (1997, 2005, 2012, 2021) [4][5][6][7], when used to predict productivity loss. In addition to shortcomings such as non-additiveness for the non-linear models, another issue was found, which is that they did not adequately address the contributing impacts from factors other than project changes. This paper will discuss the productivity impact that was not driven by the combined change amount in the context of multiple changes below.

III. RESEARCH METHODOLOGY

In order to solve the shortcomings on non-additiveness, non-monotone, and nonzero intercept, Zhao (2021) [11] developed a linear function modeling the relationship between loss of productivity (LOP) on the unchanged work and the volume of changes. In Zhao (2021), data for 162 projects were digitized based on the published chart in Ibbs (2005), in which 28 projects were excluded from the statistical analysis for potential estimating errors. While Zhao (2021) [11] focused on explaining how the volume of changes can affect labor productivity of unchanged work in the context of cumulative impact, this paper focuses on explaining the impact from factors other than the volume of changes in the context of a linear relationship between % Change and its impact on labor productivity. This author has further studied the nonzero intercept derived from the regression analysis and analyzed the variance of the reported productivity impact by expanding the statistical analysis as included in Zhao (2021) [11]. Findings and conclusions relying on the statistical results are presented below.

IV. FINDINGS

The result of the numerical analyses based on the 134 data points for this paper is a set of curves and charts that summarize the statistical relationship between the volume of changes and its potential impact on labor productivity, and the magnitude and variability of the impact from the factors other than the volume of changes.

Figure 1 shows the linear models (with and without a non-zero intercept) that describe the potential impact of changes on the labor productivity of unchanged work. The horizontal axis compares the total actual labor hours for the change orders to the total actual hours for the unchanged work, and the vertical axis compares the lost labor hours to the earned labor hours for the unchanged work. The positive slope for the linear models indicates a correlation between % LOP on unchanged work and % Change, in the sense that with the increase of % Change, the labor productivity for the unchanged work tends to get worse. The non-zero intercept indicates that factors other than the volume of changes also affect the labor productivity of the unchanged work, because it does not correlate with the volume of changes. One such factor could be the additional synergistic effect (or productivity jump-down) resulting from sudden work nature alteration if the volume of changes is over a threshold (over-threshold synergies). In addition, the factors can also include errors on planned productivity, performance impacts from parties other than the owner, inaccuracies in the data, and sample size and representativeness.[11][12] With these factors excluded, the linear model with zero intercept can generally provide a more conservative and reliable projection on the effect of the volume of changes alone than all the other models.

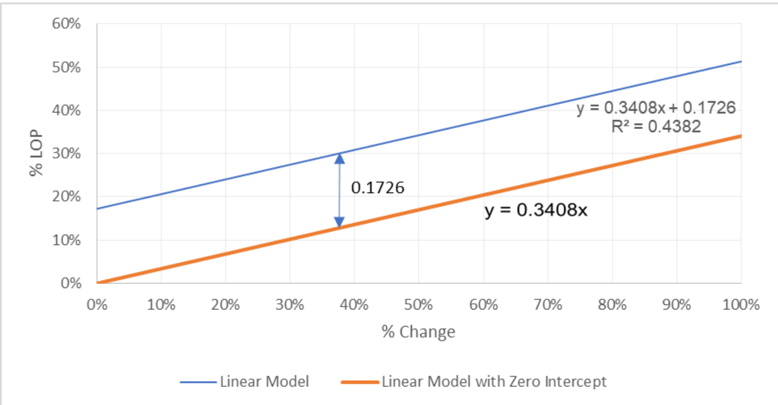

Figure 1: Linear models describing the relationship between % Change and % LOP on the unchanged work

The variability in the data reported from the 134 projects is more than the non-zero intercept of 0.1726. The actually reported % LOP can significantly deviate from the linear model with zero intercept, as shown in Figure 2. It can be as much as 0.41 more than the projected value from the linear model with zero intercept, or as much as 0.11 less. In addition to factors such as over-threshold synergies, errors on planned productivity, performance impacts (including their ripple effects) from parties other than the owner, inaccuracies in the data, and sample size and representativeness, the differences in the types of projects, locations, means and methods, skills, experiences and training of the craft labor, project management, and record keeping may also contribute to the variability and deviations.[11][12]

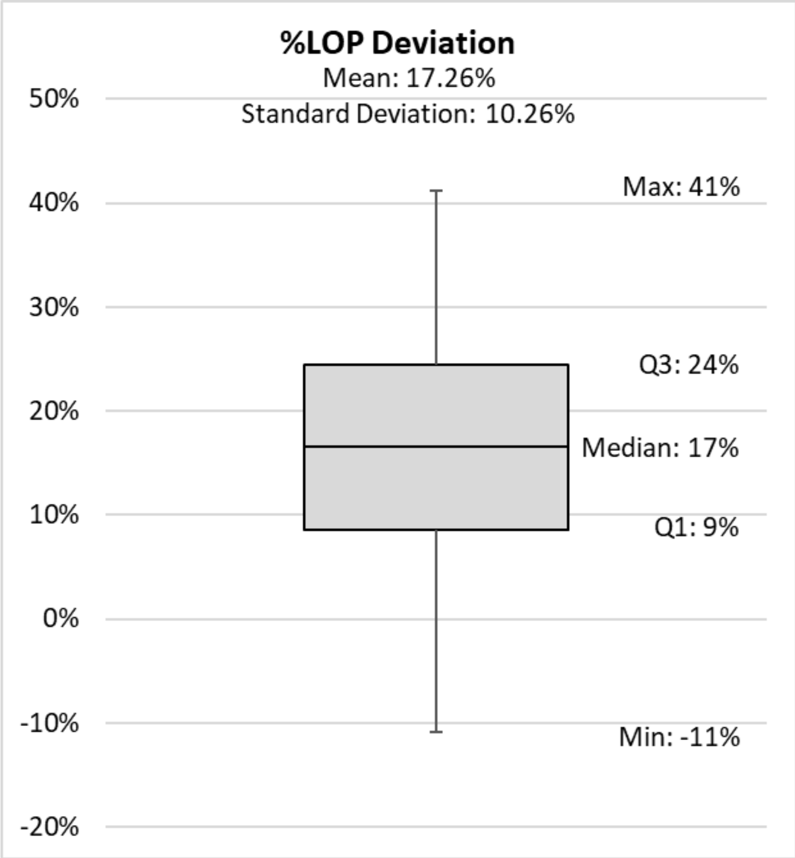

Figure 2: Reported deviations from the linear model with zero intercept

Figure 3 shows the probability of productivity loss 1) only under the impact of cumulative volume of changes or 2) under all possible factors as discussed above. For the former scenario, a normal distribution with the mean as what is projected on the linear model with zero intercept, and the standard deviation as 10.26% is assumed; for the latter scenario, the probability is calculated based on what was reported from the 134 projects considering all possible impacting factors. If labor was only impacted by the cumulative volume of changes, the probability for the instance that no productivity loss is experienced decreases with the increase of % Change. When % Change is less than 20%, the probability of non-negative productivity impact can be more than 20%. If all factors as discussed above, including the volume of changes, over-threshold synergies, estimating errors, self-inflicted or non-owner impacts, and variability in project characteristics, are considered, the probability of non-negative productivity impact would be significantly less. In particular, it is noteworthy that when % Change exceeds 20%, the probability of non-negative productivity impact approaches zero or the productivity of productivity loss for cumulative volume of changes is getting closer to 100%. This indicates that with a large volume of changes in the context of cumulative impact, negative productivity impact can be expected.

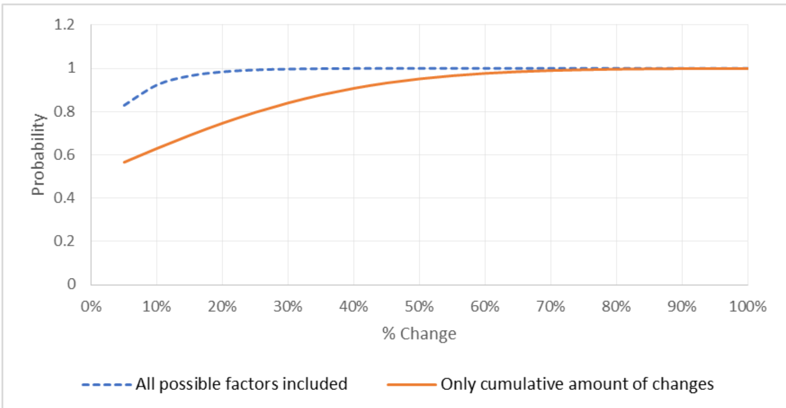

Figure 3 Probability of observed productivity loss versus % Change

Figure 4 shows the relationship between % Change and the average percentage of contribution to LOP from the volume of changes. With the increase of % Change, the contribution to LOP from the volume of changes also increases. Reducing the volume of changes by improving owner's scope definition and design management can thus be helpful to lessen the negative productivity impact due to cumulative impact of changes.

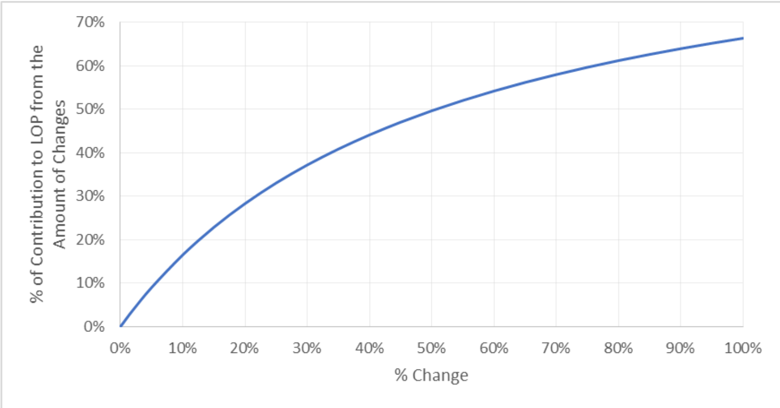

Figure 4 Contribution to LOP from the volume or amount of changes

V. CONCLUSION

The correlation between project productivity and the combined volume of changes was observed in various statistical studies. In the context of cumulative impact, the loss of productivity on the unchanged work can include a portion with a linear relationship with the volume of changes, and a productivity jump-down when the volume of changes exceeds a threshold so that the nature and complexity of work have been dramatically changed. In addition, factors such as errors on planned productivity, performance impacts (including their ripple effects) from parties other than the owner, inaccuracies in the data, sample size and representativeness, the types of projects, locations, means and methods, skills, experiences and training of the craft labor, project management, and record keeping can also contribute to the reported variability in these statistical studies.

Statistical models may be used to project the LOP for cumulative impact. In this context, the portion of LOP proportional to the volume of changes (or projected based on the linear model with zero intercept) has more reliability than the portion corresponding to the non-zero intercept in the linear model, because the non-zero intercept may be caused by factors unrelated to changes. After all, the measured mile method is the most accepted method in quantifying lost labor productivity, even in the context of cumulative impact. [1][13] The statistical studies may be considered only if the measured mile method is not applicable.

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